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July 9, 2019

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VIA EMAIL TO PLANNING@CO.COOS.OR.US

Andrew Stamp
Land Use Hearings Officer
c/o Coos County Planning Department
225 N Adams St
Coquille, OR 97423

Re: Jordan Cove Energy Project Land Use Applications
Coos County File No. REM-19-001 (HBCU-15-05/FP-15-09)
Applicant's Second Open Record Period Submittal

Dear Mr. Stamp:

This office represents Jordan Cove Energy Project L.P. ("JCEP"), the applicant requesting approval of concurrent land use applications to construct a liquefied natural gas facility, export terminal, and related project components ("Project") in Coos County File No. REM-19-001 (HBCU-15-05/FP-15-09) ("Applications"). This letter and its enclosures constitute JCEP's second open record period submittal for the Applications on remand.

Enclosed please find the following materials:

- Exhibit 1 - Technical Memorandum from David Evans & Associates, Inc. re: Omnibus Remand Adverse Impact dated July 1, 2019.
- Exhibit 2 - Comments from JCEP to Federal Energy Regulatory Commission on Draft Environmental Impact Statement ("DEIS") dated July 5, 2019.
- Exhibit 3 - Project Impacts on Salinity Memo dated November 2017.
- Exhibit 4 - Turbidity Analysis Memo dated November 2017.
- Exhibit 5 - Vertical Distribution of Infauna: A Comparison of Dredged and Undredged Areas in Coos Bay, Oregon (Jefferts, 1977).

- Exhibit 6 - Technical Memorandum, Hydrodynamic Studies - Hydrodynamic Analysis - Jordan Cove Energy Project dated September 2018.

- Exhibit 7 - Technical Memorandum, Hydrodynamic Studies - Sediment Transport Analysis - Jordan Cove Energy Project dated September 2018.

- Exhibit 8 - 2018 Eelgrass and Bathymetry Surveys Coos Bay, Oregon dated November 2018.

- Exhibit 9.1 - Gaumer, T.F., G.P. Robart, and A. Geiger. 1978. Oregon bay clam distribution, abundance, planting sites and effects of harvest. Annual Report, October 1, 1977 to September 30, 1978. ODFW.

- Exhibit 9.2 - Thom. R.M., A.B. Borde, S. Rumrill, D. L. Woodruff, G. D. Williams, J. A. Southard, S.L. Sargeant. 2003. Factors influencing spatial and annual variability in eelgrass (Zostera marina L.) meadows in Willapa Bay, Washington, and Coos Bay, Oregon, estuaries. Estuaries and Coasts, Vol 26:4, pp 1117-1129.

- Exhibit 9.3 - Chang, B.D. and C.D. Levings, (1978). Effects of burial on the heart cockle *Clinocardium nuttallii* and the Dungeness crab *Cancer magister*. Estuarine and Coastal Marine Science, Volume 7, Issue 4, October 1978, Pages 409-412.

- Exhibit 9.4 - ODFW, Summary of Information Regarding Oregon's Red Abalone Recreational Fishery. ODFW, Charleston Field Office, Charleston, OR, 2018.

- Exhibit 9.5 - Wilber, D.H. and D.G. Clarke. 2007. Defining and assessing benthic recovery following dredging and dredged material disposal. Proceedings XXVII World Dredging Congress 2007.

I have asked staff to place a copy of this submittal into the official record for this file and to place a copy before you. JCEP reserves the right to submit additional argument and evidence in this matter consistent with the extended open record scheduled established by the Hearings Officer and ORS 197.763.

Thank you for your courtesies in this matter.

Very truly yours,

Seth J. King

Encls.

cc: Jill Rolfe (via email and overnight delivery) (w/encls.)
Steve Pfeiffer (via email) (w/encls.)
Client (via email) (w/encls.)

TECHNICAL MEMORANDUM

DATE:	July 1, 2019
ATTENTION:	Perkins Coie
COMPANY:	Jordan Cove LNG
ADDRESS:	111 SW 5th Ave, Suite 1100 Portland, OR 97204
FROM:	Casey Storey
SUBJECT:	Omnibus Remand Adverse Impact Response
DEA PROJECT NAME:	Regulatory Permitting Services
DEA PROJECT NO:	JLNG0000-0003
DOCUMENT #	J1-000-TEC-TNT-DEA-00047-00
COPIES TO:	DEA File

Introduction

This memorandum outlines the habitats, species, and resources that the Oregon Department of Fish and Wildlife (ODFW) identifies as potentially affected by shoreline stabilization for the slip and barge berth and by dredging activities for the access channel and access triangle. It describes the nature of the affects to the resources as cited by ODFW and follows with a description of how the Jordan Cove Energy Project, L.P. (JCEP) has documented the avoidance, minimization, and mitigation of such impacts.

1. *ODFW ASSESSMENT OF IMPACTS*

ODFW identified the following species as being impacted by the slip and barge berth and dredging activities generally: Dungeness crab (*Cancer magister*), red rock crab (*Cancer productus*), cockles (*Clinocardium nuttallii*), gapers (*Tresus capax*), butter clams (*Saxidomus giganteus*), littleneck clams (*Protothaca staminea*), rockfish (*Sebastes spp.*), lingcod (*Ophiodon elongates*), greenling (*Hexagrammos decagrammus*), California halibut (*Paralichthys californicus*), English sole (*Parophrys vetulus*), Pacific sand dabs (*Citharichthys sordidus*), ghost shrimp (*Callianassa californiensi*), mud shrimp (*Upogebi pugettensi*), starry flounder (*Platichthys stellatus*), smelts (*Osmeridae family*), anchovies (*Engraulidae family*), sardines (*Clupeidae family*), fall run Chinook salmon (*Oncorhynchus tshawytscha*), green sturgeon (*Acipenser medirostris*), white sturgeon (*A. transmontanus*), (OC) ESA threatened coho salmon (*O. kisutch*), and possibly Pacific lamprey (*Entosphenus tridentata*). There is some potential that Pacific smelt (eulachon) (*Thaleichthys pacificus*) may be found in the JCEP area of Coos Bay.

Impacts cited by ODFW to the above species would result from the destruction of eelgrass within the access channel footprint; alteration of mudflats within the Slip and Access channel impact area, and disturbance of other subtidal, tidal, intertidal, and shoreline habitats within these affected areas. Additional impacts to the species and habitats listed above are also cited by ODFW through the frequent and prolonged disturbance associated with maintenance dredging, temporal losses during the period of impact and recolonization or reestablishment, and the extended period of disturbance during construction.

2. *RESPONSE:*

Impacts to benthic species and habitats are described in the 2016 DEA memorandum (DEA 2016) and in the Compensatory Wetland Mitigation Plan (JCEP and PCGP 2018). Species removed or disrupted by development of the Slip and Access channel are expected to recolonize portions of the Slip and Access channel where conditions meet their life history requirements within a period of less than one year. Where habitats are permanently lost and associated species are unable to colonize the post-project estuarine areas, the proposed mitigation sites will provide comparable suitable habitat for the affected species (eelgrass, mudflats, intertidal areas). As summarized in the 2016 DEA memorandum, mitigation at the Kentuck Mitigation Site, West Bridge Site, West Jordan Cove Site and Eelgrass mitigation sites would mitigate for the aquatic habitat losses as a result of project actions. Since that time, the mitigation planning has been updated and only the Kentuck Mitigation Site and Eelgrass Mitigation Sites are now included as project elements intended to replace lost functions and values as a result of Slip and Access channel and shoreline impacts.

Mitigation of Slip and Access channel impacts to eelgrass beds has been proposed by JCEP to include eelgrass bed creation near the airport. Upon establishment and progressive monitoring and adaptive management of the eelgrass mitigation area, the ultimate site would provide up to 3:1 replacement of habitat lost to the aforementioned impacts. Eelgrass reestablishment would generate an increased area where lost habitats would be available in equivalent or greater quantities and would support species associated with this habitat type. These species would include marine invertebrates, juvenile and adult marine and anadromous fishes, waterfowl, shorebirds, and wading species (herons, egrets). Similarly, the Kentuck Site would create a variety of estuarine habitats that could support benthic invertebrates, larval and adult estuarine fish species, and habitat for juvenile salmon.

The ultimate recolonization of the dredged and altered Slip and Access channel impact area combined with the net increase in estuarine habitats created through the creation of the Kentuck Site and development of the Eelgrass Mitigation Site will result in a net increase in estuarine and aquatic habitats within Coos Bay. As stated in the 2016 DEA memorandum, the effects from the impacts to the Slip and Access channel and shoreline areas will be fully mitigated with implementation of the proposed mitigation strategies. The suitability of the Eelgrass Mitigation Site to meet ODFW's habitat mitigation policy is in question by this agency to replace eelgrass habitats. Although ODFW has recommended avoidance as the proposed mitigation strategy for this habitat type, the JCEP project design process has determined that impacts to eelgrass are unavoidable. Therefore, the proposed mitigation in combination with creation of the Kentuck Mitigation Site have been proposed to replace eelgrass in-kind while creating other habitats that would replace unavoidable impacts associated with the Slip and Access channel.

Temporal losses to estuarine habitats in the Slip and Access channel and shoreline impact areas will be mitigated through the same avenues as the permanent impacts – with higher ratios and larger total areas of estuarine habitat being created with the development of the mitigation sites (Kentuck and Eelgrass sites).

JCEP is proposing to avoid and minimize impacts to the resources above by limiting dredging and other in-water construction activities to the in-water work period (October 1 – February 15). Structural controls including sequencing and isolation measures will be implemented to minimize impacts of the slip development on estuarine resources during construction. (JCLNG Terminal Dredging Pollution Control Plan, JCEP 2019). Additionally, a number of operational controls, including monitoring, will limit and control turbidity and water quality impacts of proposed in-water work activities associated with creation of the Slip and Access channel. Monitoring, control and reporting standards will adhere to Oregon Department of Environmental Quality (ODEQ) general conditions and as outlined in the JCLNG Terminal Dredging Pollution Control Plan (JCEP 2019).

Development of the Slip and Access channel will result in a net increase in deep subtidal habitat that can be colonized by invertebrates and utilized by marine mammals, adult and juvenile fish, waterfowl, and other marine and estuarine species. Ongoing disturbance of the Slip and Access channel as a result of maintenance dredging will result in future temporal losses of benthic species that have re-colonized proposed work areas. However, maintenance dredging and other disturbance activities will adhere to environmental controls and regulatory requirements related to the proposed activities at the time such actions are authorized.

REFERENCES:

David Evans and Associates, Inc. 2016. Land use Omnibus Response Memorandum. Prepared for Perkins Coie, LLP. January 26, 2016.

Jordan Cove Energy Project (JCEP) and Pacific Connector Gas Pipeline Project (PCGP) 2018. Compensatory Wetland Mitigation Plan. Prepared for by David Evans and Associates, Inc. November 2, 2018.

Jordan Cove Energy Project (JCEP). 2019. LNG Terminal Dredging Pollution Control Plan. Prepared by KBJ, April 9, 2019.

Casey M. Storey
Associate, Environmental Specialist/Project Manager

Casey is a biologist, environmental specialist, and project manager with 15 years of experience conducting natural resource studies, regulatory compliance reviews, and project permitting. He specializes in facilitating complex permitting efforts with a wide range of stakeholders including private property owners, tribes, federal and state regulators and agencies, land use planners, and the public. His project portfolio includes natural resource reporting; endangered species documentation; planning and coordinating large-scale field data collection; and permitting for linear transportation projects, bridges, pipelines, transmission line corridors, substations, private residential development, airports, and restoration projects. He has completed training for wetland delineations, endangered species reporting and consultations, NEPA documentation, airport noise analysis, erosion and sediment control and stormwater management. Casey holds an ODOT Biological Assessment Qualification, a certification in erosion control inspection, and has electrofisher training.

Education:

MBA, Sustainable Business, 2012,
Marylhurst University

MS, Conservation Ecology and Sustainable Development, 2003
University of Georgia

BA, Environmental Studies, 2000
Prescott College

Certifications

ESCL, 2018 – Oregon and Washington
Oregon Department of Transportation – Biological Assessment Qualified Biologist

July 5, 2019

Ms. Kimberly D. Bose, Secretary
Federal Energy Regulatory Commission
888 First Street, N.E.
Washington, D.C. 20426

Re: *Pacific Connector Gas Pipeline, LP* and *Jordan Cove Energy Project L.P.*
Docket Nos. CP17-494-000 and CP17-495-000
Comments on Draft Environmental Impact Statement

Dear Ms. Bose:

On September 21, 2017, Jordan Cove Energy Project L.P. ("JCEP") filed an application pursuant to Section 3(a) of the Natural Gas Act, as amended,[1] and Parts 153 and 380 of the regulations of the Federal Energy Regulatory Commission ("FERC" or the "Commission"),[2] for authorization to site, construct, and operate certain liquefied natural gas facilities ("LNG Terminal"). On the same day, Pacific Connector Gas Pipeline, LP ("PCGP", and together with JCEP, "Applicants") filed an application pursuant to Section 7(c) of the NGA,[3] and Parts 157 and 284 of the Commission's regulations,[4] for a certificate of public convenience and necessity authorizing PCGP to construct, install, own, and operate a new natural gas pipeline ("Pipeline"). On March 29, 2019, the Commission Staff issued its Draft Environmental Impact Statement ("DEIS") for the Project, establishing a deadline for comments on the DEIS of July 5, 2019.

Applicants hereby submit their comments on the DEIS in Volumes I and II. Volume I includes Attachments A, B, and C. Attachment A provides a narrative of Applicants' comments on the DEIS. Additionally, Applicants provide technical comments and suggest certain clarifications to the DEIS, all of which are listed in tabular form in Attachment B. Applicants also include comments on the DEIS recommended mitigation conditions in Attachment C.

Pursuant to 18 C.F.R. § 388.112, Applicants request that the information contained in Volume II be treated as privileged and confidential because it contains confidential environmental, cultural resource, or landowner information. Applicants have marked such information with **"CONTAINS PRIVILEGED INFORMATION—DO NOT RELEASE (CUI//PRIV)."** Privileged information should be treated as confidential and is for use by Commission Staff only and not to be released to the public.[5] Questions pertaining to confidential information may be submitted to:

[1] 15 U.S.C. § 717b(a) (2012).
[2] 18 C.F.R. Pts. 153 and 380 (2019).
[3] 15 U.S.C. § 717f (2012).
[4] 18 C.F.R. Pts. 157 and 284.
[5] *Id.* at § 388.112.

Natalie Eades
Manager, Environment & Regulatory
Jordan Cove Energy Project L.P.
Pacific Connector Gas Pipeline, LP
5615 Kirby, Suite 500
Houston, Texas 77005
Phone: 832-255-3841
Email: NEades@pembina.com

Should you have any questions, please contact me at neades@pembina.com or 832-255-3841.

Sincerely,

/s/ Natalie Eades
Natalie Eades
Jordan Cove Energy Project L.P.
Pacific Connector Gas Pipeline, LP

Enclosures

cc: John Peconom (FERC)
John Crookston (Tetra Tech)

CERTIFICATE OF SERVICE

I hereby certify that I have this 5th day of July, 2019, served the foregoing document upon each person designated on the official service lists compiled by the Secretary in these proceedings.

_/s/ Victoria R. Galvez_____
Victoria R. Galvez
Attorney for
Jordan Cove Energy Project L.P.
Pacific Connector Pipeline, LP

Attachment A

Comments on DEIS

DEIS Comments

I. Alternatives Analysis for the Siting of JCEP's LNG Terminal

In the Draft Environmental Impact Statement's ("DEIS") analysis of potential alternatives, Federal Energy Regulatory Commission ("FERC" or "Commission") Staff evaluated alternatives using three criteria: (1) whether the alternative meets the stated purpose of the project; (2) whether the alternative is technically and economically feasible and practical; and (3) whether the alternative offers a significant environmental advantage over the proposed action.[1] FERC Staff dismissed two alternatives—an inland (non-waterfront) terminal site alternative (the "Inland Alternative") and a Humboldt Bay terminal site alternative (the "Humboldt Bay Alternative")—under the third criterion because they do not have a significant environmental advantage over the proposed action. For the reasons below, each of these alternatives should also be dismissed from further analysis under the second criterion because they are not technically or economically feasible or practical. The Council on Environmental Quality has long supported the dismissal of potential alternatives from further National Environmental Policy Act ("NEPA") analysis when they are not practical or feasible from a technical or economic standpoint.[2]

1. The Inland Alternative is not technically or economically feasible or practical.

Although Jordan Cove Energy Project L.P. ("JCEP") agrees with FERC Staff's conclusion that the environmental impacts of the Inland Alternative outweigh potential environmental impacts from siting the facilities at Coos Bay, the Final Environmental Impact Statement ("Final EIS") should clarify that the Inland Alternative should also be dismissed from further analysis because it is not technically or economically feasible or practical. In Section 3.3.4 of the DEIS, FERC Staff notes that an Inland Alternative would require either a liquefied natural gas ("LNG") trucking system or a cryogenic pipeline at least five miles long in order to deliver LNG from the liquefaction and LNG storage facilities located at an upland location outside of Coos Bay to a marine berth and loading facility at Coos Bay.[3] As discussed more fully below, the LNG trucking system and the cryogenic pipeline proposals are neither practical nor feasible.

The DEIS provides the basis for why a trucking system would be impractical: it would require thousands of truck trips per day to meet the proposed output volumes.[4] It would take over 4,200 trips using pressurized cryogenic 18-wheel semi-trucks (each with a gross volume of 12,570 gallons) to supply a single LNG carrier with a capacity of 180,000 cubic meters, which would need to occur over one hundred times each year. JCEP is not aware of any project that

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[1] Draft Environmental Impact Statement for Jordan Cove Energy Project L.P. and Pacific Connector Gas Pipeline, LP at 3-2, Docket Nos. CP17-494-000, *et al.* (issued Mar. 29, 2019) ("DEIS").

[2] *See* 40 C.F.R. § 1502.14(a) (noting the review of "reasonable" alternatives and the dismissal of others); Council On Environmental Quality's *Forty Most Asked Questions Concerning CEQ's National Environmental Policy Act Regulations*, 46 Fed. Reg. 18026 (March 23, 1981) ("Reasonable alternatives include those that are practical or feasible from the technical and economic standpoint and using common sense . . . .); *Guidance Regarding NEPA Regulations*, 48 Fed. Reg. 34,263 at 34,267 (July 28, 1983) (stating that "reasonable alternatives include those that are practical or feasible from the technical and economic standpoint").

[3] DEIS at 3-14.

[4] DEIS at 3-14.

relies on a fleet of this size to transport LNG short distances for vessel loading, which further demonstrates its impracticability. Furthermore, it is unclear whether there is even an adequate supply of these specialized vehicles to create such a fleet. The impracticality and infeasibility issues with these thousands of truck trips each day, as well as the time required for their loading and unloading, render this alternative unreasonable. The Final EIS should dismiss it under the second criterion of technical and economic feasibility and practicality. JCEP further agrees with FERC Staff's conclusion that an inland terminal with a trucking system would not provide a significant environmental advantage over the proposed LNG terminal given public safety issues, the impacts on roadways, and exhaust emissions from these thousands of trucks per day.

The Inland Alternative with a cryogenic pipeline should similarly be dismissed under the second criterion as impractical and infeasible. A cryogenic pipeline would be subject to regulation by the U.S. Department of Transportation ("USDOT") under a different section of USDOT's regulations (49 C.F.R. Part 193) than applies to Pacific Connector Gas Pipeline, LP's ("PCGP") natural gas pipeline (49 C.F.R. Part 192). USDOT's Part 193 regulations apply to components of LNG facilities, including components such as cryogenic pipelines used in transferring liquefied natural gas.[5] Application of required siting and safety standards embedded within these regulations demonstrate why a cryogenic pipeline is neither technically nor economically feasible or practical.

First, the DEIS discusses the potential for the cryogenic pipeline to be placed in a tunnel system to convey LNG across a distance of at least five miles. However, placing a five-mile cryogenic pipeline in an enclosed space such as a trench, channel, or tunnel system is not permissible under USDOT regulations, as interpreted and applied by the Pipeline and Hazardous Materials Safety Administration ("PHMSA").[6] Thus, this alternative would require an aboveground pipeline, which is infeasible given the required Highway 101 and Coos Bay water crossings necessary to traverse over five miles of developed area to the east of the marine berth location. In particular, USDOT regulations would require prohibitively extensive vapor dispersion exclusion zones for any cryogenic pipeline.[7] JCEP would have to build large elevated trestle bridges to convey the cryogenic pipeline over Highway 101 and Coos Bay. Placing the pipeline at this height and at these locations would be impermissible for several reasons. JCEP would not be able to legally control the activities of all others at these public and highly trafficked areas, and therefore, any cryogenic pipeline crossing would fail to satisfy the vapor dispersion exclusion zone requirements of the Part 193 regulations. The cryogenic pipeline would face similar barriers to feasibility in meeting the spill containment system requirements and the expanded thermal exclusion zones for that system, which also require legal control of all activities in the expanded thermal exclusion zones.[8] Independent of the infeasibility for exclusion zone reasons, siting the cryogenic pipeline at elevated heights near the airport would also likely be impermissible.

Furthermore, USDOT's regulations could require vapor exclusion zones of up to 1,400 feet on each side of the cryogenic pipeline, which for a five-mile pipeline would result in 1,700 additional acres of land encumbered by the permanent operational easements sufficient to allow

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[5] *See* 49 C.F.R. §§ 193.2001(a), 193.2007.
[6] *See* 49 C.F.R. § 193.2167; NFPA 59A § 2.2.2.3 (2001).
[7] *See* 49 C.F.R. § 193.2059.
[8] *See* 49 C.F.R. § 193.2057.

JCEP to legally control the land to maintain exclusion zone effectiveness.[9] Putting aside the dramatically increased impact on landowners and local land use, without eminent domain authority, which is not available for the LNG components necessary to implement this cryogenic alternative, it is unlikely that five miles of contiguous parcels would be available for purchase from willing sellers, further demonstrating the infeasibility of this alternative.

A cryogenic pipeline system would also require extensive supporting equipment, as discussed in the DEIS: LNG ship loading pipe, LNG recirculating and cooldown pipe, ship vapor return pipe, access points for inspection and maintenance work, insulation, and pump stations.[10] The additional components and the necessary pump and compressor stations would need electrical power, security, firewater, control rooms, and other associated facilities. Further, the additional facilities and equipment would require a larger operational easement and significant additional construction activity, including a larger construction and permanent right of way. FERC Staff correctly concluded in the DEIS that these additional facilities and equipment would render the Inland Alternative impractical. The Final EIS should clarify that the Inland Alternative is also infeasible for the same reasons.

As described above, FERC Staff's analysis adequately demonstrates why the Inland Alternative is not feasible. The DEIS does not provide any examples of LNG terminals using cryogenic pipelines of any length approximating what the Inland Alternative would require in the DEIS, and the Applicants are aware of none. The DEIS initially states that the Inland Alternative is "technically feasible," then "perhaps technically feasible," but, ultimately, "not . . . practical."[11] With additional consideration of the issues already highlighted in the DEIS analysis as well as those discussed above, the Final EIS should clarify that the Inland Alternative is neither practical nor feasible from a technical or economic standpoint. The record contains no evidence to the contrary.

2. The Humboldt Bay Alternative is not technically or economically feasible or practical.

As with the Inland Alternative, JCEP agrees with FERC Staff's conclusion that the Humboldt Bay Alternative would not offer a significant environmental advantage over the proposed action and therefore does not warrant further analysis. However, the Final EIS should clarify that the Humboldt Bay Alternative also merits dismissal because it is not technically or economically feasible or practical. To be considered technically feasible, a site must have reasonable access to an existing channel deep enough for safe transit of LNG vessels—determined to be 36 feet mean lower low water ("MLLW").[12] When considering the feasibility of using a particular channel, additional factors affecting navigational accessibility must be considered, such as shoaling, swift currents, existing bridges, and existing high levels of ship traffic. The Humboldt Bay Alternative (including terminal siting on the Samoa Peninsula) is not technically feasible on several navigational accessibility grounds.

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[9] The 1,400-foot exclusionary zone was calculated based on a 2-inch un-mitigated horizontal release.
[10] DEIS at 3-14.
[11] *Id.* at 3-13 to 3-14.
[12] *See* DEIS at 3-10.

Heavy shoaling is a recurring issue in Humboldt Bay and renders many channels navigationally inaccessible to deep-draft vessels.[13] The 2018 Humboldt Bay Maritime Industrial Use Market Study explains that after maintenance dredging, sand accumulates outside of the Humboldt Bay entrance, with strong waves and currents carrying the sand into Humboldt Bay's interior channels.[14] This type of heavy shoaling results in operating restrictions for deep-draft vessels and renders the bay navigationally inaccessible.[15] Indeed, the Corps of Engineers has proposed a study to evaluate long-term solutions to this shoaling, but the study has not been funded and no solution is being implemented to address this limiting factor.

As a result of this heavy shoaling and silting, no channel is reliably deep enough to accommodate the anticipated LNG vessels with a loaded draft of 36 feet. This is notwithstanding the authorized depths of the Bar, Entrance, and North Bay Channels serving the Samoa Peninsula being 48 or 38 feet, as FERC Staff noted in the DEIS.[16] The technical infeasibility of LNG vessel traffic traversing these navigational channels is evident in the National Oceanic and Atmospheric Administration's March 2018 tabulation of controlling depths of federal navigation channels at Humboldt Bay, where most of the horizontal extent of each of these channels is less than the required 36-foot MLLW depth.[17] In particular, 75% of the Bar Channel is 33 feet deep or shallower (ranging from 31 to 33 feet), with only one quarter showing a measurement of 37 feet; 75% of the Entrance Channel is 35 feet deep or shallower (ranging from 32 to 35 feet) with only one quarter showing a measurement of 39 feet; and 75% of the North Bay Channel is 35 feet or shallower (ranging from 18 to 34 feet) with only one quarter showing a measurement of 36 feet.[18] Moreover, several reaches are wholly inaccessible due to depths that are too shallow, including the Eureka Channel outer reach where depths range from 15 to 30 feet, and the Samoa Channel turning basin, where depths range from 22 to 35 feet.[19]

Furthermore, the Humboldt Bay Alternative is infeasible because it lacks an available parcel or combination of parcels equaling approximately 200 acres, which is a site requirement in the DEIS's analysis of potential LNG terminal sites.[20] The DEIS states that it is unknown whether a combination of land zoned for industrial use is available on Samoa Peninsula equaling 200 acres.[21] The Samoa Peninsula has 948 acres of land zoned for industrial and coastal-dependent uses, with the Eureka Municipal Airport currently occupying 344 of those acres.[22] Further study reveals several other facilities operating on Samoa Peninsula, including the Fairhaven Terminal, DG Fairhaven Power Company (a biomass-fueled power plant); Fox Farm Soil and Fertilizer Company; and several aquafarm operations, as well as a historic redwood marine terminal and pulp mill that is undergoing environmental cleanup. These unavailable parcels divide the land in

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[13] Humboldt County Planning and Building Department, Humboldt Bay Maritime Industrial Use Market Study 25 (2018), https://humboldtgov.org/DocumentCenter/View/64265/Humboldt-Bay-Maritime-Industrial-Use-Market-Study-2018-PDF.
[14] *Id*.
[15] *Id*.
[16] DEIS at 3-9.
[17] National Oceanic and Atmospheric Administration, *Humboldt Bay Nautical Chart: Soundings in Feet* (2018), https://charts.noaa.gov/PDFs/18622.pdf.
[18] *Id.*
[19] *Id.*
[20] DEIS at 3-10.
[21] DEIS at 3-9.
[22] *Id*.

such a way that there is no available single parcel or combination of adjacent parcels equal to 200 acres that is zoned consistent with the Project's required industrial land use and situated in such a way to make the Project feasible. Thus, the Humboldt Bay Alternative is a technically infeasible site for the Project.

Humboldt Bay's shallow channel depths caused by heavy shoaling, and the lack of parcels of sufficient size to accommodate the LNG terminal, render the Humboldt Bay Alternative technically infeasible. The Final EIS should clarify that the Humboldt Bay Alternative is impracticable and warrants no further analysis because it is neither technically nor economically feasible, in addition to having no significant environmental advantage over the Proposed Action.

II. Alternatives Analysis for the Siting of PCGP's Pipeline at the Blue Ridge Variation

In the DEIS, FERC staff analyzed the environmental impacts associated with two route alternatives between approximately milepost ("MP") 11 and MP 25: the route PCGP proposed in 2017 ("PCGP's Proposed Route") and the DEIS-analyzed Blue Ridge Variation ("FERC's Blue Ridge Variation").[23] This discussion in the DEIS ends with the recommendation that FERC's Blue Ridge Variation be the preferred alternative over PCGP's Proposed Route between MP 11 and MP 25.[24] PCGP disagrees. The following sections present a comparative analysis of the environmental impacts of FERC's Blue Ridge Variation (as submitted in PCGP's Resource Report 10 in 2017 and carried forward in the DEIS), and PCGP's Proposed Route. Based on this analysis, PCGP does not believe there is a compelling scientific reason to conclude that FERC's Blue Ridge Variation offers significant environmental advantages over PCGP's Proposed Route and therefore urges FERC to adopt PCGP's Proposed Route as the preferred alternative.

FERC Staff based its recommendation to adopt FERC's Blue Ridge Variation as the preferred alternative on an "attempt to balance the overall impacts" and in recognition of "the trade-offs between the proposed route and the variation; the differences between terrestrial and aquatic resource impacts in regard to temporal effects, as well as the scope of avoidance, minimization, and mitigation for these effects; and the magnitude of the effects."[25] FERC Staff described the primary tradeoffs that factored into the recommendation as "between terrestrial (e.g., [Late Successional Old Growth ("LSOG")] forest and [marbled murrelet ("MAMU")] stands/habitat) and aquatic resources (e.g., waterbody crossings and anadromous fish habitat), as well as public and private lands."[26] Comparisons between PCGP's Proposed Route and FERC's Blue Ridge Variation rely on flawed assumptions regarding the significance of the impacts.

As discussed in Section I above, and to satisfy its NEPA obligations, FERC Staff evaluated alternatives using three criteria: (1) whether the alternative meets the stated purpose of the project; (2) whether the alternative is technically and economically feasible and practical; and (3) whether the alternative offers a significant environmental advantage over the proposed action.[27] In determining whether an alternative route analyzed in the DEIS offers a significant environmental advantage over the applicant's proposed route, FERC Staff's determination should be informed by

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[23] DEIS at 3-20 to 3-24.
[24] *Id.* at 3-21.
[25] *Id.*
[26] *Id.* at 3-20.
[27] *Id.* at 3-2.

how "significance" is defined for purposes of NEPA, including consideration of context (which could include geographic, biophysical, and social context) and intensity (meaning the severity of the impact).[28] PCGP's analysis of impacts to LSOG, waterbody crossings, and coho salmon and their critical habitat demonstrates that FERC's evaluation of the relative impacts of the Blue Ridge Variation is based on flawed assumptions regarding the context and intensity of those impacts.

Based on PCGP's analysis of the existing data, some of which is not reflected in the DEIS for MAMU habitat and population trends but which is referenced and provided here,[29] it is clear the two routes have different, but overall comparable environmental impacts. Because FERC's Blue Ridge Variation does not offer a significant environmental advantage PCGP's Proposed Route, the Final EIS should adopt PCGP's Proposed Route as the preferred alternative.

1. Late-Successional Old Growth Forest (LSOG) and Late-Successional Reserves (LSR)

The DEIS states that FERC Staff recommended FERC's Blue Ridge Variation "based primarily on the variation's ability to reduce long-term to permanent impacts on particularly valuable LSOG habitat affected by the proposed route," noting that "[b]oth the sensitivity and value of this habitat and the duration of the impact contribute to this finding."[30] Embedded in this conclusion is the key assumption that habitat mapped as LSOG is particularly valuable.

The DEIS defines LSOG to encompass two forest age classifications: 1) late-successional (stands 80-175 years old) and 2) old growth (stands older than 175 years).[31] Although FERC Staff acknowledge and define these two separate elements of LSOG, they assess LSOG throughout the DEIS as a single unit without assessing the different intensities of impacts—different sensitivities, ecological functional values, and impact durations between late successional and old growth habitat. The DEIS's assessment of LSOG as a single unit is exemplified in the following statement:

> "LSOG forests west of the Cascade Range typically consist of old large overstory trees, such as Douglas-fir and western hemlock, multiple tree canopy levels, shade-tolerant tree species in the understory, large course woody debris and snags, a lush understory shrub layer, and infrequent stand replacement fire events."[32]

This definition of LSOG is an accurate textbook description of old growth, however it does not accurately describe characteristics of late successional forests that often include single-story canopy structure, little to no development of large wood or snags, and limited understory growth. Nor does the textbook description of old growth accurately describe LSOG habitat that actually occurs along PCGP's Proposed Route. PCGP used existing U.S. Bureau of Land Management ("BLM") Forest Operations Inventory ("FOI") data to identify whether old growth forest exists

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[28] 40 C.F.R. § 1508.27.
[29] *See* Appendix 1 (Edge Environmental, Inc., Summary of Recent Marbled Murrelet Habitat Surveys Conducted along PCGP's Blue Ridge Proposed Route and FERC's Blue Ridge Variation, June 27, 2019).
[30] DEIS at 3-21.
[31] *Id.* at 4-155.
[32] *Id.* at 4-158.

along the PCGP's Proposed Route and FERC's Blue Ridge Variation, and PCGP summarized the data in Table I-6.[33] Further, Geographic Information Systems ("GIS") analysis of data provided in Table I-6 shows that none of the old growth (age range 175+) listed in Table I-6 occurs along either PCGP's Proposed Route or FERC's Blue Ridge Variation. Table 1 below summarizes FOI data applicable to PCGP's Proposed Route. It shows that most of the stands summarized as LSOG on PCGP's Proposed Route are even-aged stands at the low-end of the age-class range for LSOG, and they lack the structural and functional characteristics of old growth habitat. Simply stated, the structural components that make LSOG "particularly valuable" are not present in most of the LSOG stands along PCGP's Proposed Route. Figure 1 in comments submitted to FERC by Mark Sheldon on June 14, 2019,[34] is a typical photograph illustrating the lack of functional complexity in most of the LSOG along PCGP's Proposed Route. Although younger late-successional stands have the potential to develop the old growth characteristics described above, past human disturbance (including clearcutting and the resultant development of even-aged stands) results in conditions that often require stand management to facilitate development of old growth features.

The DEIS states that FERC's Blue Ridge Variation would impact 8.8 acres of LSOG, whereas PCGP's Proposed Route would impact 40.5 acres of LSOG. As an initial matter, the 40.5 acres of LSOG attributed to PCGP's Proposed Route is incorrect and appears to be a clerical error, as the number of acres of LSOG should be the same as number given for acres of nesting, roosting, foraging ("NR") habitat (which is equivalent to LSOG)—23.8 acres.[35] With 23.8 acres impacted, the difference is only 15 acres between the two routes. More importantly, though, only late-successional forest stands are present along both routes, and no impacts are proposed within old growth stands for either route, as documented in the previous paragraph.

In the context of the total Pipeline route, 517 acres and 502 acres of MAMU and NSO LSOG would be impacted along PCGP's Proposed Route and FERC's Blue Ridge Variation, respectively. The 23.8 acres of late successional impact within PCGP's Proposed Route represent 4.6 percent of the total LSOG impacts, whereas the 8.8 acres of late successional impact within the FERC Blue Ridge Variation Route represent 1.7 percent of the total LSOG impacts. This difference of 2.9 percent between the two routes cannot be considered significant.

The DEIS further states that both the sensitivity and value of this LSOG habitat and the duration of the impact contribute to FERC Staff's finding that FERC's Blue Ridge Variation is preferable.[36] In the Cumulative Impacts section, FERC Staff notes that some habitats may be more sensitive to disturbance than others, such as those that are "irreplaceable, essential, or limited,"[37] borrowing this definition of sensitivity from the definition of Category 1 habitat from the Oregon Department of Fish and Wildlife ("ODFW") Habitat Mitigation Policy. ODFW's Habitat Mitigation Policy is not a sensitivity analysis, nor does ODFW classify all LSOG habitat as Category 1 (i.e., "irreplaceable," the characteristic distinguishing Category 1 from all others). The inclusion of stands as young as 80 years means that LSOG stands comprise 53 percent of BLM's

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[33] DEIS Section 4.4.3.1 at 4-173, and DEIS Appendix I, Table I-6.
[34] Comment of Mark Sheldon, Accession No. 20190614-5013 (June 14, 2019).
[35] See DEIS at 3-23, Table 3.4.2.2-1.
[36] *Id.* at 3-21.
[37] *Id.* at 4-797.

land holdings in Western Oregon.[38] Additionally, the BLM's Coos Bay District, where the majority of the impacts to LSOG are located, contains an estimated 129,467 acres of LSOG,[39] which belies the concept that LSOG is limited in the local region or that removal of an additional 15 acres of LSOG on PCGP's Proposed Route would be significant given that this is 0.01 percent of the available LSOG in the BLM's Coos Bay District.

In a broader geographic context, the 15-acre difference between impacts associated with PCGP's Proposed Route and FERC's Blue Ridge Variation is *de minimis*. Impacts associated with PCGP's Proposed Route encompass 0.002 percent of the available LSOG in BLM's Western Oregon ownership (1,156,425 acres). In addition, the BLM anticipates that mature forest habitat and structurally complex forest habitat would increase by 50 percent from 4,007,672 acres in 2013 to 6,0241,836 acres across Western Oregon by 2063,[40] which is within the lifetime of the Pipeline. Similar to the project context, the difference when viewed in this regional geographic context cannot be considered a significant difference between the two routes.

Moreover, late-successional stands do not intrinsically convey a higher value than younger stands. Impacts to LSOG within PCGP's Proposed Route, as shown in Table 1 below, would occur within typically even-aged Douglas fir (*Pseudotsuga menziesii*) stands with little to no forested understory and a paucity of large woody debris and snags, characteristics that count as high value habitat for either MAMU or NSO.[41] Table 1, extracted from BLM FOI data used to create DEIS Table I-6, depicts the BLM FOI stand age data for all designated late successional impacts within PCGP's Proposed Route. Less than half of the proposed impacts to late successional habitat are within mapped multi-storied habitat (FOI age 139), which is 25 years shy of being considered old growth. Note that FOI data is only available for BLM land; 20.0 acres of FOI-mapped LSOG would be impacted for PCGP's Proposed Route. However, 23.8 acres LSOG were mapped for the entirety of PCGP's Proposed Route on public and private land. This 3.8-acre difference represents private lands where forest canopy and diameter classes have not been determined.

Table 1. FOI Age Classes within Designated LSOG within the Footprint of PCGP's Proposed Route

FOI Age	FOI Stand Description	FOI Stand Description*	Impact (Acres)
39	FMX D2RA1-=1980	Forest mix with between 35-65% conifer and the rest hardwood. Douglas fir (diameter class 2) and red alder (diameter class 1) dominant in upper story, well stocked, planted around 1980.	0.15

[38] U.S. Department of Interior. 2015. Proposed Resource Management Plan/Final Environmental Impact Statement: Western Oregon. Volume 1. Available: https://www.blm.gov/or/plans/rmpswesternoregon/files/prmp/RMPWO_Volume_1.pdf
[39] *Id.*
[40] U.S. Department of Interior. 2015. Proposed Resource Management Plan/Final Environmental Impact Statement: Western Oregon. Volume 4. Available: https://www.blm.gov/or/plans/rmpswesternoregon/files/prmp/RMPWO_Volume_4.pdf
[41] See discussions of suitable habitat for these two species in footnotes 24 and 33 in BLM's Southwestern Oregon Record of Decision and Approved Resource Management Plan, Klamath Falls Field Office of Lakeview District, Medford District, and South River Field Office of Roseburg District, dated August 2016, which is available at https://www.blm.gov/or/plans/rmpswesternoregon/files/rod/SWO_ROD_RMP.pdf.

FOI Age	FOI Stand Description	FOI Stand Description*	Impact (Acres)
79	FCO D4-=1940	Forest conifer with ≥65% conifer, Douglas fir dominant, well-stocked, diameter class 4, planted around 1940	0.98
89	FCO D4-=1930	Forest conifer with ≥65% conifer, Douglas fir dominant, well-stocked, diameter class 4, planted around 1930	0.04
99	FCO D4-=1920	Forest conifer with ≥65% conifer, Douglas fir dominant, well-stocked, diameter class 4, planted around 1920	1.80
	FHD HD3-=1920	Forest hardwoods with ≥65% hardwoods, well-stocked, diameter class 3, planted around 1920	3.08
129	FCO D4=1890	Forest conifer with ≥65% conifer, Douglas fir dominant, medium stocked, diameter class 4, planted around 1890	0.39
	FCO D4-=1890	Forest conifer with ≥65% conifer, Douglas fir dominant, well-stocked, diameter class 4, planted around 1890	1.49
139	FCO D4-=1880	Forest conifer with ≥65% conifer, Douglas fir dominant, well-stocked, diameter class 4, planted around 1880	2.70
	FMX D4=1880//RA3M3-1900	Forest mix with between 35-65% conifer and the rest hardwood. Douglas fir dominant in upper story, medium stocked, with diameter class 4, planted around 1880. Red alder and big-leaf maple dominant in understory, under stocked, diameter class 3, planted around 1900	2.61
	FMX D4-1880//HD3=1910	Forest mix with between 35-65% conifer and the rest hardwood. Douglas fir dominant in upper story, under stocked, diameter class 4, planted around 1880. Hard woods dominant in understory, medium stocked, diameter class 3, planted around 1910	6.77
Total			20.00

* poorly stocked 10-39% cover, medium stocked 40-69% cover, well stocked 70-100% cover; diameter class 2 5-11-inch diameter breast height diameter class 3 11-21-inch diameter breast height, diameter class 4 >21-inch diameter breast height; diameter class 5 large old growth +21-inch diameter breast height.

Moreover, PCGP's Proposed Route in this area was sited in large part along an existing gravel road to minimize the amount of tree removal, habitat fragmentation, and creation of new edges. In addition, although the DEIS's suggestion that it would take 80 years to replace the LSOG impacts (which are 23.8 acres, and not 40.5 acres, as discussed above) is true, PCGP's proposed protections of late-successional reserves on federal lands will increase LSOG habitat many times greater than 23.8 acres over the life of the Project based on BLM projections cited above regarding aging stands.[42]

In summary, the DEIS relies on textbook rather than *in situ* conditions to conclude that LSOG habitat on PCGP's Proposed Route is "particularly valuable" and "more sensitive." Furthermore, there is no old growth habitat located along either FERC's Blue Ridge Variation or PCGP's Proposed Route. Growth rates suggest that temporal loss would be offset in less than 80

[42] See footnote 40 and associated text.

years by maturation of mid-seral forests from late-successional reserve protections proposed for the Pipeline on federal lands.

2. Marbled Murrelet and Northern Spotted Owl

PCGP acknowledges that protocol surveys and desktop analyses have documented more occupied and presumed occupied MAMU stands along PCGP's Proposed Route than along FERC's Blue Ridge Variation. Although there are more occupied MAMU stands, potential impacts to MAMU habitat are not measurable in terms of affecting population trends. Even though adverse effects may be measurable at the individual level, they will not be measurable at the population level.

The area of impacts to NRF habitat would be greater along PCGP's Proposed Route than FERC's Blue Ridge Variation. However, DEIS Table 3.4.2.2-1 contains an error that merits correction.[43] The number of acres of removal of LSOG habitat (a clerical error, incorrectly listed as 40.5 acres) should be the same as removal of High NSO NRF and NRF: 23.8 acres, a difference of about 15 acres between the two routes. For the reasons above, PCGP does not believe this difference can be found to be significant in the context of the available habitat.

Overall, the amount of MAMU and NSO habitat removed would be about 2,076 acres along PCGP's Proposed Route. Habitat removed along the entirety of FERC's Blue Ridge Variation would amount to about 2,092 acres, reflecting the fact that FERC's Blue Ridge Variation is longer than PCGP's Proposed Route. Impacts to LSOG (or NRF) habitat would be 501.8 acres and 516.77 acres for FERC's Blue Ridge Variation and PCGP's Proposed Route, respectively. In the context of the entire route, the difference of 15 acres amounts to a difference of only approximately 3 percent. To put this in context, forest habitat between MP 0 and MP 190 amounts to 2,109 acres, based on PCGP's Proposed Route. In other words, in either alternative, over 98 percent of forested habitat within the construction corridor would be removed. FERC's Variation is not significantly different than PCGP's Proposed Route from a quantitative perspective. Since most of the LSOG on PCGP's Proposed Route does not have the functional characteristics of "particularly valuable" habitat, there is similarly not a significant difference between the routes from a qualitative perspective.

The DEIS notes that PCGP's Proposed Route would pass through 0.47 more miles of an NSO home range than FERC's Blue Ridge Variation.[44] The NSO home range crossed by both routes is one and the same. Missing in the DEIS's summarized analysis is that neither route would result in the removal of NRF habitat within the NSO home range. Furthermore, habitat crossed by PCGP's Proposed Route would be pasture and a recent clear-cut, whereas the habitat crossed on FERC's Blue Ridge Variation would be pasture only. For NSO, the quality of the impacts across a portion of one NSO home range does not confer a significant advantage to FERC's Blue Ridge Variation.

The DEIS recommends selecting FERC's Blue Ridge Variation over PCGP's Proposed Route, in part, based on the number of MAMU stands that would be impacted. In late 2018 and early 2019, PCGP gained access to a number of parcels previously identified as Presumed

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[43] DEIS at 3-23.
[44] *Id.* at 3-20.

suitable/Presumed occupied habitat. Upon further field investigation, PCGP was able to eliminate stands as not having suitable nesting structure, reducing the number of Occupied/Presumed occupied stands from 21 to 17 (3 Occupied, 14 Presumed occupied) along PCGP's Proposed Route.[45] PCGP has now confirmed only 3 Presumed occupied stands on FERC's Blue Ridge Variation. This reduces the difference between Occupied/Presumed occupied on PCGP's Proposed Route and FERC's Blue Ridge Variation from 17 to 14.

The analysis of MAMU habitat assumes that impacts to MAMU habitat would have a negative effect on MAMU population numbers; however, this is not supported by the existing scientific literature. MAMU population trends in Oregon from 2000 to 2016 indicate that MAMUs in Oregon are slowly recovering, not merely sustaining themselves.[46] There are more than 4,300 documented known nest sites or occupied sites in Oregon, plus vast amounts of un-surveyed habitat.[47] Given this data, the reasonable conclusion to be drawn is that there is ample habitat in Oregon to sustain MAMU over time, notwithstanding modest impacts to small portions of their habitat.

According to joint at-sea monitoring by the U.S. Fish and Wildlife Service and the U.S. Forest Service, as of 2017, Oregon had more MAMUs (10,060 birds) than each of Washington (7,095 birds) and California (6,073 birds).[48] From 2000 to 2016, the at-sea population of MAMU in Oregon has increased at an average annual rate of change of 1.8%.[49] Over a similar time period, 1993 to 2012, the U.S. Fish and Wildlife Service and the U.S. Forest Service estimated that a net of 59,200 acres of higher suitability murrelet habitat was lost in Oregon due to timber harvest on non-federal lands.[50] Federal agency researchers have observed while "murrelet nesting habitat seems to be the primary driver of murrelet population status and trend, at least in recent decades, […] that relationship has not been tested empirically and a cause-effect relationship has not been established."[51]

In developing a nest distribution model for Oregon, Washington and California, the U.S. Fish and Wildlife Service and the U.S. Forest Service utilized records of more than 4,300

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[45] *See* Appendix 1 (Edge Environmental, Inc., Summary of Recent Marbled Murrelet Habitat Surveys Conducted along PCGP's Blue Ridge Proposed Route and FERC's Blue Ridge Variation, June 27, 2019).
[46] Pearson, Scott F., B. McIver, D. Lynch, J. Baldwin, N. Johnson, M. M. Lance, M.G. Raphael, C. Strong, R. Young, Marbled Murrelet Effectiveness Monitoring: Northwest Forest Plan, U.S. Forest Service. May 2018, available at https://www.fs.fed.us/r6/reo/monitoring/murrelet/NwfpAnnualMonitoringReportMurrelet2018.pdf [hereinafter Pearson et. al 2018].
[47] Falxa, G. A., M. G. Raphael, C. Strong, J. Baldwin, M. Lance, D. Lynch, S. F. Pearson, and R.D. Young. 2016. Status and trend of Marbled Murrelet populations in the Northwest Forest Plan area. Pages 1-36 in Northwest Forest Plan – the first 20 years (1994-2013): status and trend of Marbled Murrelet populations and nesting habitat, General Technical Report PNW-GTR-933 (G.A. Falxa and M. G. Raphael, Tech. Coords.). U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station Portland, Oregon, available at https://www.fs.fed.us/pnw/pubs/pnw_gtr933.pdf [hereinafter Falxa et al. 2016].
[48] Pearson *et al.* 2018.
[49] *Id.*
[50] Falxa *et al.* 2016.
[51] Raphael, M.G.; Falxa, G.A.; Burger A.E. 2018. Synthesis of Science to Inform Land Management Within the Northwest Forest Plan Area; Volume 1, Chapter 5: Marbled Murrelets. Gen. Tech. Rep. PNW-GTR-966. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, available at https://www.fs.fed.us/pnw/pubs/pnw_gtr966_vol1.pdf.

individual known nest sites or surveyed "occupied sites" located in Oregon.[52] That is 1 potential nesting site for every 2.3 MAMUs (10,060 birds/4,300 sites) in Oregon. Given that MAMU nest in pairs and only nest every other year, that is nearly double the number of nest sites needed to fulfill the nesting needs of a 10,000-bird population. There are also large areas of potentially suitable habitat in Oregon that have not been surveyed for nests or MAMU presence.[53]

Consistent with the phenomenon that MAMUs in Oregon have been increasing at the same time that potentially suitable habitat has been slowly declining (primarily on private land and as a result of wildfires), researchers of MAMUs in California have hypothesized that "habitat availability is not presently limiting reproductive output."[54] They observed that despite the fact that MAMU habitat quantity and quality in California has remained relatively stable, the habitat remains underutilized.[55] This has also been observed by Peery and Henry,[56] where they found that decreasing corvid predation rates would be more likely to increase MAMU populations than increasing the amount of nesting habitat. Nest success rates are low, estimated between 23 and 46% in modeling conducted by McShane *et al*.[57] There are a number of factors that contribute to low rates of nesting success, among them, ocean conditions where the U.S. Fish and Wildlife Service believes that "murrelet reproduction is likely caused by a shift to a reduced trophic level of available prey."[58] Falxa, *et al*. also acknowledged that prey abundance may play a role in MAMU distribution and trends.[59]

Impacts to MAMU stands along PCGP's Proposed Route would not result in the loss of a stand in its entirety, nor necessarily result in a significant loss of nest sites. The degree to which MAMU exhibit nest-site fidelity at various spatial scales was reviewed by Plissner *et al*. and contributes to the understanding of the scale at which habitat may be affected.[60] A review of the literature by Plissner *et al*. indicated that there is stronger evidence of nest-fidelity at the watershed

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[52] Falxa *et al*. 2016.
[53] *Id*.
[54] Colwell, M.A., T.L. George, and R.T Golightly. 2009. A predator management strategy to address corvid impacts on productivity of Snowy Plovers (*Charadrius alexandrinus*) and Marbled Murrelets (*Brachyramphus marmoratus*) in coastal northern California. Final Report submitted to U.S. Fish and Wildlife Service, Arcata, CA. 115 pp., available at https://www.researchgate.net/publication/281524653_A_Predator_Management_Strategy_to_Address_Corvid_Impacts_on_Productivity_of_Snowy_Plovers_Charadrius_alexandrinus_and_Marbled_Murrelets_Brachyramphus_marmoratus_in_Coastal_Northern_California.
[55] *Id*.
[56] Peery, Z.P. and Henry, R.W. Recovering marbled murrelets via corvid management: A population viability analysis, Biological Conservation 143 (2010); 2414-2424, available at https://www.fs.fed.us/pnw/pubs/journals/pnw_2010_peery001.pdf.
[57] McShane, C., T. Hamer., H. Carter, G. Swartzman, V. Friesen, D. Ainley, R. Tressler, K. Nelson, A. Burger, L. Spear, T. Mohagen, R. Martin, L. Henkel, K. Prindle, C. Strong, and J. Keany. 2004. Evaluation report for the 5-year status review of the Marbled Murrelet in Washington, Oregon, and California. Report prepared for the U.S. Fish and Wildlife Service, Region 1, Portland, Oregon. EDAW, Inc., Seattle, Washington, available at https://www.fws.gov/wafwo/species/Fact%20sheets/5%20Year%20Status%20Review%202004.pdf.
[58] U.S. Fish and Wildlife Service, 2009. Marbled Murrelet (Brachyramphus marmoratus) 5-Year Review. Lacey, WA. June 12, 2009, p. 22.
[59] Falxa *et al*. 2016.
[60] Plissner, J.H., B. A. Cooper, R. H. Day, P. M. Sanzenbacher, A.E. Burger, M. G. Raphael 2015.A Review of Marbled Murrelet Research Related to Nesting Habitat Use and Nest Success. Final Report. Oregon Department of Forestry, Salem, OR. September 2015, available at https://www.oregon.gov/ODF/Documents/WorkingForests/ReviewofMAMUResearchRelatedToNestingHabitatUseandNestSuccess.pdf.

or stand level than to a specific tree or limb on a tree.[61] Thus, it is inappropriate to conclude that partial removal of a suitable stand or removal of some nest trees would equate to a significant loss of nesting habitat or a significant decline in the population.

PCGP acknowledges that removing trees through a suitable stand could create new edges and subject nesting MAMU to a higher risk of predation. PCGP acknowledged this potential impact by routing PCGP's Proposed Route on a ridge line, along existing roads, and along the edges of stands in order to minimize creating new edge effects and impacting interior forest habitat.

In the Cumulative Effects discussion, the DEIS concluded that "the resulting cumulative impact of the Project and other projects would not be significant because of the total amount of land and habitat affected relative to the amounts available within the watersheds crossed and wildlife's general ability to avoid construction activities."[62] The DEIS acknowledges that many federally protected species in the Project area depend on LSOG for one or more life stages.[63] However, there is a lack of evidence in the DEIS to support the assumption that all LSOG is "particularly valuable," or the assumption of the extent to which impacts to the habitat on which MAMU depend (from PCGP's Proposed Route) is limiting recovery.

Furthermore, in light of recent MAMU population estimates showing population growth in the face of habitat loss and data indicating ocean conditions are likely a limiting factor to successful reproduction, the DEIS does not support a conclusion that Project impacts would necessarily lead to a decline in the MAMU population. Nor is there conclusive evidence that the difference in impacts to stands or area of suitable habitat between PCGP's Proposed Route and FERC's Blue Ridge Variation would be of a magnitude that could be measurable at the population level for Oregon, in general, or within Conservation Zones 3 and 4 where the Project is located. Therefore, even without taking mitigation into consideration, the DEIS does not support recommending FERC's Blue Ridge Variation as having significant environmental advantages over PCGP's Proposed Route based on the information presented.

3. Mitigation for LSOG/MAMU Impacts

The DEIS states that the Applicants have not proposed mitigation for permanent impacts to LSOG and MAMU habitat.[64] This statement overlooks the mitigation plans and related discussions and commitments in DEIS Appendix F.2 *Forest Service Proposed Amendments and CMP*. PCGP is committed to funding the listed projects. Projects listed in Appendix F.2 would occur on over 6,500 acres, accelerating the creation of functional LSOG and reducing the risk of high-intensity fire that would benefit MAMU and NSO and thus off-set the temporal loss of potentially suitable habitat as well as disturbance/disruption impacts.

PCGP is also committed to funding projects on BLM land, designed for similar purposes. The BLM list of projects, although not provided in the DEIS as they were under review by PCGP, are commitments PCGP is making voluntarily to offset low quality capable habitat and disturbance/disruption. The list of projects on BLM lands includes fuel reduction on 2,553 acres

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[61] *Id.*
[62] DEIS at 7-797.
[63] *Id.*
[64] *Id.* at 3-20.

that would reduce risk of loss of developing and existing mature stands to high-intensity fire. These fuel reduction projects would address wildfire risks, which are a major threat to MAMU and NSO habitat. The combination of Forest Service and BLM projects would amount to over 9,000 acres of forest management treatments that would benefit MAMU and NSO.

PCGP is negotiating with one or more private timber companies to acquire a minimum of 1,500 acres of private forest land in the Oregon Coast range to off-set impacts to MAMU and NSO habitat. Approximately 1,000 acres of late-seral (age class 112 to 160 years) and old growth (200+ years) would be acquired and preserved, roughly twice the amount of LSOG that would be removed. Approximately 500 acres of mid-seral (age class 40 to 80 years) and early-seral stage (age class 0 to 40 years) would be preserved. In the absence of acquisition and preservation, stands in the age class 40 to 120 years will be scheduled for harvest within 1 to 5 years. The DEIS suggested that it would take 80 years to replace LSOG trees harvested in the Pipeline right-of-way.[65] Preservation of trees in age class 40 to 120 years would replace LSOG in less than 80 years. PCGP is targeting privately-owned in-holdings within the proclamation boundaries of Forest Service land or parcels adjacent to BLM or state forest lands. Geographic location of acquisitions would increase interior forest habitat, off-setting creation of edge effect and interior forest impacts, thereby increasing the value of these lands in terms of mitigating impacts from the Pipeline.

In addition, PCGP is proposing to provide $350,000 (plus reasonable administrative overhead) to support a program, identified by the U.S. Fish and Wildlife Service, to reduce MAMU nest predation. The supported program would be designed to reduce nest predation by corvids, generally through public outreach efforts (including seasonal interpretive rangers and materials) and control of anthropogenic food sources at Oregon State Parks that support or are adjacent to MAMU suitable habitat. Nest predation was identified as a threat to MAMU survivorship in the MAMU Recovery Plan.[66]

Similarly, PCGP is proposing to provide $197,400 (plus reasonable administrative overhead cost) to support the barred owl management program in a manner identified by the FWS. This mitigation would address the threat of barred owls, an integral part of the NSO recovery plan strategy.[67]

PCGP anticipates finalizing these proposed mitigation measures during summer 2019 and will file supporting documentation regarding these commitments with the Commission without delay.

In sum, PCGP is committed to providing habitat mitigation equivalent to approximately 10,500 acres through a combination of management activities and land acquisition, which is over double the total acreage of habitat removal (all types) over the length of the Pipeline (about 4,500

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[65] *Id.* at 3-21.

[66] U.S. Fish and Wildlife Service. 1997. Recovery Plan for the Threatened Marbled Murrelet (*Brachyramphus marmoratus*) in Washington, Oregon, and California, Portland, Oregon. 203 pp.

[67] U.S. Fish and Wildlife Service. 2011. Revised Recovery Plan for the Northern Spotted Owl (*Strix occidentalis caurina*). U.S. Fish and Wildlife Service, Portland, Oregon. xvi + 258 pp.

acres); more than 4 times the forested acreage along the Pipeline (approximately 2,100 acres); and 20 times the amount of LSOG or NRF habitat (approximately 517 acres).[68]

4. Waterbody Crossings and Impacts to Fish

The DEIS discusses the tradeoff between terrestrial and aquatic resource impacts and concludes that FERC Staff's "experience from reviewing stream crossings by FERC-regulated pipelines constructed in numerous habitats across the U.S. has confirmed that the short duration of the crossing and the prompt restoration of the stream bed and stabilization of the stream banks results in very few impacts on waterbodies that extend in time beyond the construction and initial restoration of the right-of-way."[69] Stream crossings along FERC's Blue Ridge Variation pose greater risks that stream crossings along PCGP's Proposed Route. Based on the Stream Crossing Risk Analysis, a document commissioned by PCGP which relies on methodology utilized by the U.S. Fish and Wildlife Service "to focus resources on those waterbody pipeline crossings that present the greatest risk of impacts to beneficial uses through construction impacts or maintenance of the pipeline over the life of the project,"[70] PCGP's Proposed Route would not cross any high risk streams.

The same is not true for FERC's Blue Ridge Variation, which would cross six. PCGP's Proposed Route would cross only 5 moderate risk streams, but FERC's Blue Ridge Variation would cross 20.[71] This reveals that there are more potential impacts from FERC's Blue Ridge Variation, which creates less certainty in the restoration success of these crossings, five of which are critical habitat for coho salmon.

As described in the DEIS, FERC's Blue Ridge Variation would cross 41 perennial streams and 23 intermittent streams, whereas PCGP's Proposed Route would cross 4 perennial and 4 intermittent streams."[72] As such, FERC's Blue Ridge Variation Route crosses eight times as many streams as PCGP's Proposed Route.

In addition, the DEIS states that PCGP's Proposed Route would cross the Coast Range and within "those mountains, the pipeline route would follow ridgelines, where feasible, to minimize the amount of cut and fill, and to avoid steep slopes, geologic hazards, and waterbody crossings, and to reduce erosion potential."[73] FERC's Blue Ridge Variation is largely sited outside of ridgelines, which results in potentially riskier waterbody crossings as shown through the Stream Crossing Risk Analysis discussed above and summarized in Table 3 below.

a. Coho and Green Sturgeon Occupied Streams and Critical Habitat

The DEIS states that of the streams crossed by FERC's Blue Ridge Variation, 14 are known or assumed to support anadromous species (including essential fish habitat [EFH] and Endangered

[68] *See id.* at 2-34 and 2-35 (Table 2.1.5-1 summarizing mitigation projects on National Forest Service Lands); DEIS Appendix F.2.
[69] *Id.*
[70] GeoEngineers. April 6, 2018. Stream Crossing Risk Analysis Addendum.
[71] These data do not match data provided in Table 3.6.2.1-1 in DEIS Appendix F.9, which PCGP was unable to replicate.
[72] DEIS at Appendix F.9 3-67.
[73] *Id.* at 2-59.

Species Act [ESA] species) and 12 are known or assumed to support resident fish species.[74] Of the streams crossed by PCGP's Proposed Route, only four are known or assumed to support anadromous fish species (including EFH and ESA species) and only five are assumed to support resident species.[75]

The DEIS failed to include coho and green sturgeon critical habitat in the comparative analysis of the Proposed Route and FERC's Blue Ridge Variation, and critical habitat is only addressed in Table 3.4.2.2-1. FERC's Blue Ridge Variation would cross five streams that are designated critical habitat; five for coho and four for green sturgeon. There are an additional six waterbodies between 250 and 2,000 feet downstream of dry open cut crossings with designated critical habitat. PCGP's Proposed Route would cross four streams designated as critical habitat for coho.

FERC's Blue Ridge Variation coho and green sturgeon critical habitat crossings have more potential impacts than PCGP's Proposed Route crossings. Based on the Stream Crossing Risk Analysis Addendum commissioned by PCGP, of the five crossings in FERC's Blue Ridge Variation, two are rated high risk (orange; Stock Slough and Catching Slough) and one is rated moderate risk (yellow; Catching Creek).[76] The remaining two crossings along FERC's Blue Ridge Variation and the four crossings along PCGP's Proposed Route would be assessed after access is granted.

Overall, coho and green sturgeon critical habitat impacts must be reviewed in the collective aquatic environment assessment due to the inherent risks associated with choosing a route with greater potential impacts as shown by the Stream Crossing Risk Analysis Addendum.

b. Riparian Area Impacts

FERC's Blue Ridge Variation and PCGP's Proposed Route would impact 103 and 50 acres of riparian area, respectively. FERC's Blue Ridge Variation would result in two times more impact to riparian area than PCGP's Proposed Route.

c. Riparian Reserve Impacts

FERC's Blue Ridge Variation and PCGP's Proposed Route would impact 12.3 and 9.1 acres of riparian reserves, respectively. PCGP's Proposed Route would impact 26 percent less riparian reserve than FERC's Blue Ridge Variation. In a broader geographic context, "the overall impacts to the Riparian Reserve within each fifth-field watershed would equate to less than one percent of the total area of the Riparian Reserve managed by BLM in these watersheds."[77]

d. Water Quality Limited Crossings

In terms of water quality, the specific focus for PCGP's Pipeline has been on temperature, turbidity/sedimentation, dissolved oxygen, and nutrients, where instream construction, hydraulic

[74] *Id.* at Appendix F.9 3-67
[75] *Id.*
[76] GeoEngineers. April 6, 2018. Stream Crossing Risk Analysis Addendum.
[77] DEIS at Appendix F.9, 3-12.

disconnection, and unstable channels following pipeline construction could potentially degrade water quality and aquatic habitat resources.[78] Based on the DEIS, FERC's Blue Ridge Variation and PCGP's Proposed Route would cross four and one streams, respectively, that are water quality limited.[79] Of these, FERC's Blue Ridge Variation would cross one stream listed for temperature and another listed for dissolved oxygen, whereas PCGP's Proposed Route would not cross streams listed for these focal criteria (Table 2).

Table 2. Water Quality Limited Streams Crossed by PCGP's Proposed Route and FERC's Blue Ridge Variation

PCGP's Proposed Route	
Stock Slough	Fecal Coliform/Year-Round
FERC's Blue Ridge Variation *	
Stock Slough	Fecal Coliform/Year-Round
Catching Slough	Fecal Coliform/Year-Round
Catching Creek	Fecal Coliform/Year-Round; Temperature; Biocriteria**
Cunningham Creek	Fecal Coliform/Year-Round; Dissolved Oxygen/Year-Round; Habitat Modification; Flow Modification

* Ross Slough listed in DEIS table 3.4.2.1-1, but not crossed by FERC's Blue Ridge Variation.

**Temperature and Biocriteria not included in DEIS table 3.4.2.1-1.

5. Floodplain Impacts

Executive Order 11988 mandates federal agencies to "avoid to the extent possible the long- and short-term adverse impacts associated with the occupancy and modification of floodplains and to avoid direct or indirect support of floodplain development wherever there is a practicable alternative."[80] However, floodplains are not analyzed in the DEIS's analysis of FERC's Blue Ridge Variation. Using GIS, PCGP overlaid FERC's Blue Ridge Variation and PCGP's Proposed Route onto FEMA Floodplain maps.[81] FERC's Blue Ridge Variation and PCGP's Proposed Route would cross 11,459 linear feet (2.17 miles) and 4,303 linear feet (0.82 mile) of mapped 100-year floodplain, respectively. FERC's Blue Ridge Variation would require an additional 7,156 linear feet (1.35 miles) of impact to floodplains above that required by PCGP's Proposed Route.

6. Landowner Considerations

a. Number of Private and Public Landowners

Although the DEIS lists the number of private and public parcels the routes would cross, the number of landowners along the two routes is not analyzed. FERC's Blue Ridge Variation would impact more than twice the number of private landowners (31) as PCGP's Proposed Route (12). As of March 2019, of the 31 private landowners on FERC's Blue Ridge Variation, 17 are

[78] GeoEngineers. April 6, 2018. Stream Crossing Risk Analysis Addendum.
[79] DEIS at Appendix F.9, Table 3.4.2.1-1, 3-29
[80] 42 Fed. Reg. 26951 (May 24, 1977).
[81] See geospatial data from the FEMA National Flood Hazard Layer, available at https://www.fema.gov/national-flood-hazard-layer-nfhl.

intervenors, representing 30 percent of the 54 total intervenors along the entire pipeline route who oppose acquisition of a ROW across their lands. Unless these owners reverse their current position, PCGP will likely have to exercise eminent domain to acquire the necessary land interests.

In addition, as of June 2019, PCGP has acquired easements for eight of 12 private landowners (67%) along PCGP's Proposed Route.

As part of the Commission's public interest review for new pipeline construction under the Natural Gas Act, the Commission has a goal to give appropriate consideration to, among other things, the avoidance of unnecessary disruptions of the environment as well as the unneeded exercise of eminent domain.[82]

b. Prime Farmland and Exclusive Farm Use

Based on DEIS Tables 3.3.1-2a and b,[83] FERC's Blue Ridge Variation (3.9 miles, 74 acres) would affect more than twice as many acres of designated prime farmland as PCGP's Proposed Route (1.9 miles, 31 acres). The intensity of impacts to "unique characteristics of the geographic area such as proximity to…prime farmlands" is a specific factor to be considered in determining whether effects are significant under NEPA.[84] Similarly, FERC's Blue Ridge Variation would cross more than three times the length of land designated exclusive farm use (2.6 miles) than PCGP's Proposed Route (0.8 mile).[85]

7. Geological Resources

As shown in the DEIS, there are 5 landslide areas (7,137 linear feet) crossed by FERC's Blue Ridge Variation, with only 2 landslide areas (3,267 linear feet) crossed by PCGP's Proposed Route.[86]

8. Conclusion

The DEIS described the primary tradeoffs that factored into the recommendation as "between terrestrial (e.g., LSOG forest and MAMU stands/habitat) and aquatic resources (e.g., waterbody crossings and anadromous fish habitat), as well as public and private lands."[87] FERC Staff's recommendation is based on an "overall advantage" without concluding that the advantage would be significant. PCGP's analysis shows that FERC's Blue Ridge Variation would not confer a ***significant*** environmental advantage, and therefore, PCGP disagrees with the DEIS recommendation that FERC's Blue Ridge Variation be incorporated into the Proposed Route between MPs 11 and 25.

In light of the increasing population of MAMU, knowledge about the importance of foraging conditions in the ocean, and the insignificant amount of difference in removal of LSOG habitat between PCGP's Proposed Route and FERC's Blue Ridge Variation, the DEIS does not

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[82] *Certification of New Interstate Natural Gas Pipeline Facilities, Statement of Policy*, 88 FERC ¶ 61,227 at 2 (1999).
[83] DEIS at Appendix F.9, 3-22 and 3-23.
[84] 40 C.F.R. § 1508.27(b)(3).
[85] DEIS at Appendix F.9, 3-6.
[86] *Id.* at 3-23.
[87] DEIS at 3-20

contain sufficient evidence to support a conclusion that PCGP's Proposed Route would have a significant negative effect on MAMU population numbers, or that FERC's Blue Ridge Variation would provide significant environmental advantages to MAMU.

PCGP is committed to mitigating the impacts stemming from the Pipeline. Collectively, these voluntary mitigation actions would more than offset impacts due to habitat removal, temporal loss of habitat, edge effects, and loss of interior habitat.

In light of this and PCGP's analysis on the magnitude and intensity of impacts to LSOG habitat, negligible impacts to the MAMU population, and mitigation commitments, the DEIS does not support the conclusion that there would be a significant environmental advantage of FERC's Blue Ridge Variation over PCGP's Proposed Route.

With respect to stream crossings, floodplain, and landowner impacts, the number of stream crossings on FERC's Blue Ridge Variation would be eight times that of PCGP's Proposed Route and would impact streams with high risk classifications. The distance of floodplain crossings would be two times greater on FERC's Blue Ridge Variation than PCGP's Proposed Route. Similarly, the number of landowners, many of whom are intervenors, would be two times greater on FERC's Blue Ridge Variation than PCGP's Proposed Route. Balancing the trade-offs between LSOG/MAMU habitat impacts, streams, and landowners does not demonstrate a significant advantage of FERC's Blue Ridge Variation over PCGP's Proposed Route.

PCGPs findings are summarized in Table 3.

Table 3. DEIS and PCGP's Comparison of Impacts between the PCGPs Proposed Route and FERC's Blue Ridge Variation.

Impact/Issue	DEIS		PCGP's Analysis	
	PCGP's Proposed Route	FERC's Blue Ridge Variation	PCGP's Proposed Route	FERC's Blue Ridge Variation
Late-Successional Old Growth (LSOG)	40.5 acres	8.89 acres	23.8 acres (no old growth impacts, most stands lack textbook functional characteristics)	8.8 acres (no old growth impacts)
Late-Successional Reserves (LSR)	5.5 mile/12.3 acres	0.4 mile/5.2 acres	5.5 mile/12.3 acres	0.4 mile/5.2 acres
Marbled Murrelet	Implies habitat impacts would contribute to population decline	Implies habitat impacts would result in less population decline than the PCGP's Proposed Route	No measurable decline in population. No evidence that LSOG is limiting recovery.	No measurable decline in population. No evidence that LSOG is limiting recovery.

Impact/Issue	DEIS		PCGP's Analysis	
	PCGP's Proposed Route	**FERC's Blue Ridge Variation**	**PCGP's Proposed Route**	**FERC's Blue Ridge Variation**
Northern Spotted Owl	Not a significant issue	Not a significant issue	Not a significant issue	Not a significant issue
Waterbody Crossing Risk Categories	3 yellow (moderate) 4 blue (low) 1 green (low) (Table 3.6.2.1-1 Appendix F.9)	6 orange (high) 21 yellow (moderate) 20 blue (low) (Table 3.6.2.1-1 Appendix F.9)	5 yellow (moderate)	6 orange (high) 20 yellow (moderate) 8 blue (low)
Waterbody Crossings	64 (41 perennial/ 23 intermittent)	8 (4 perennial/4 intermittent)	64 (41 perennial/ 23 intermittent)	8 (4 perennial/4 intermittent)
Waterbody Crossings with Designated Critical Habitat	4 total 4 coho 0 green sturgeon	10 total 7 coho 3 green sturgeon	4 total 4 coho 0 green sturgeon	10 total 7 coho 3 green sturgeon
Riparian Area	50 acres	103 acres	50 acres	103 acres
Riparian Reserve	13.5 acres (Table 3.1.4.3-2) 12.3 acres (Table 3.4.2.2-1)	15.8 acres (Table 3.1.4.3-2) 9.1 acres (Table 3.4.2.2-1)	12.3 acres	9.1 acres
Water Quality Limited Crossings/ Water Quality Limited Crossings for Focal Criteria	1	4	1 0	4 2
Floodplains	Not included	Not included	11,459 linear feet	4.303 linear feet
Number of landowners	Not included	Not included	23 private landowners, 3 public landowners	53 private landowners, 2 public landowners
Number of parcels crossed	36 24 private, 12 public	55 53 private, 2 public	38 23 private, 15 public	67 53 private, 14 public
Prime Farmland	1.9 miles	3.9 miles	1.9 miles/31 acres	3.9 miles/74 acres

Impact/Issue	DEIS		PCGP's Analysis	
	PCGP's Proposed Route	FERC's Blue Ridge Variation	PCGP's Proposed Route	FERC's Blue Ridge Variation
Exclusive Farm Use	0.8 mile	2.6 miles	0.8 mile	2.6 miles
Landslides	2 crossed (3,267 linear feet)	5 crossed (7,137 linear feet)	2 crossed (2,367 linear feet)	5 crossed (7,137 linear feet)

III. <u>Section 106 Review</u>

The Commission Staff has conflated the Section 106 requirement to consult with interested Tribes in order to make a good-faith effort to identify resources within the Area of Potential Effect ("APE"), with the broader—and voluntary—ethnographic study of tribal cultural resources that Applicants agreed to support as part of the Cultural Resources Working Group.

Section 106 of the National Historic Preservation Act ("NHPA") requires federal agencies "take into account the effect [of any federal undertaking] on any historic property."[88] This process includes consulting with interested Tribes to identify and evaluate properties with "religious [or] cultural significance *that may be affected by [the] undertaking*."[89] The agency must make a "reasonable and good faith effort to carry out appropriate identification efforts."[90] The required identification of properties potentially affected by the undertaking, however, is limited to the Project's APE. A "reasonable and good faith identification" of eligible properties "does *not* require . . . investigations outside of, or below, a properly documented APE."[91] "Because the APE defines the geographic limits of federal agency responsibility for purposes of Section 106 review, identification efforts are carried out within its boundaries."[92]

In its June 9, 2017 Notice of Intent and the DEIS, the Commission defined the Project's APE to encompass "all areas subject to ground disturbance," from the construction, operation, and maintenance of the LNG terminal and pipeline, "including the construction right-of-way, temporary extra work spaces, contractor/equipment storage yards, disposal areas, aboveground facilities, and new or to-be-improved access roads."[93] The APE may also encompass properties that are not subject to ground disturbance, but are subject to noise or visual impairments that affect the characteristics for which a historic property is listed or determined eligible for listing.[94] The scope of Applicants' identification efforts relating to properties within the direct APE are documented in Appendix L of the DEIS. Even with the inclusion of the traditional cultural property currently under consideration by the Oregon State Historic Preservation Office and the

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[88] 54 U.S.C. § 306108.
[89] 36 C.F.R. § 800.2(c)(ii) (emphasis added).
[90] 36 C.F.R. § 800.4(b)(1).
[91] Advisory Council on Historic Preservation, Meeting the "Reasonable and Good Faith" Identification Standard in Section 106 Review, at 3 (Nov. 15, 2011) (emphasis added).
[92] *Id.*
[93] DEIS at 4.11.2.
[94] *See id.* at 4.11.2.1 – 4.11.2.2.

National Park Service, Applicants have not identified, and no Tribe has brought to Applicants' attention, any listed or potentially eligible property that might be indirectly affected outside the area of direct ground-disturbing activity.

Nonetheless, Commission Staff recommends as a condition necessary to satisfy Section 106 that "Jordan Cove and Pacific Connector shall file with the Secretary a revised Ethnographic Report describing sites of religious and cultural significance to Indian Tribes and other tribal information as outlined in the FERC Staff's October 23, 2018 environmental information request." Many of the activities requested by Commission Staff and various Tribes in the context of this broader ethnographic study fall well outside the APE, and are therefore beyond the scope of Section 106 consultation. The Commission Staff takes the position, for example, that the Ethnographic Report should identify "historical villages, burials, ritual stone cairns, plant harvesting areas, and key fishing sites of the Klamath and Modoc people," with no limitation on where these sites are located in relation to the APE. Many of these sites are located well beyond any rational limit of even the indirect effects of the Project, and as a result outside any possible definition of the APE.[95] The Klamath people "lived along the Klamath Marsh, on the banks of Agency Lake, near the mouth of the Lower Williamson River, on Pelican Bay, beside the Link River, and in the uplands of the Sprague River Valley."[96] The Modoc people lived along "the Lower Lost River, around Clear Lake, and the territory that extended south as far as the mountains beyond Goose Lake."[97] Pelican Bay is over 100 miles from the nearest part of the Project; Clear Lake is over 150 miles from the nearest part of the Project; Goose Lake is over 50 miles from the nearest part of the Project. Identification of sites in these (and other) areas outside the APE of the Project is well beyond the scope of the NHPA Section 106 process.

As further detailed in Appendix 2, Applicants have made extensive efforts to work with the relevant Tribes, the Oregon State Historic Preservation Officer (or "SHPO"), and other consulting parties to identify and evaluate properties within the APE, as defined by FERC. Applicants made two separate formal attempts to fund and conduct ethnographic studies within the APE. The first, offered in November 2018, offered each Tribe funding in the amount of $25,000 to support an ethnographic study of lands used or crossed by the Jordan Cove Energy Project and the Pacific Connector Gas Pipeline. In its letter, Applicants asked for this information by June 25, 2019, so that it could be used by FERC in its Section 106 consultation and by Applicants to inform their proposed avoidance, minimization and mitigation measures.

In response to concerns expressed by some Tribes that the area for ethnographic study area was not broad enough, the amount of funding was insufficient, and the time requirement too restrictive, Applicants made a further attempt to work with the Tribes, culminating in a letter that was sent in March 2019. In that letter, Applicants again requested Tribal assistance in identifying

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[95] Among other issues, FERC Staff also seeks to have Applicants submit a revised Ethnographic Report including such elements as: a review of ethno-historical sources such as observations of early Euro-American fur traders, missionaries, explorers, Indian agents, and settlers (apparently without any geographic limitations); identification of sites used by the Takelma for subsistence, seasonal settlement, and ritual activity between Cow Creek and Spencer Creek; identification of historical villages, burials, ritual stone cairns, plant harvesting areas, and key fishing sites of the Klamath and Modoc people; and details about the Yurok Tribe's Klamath River "Riverscape", which the Applicants understand is located in California.

[96] History, The Klamath Tribes, *available at* http://klamathtribes.org/history/.

[97] *Id.*

properties within the project area that held religious and cultural significance for the Tribes. Tribes were offered $25,000 for this undertaking, and asked to provide this information by August 30, 2019. Further, although Applicants do not believe that an ethnographic study that encompasses areas outside the APE is required by NHPA, in the March 2019 letter Applicants offered to support such a study in the interests of furthering a working relationship with the Tribes. Specifically, Applicants offered to financially support a broader Ethnographic Study with participation from the four Tribes who expressed an interest at the Cultural Resources Working Group meetings (the Confederated Tribes of Coos, Lower Umpqua and Siuslaw, the Coquille Indian Tribe, the Cow Creek Band of Umpqua Tribe of Indians, and the Confederated Tribes of Grand Ronde), with no financial limit on what Applicants would pay a third party contractor for completing this broad ethnographic study. Applicants also offered to fund a temporary staff position that would report directly to the Tribes, to oversee the work of the third party contractor. This study is not limited by the APE of the Project.

The Coquille Tribe responded to Applicants' March 2019 letter by asserting that they would only agree to an ethnographic study under conditions including a lack of temporal or financial constraints and a right not to share any information gained from the study, which defeats the purpose of Section 106 consultation. In the absence of those conditions, the Coquille Tribe asserted that their area of religious and cultural significance comprises the counties of Josephine, Coos, Curry, Douglas, Jackson, and Lane—areas that extend well beyond the Project's APE.

Applicants' efforts to consult with the Tribes satisfies the reasonable and good faith standard applicable to federal agencies for identifying properties that hold religious or cultural significance to Tribes that may be affected by the undertaking. The fact that certain Tribes have requested an ethnographic study that extends beyond the APE does not mean that it is required by the NHPA. Consulting parties such as a SHPO or Tribal Historic Preservation Officer ("THPO") "advise and assist the federal agency official in developing its identification efforts, but do not dictate its scope or intensity[.]"[98] A "reasonable and good faith identification effort does not require [t]he 'approval' of a SHPO/THPO or other consulting party."[99] Applicants respectfully request that the Commission omit the proposed condition requiring the completion of ethnographic studies beyond that required by the NHPA.

IV. <u>Incidental Harassment Authorization Application</u>

The Final EIS should reflect the updated information related to pile driving and acoustic impacts provided in the Incidental Harassment Authorization Application submitted to the Commission and to the National Marine Fisheries Services on April 23, 2019.

V. <u>PCGP – Summary of Changes Since 2017 Certificate Application</u>

Since submission of PCGP's certificate application on September 21, 2017, PCGP has conducted detailed construction reviews, completed easement negotiations with a significant number of landowners, completed civil surveys on previously un-surveyed parcels, and completed additional detailed engineering. With the additional information, PCGP has incorporated

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[98] Advisory Council on Historic Preservation, Meeting the "Reasonable and Good Faith" Identification Standard in Section 106 Review, at 3 (Nov. 15, 2011).
[99] *Id.*

refinements into the proposed centerline and construction right-of-way. The refinements include route variations recommended by the U.S. Forest Service, relocated block valves, and minor centerline and construction right-of-way adjustments to facilitate safe construction, minimize grading requirements, and to optimize restoration efforts. Minor alignment modifications were also incorporated based on landowner agreements, to avoid cultural sites, and to improve stream crossings. Appendix 3 provides a list of the modification locations by milepost and landowner (private, BLM, Forest Service) and includes a brief summary of the modification. Topographic maps showing the location of the modifications are also provided in Appendix 4, with the map numbers referenced in Appendix 3.

VI. Incorporation of Requirements from 2016 BLM Resource Management Plan Amendments and Accompanying FWS Biological Opinion

Recommended Condition 27 in the DEIS directs PCGP to file with FERC its commitment to adhere to certain FWS-recommended timing restrictions related to construction, operations, and maintenance in proximity to MAMU and NSO stands.[100] The text of the DEIS states that those conditions originate in a 2016 FWS Biological Opinion ("BO") following formal consultation for BLM's approval of the then-proposed Resource Management Plan ("RMP") for Western Oregon.[101] Those conditions, however, were developed for and relate to an RMP that did not contemplate the plan amendment BLM has proposed to accommodate the Project, which is discussed at length in the DEIS. It is incorrect for FERC Staff to recommend incorporating into Condition 27 requirements that flow from a predecessor RMP and BO that never contemplated the Project. Requirements specifically tailored to the Project will be developed by BLM and FWS in the course of the Project-specific plan amendment and BO following formal consultation for the Project. It is those Project-specific conditions, and not those from an older RMP and BO that never considered the Project, that should be incorporated into any recommended conditions.

Furthermore, Condition 27 should define the timing restrictions applicable to the Project to be those that are incorporated into BLM's right-of-way grant following formal consultation. When FWS prepares its BO for the approvals necessary to allow PCGP to develop its Pipeline, FWS will set forth the terms and conditions that the agencies and PCGP must implement to minimize impacts to the species.[102] When BLM issues its right-of-way grant, it will incorporate those terms and conditions from the BO that PCGP must implement to minimize impacts to MAMU and NSO. Thus, any final recommended Condition 27 should read as follows:

> Prior to construction, Pacific Connector shall file with the Secretary its commitment to adhere to timing restrictions identified in BLM's right-of-way grant regarding threshold distances of MAMU and NSO stands during construction, operations, and maintenance of the pipeline facilities that have been recommended by FWS following formal consultation.

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[100] DEIS at 4-326, 5-18.
[101] DEIS at 4-326 (relating to timing restrictions for MAMU), 4-329 (relating to timing restrictions for NSO).
[102] *See* 50 C.F.R. § 402.14(i)(1)(iv).

Attachment B

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
Executive Summary					
ES	ES-3	Paragraph 3	Constructing the LNG terminal would temporarily impact the Coos Bay area short-term housing market.	Clarify that housing impacts from the LNG terminal and pipeline will be temporary.	Suggest revising to: "Co-construction of the LNG terminal and Pacific Connector pipeline would temporarily impact the Coos Bay area short-term housing market. Potential impacts to housing would be short term, and would end with construction completion."
ES	ES-3	Paragraph 4	Permanent and temporary structures at the LNG terminal as well as LNG carrier operations in the Federal Navigational Channel would exceed FAA obstruction standards and there is a potential significant impact to the safe air operations of the Southwest Oregon Regional Airport if a resolution cannot be settled between Jordan Cove and FAA.	A final determination regarding hazard or no hazard has not yet been issued by the FAA. The existing statement inaccurately suggests that Jordan Cove and the FAA are at an impasse regarding impacts how to address potential impacts to airport operations from the terminal structures. Based on the requirements of FAA Form 7460-1, applicants must submit information on structures to the FAA at least 45 days before the start date of the proposed construction or alteration or the date an	Consider replacing with: "Permanent and temporary structures at the LNG terminal as well as LNG carrier operations in the Federal Navigational Channel would exceed FAA obstruction standards; however, a final determination has not been issued by the FAA. The final determination will be based on the final design elevation of structures at the project site. Jordan Cove and the FAA are in consultation to address potential impacts to operations of the Southwest Oregon Regional Airport".

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
				application for a construction permit is filed, whichever is earliest. Jordan Cove has been actively working with the FAA well in advance of this minimum requirement and will continue consultations until a final determination is issued.	
ES	ES-5	Paragraph 3	Specifically, we conclude that constructing the Project would temporarily but significantly impact housing in Coos Bay and that constructing and operating the Project would permanently and significantly impact the visual character of Coos Bay.	Clarify that housing impacts will be temporary.	Suggest revising to: "Specifically, we conclude that constructing the Project would temporarily ~~but significantly~~ impact housing in Coos Bay. <u>Potential housing impacts would be short term, and would end upon completion of the LNG terminal construction. In addition,</u> constructing and operating the Project would permanently ~~and significantly~~ impact the visual character of Coos Bay."
1.0					
1.1	1-2	Paragraph 2	Consistent with federal regulations, applicable guidance, and other agreements,… U.S. Department of Commerce National Oceanic and Atmospheric	Update to reflect that the Marine Mammal Section of NOAA should also be listed as a cooperating agency.	Consider replacing with: "Consistent with federal regulations, applicable guidance, and other agreements,… U.S. Department of Commerce National Oceanic and Atmospheric Administration's

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
			Administration's (NOAA) National Marine Fisheries Service (NMFS) Oregon Coast Branch;…		(NOAA) National Marine Fisheries Service (NMFS) Oregon Coast Branch <u>and Marine Mammal Section</u>;…"
1.3.2	1-7	Paragraph 1	Throughout	The discussion of BLM approvals for activities on BLM land is solely focused on PCGP's Pipeline, and it omits reference to BLM's approval of an authorization for JCEP's industrial wastewater pipeline in the existing utility corridor	Add the following language at the end of Section 1.3.2: "In addition, the LNG Terminal's industrial wastewater pipeline would be placed within an existing utility corridor that crosses BLM land. BLM would grant approval for the pipeline's placement in that utility corridor."
1.3.6	1-12	Paragraph 2	"…the federal pike structure west of the proposed slip (where a rock apron is currently proposed to minimize impacts to this structure), and a 40-acre multi-use COE real estate easement located partially within the proposed LNG terminal tank site."	The text does not discuss a temporary construction license for placement of the rock apron, or consent agreements that COE would enter into with the landowners affected by the easement at the LNG Terminal site (i.e., Fort Chicago Holdings II US LLC and Roseburg Forest Products) to allow for facility construction while providing for the intent of the easement to be met.	Correct the reference to the "pike structure" to be the "pile dike structure." In addition, add the following language to the end of the second paragraph on page 1-12: "Placement of the rock apron would require the COE to grant a temporary construction license, and the Project would require that USACE grant consent in the form of consent agreements with the landowners affected by the easement (i.e., Fort Chicago Holdings II US LLC and Roseburg Forest Products)."
1.3.9	1-14	Paragraph 3	On May 10, 2018, a revised LOR was issued, in which the Coast Guard stated that "the Coos Bay Channel be	Update paragraph to incorporate the latest correspondence from the USCG issued to the Jordan Cove on	Consider replacing with: "On May 10, 2018, a revised LOR was issued, in which the Coast Guard stated that "the Coos

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
			considered suitable for accommodating the type and frequency of LNG marine traffic associated with this project."	November 7, 2018 and provided in Appendix 1.	Bay Channel be considered suitable for accommodating the type and frequency of LNG marine traffic associated with this project." During 2018, Jordan Cove conducted vessel transit simulation studies (at the California Maritime Academy) for newer, larger capacity LNG carriers that exceed the 148,000 m^3 'nominal' capacity spherical containment class vessel. The simulated transits were piloted by the Coos Bay Pilots and witnessed by the USCG. These simulations were conducted to demonstrate that the Coos Bay Pilots can safely, consistently, reliably and successfully maneuver LNG carriers up to 299.9m length x 49m beam x 11.9m draft (equivalent nominal capacity of 180,000 m^3) dimensionally while transiting the channel. On November 7, 2018, the USCG confirmed that these successful simulations expand the ability for Jordan Cove to use any class of LNG carrier (membrane, Moss, or SBT) with physical dimensions equal to or smaller than those observed during the simulated transits."
1.5	1-19	Table 1.5.1-1	BLM row	The BLM rows on the table do not discuss a BLM authorization for placement of the industrial wastewater	Add the following to the BLM row on Table 1.5.1-1: Agency: BLM

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
				pipeline within an existing utility corridor that crosses BLM land.	Authority/Regulation/Permit: Federal Land Policy and Management Act of 1976, as amended Agency Action: Approval of a right-of-way across BLM land for the LNG Terminal's industrial wastewater pipeline Initiation of Consultations and Permit Status: Pending.
1.5	1-20	Table 1.5.1-1	COE row	The COE rows on the table do not discuss a temporary construction license for placement of the rock apron, or consent agreements that COE would enter into with the landowners affected by the easement at the LNG Terminal site (i.e., Fort Chicago Holdings II US LLC and Roseburg Forest Products) to allow for facility construction while providing for the intent of the easement to be met.	Add the following to the COE rows on Table 1.5.1-1: Agency: COE Authority/Regulation/Permit: Consents to Easement Structures Agency Action: Approval of consents to easement structures Initiation of Consultations and Permit Status: Pending. Draft consent agreements being negotiated. Agency: COE Authority/Regulation/Permit: Temporary Construction License Agency Action: Approval of temporary construction license Initiation of Consultations and Permit Status: Pending. Draft license agreement being negotiated.

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1.5	1-23	Table 1.5.1-1	ODEQ, Section 402: "NPDES permit for storm water issued in July 2015 and expires in June 2020"	NPDES Permit No. 101499 is for effluent discharge to the ocean outfall.	Consider replacing with: "NPDES permit for effluent discharge to the ocean outfall issued in July 2015 and expires June 2020"
1.5.1	1-23	Table 1.5.1-1	ODEQ, Second Column, "Prevention of Significant Deterioration"	Table 1.5.1-1 lists the major federal, state, and local permits identified for the project. The Jordan Cove LNG Project is not a PSD project.	Remove "Prevention of Significant Deterioration" and add "Air Contaminant Discharge Permit"
1.5.1	1-23	Table 1.5.1-1	ODEQ, Prevention of Significant Deterioration, Third Column, "Review Best Available Control Technology to minimize discharges from new major sources, and review…"	Type B State NSR permit applications do not include Best Available Control Technology analysis.	Suggest removing "Review Best Available Control Technology to minimize discharges from new major sources, and"
1.5.1	1-23	Table 1.5.1-1	ODEQ, Third Column, "review air quality analyses to ensure compliance with National Ambient Air Quality Standards."	Permit application demonstrates modeled compliance with all applicable Ambient Air Quality Standards.	Suggesting changing to: "Review air quality analyses to ensure compliance with all applicable Ambient Air Quality Standards."
1.5.1	1-23	Table 1.5.1-1	ODEQ, Prevention of Significant Deterioration, Fourth Column, "Pending"	Suggest including the submittal date of the Type B State NSR permit application.	Revise language to: "Pending. Type B State NSR permit application submitted September 2017."
2.0					

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2.1.1.3	2-5	Paragraph 3	The top of the tanks (dome) would be about 180 feet above grade	The elevation referenced in this paragraph corresponds to the top of the tank wall, not dome, as described in Resource Report 13.	Consider replacing with: "The top of the tanks (dome) would be approximately 190 feet above grade"
2.1.1.3	2-5	Paragraph 3	Jordan Cove proposes to enclose the LNG storage tanks within an earthen berm that would be about +46 feet high. The berm would be designed to contain the contents of one 160,000 m^3 storage tank.	The height of the LNG storage tank protective berm stated in this DEIS paragraph is incorrect. As indicated in Table 13.2-2 in Resource Report 13, the tank foundation grade elevation is +27 ft and the top of the protective berm elevation is +46 ft, thus the height of the berm is 19 ft. As indicated in Resource Report 13 Section 13.34.1.3, "Berms at an elevation of 19 feet greater than the LNG tank base slab at grade will be above the tsunami and flooding elevations but are not required for LNG containment."	Consider replacing with: "Jordan Cove proposes to enclose the LNG storage tanks within an earthen berm that would be about +19 feet high. Although not required by regulation, the berm would be designed to provide spill containment capacity for the contents of one 160,000 m^3 storage tank. The full-containment LNG storage tanks are designed to contain an LNG spill in accordance with NFPA 59A. According to 49 CFR 193.2181, the secondary containment volume required for an LNG tank spill equals 110 percent of the liquid volume of the inner tank, which is accomplished by the outer concrete shell. Jordan Cove proposes to satisfy this secondary containment requirement through the use of such an outer shell."

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
2.1.1.3	2-5	Paragraph 4	Cellular glass insulation would be incorporated into the foundation…	Revise to align with the description in the DEIS and Resource Report 13, Section 13.11.1.4.	Considering replacing with: "Cellular glass would be applied to the bottom insulation and secondary bottom…"
2.1.1.5	2-7	Paragraph 2	LNG vapors, which would be recovered and directed into a vapor handling system and recycled into the liquefaction process.	Alignment of description in the DEIS and Resource Report 13 Section 13.12.1.	Replace with: "LNG vapors (boil-off gas), which would be recovered and directed into a vapor handling system and used as fuel gas or recycled into the liquefaction process for re-condensation."
2.1.1.5	2-7	Paragraph 3	The flare systems would only be used during plant protection situations, maintenance activities, cases of purging and gassing-up an LNG carrier, and initial commissioning/start-up.	Alignment of description in the DEIS and Resource Report 13 Section 13.33.1.	Consider replacing with: "The flare systems would only be used during emergency/plant protection situations, maintenance activities, cases of purging, off-design loading scenarios (e.g. warm or contaminated ship gassing up), and initial commissioning/start-up."
2.1.1.5	2-7	Paragraph 6	Electrical power to the LNG terminal would be supplied via two 30-megawatt (MW) steam turbine generators and one spare 30 MW steam turbine generator, with the steam generated by heat recovery from gas turbine operation. A black-start auxiliary boiler	Alignment of DEIS description with Resource Report Supplement submitted to FERC on May 2, 2019.	Consider replacing with "Electric power to the LNG terminal would be supplied via three on-site steam turbine generators ("STGs") generating up to a total maximum of 24.4 MW and imported power capacity ranging from 15 to 26 MW. The steam for the STGs is efficiently generated by

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
			would be used to generate steam for power when gas turbines are not in operation. The system would also include two standby diesel generators for the LNG facility and two for the SORSC.		HRSGs using exhaust from the refrigerant compressor combustion turbine drivers. Black start power supply for the STGs will be available from the grid. However, during the detail design phase of the Project, Jordan Cove will consider installing one standby diesel generator to provide redundant black start power supply. There are two standby diesel generators for the SORSC."
2.1.1.6	2-10	Paragraph 3	Jordan Cove intends to replace three existing buoys with the new buoys (one located in the Pacific Ocean near the bay entrance, and one within Coos Bay along the LNG carrier route), and two new buoys located near the access channel.	Description of proposed activities for existing and new buoys updated to align with Jordan Cove's response to Request No. 15 in FERC January 3, 2018, data request, submitted on January 26, 2018, relating to Resource Report 3.	Consider replacing with: "Jordan Cove intends to upgrade and modify three existing buoys (two within Coos Bay and one located offshore near the Coos Bay entrance) by installing physical oceanographic real-time system sensors to the buoys and anchoring systems. Two new buoys will be installed and located near the access channel."
2.1.1.7	2-12	Paragraph 1	The access channel would begin at the confluence between the Jarvis Turn and the Upper Jarvis Range at about navigation channel mile (NCM) 7.5,….	Alignment of DEIS description with Resource Reports.	Consider replacing with: "The access channel would begin at the confluence between the Jarvis Turn and the Upper Jarvis Range at about navigation channel mile (NCM) 7.3,…"
2.1.1.8	2-16	Paragraph 2	Of this, about 3.6 mcy would be dry excavated and then dredged in the fresh water pocket in the slip area and	Currently as written in the DEIS the impacts to the upland, freshwater and saltwater areas are conflated based on only a	Consider replacing with: "Of this, approximately 3.8 mcy would be dredged and excavated for the proposed slip.

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			access channel….The remainder of the dredge material would be removed during open water dredging while exposed to the bay and Federal Navigation Channel.	total of the volume estimated for the marine slip dredging. This revision is to clearly describe the dredge material that will be removed as part of the construction of the marine slip. The total volume of dredge material for the proposed slip is approximately 3.8 mcy described in a Design Supplement submitted to FERC on 11/2/18 (Table 1.5-2).	About 1.4 mcy would be dry excavated and then about 2.2 mcy would be dredged in the fresh water pocket in the slip area and access channel….The remaining 0.2 mcy of approximate 3.8 mcy of the dredge material would be removed during open water dredging while exposed to the bay and Federal Navigation Channel."
2.1.1.8	2-16	Paragraph 2	Dredging for the marine facilities, including the marine waterway modifications, would generate about 6.32 million cubic yards (mcy) of dredged and excavated material (see table 2.1.1.8-1). Of this, about 3.6 mcy would be dry excavated and then dredged in the fresh water pocket in the slip area and access channel behind an earthen berm that would remain in place to separate work prior to dredging activities in the bay. The remainder of the dredge material would be removed during open water dredging	Update Table 2.1.1.8-1 and Paragraph 2 to reflect the DMMP provided to DSL and USACE in October 2017.	Revise table and Paragraph 2 to reflect Appendix 2.

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			while exposed to the bay and Federal Navigation Channel.		
2.1.1.8	2-17	Paragraph 2	Jordan Cove proposes to conduct maintenance dredging about every 3 years with about 115,000 cy of material removed per dredging interval for the first 12 years of operation…	The current description of the maintenance dredging interval in the DEIS does not capture Jordan Cove's current proposed intervals of operational maintenance dredging provided by the Project. The proposed revision aligns the DEIS with information submitted to other federal agencies and state agencies such as the COE (i.e. 408 application) Department of State Lands (i.e. Removal Fill Permit). This is described in detail in the DMMP.	Consider replacing with: "Jordan Cove proposes to conduct maintenance dredging about every 3 years with about 115,000 cy of material removed per dredging interval for the first 10 years of operation…"
2.1.1.10	2-18	Paragraph 3	A temporary dredge pipeline would also be laid adjacent to the Federal Navigation Channel (via a floating or submerged pipe) to transport dredge material from the four marine waterway modification sites to the APCO Sites 1 and 2, and a temporary dredge line would be laid between the Federal Navigation Channel and the	There is no mention of the temporary dredge pipeline extending west from the Eelgrass Mitigation site to the Federal Navigation Channel (FNC), where dredge material will be onloaded to barges for transport to an upland disposal site. Consider adding a reference to the temporary dredge pipeline.	Consider adding additional sentence below: "A temporary dredge pipeline would also be laid extending west from the Eelgrass Mitigation site to the FNC, where dredge material will be onloaded to barges for transport to an upland disposal site."

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			Kentuck project site to transfer dredge material from marine transport barges to the disposal sites.		
2.1.2.1	2-20	Paragraph 1	The Jordan Cove Meter Station would be located within the South Dunes portion of the terminal.	Clarification of delineation between 49 CFR 192 and 193 facilities consistent with Resource Report 13.	Consider replacing with: "The Jordan Cove Meter Station (a Part 192 facility) would be located on South Dunes. The battery limits of the LNG Terminal (the Part 193 facility) are delineated at the insulating flange downstream of the pipeline metering station."
2.1.2.1	2-20	Table 2.1.2-1	Starveout Communication Tower / Douglas County	Revise to reflect the tower will be in Jackson County.	Revise to: "Starveout Communication Tower / Jackson County"
2.1.2.1	2-21	Paragraph 3	Pig launchers and receivers would allow Pacific Connector to maintain the interior of its pipeline using remotely operated pipe inspection and cleaning tools (known as "pigs").	These 'pigs' are not remotely operated; therefore, Jordan Cove recommends deleting these two words.	Consider replacing with: "Pig launchers and receivers would allow Pacific Connector to maintain the interior of its pipeline using pipe inspection and cleaning tools (known as "pigs")."
2.1.3.1	2-22	Paragraph 2	Additional analysis concluded that the clearing and removal of vegetation required within the LSR for the proposed Project would likely result in some	Jordan Cove cannot locate any analysis to support the conclusions regarding MAMU and NSO effects "… would likely result in some NSO	Suggest citing source of analysis or deleting this statement.

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			NSO habitat no longer continuing to support nesting and roosting at the stand level, and some MAMU habitat no longer continuing to support nesting at the stand level.	habitat no longer continuing to support nesting and roosting at the stand level, and some MAMU habitat no longer continuing to support nesting at the stand level."	
2.1.3.1	2-22	Paragraph 3	BLM staff concluded that construction of the Project would likely result in disruption of MAMU nesting at some occupied sites within these two discrete geographic ranges.	Clarify that the proposed construction timing restrictions avoid disruption during MAMU nesting seasons.	Suggest adding the following sentence: "However, the proposed construction timing restrictions avoid disruptions during MAMU nesting seasons."
2.2.1	2-37	Paragraph 2	We do not have any information about the exact carriers that would be used to transport the LNG from the terminal; however, the slip and berth would be designed to accommodate LNG carriers as large as 217,000 m^3 in capacity	Alignment of DEIS description with design parameters considered for the loading berth provided in Resource Report 13.	Consider replacing with: "<u>Jordan Cove does not currently have</u> information about the exact <u>LNG</u> carriers that would be used to transport the LNG from <u>the LNG Terminal; however, Jordan Cove provided LNG carrier design data for the range of LNG carriers considered in design of the slip and loading berth. The LNG carrier loading berth will be capable of accommodating LNG carriers with a cargo capacity range of 89,000 m^3 to 217,000 m^3</u>."
2.3.1	2-38	Paragraph 3	The Jordan Cove LNG Project would require the use of about 1,355 acres of land. When	Revise to correctly match the acreage presented in the Design Supplement submitted to FERC	Consider replacing with:

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			complete, the Jordan Cove LNG terminal would occupy about 197 acres.	on November 2, 2018 (pg 6-8). The DEIS currently states that the Jordan Cove Project requires 1,355 acres of land, which may be misleading because the total of 1,355 acres is specific for the Terminal and excludes the Pipeline. See the Design Supplement for more information.	"The Jordan Cove LNG Terminal would require the use of about 1,355 acres of land. When complete, the Jordan Cove LNG terminal would occupy about 200 acres."
2.3.2.1	2-41	Paragraph 3	After construction, workspace outside of the maintenance easement would be restored to its original condition and use (although mature forest would take many years to be re-established).	It may not be possible to restore the easement to its original condition or it may be difficult to assess. Jordan Cove recommends adding the word "approximate" in front of "original".	Consider revising to: "After construction, workspace outside of the maintenance easement would be restored to its approximate original condition and use (although mature forest would take many years to be re-established)."
2.4.1.4	2-47 to 2-49	Throughout	Throughout	Jordan Cove submitted its Incidental Harassment Authorization Application with NMFS and FERC on April 23, 2019. Recommend FERC include this information on pile totals and methods for the LNG Terminal as part of the FEIS.	Update section with updated pile descriptions and quantity of piles with the updated information provided in the Jordan Cove Project Incidental Harassment Authorization application, provided to FERC on April 23, 2019.
2.4.1.5	2-49	Paragraph 4	Dredged material that would be disposed of at the Kentuck Project site would be transported along the Federal Navigation Channel via marine	Dredging from the slip area that will be transported to Kentuck will be "wet".	Suggest revising to: "Portion of dredged material that would be disposed of at the Kentuck Project site would be transported along the Federal Navigation

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			transport barge and then deposited on the site using a temporary transfer pipeline. The materials would be dredged "in the dry" (i.e., the material would be dry when dredged), and then re-liquefied and piped through the transfer pipeline to Kentuck.		Channel via marine transport barge and then deposited on the site using a temporary transfer pipeline. The materials would be dredged "in the wet", transported via barge and then re-liquefied and piped through the transfer pipeline to Kentuck."
2.4.2.1	2-53	Figure 2.4-1	Figure 2.4-1 Typical Construction Pipeline Sequence	Figure 2.4-1 is the previous version with the asterisks denoting "Owner's Responsibility," which was removed from the figure filed in Resource Report 1.	Replace with updated Figure 1.3-1 from Resource Report 1.
2.4.2.1	2-56	Last Paragraph	The required volume of test water would range between approximately 16 to 60 million gallons depending on how much water would be reused by cascading.	Recommend updating with information from the Hydrostatic Test Plan, which was filed with FERC on November 8, 2018.	Recommend replacing with: "The required volume of test water would range between approximately 26 to 65 million gallons depending on how much water would be reused by cascading."
2.4.2.1	2-57	Paragraph 4	Water for dust control would be obtained from commercial or municipal sources, and all appropriate approvals and/or permits would need to be obtained prior to withdrawal.	Water source could be from other than commercial or municipal, therefore recommending rephrasing to multiple sources.	Recommend replacing with: "Water for dust control would be obtained from multiple sources, and all appropriate approvals and/or permits would need to be obtained prior to withdrawal."

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2.4.2.1	2-58	Table 2.4.2.1-1	b/ Granitic formations would be crossed by the pipeline between: MPs 79.1 to 80.5; MPs 81.6 to 82.2; MPs 87 to 88.8; MPs 97.0 to 101.2; MPs 103.0 to 105.4; and MPs 114.8 to 115.0.	Footnote was updated in the APDBA filed with FERC in September 2017.	Replace b/ footnote with: "Granitic formations would be crossed by the pipeline between: MPs 87.43 to 87.69; MPs 88.35 to 88.82; MPs 95.28 to 95.52; MPs 96.96 to 100.42; MPs 100.46 to 101.16; MPs 102.99 to 103.19; and 103.30 to 103.69"
2.4.2.2	2-60	Paragraph 2	Construction of the Pacific Connector pipeline would affect approximately 352 waterbodies	Resource Report 1, Section 1.3.1.4, says: The Pipeline will cross approximately 326 waterbodies as discussed further in Resource Report 2.	Replace with: "Construction of the Pacific Connector pipeline would cross approximately <u>342</u> waterbodies."
2.7.2	2-71 to 2-72	Last Paragraph	In addition, the pipeline and aboveground facilities would be monitored at all time using Pacific Connector's gas control communication system and radio towers reporting back to a command center at the Williams' office in Salt Lake City, Utah.	The current plan is to report back to Pacific Connector gas control center which will be co-located with Pacific Connector Operator gas control facilities.	Consider revising to: "In addition, the pipeline and aboveground facilities would be monitored at all time using Pacific Connector's gas control communication system and radio towers reporting back to <u>the Pacific Connector gas control center</u>."
2.7.2	2-71	Paragraph 5	Herbicides would not be used in or within 100 feet of a waterbody's mean high-water mark	In Resource Report 1, Section 12.6, states that herbicides will not be used within 100 feet of a wetland or waterbody, unless allowed by the appropriate agency.	Recommend replacing with: "Herbicides would not be used in or within 100 feet of a waterbody's mean high-water mark <u>except as allowed by the appropriate land management or state agency</u>."
3.0					

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3.4.2.1	3-19	Table 3.4.2.1-1	Landownership (miles)	The current miles listed are not appropriately aligned in the table.	The 3 rows of miles under "Impact/Issue" should be shifted to the right, which will correct the 4 columns.
3.4.2.2	3-23	Table 3.4.2.2-1	40.5 acres [of LSOG affected by Proposed Route]	Of the 40.5 acres of LSOG affected by the proposed route, there is approximately 17.3 acres that become 80-years of age in 2020 based on year of harvest identified in available BLM FOI (2019). Also, as a result of 2017 and 2019 habitat surveys in some presumed occupied stands, there are updates to the number of MAMU stands and suitable MAMU habitat that would be affected by the Pipeline.	Suggest the following edits to Table 3.4.2.2-1: Coniferous Forest - LSOG Proposed: Change 40.5 acres to 23.8 acres MAMU stands crossed by ROW - Proposed: Change 18 presumed occupied stands to 12 - Blue Ridge Variation: Change 4 presumed occupied stands to 3 MAMU Suitable Habitat Removed acres - Proposed: Change 32.2 acres to 26.17 (6.57 acres occupied, 18.59 acres presumed) - Blue Ridge Variation: Change 3.0 acres to 3.11 acres"
4.0					
4.1 -Geology,					
4.1.1.1	4-3	Paragraph 3	The LNG terminal site is underlain by loose to dense fill and a relatively clean, fine-grained sand, which is in turn	The site-specific geology summary in this section of the DEIS is not consistent with the geology summary in Section 4.13.1.5, paragraph 3 on Page	Consider revising to: "The LNG terminal site is underlain by loose to dense fill and a relatively clean, fine-grained

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			underlain by a weathered sandstone.	4-731. The geology summary in Section 4.13.1.5 is better aligned with the Jordan Cove LNG Project site geologic setting. Please update the geology summary in Section 4.1.1.1 to be consistent with Section 4.13.1.5.	sand, which is in turn underlain by a <u>very dense silt-sand unit</u>."
4.1.1.1	4-3	Paragraph 4	Weathered sandstone is generally encountered beneath the dune sands to a depth of 125 feet (GRI Geotechnical and Environmental Consultants [GRI] 2007a).	The site-specific geology summary in this section of the DEIS is not consistent with the geology summary in Section 4.13.1.5, paragraph 3 on Page 4-731. The geology summary in Section 4.13.1.5 is better aligned with the Jordan Cove LNG Project site geologic setting. Please update the geology summary in Section 4.1.1.1 to be consistent with Section 4.13.1.5.	Consider deleting this sentence or changing to: "Sand is generally encountered below the dune sands to elevations of approximately -110 to -140 feet."
4.1.1.1	4-4	Paragraph 1	Any shoreline areas disturbed by construction would be armored to protect against erosion or shifting beyond the Jordan Cove project design limits.	Resource Report 6 does not present any shoreline armoring to protect against erosion or shifting.	Consider revising to: "~~Any shoreline~~ <u>Where required</u>, areas disturbed by construction would be ~~armored to~~ protect<u>ed</u> against erosion or shifting beyond the Jordan Cove project design limits <u>per federal, state and local regulations</u>."
4.1.2.1	4-6	Paragraph 6	Approximately 40 miles (approximately MP 120 to MP	Resource Report 6 indicates approximately 60 miles	Suggest revising to:

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			160) of the route crosses Oregon's southern Cascade Range.	The inset on Resource Report 6, Figure 1 indicates that pipeline runs through the Cascade Range from about MP 120 to MP 180.	"Approximately 60 miles (approximately MP 120 to MP 180) of the route crosses Oregon's southern Cascade Range."
4.1.2.1	4-7	Paragraph 4	Approximately the easternmost 45 miles (approximately MP 160 to MP 224) of the pipeline alignment pass through the southwestern corner of the Basin and Range province in Oregon, a geographic area named the Klamath Basin.	MP and total miles may be incorrect if page 4-6 Paragraph 6 is revised per prior comment for Cascade Range length/MPs	Suggest revising to: "Approximately the easternmost 45 miles (approximately MP 180 to MP 224) of the pipeline alignment pass through the southwestern corner of the Basin and Range province in Oregon, a geographic area named the Klamath Basin."
4.1.2.2	4-8	Paragraph 3	Table B-5 of Appendix B from GeoEngineers (2017a) identified the active, inactive, and planned mineral resources or mining sites (organized by MP) within 0.25 mile of the pipeline. Twenty-nine mineral or mine locations were identified as within 500 feet of the pipeline. Sixteen of these mines identified within 500 feet of the alignment are aggregate or quarry-related mines.	GeoEngineers (2017a) Resource Report 6, Table B-5 indicates 22 sites within 500 ft, of which five are not aggregate/quarry sites. Resource Report 6, Section 4.9.1 (page 48) states: "A total of 16 of the 29 mines identified within 500 feet of the alignment are aggregate or quarry-related mines." which appears consistent with the DEIS. However, when looking at Table B-5, there are 32 mines listed, of which 22 are within	Suggest revising to: "Table B-5 of Appendix B from GeoEngineers (2017a) identified the active, inactive, and planned mineral resources or mining sites (organized by MP) within 0.25 mile of the pipeline. Twenty-two mineral or mine locations were identified as within 500 feet of the pipeline. Sixteen of these mines identified within 500 feet of the alignment are aggregate or quarry-related mines."

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				500 feet of pipeline and of these 22, 16 are aggregate or quarry-related mines.	
4.1.2.2	4-9	Paragraph 1	Coos County recognizes three coal-basin resource areas between MPs 0 and 7.6; and one between MP 13.2BR and 13.4BR. Eighteen oil and gas areas are located between MP 10.4R and 45.7 in Coos County. Two mining claims are located between MPs 0 and 1.4 in Coos County. Seven oil and gas areas, two placer mining claims, one mine, four lode mining claims, a chromite resource, and a quarry are located in the vicinity of the pipeline alignment between MPs 46.9 and 110 in Douglas County. Ten oil and gas areas and two lode mining claims are located in the vicinity of the pipeline alignment between MPs 115.4 and 166.4 in Jackson County. One lode mining claim, one oil and gas area, and two geothermal resources areas are located in the vicinity of the pipeline	Clarify that many of the resources identified are closed claims.	Propose adding the following at the end of this text: "Of the 57, 45 are known to be closed."

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			alignment between MPs 170.1 and 216.8 in Klamath County.		
4.1.2.2	4-9	Paragraph 5	According to Pacific Connector's application (Table B-5 of Appendix B from GeoEngineers 2017a), the pipeline alignment was identified as being within 500 feet of potential mine hazards based on the information provided in the databases at 29 locations. Sixteen of the 29 mines identified within 500 feet of the alignment are aggregate or quarry-related mines.	Table B-5 statement for potential mine hazards lists all as "No" or "Unlikely". Text does not reflect number of sites in current (GeoEngineers 2017a) Table B-5 consistent with previous comment. Resource Report 6, Section 4.9.1 (page 48) states: "A total of 16 of the 29 mines identified within 500 feet of the alignment are aggregate or quarry-related mines." which appears consistent with the DEIS. However, when looking at Table B-5, there are 32 mines listed, of which 22 are within 500 feet of pipeline and of these 22, 16 are aggregate or quarry-related mines.	Propose the following replacement: "According to Pacific Connector's application (Table B-5 of Appendix B from GeoEngineers 2017a), the pipeline alignment was identified as being within 500 feet of potential mine hazards based on the information provided in the databases at 22 locations. Sixteen of the 22 mines identified within 500 feet of the alignment are aggregate or quarry-related mines."
4.1.2.2	4-10	Paragraph 6	The BLM and Pacific Connector determined that due to the proximity of the pipeline to the quarry and the incompatibility of production blasting the rock quarry near the pipeline; that 70,000 cubic	Revise to align with the BLM POD Blasting appendix, section 5.1: "Once shot, the blasted rock will remain in place for future use as determined by the	Recommended revision: "The BLM and Pacific Connector determined that due to the proximity of the pipeline to the quarry and the incompatibility of production blasting the rock quarry near the pipeline; that 70,000 cubic yards of rock would be

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
			yards of rock would be blasted at the expense of Pacific Connector and left on site.	BLM. The BLM is requiring this blasting because the BLM will not assume unknown risk associated with complications, limitations, or liability associated with developing this quarry in the future. The BLM will provide compensation to PCGP for all work associated with pre-blasting the Heppsie Mountain Quarry prior to the start of construction."	blasted. Once shot, the blasted rock will remain in place for future use as determined by the BLM. The BLM will provide compensation to PCGP for all work associated with pre-blasting the Heppsie Mountain Quarry prior to the start of construction."
4.1.2.2	4-11	Paragraph 1	Pacific Connector has told the BLM that it would use this quarry to purchase approximately 70,000 cubic yards of rock to crush, per 43 CFR 3600.	Revise to be consistent with comment for 4.1.2.2, page 4-10.	Propose deleting this sentence.
4.1.2.3	4-11	Paragraph 3	However, with the exception of the Klamath Falls area, these mapped surface faults are not considered active based on evidence of recent Quaternary tectonic activity and are not believed to be capable of renewed movement or earthquake generation (USGS 2009a, 2010)	More recent data from USGS 2014a, b, c and references used in the GeoEngineers (2017a) RR-6 report to support the conclusion of this sentence	Suggest revising to: "However, with the exception of the Klamath Falls area, these mapped surface faults are not considered active based on evidence of recent Quaternary tectonic activity and are not believed to be capable of renewed movement or earthquake generation (USGS 2009a, 2010, 2014a, b, c)"

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
4.1.2.3	4-13	Paragraph 3	Using the historical seismicity record including the records for CSZ earthquakes and the available data on Quaternary faults in the United States, the USGS (2009a) has produced probabilistic seismic hazard mapping for the United States in general, and for the region that would be crossed by the pipeline in particular.	More recent data used by USGS for 2014 national seismic hazard mapping as presented in the GeoEngineers (2017a) RR-6 report.	Suggest revising to: "Using the historical seismicity record including the records for CSZ earthquakes and the available data on Quaternary faults in the United States, the USGS (2009a, 2014a, b, c) has produced probabilistic seismic hazard mapping for the United States in general, and for the region that would be crossed by the pipeline in particular."
4.1.3.2	4-35	Paragraph 2	It was determined by the BLM and Pacific Connector that due to the proximity of the pipeline to the quarry and the incompatibility of production blasting the rock quarry near the pipeline, that 70,000 cubic yards of rock will be blasted at the expense of Pacific Connector and left on site.	Revise to be consistent with prior text in section 4.1.2.2: Pacific Connector has told the BLM that it would use this quarry to purchase approximately 70,000 cubic yards of rock to crush, per 43 CFR 3600. Please see the comment above for section 4.1.2.2, page 4-10, paragraph 6.	Recommend adding the following sentence to the end of the paragraph: "The BLM and Pacific Connector determined that due to the proximity of the pipeline to the quarry and the incompatibility of production blasting the rock quarry near the pipeline; that 70,000 cubic yards of rock would be blasted. Once shot, the blasted rock will remain in place for future use as determined by the BLM. The BLM will provide compensation to PCGP for all work associated with pre-blasting the Heppsie Mountain Quarry prior to the start of construction."
4.2 - Soils and sediment					
4.2.1.1	4-41	Paragraph 2	Jordan Cove performed geotechnical investigations in	The site-specific geology summary in this section is not	Consider revising to:

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
			the area of the proposed LNG storage tanks and process area in April through May 2013 (GRI 2013). The subsurface data revealed that surficial material in this area is generally fine- grained sand with traces of silt that is underlain by weathered sandstone. The sand layer extends from the surface to a depth of at least 124 feet. Another geotechnical investigation was performed in April 2012 (GRI 2012) in the South Dunes portion of the site. The upper 10 to 20 feet of the South Dunes site was found to be reworked dune sand that is underlain by weathered siltstone. Based on the geotechnical borings, the sands in the access and utility corridor are composed of areas of fill and native material. Organics and peat were encountered only in the western endo of the access and utility corridor at depths of approximately 11 feet below grade. At depths below 30 feet, the conditions for	consistent with the geology summary in Section 4.13.1.5, Pages 4-729 to 4-732. The geology summary in Section 4.13.1.5 is better aligned with the Jordan Cove LNG Project site geologic setting. Please update the geology summary in Section 4.1.1.1 to be consistent with Section 4.13.1.5.	"Jordan Cove performed geotechnical investigations in the area of the proposed LNG storage tanks and process area. The subsurface data revealed that surficial material in this area is generally fine- grained sand with traces of silt that is underlain by <u>a silt-sand unit at approximately elevation -110 to -140 feet. In the South Dunes portion of the site, above elevation -30 feet, the conditions vary mainly because of variation in the sands and the presence or absence of peat/organics. Below elevation -30 feet, the South Dunes subsurface conditions are fairly consistent. A deep boring at the South Dunes indicates that the native sand extends to elevation -151 feet.</u> <u>Below elevation -151 feet, very stiff to very hard, clayey silt with sand and cementation was encountered.</u> Based on the geotechnical borings, the sands in the access and utility corridor are composed of areas of fill and native material. Organics and peat were encountered only in the western end of the access and utility corridor at depths of approximately 11 feet below grade. <u>Below elevation -30</u> feet, the conditions for the access and utility corridor are similar to those described for the LNG terminal site."

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
			the access and utility corridor are similar to those described for the LNG terminal site.		
4.2.1.2	4-44	Paragraph 2	For portions of the storm surge/tsunami barrier and terminal areas above +25 feet in elevation, which are not expected to normally be subjected to severe wind or water conditions (but may be affected by storm surge or tsunami events), alternative erosion control would be used.	The +25 feet storm surge elevation at the LNG Terminal site in this paragraph is incorrect. The storm surge elevation at the entrance of the Coos Bay (Charlestown) is +24.62 feet (NAVD 88), approximately 7 miles from the project site. The storm surge elevation at the LNG terminal is approximately +14.8 feet.	Suggest replacing "+25 feet" with "**+14.8 feet**".
4.2.1.2	4-44	Paragraph 4	Jordan Cove would test subsoil for compaction at regular intervals in areas disturbed by construction activities; and would implement BMPs—especially in areas that have not been historically disturbed by industrial land use—as described in Jordan Cove's ECRP. Such BMPs would include limiting construction in wet weather conditions and application of soil amendments to facilitate plant establishment.	Jordan Cove will be testing engineered fills placed in construction areas for compaction during construction. Wet weather BMPs do not include limiting construction in wet weather conditions, Jordan Cove will follow wet weather BMPs detailed in the JCEP Erosion and Sediment Control Pan (J1-000-CIV-RPT-KBJ-50003-00) included in Appendix H.7 of Resource Report 7.	Consider revising to: "Jordan Cove would test engineered fill for compaction at regular intervals in areas as part of construction; and would implement BMPs – especially in areas that have not been historically disturbed by industrial land use – as described in the JCEP Erosion and Sediment Control Plan (ESCP). ~~Such BMPs would include limiting construction in wet weather conditions and application of soil amendments to facilitate plant establishment~~"

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
4.2.1.2	4-44	Paragraph 4	The design of the slope protection against waves would be developed through consultation with DOGAMI.	Resource Report 6, Section 6.4.4.4.5, and Resource Report 13, Section 13.3.5.1.3, specify the design of the proposed slope scour protection system. Where required by law, Jordan Cove will consult with the DOGAMI to determine impact of possible tsunamis and discuss structural mitigation strategies.	Suggest revising to: "The design of the slope protection against waves would be developed through consultation with DOGAMI, where required by law."
4.2.1.2	4-44	Paragraph 4	Jordan Cove would test subsoil for compaction at regular intervals in areas disturbed by construction activities; and would implement BMPs—especially in areas that have not been historically disturbed by industrial land use—as described in Jordan Cove's ECRP.	The Jordan Cove Upland Erosion Control, Revegetation, and Maintenance Plan, included as part of the Section 401 permit application filed March 29, 2018, states, on page 13, it would test topsoil and subsoil for compaction at regular intervals in agricultural and residential areas disturbed by construction activities.	Suggest revising to: "Jordan Cove would test subsoil for compaction at regular intervals in agricultural and residential areas disturbed by construction activities; and would implement BMPs—especially in areas that have not been historically disturbed by industrial land use—as described in Jordan Cove's ECRP."
4.2.2.3	4-62	Paragraph 3	Pacific Connector has identified rock disposal sites. These sites are listed in table 4.1.2.4-1.	Table 4.1.2.4-1 is not included in the DEIS	Suggest revising to: Pacific Connector has identified rock disposal sites. These sites are listed in table 4.1.2.5-1.
4.2.2.3	4-63, 4-64	Table 4.2.2.3-1	Footnote for Prime Farmland on second page of table.	This footnote is incorrect.	Footnotes in table headings should be corrected. High compaction should be "f", Revegetation potential should be "g" and

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
					prime farmland should be changed to footnote "h""
4.2.2.3	4-67	Table 4.2.2.3-2	Table data.	Not all of the Sensitive Soil Characteristics are listed in the footnotes.	Sensitive soil characteristics footnotes for each yard should be corrected to match the footnotes at the bottom of the table. The information copied from Resource Report 7 refers back to Table 7.2-1. The DEIS does not use the same footnote format so the numbers and text need to be updated. Also note that on the other soil tables "sensitive soil characteristics" has been changed to "soil limitations"
4.3 -Water resources and wetlands					
4.3.1.1	4-76	Paragraph 2	Jordan Cove would drill new wells to the east to replace the buried wells.	Roseburg Forest Products, not Jordan Cove, will drill the wells.	Suggest revising to: "<u>Roseburg Forest Products will</u> drill new wells to the east to replace the buried wells."
4.3.1.1	4-77	Paragraph 1	Water associated with construction dewatering would not be directly discharged to waterbodies until either filtered or directed to a settling pond before discharge in accordance with Jordan Cove's ESCP and their Plan and Procedures.	Revise to align with the ESCP.	Suggest revising to: "Water associated with construction dewatering would not be directly discharged to waterbodies until either filtered or directed to ~~a settling pond~~ <u>treatment systems approved by DEQ</u> before discharge in accordance with Jordan Cove's ESCP and their Plan and Procedures."
4.3.2.1	4-83	Paragraph 5	Wastewater generated during construction and operation of	The following construction waste streams will be directed to a wastewater collection sump	Suggest revising to:

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
			the Jordan Cove LNG Project would be treated by the City of North Bend's wastewater treatment system via a new sewer line, and therefore the Project is not likely to add fecal coliform to Coos Bay.	and discharged to the ocean outfall via the IWWP: construction dewatering, oil-water separator, LNG Tank hydrostatic testing, washcar facility treated sanitary effluent, Ingram Yard sanitary package plant effluent, and South Dunes sanitary package plant effluent.	"Wastewater generated during construction and operation of the Jordan Cove LNG Project would be treated (a permit application to modify the existing NPDES permit 101499 was filed with ODEQ on 1/31/19) and discharged to the ocean outfall via a new Industrial Wastewater Pipeline (IWWP) sewer line, and therefore the Project is not likely to add fecal coliform to Coos Bay."
4.3.2.1	4-84	Paragraph 3	Constructing the slip and access channel would result in suspended sediment that would exceed about 20 mg/l over background levels within about 0.2 to 0.3 miles of the dredging site and exceed about 500 mg/l within about 0.1 mile with either dredging method (clamshell or cutter section dredge) (Moffat & Nichols 2017c).	This requested change is a clarification to reflect the conclusions of the study conducted by Moffatt and Nichol in 2006.	Suggest revising to: "Constructing the slip and access channel would result in suspended sediment that would exceed about 20 mg/l over background levels within about 0.2 to 0.3 miles of the dredging site. Modeled suspended sediment concentrations associated with open clamshell dredging are expected to generate a maximum TSS of 6,000 mg/L at the dredge location rapidly decreasing to less than 50 mg/L at 200 m (about 660 ft or 0.1 mile). For hydraulic cutterhead dredging, TSS levels would reach a maximum of 500 mg/L in the vicinity of the dredge but would reduce rapidly to a maximum of 14 mg/L at a distance of 60 m (about 200 ft or 0.04 mile). (Moffat & Nichols 2006a)."
4.3.2.1	4-84	Paragraph 4	Areas of high concentrations, over about 500 mg/l, would	Revise to align with Appendix H.2 and Part 1, Attachment A.3	Suggest replacing sentence with:

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
			generally extend about 0.1 mile from dredge site for cutter suction and clamshell dredges and 1.0 mile from dredge site for cutter suction and clamshell dredges and 1.0 mile for hopper dredge.	of the Joint Permit Application filed with the Oregon DSL on November 7, 2018.	"The overall maximum distribution of areas (i.e., plume extents) that exceed background levels of suspended sediment by over 10 NTUs (20 mg/L) would extend a combined upstream to downstream distance of 5,508 ft (about 1 mile) from the specific capital dredging site. This distance represents an average for the four channel expansion areas using cutter suction and clamshell methods. Areas of high concentrations of suspended sediment, about 6,000 mg/L, would generally extend from locations where open clamshell dredging takes place but would rapidly decrease with distance to less than 50 mg/L at 200 m (about 660 ft or 0.1 mile). For hydraulic cutterhead dredging, TSS levels would reach a maximum of 500 mg/L in the vicinity of the dredge and would reduce rapidly to a maximum of 14 mg/L at a distance of 60 m (about 200 ft or 0.04 mile)."
4.3.3.2	4-93	Paragraph 1	The pipeline would be constructed across or near 352 waterbodies. Of the 352 waterbodies, only about 20 percent (69) are identified as perennial streams. Of the remaining affected waterbodies, 270 are intermittent streams	Pacific Connector suggests using the updated numbers that were included in the Joint Permit Application filed with the Oregon DSL on November 7, 2018.	Revise the sentence to the following: "The pipeline would be constructed across or otherwise affect 342 waterbodies. Of the 342 waterbodies, only about 19 percent (66) are identified as perennial streams. Of the remaining waterbodies, 263 are intermittent streams (which includes 100 intermittent

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
			(which includes 99 intermittent ditches[78]), 9 are perennial ponds (including stock ponds, an industrial pond, and excavated depressions), and 4 are estuaries. In Coos County, the Project would affect 52 waterbodies, in Douglas County 94 waterbodies, in Jackson County 91 waterbodies, and in Klamath County 117 waterbodies.		ditches[78]), 9 are perennial ponds (including lakes or stock ponds), and 4 are estuarine (Coos Bay/2 HDD crossings, the HDD pullback at MP 0.0, and the Coos River). Overall, the pipeline would be constructed across or otherwise affect 47 waterbodies in Coos County, 89 waterbodies in Douglas County, 90 waterbodies in Jackson County, and 116 waterbodies in Klamath County. A table of waterbody crossings, including the proposed crossing method, is included in appendix H (table H-3)."
4.3.2.2	4-95	Paragraph 5	As discussed in section 4.2, a review of ODEQ's Environmental Cleanup Site Information (ECSI) database and EPA's EnviroMapper - Facility Detail Report indicated there are numerous locations within 0.25 mile of the route (see table 4.2.2.3-2) primarily considered pipeline storage sites with either cleaned-up, potential, or confirmed soil and/or groundwater contamination.	The reference to table 4.2.2.3-2 does not seem applicable here.	Suggest revising to: "As discussed in section 4.2, a review of ODEQ's Environmental Cleanup Site Information (ECSI) database and EPA's EnviroMapper -Facility Detail Report indicated there are numerous locations within 0.25 mile of the route (see table G-2 in appendix G ~~table 4.2.2.3-2~~) primarily considered pipeline storage sites with either cleaned-up, potential, or confirmed soil and/or groundwater contamination."
4.3.2.2	4-108	Paragraph 2	From the results of the channel migration and scour analysis, Pacific Connector would design	Pacific Connector provided additional information and language in its supplemental response to the January 3, 2018	Revise text to the following: "From the results of the channel migration and scour analysis, Pacific Connector would design

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			all crossings that were assessed in detail to bury the pipe below the 100-year scour depth or into competent bedrock, whichever is shallower, and, for streams likely to have channel migration, outside and below the 50-year channel migration zone	data request, filed on June 13, 2018.	all crossings that were assessed in detail to bury the pipe below the 100-year scour depth or into competent bedrock, whichever is shallower, and, for streams likely to have channel migration, bury the pipe below the projected depth of the channel thalweg (lowest streambed elevation) within the 50-year CMZ.”
4.3.2.2	4-110	Table 4.3.2.2-7	Spread 7, test section 28, Estimated Volume (gal)	Update to align with the amount in the May 24, 2018 filing (see FERC Accession No. 201805-24-5118)	Update “Spread 7/Estimated Volume ~~1,635,000~~ to 4,635,000”
4.3.2.2	4-113	Paragraph 2	Fifteen stream crossings were categorized as having a high sensitivity to hyporheic zone alteration	Revise to reconcile with Section 2.2.6.15 of Resource Report 2.	Suggest revising to: “~~Fifteen~~ Fourteen stream crossings were categorized as having a high sensitivity to hyporheic zone alteration”
4.3.2.2	4-113	Paragraph 3	A “moderate” sensitivity indicates that the stream crossing displays some indicators that a hyporheic zone is active and functional; approximately 66 crossings fit this category, most of them upper to middle watershed streams. A “low” sensitivity indicates that the stream crossing does not likely support either an extensive or	Revise to reconcile with Resource Report 2.	Suggest revising to: “A “moderate” sensitivity indicates that the stream crossing displays some indicators that a hyporheic zone is active and functional; approximately ~~66~~ 63 crossings fit this category, most of them upper to middle watershed streams. A “low” sensitivity indicates that the stream crossing does not likely support either an extensive or functional hyporheic zone; approximately ~~123~~ 127 stream crossings fit into this category.”

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
			functional hyporheic zone; approximately 123 stream crossings fit into this category		
4.3.2.2	4-114	Last Paragraph	This analysis also used the Stream Segment Temperature Model (SSTEMP) by Bartholow (2002) to estimate potential temperature effects at 15 pipeline crossing locations (<u>each a 75- 95-foot-wide clearing along the whole route</u> (table 4.3.2.2-9).	The results in the referenced table represent a 75-foot-wide clearing.	Revise underlined text to: "(each modeled using a 75-foot-wide clearing)"
4.3.3.1	4-126	Paragraph 3	Emergent wetlands occur in various portions of the LNG terminal area as well as at the APCO and Kentuck Project sites.	Revise to reflect updated information provided in the Design Supplement filed on November 2, 2018 (Accession No. 20181102-5128).	Revise text to: "Emergent wetlands occur in various portions of the LNG Terminal <u>site and the Panhandle Site</u>. <u>Wetlands are present throughout the Lagoon site. Wetlands on the site have not been delineated, but habitat/reconnaissance level wetland mapping has occurred, and no work is proposed in these wetlands</u>."
4.3.3.1	4-126	Paragraph 4	Scrub-shrub wetlands occur in the various portions of the LNG terminal area, and at the APCO site.	Revise to reflect updated information provided in the Design Supplement filed on November 2, 2018 (Accession No. 20181102-5128).	Revise text to: "Scrub-shrub wetlands occur in various portions of the LNG <u>Terminal site and the Panhandle site. Habitat-level reconnaissance surveys have identified scrub-shrub wetlands</u>

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					along the eastern edge of the North Bank Site and a small drainage containing scrub-shrub wetland runs through the center of the site. All ecological uplift activities proposed for the North Bank Site will take place outside the limits of these wetland areas and will not affect them."
4.3.3.1	4-127	Paragraph 1	Forested wetlands occur in the north-central portion of the LNG terminal area and at the APCO and Kentuck Project sites.	Revise to reflect updated information provided in the Design Supplement filed on November 2, 2018(Accession No. 20181102-5128).	Revise text to: "Forested wetlands occur in the north-central portion of the LNG Terminal site near the Access and Utility Corridor, within Wetland K on the eastern South Dunes area, and on the Panhandle Site."
4.3.3.1	4-129	Paragraph 1	Dredging for construction of the Eelgrass Mitigation site could result in approximately 10.3 acres of temporary short-term impacts.	Could not reconcile these acreage numbers with the revised Compensatory Mitigation Plan, filed on January 29, 2019 (Accession No. 20190129-5158).	Suggest revising to: "Dredging for construction of the Eelgrass Mitigation site could result in approximately 9.3 acres of temporary short-term impacts."
4.3.3.1	4-130	Paragraph 1	..and approximately 7.7 acres would be enhanced at the Eelgrass Mitigation site for a total of approximately 99.1 acres of mitigation…	Revised to reflect updated information included in the revised Compensatory Mitigation Plan, filed on January 29, 2019 (Accession No. 20190129-5158).	Revise text to: "…and approximately 9.3 acres would be enhanced at the Eelgrass Mitigation site for a total of approximately 109.9 acres of mitigation…"
4.3.3.2	4-132	Last paragraph	The pipeline would cross 18 (fifth-field) watersheds;	Table 4.2.2.2-1 shows the miles crossed by watershed on page	Suggest revising to:

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				4-93. The pipeline crosses 19 fifth field watersheds , however, there are only impacts to wetlands and waterbodies in 17 of them. Note - Table H-1b in Appendix H only summarizes wetland impacts. It does not include waterbodies affected so not all of the watersheds are listed.	"The pipeline would cross 19 ~~18~~ (fifth-field) watersheds;"
4.3.4.2	4-137	Table 4.3.4.2-2	Key Watersheds crossed by the Proposed Pacific Connector Pipeline, acreage impacts	Recommend using Table 2.2-4 from Resource Report 2 and deleting the BLM and private land information. It appears that 5th field watersheds are confused with Key Watersheds on the Umpqua National Forest. Table 2.2-4 calculates acreages for the 30-foot Operational Easement; whereas DEIS Table 4.3.4.2-2 states 'Operational Easement' but calculates using the 50-foot Permanent Easement.	Suggest FERC uses Table 2.2-4 from Resource Report 2 and deletes the BLM and private land information.
4.3.4.3	4-143	Last Paragraph	The Pacific Connector would cross approximately 0.2 mile of wetlands on federally managed land, affecting a total of approximately 2.2 acres (see table H-1a in appendix H).	Revise to align with acres provided in Table H-1a in Appendix H, on federal lands.	Revise text to: "The Pacific Connector would cross approximately 0.1 mile of wetlands on federally managed land, affecting a total of

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					approximately <u>0.9</u> acres (see table H-1a in appendix H)."
4.3.4.3	4-143	Last Paragraph	This 0.2 acre of permanent conversion would occur to three wetlands:	Revise to align with Table H-1a.	Revise text to: "This 0.2 acre of permanent conversion would occur to <u>four</u> wetlands:" Further, add the following at the end of the list: "EW-85 on land managed by the Forest Service (on the Fremont-Winema National Forest)."
4.4 -Vegetation					
4.4.1.1	4-148	Paragraph 2	Additionally, 23 Port Orford cedars were observed at sites located adjacent to Jordan Lake, in areas that would be preserved as part of the Jordan Cove LNG Project.	This area is part of Dune Forest A which will be permanently impacted by the Access and Utility Corridor & Roseburg laydown.	Suggest revising to: Additionally, 23 Port Orford cedars were observed at sites located adjacent to Jordan Lake~~, in areas that would be preserved as part of the Jordan Cove LNG Project~~.
4.4.2.4	4-161	Table 4.4.2.4-1	Table 4.4.2.4-1	The DEIS omitted unvegetated areas, including urban, industrial, beaches, roads, and open water, as shown in Table 3.3-14 in Resource Report 3. Thus, the total of 4,186 acres in the DEIS does not align with	Include the omitted Table 3.3-14 data.

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				the total of 4,942 acres in Resource Report 3. Wetlands only included "emergent;" acres associated with shrub and forested wetlands are not included in table. Because of these omissions, other subtotals do not align with Resource Report 3.	
4.4.2.4	4-163	Table 4.4.2.4-2	Table 4.4.2.4-2	Similar issues as above, in Table 4.4.2.4-1. The wetlands data aligns with Table 3.3-15 in Resource Report 3 but differs from the DEIS "construction" table; permanent access road totals are different (revised Table 3.3-15 identifies 2 acres, not considering open water and barren); and rounding acreages from the Resource Report 3 table into DEIS table lost an acre of permanent access roads).	Include the omitted Table 3.3-15 data.
4.5 -Wildlife and aquatic resources					
4.5.1.1	4-186	Table 4.5.1.1-2 (notes)	Mill Casino	Mill Casino is no longer part of the Project.	Delete "Mill Casino".

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Throughout	Throughout	Throughout	Boxcar Hill Laydown Area, Boxcar Hill site, Boxcar Hill Laydown and Parking Area, Boxcar Hill Staging Area	Multiple terms are used for Boxcar Hill, which may: (1) imply that there are different activities or areas within the Boxcar Hill site, and/or (2) limit activities that can occur on the Boxcar Hill site to those that are named in the DEIS. Need to define Boxcar Hill site and activities that occur therein early in the DEIS.	Boxcar Hill should be consistently referred to throughout the DEIS as the "Boxcar Hill site". In DEIS Section 2.1.1.10 under the heading "Laydown Yards", define the uses that are planned to occur on the Boxcar Hill site which are "offices, batch plant, parking, laydown, and staging".
4.5.1.2	4-195	Paragraph 3	Mature (greater than 40 years old), late successional (80 to 175 years old), and old-growth (greater than 175 years old) forests are unique, important habitat elements.	The age range identified, "greater than 40 years old", is considered "mid-seral", rather than "mature".	Suggest revising to the following: "~~Mature~~ Mid-seral (greater than 40 years old), late successional (80 to 175 years old), and old-growth (greater than 175 years old) forests are unique, important habitat elements."
4.5.1.2	4-197	Paragraph 4	The Pacific Connector pipeline crosses two BCRs: (1) BCR 5 – Norther Pacific Rainforest, from MP 1.5R to MP 168.15;	Revise to align with the Draft Migratory Bird Conservation Plan filed in the response to the January 3 Data Request on August 31, 2018.	Suggest revising to the following: "The Pacific Connector pipeline crosses two BCRs: (1) BCR 5 – Northern Pacific Rainforest, from MP 0.0 ~~1.5R~~ to MP 168.15;"
4.5.1.2	4-198 and 199	Table 4.5.1.2-3	Table on Birds of Conservation Concern in BCR-5 and BCR-9 that Have Been Observed on BBS Routes within 50 Miles of the Pacific Connector Pipeline Project with Regional and	Data for pelagic cormorant, bald eagle, rufous hummingbird, white-headed woodpecker, pinyon jay, sage thrasher, Brewer's sparrow,	Data in the Regional BCR Trend column of Table 3.4-2 in the August 2018 Migratory Bird Conservation Plan was updated to show regional trends from 2005 to 2015 (earlier data

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			Local Population Trends, and Breeding Dates, if known.	sagebrush sparrow, and tricolored blackbird does not match the table in the draft Migratory Bird Conservation Plan (in the Response to January 3 Data Request filed on August 31, 2018). Willow flycatcher is missing from the DEIS table and eared grebe is listed twice.	no longer available). That table should replace Table 4.5.1.2-3 in the DEIS. The paragraph below Table 4.5.1.2-3 in the DEIS should be replaced as: "Regional trends of BCC species within the Oregon portion of BCR-5 show that four BCC – rufous hummingbird, olive-sided flycatcher, willow flycatcher, and horned lark – are apparently decreasing across BCR-5, but local populations of rufous hummingbird, willow flycatcher, and purple finch are increasing. Regional populations of bald eagles and willow flycatchers have been increasing in BCR-9, but Brewer's sparrows are declining in the region. There are no significant trends for local populations of any BCC in the vicinity of the Pipeline over the past 20 years in BCR-9."
4.5.1.2	4-206	Table 4.5.1.2-6	Throughout table.	There are some discrepancies in the acres provided: Subtotal for Grasslands-Shrublands for 30-foot corridor and permanent access roads are incorrect and should be 123 and 2, respectively; however, total of habitat type is correct.	Suggest revising to the following: Subtotal Grasslands-Shrubland for 30-foot Maintenance Corridor = 123 ~~101~~ Permanent Access Roads acreages should be revised to match acreages in Table 4.4.2.4-2.

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
				The acres for permanent access roads had been incorrectly provided and subsequently updated, but is not included here; total affected should be 2 acres.	
4.5.1.2	4-211	Last paragraph	Noise from HDD drilling would range from Ldn of about 32 to 73 dBA at NSAs, with no noise mitigation. This compares to current ambient Ldn levels at these NSAs ranging from about 42 to 66 dBA.	Resource Report 9, Table 9.8-10 shows a range of Ldn of about 35 to 79 dBA at NSAs, with no noise mitigation. Also, footnote 113 should be checked, as Appendix B of the POD does not mention Ldn, nor does it appear to be directly associated with Table 4.5.1.2-7.	Suggest revising to: "Noise from HDD drilling would range from Ldn of about ~~32~~ 35 to ~~73~~ 79 dBA at NSAs, with no noise mitigation. This compares to current ambient Ldn levels at these NSAs ranging from about 42 to 66 dBA." Remove footnote 113.
4.5.1.2	4-214	Paragraph 4	The expected increase in Ldn noise levels would range from 0.5 dBA to 7.2 dBA above current ambient noise at the nearby NSAs during normal station operations.	Resource Report 9, Table 9.8-6 shows the estimated Klamath Compressor Station Operation Noise Levels at NSAs, including the expected increases at each NSA. The range shown is from 0.5 to 8.0. The 8.0 figure is associated with NSA #3.	Revise to: "The expected increase in Ldn noise levels would range from 0.5 dBA to 8.0 dBA above current ambient noise at the nearby NSAs during normal station operations."
4.5.1.2	4-215 403	Paragraph 3	During operations, Pacific Connector would use mechanical vegetation	The reference to the "existing right-of-way" should be	Suggest revising to:

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			management methods or, where access of machinery is infeasible, manual clearing to maintain the existing right-of-way; this vegetation management would increase the edge effect beyond the maintained right-of-way (e.g., light and wind would be able to penetrate farther into previously "interior" forests).	limited to the 30-foot-wide maintenance corridor.	"During operations, Pacific Connector would use mechanical vegetation management methods or, where access of machinery is infeasible, manual clearing to maintain the 30-foot wide maintenance corridor ~~existing right-of-way~~; this vegetation management would increase the edge effect beyond the maintained right-of-way (e.g., light and wind would be able to penetrate farther into previously "interior" forests)."
4.5.1.2	4-217	Last paragraph	tree felling within 330 feet of MAMU stands would occur after September 15 but before April 1.	The draft MB Plan (provided as Accession No. 20180831-5054) says within "300 feet"	Tree felling within ~~330~~ 300 feet of MAMU stands would occur after September 15 but before April 1.
4.5.2.1	4-231	Paragraph 4 and Appendix Table I-1	A common group of anadromous fish species found in the waterway for LNG carrier traffic to the terminal includes Chinook salmon (Oncorhynchus tshawytscha), coho salmon (O. kisutch), chum salmon (O. keta),…	Section 4.5.2.1, p 4-231, first sentence in the fourth paragraph on this page lists chum salmon as a common anadromous fish species that occurs in the Coos Bay waterway. Needs to be added to Appendix Table I-1.	Add Chum salmon to the list of fish species shown in Appendix Table I-1.
4.5.2.2	4-241	Paragraph 1	The slip, access channel, MOF, and adjacent rock pile apron for Jordan Cove's terminal would cover about 37 acres below the mean higher high water line.	The replacement is to clarify that the 37 acres described in the DEIS are total of temporary and permanent impacts. As noted in Table 3.1-3 on page 23	~~The slip, access channel, MOF,~~ The construction of the slip, access channel, MOF, and adjacent rock pile apron for Jordan Cove's terminal would affect ~~and adjacent rock pile apron for Jordan Cove's terminal would cover~~

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
			This would include less than 1 acre of salt marsh, about 13 acres of intertidal area of unvegetated sand plus algae/mud/sand habitat, about 4 acres of shallow subtidal, about 18 acres of deep subtidal, and about 2 acres of eelgrass.	of a Design Supplement submitted to FERC on 11/2/18, the acreages of wetland and estuarine resources from the slip, access channel, pile dike rock apron and MOF (~37 acres) described include areas affected by operations which are calculated to be ~18 acres.	about 37 acres through temporary and permanent impacts below the mean higher high water line. This would include less than 1 acre of salt marsh, about 13 acres of intertidal area of unvegetated sand plus algae/mud/sand habitat, about 4 acres of shallow subtidal, about 18 acres of deep subtidal, and about 2 acres of eelgrass."
2.5.2.2	4-241	Paragraph 1	Nearly all this habitat change would be permanently converted to deepwater habitat.	The statement currently used in the DEIS depicts that almost all of the wetland and estuarine resources associated with the slip, access channel, pile dike rock apron, and MOF would be deep subtidal post construction. The revision recommended is to clarify that about 18 acres of the approximate 37 acres of construction would be permanently impacted; therefore no more than half of the temporarily impacted habitats are expected to be permanently converted to deep subtidal habitat. In fact nearly 50% of the estimated 37 acres are currently deep subtidal. Furthermore, noted in Table	Revise language to state: "Approximately 18 acres of the habitat impacted by construction would be permanently converted to deepwater habitat."

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
				3.1-3, "Impacts to deep subtidal habitat are not expected during operation, because natural recovery of benthic communities within this habitat is expected within a relatively short time frame following construction." This information is described in detail by resources in Table 3.1-3 on page 23 of a Design Supplement submitted to FERC on 11/2/18.	
4.5.2.2	4-241	Paragraph 1	The largest other area disturbing estuarine habitat would be from marine waterway modifications (i.e., the proposed modifications in the navigation channel) totaling about 40 acres of mostly deep subtidal habitat including the 27 acres from dredging and 13 acres from the dredge lines used for this dredging."	The statement currently used in the DEIS does not distinguish that the wetland and estuarine resources associated with the Navigational Reliability Improvements would be temporary or permanent. The revision recommended is to clarify that the estimated 40 acres of habitat impacted would be temporary and are not expected to have permanent impacts to these habitats. This information is described in detail by resources in Table 3.1-3 on page 23 of a Design	The largest area of estuarine habitat impacted by construction would be temporary and come from the marine waterway modifications (i.e., the Navigational Reliability Improvements proposed) totaling about 40 acres of mostly deep subtidal habitat including the 27 acres from dredging and 13 acres from the dredge lines used for this dredging. The dredging impacts would be temporary and operation of the Terminal is not expected to permanently impact these habitats.

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
				Supplement submitted to FERC on November 2, 2018.	
4.5.2.2	4-243	Paragraph 4	About 1.4 mcy would be removed by marine dredging during creation of the access channel in the bay.	This replacement is to correctly capture the FERC submitted information related to dredge material for the access channel submitted as part of the EFH and APDBA (pg 4-20) on 9/14/18.	~~1.4 mcy~~ "1.3 mcy".
4.5.2.2	4-243	Paragraph 4	The creation of the access channel would result in the modification of about 37 acres of present-day subtidal and intertidal habitat to deeper water habitat in the bay.	This replacement is to correctly capture the FERC submitted information related to permanent impacts to habitats associated with the slip, access channel, MOF and rock apron as described in Table 3.1-3 on page 23 of the FERC submitted Design Supplement on 11/2/18.	The creation of the access channel would result in the modification of about ~~37 acres~~ 18 acres of present-day subtidal and intertidal habitat to deeper water habitat in the bay
4.5.2.2	4-243	Paragraph 4	About 19 acres of intertidal to shallow subtidal habitat, including approximately 2 acres of eelgrass habitat and less than 1 acre of salt marsh, would be modified to primarily deep subtidal habitat during the dredging process of the deepened channel.	The estimated 19 acres of intertidal and shallow subtidal habitat is a combination of the acreages associated with not only the access channel but the slip, TMBB MOF and Rock pile apron. This is described in Table 3.1-3 of the 11/2/18 filed Design Supplement and in Table 4.5.2.2-2 of the DEIS.	Consider revising to: "About 19 acres of intertidal to shallow subtidal habitat, including approximately 2 acres of eelgrass habitat and less than 1 acre of salt marsh, would be modified to primarily deep subtidal habitat during the dredging process of the access channel, marine slip, MOF and rock pile apron."

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
4.5.2.2	4-244	Paragraph 6	The loss of 2 acres of eelgrass would be mitigated by off-site development and planting of a minimum of 6 acres of eelgrass habitat in the bay.	The distinction is made because eelgrass in the Access Channel would not be lost, but would be relocated, prior to dredging. It's the eelgrass habitat that would be converted to deep water habitat. The Eelgrass Mitigation site replaces that habitat. Reference Compensatory Wetland Mitigation Plan submitted to FERC on 01/29/19 Page 5-6.	Consider replacing with: "The loss of 2 acres of eelgrass habitat would be mitigated by off-site development and planting of a minimum of 6 acres <u>within the proposed 9.34 acres</u> of eelgrass habitat in the bay."
4.5.2.2	4-245	Paragraph 1	There would be some short-term loss of eelgrass habitat from those areas dredged during construction and from the removal of donor stock areas when the Eelgrass Mitigation site is planted.	Suggested revision is to add context with respect to the analysis.	Add the following language: "Short-term loss of eelgrass from construction would be minimal, because very little eelgrass is present within the Eelgrass Mitigation site footprint. JCLNG will use USACE guidelines to remove donor stock eelgrass such that minimal loss in productivity will occur and recovery of the donor bed will be rapid."
4.5.2.2	4-245	Paragraph 2	This mitigation site would reestablish 67 acres of tideland habitat and additional wetland acreage.	This replacement is to capture the updated Compensatory Wetland Mitigation Plan submitted to FERC on 01/29/19. Page 7 of this plan provides further detail in the calculation of the proposed mitigation.	Consider replacing with 67 acres with "a minimum of about 73 acres".

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4.5.2.2	4-248	Paragraph 3	The Kentuck project would provide about 67 acres of shallow water habitat as mitigation for the loss of about 16 acres of shallow estuarine water habitat at the access channel and the Eelgrass Mitigation site would provide 6 additional acres of eelgrass habitat as mitigation for the loss of 2 acres of eelgrass habitat.	This replacement is to capture the updated Compensatory Wetland Mitigation Plan submitted to FERC on 01/29/19. Pages 5-7 of this plan provides further detail in the calculation of the proposed mitigation.	Consider revising to: The Kentuck project would provide a minimum of about ~~67~~ 73 acres of shallow water habitat as mitigation for the loss of about 16 acres of shallow estuarine water habitat at the access channel and the Eelgrass Mitigation site would provide a minimum of about 6 additional acres of eelgrass habitat as mitigation for the loss of 2 acres of eelgrass habitat
4.5.2.3	4-254	Paragraph 6	Stormwater runoff from the disturbed portions of the site would be managed in accordance with Jordan Cove's ESCP and ODEQ-approved Storm Water Management Plan (see section 4.3.2.2).	This section only discusses construction related stormwater runoff, the SWMP is for post-construction stormwater runoff.	Suggest revising to: Stormwater runoff from the disturbed portions of the site would be managed in accordance with Jordan Cove's ESCP included in the National Pollutant Discharge Elimination System Permit Number 1200-C for stormwater discharged during construction activities ~~and ODEQ-approved Storm Water Management Plan (see section 4.3.2.2).~~
4.5.2.3	4-255	Paragraph 2	Hydrostatic Testing: The source of water would be local untreated potable supply from the CBNBWB.	Revision for clarity.	Suggest replacing "local untreated potable supply" with "potable and raw water."
4.5.2.3	4-261	Paragraph 2	All areas where LNG may be present would be curbed and graded so that any spill would flow to containment trenches	The height of the LNG storage tank protective berm stated in this DEIS paragraph is incorrect. As indicated in Table	Consider revising first sentence to:

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			leading to impoundment basins. The two LNG storage tanks would be surrounded by a 65-foot-high barrier. Any spills of hazardous materials would be handled in accordance with Jordan Cove's SPCC Plan (see section 4.3.2.2).	13.2-2 in Resource Report 13, the tank foundation grade elevation is +27 ft and the top of the protective berm elevation is +46 ft, thus the height of the berm is 19 ft.	"All areas where LNG may be present would be curbed, bermed and/or graded so that any spill would flow to containment trenches leading to impoundment basins or flow directly to the impoundment basins." Suggest deleting second sentence, as it is not correct (regarding height of the wall) and the third sentence of the paragraph directs the reader to a more complete discussion in Section 4.3.2.2.
4.5.2.3	4-263	Second to last paragraph	The Pacific Connector Pipeline would cross or affect 352 waterbodies: 69 perennial streams, 270 intermittent streams (99 of these are considered ditches), 9 ponds (i.e., all ponds are adjacent to the line and would not be directly crossed), and 4 estuarine channels. Available data indicate that about 71 of these waterbodies are known or assumed to be inhabited by fish.	Revise to reflect the November 7, 2018 filing the Oregon DSL.	Suggest revising to: "The Pacific Connector pipeline would cross or affect 342 waterbodies: 66 perennial streams, 263 intermittent streams (100 of these are considered ditches), 9 ponds (i.e., all ponds are adjacent to the line and would not be directly crossed), and 4 estuarine channels. Available data indicate that about 64 of these waterbodies are known or assumed to be inhabited by fish."
4.5.2.3	4-265	Paragraph 2	Anadromous fisheries in the pipeline area comprise eight species: Chinook salmon, Coho salmon, chum salmon, steelhead, coastal cutthroat	Suggest removing chum salmon from the list. The sentence says eight, however nine species are listed. The list of eight in the	Suggest revising to: "Anadromous fisheries in the pipeline area comprise eight species: Chinook salmon, coho

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			trout, Pacific lamprey, river lamprey, Pacific eulachon, and green sturgeon.	APDBA (Accession No. 20180917-5000) does not include Pacific eulachon. The list provided in the DEIS on page 4-265 (DEIS) is not consistent with Pacific Connector Resource Report 3 which states that chum salmon have been extirpated in all sub-basins crossed by the pipeline, including Coos Bay, and should not have been included in the APDBA.	salmon, steelhead, coastal cutthroat trout, Pacific lamprey, river lamprey, Pacific eulachon, and green sturgeon."
4.5.2.3	4-266	Second to last paragraph	The pipeline route would cross under 2.3 miles of estuarine habitat in Coos Bay and cross or pass near an additional 349 waterbodies, of which about 71 are known or presumed to be inhabited by fish. In addition, 4 new stream crossings would occur along the 10 temporary or 15 permanent roads, 2 of which are known to have fish.	Revise to reflect the November 7, 2018 filing the Oregon DSL.	Suggest revising to: "The pipeline route would cross under 2.3 miles of estuarine habitat in Coos Bay (not including estuarine habitat in the Coos River) and cross or pass near an additional 349 waterbodies, of which about 64 are known or presumed to be inhabited by fish. In addition, 2 new stream crossings would occur along the 10 temporary or 15 permanent roads, 1 of which is known to have fish."
4.5.2.3	4-271 459	2nd full paragraph	Construction of the pipeline would affect 69 perennial stream sites, 270 intermittent stream sites, 9 ponds, and 4	Revise to reflect the November 7, 2018 filing the Oregon DSL.	Suggest revising to:

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			estuary channels (table 4.5.2.3-1; including Coos Bay crossings discussed above). A total of 285 locations would be direct channel crossings, while 67 would be locations where the waterbody is in the right-of-way clearing area.		"Construction of the pipeline would affect 66 perennial stream sites, 263 intermittent stream sites, 9 ponds, and 4 estuary channels (table 4.5.2.3-1; including Coos Bay crossings discussed above). A total of 278 locations would be direct channel crossings, while 64 would be locations where the waterbody is in the right-of-way clearing area."
4.5.2.3	4-271	Paragraph 4	Of the streams that would be crossed using the dry-open cut method, about 29 are known to support anadromous salmon and/or steelhead and another 13 streams are assumed to also have anadromous species….34 coldwater, 18 residential, 71 assumed to have fish, 55 EFH….	Revise to reflect the November 7, 2018 filing the Oregon DSL.	Propose replacing this paragraph with: "At one crossing of the South Umpqua River, Pacific Connector would use a diverted open cut. All other waterbody crossings that have flow at the time of construction would be crossed using dry open cut, which is designed to minimize activities directly in flowing water. Of streams that would be crossed using the dry open-cut method, about 30 are known to support anadromous salmon and/or steelhead and another 12 streams are assumed to also have anadromous species. Thirty-four streams crossed are known to support primarily coldwater resident fish, estuarine fish, or important endemic species in the Klamath River Basin. Eighteen additional streams that would be crossed with dry open cut are assumed to support important resident fish. Resident trout are mostly cutthroat trout. In all, about 64 of the waterbodies that would be

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					crossed by, or adjacent to, the pipeline are known or assumed to have fish. Pipeline construction could adversely affect EFH species in up to 38 streams, as well as 2 additional streams with numerous special status fish species crossings (see section 4.6 for ESA listed species). Our pending EFH assessment and BA will describe effects on those species occupying inland streams, and measures Pacific Connector would implement to avoid, minimize, or mitigate the effects."
4.5.2.3	4-279	Footnote 124	Attachment FERC-PCGP-RR3-10 submitted to the FERC in a supplemental filing on May 4, 2018.	No May 4, 2018 filing on the docket. This should be May 24 (20180524-5118).	Correct footnote filing date to May 24, 2018.
4.5.2.3	4-298	Paragraph 2	Total water used for hydrostatic testing would be about 64 million gallons. Pacific Connector would obtain its hydrostatic test water from commercial or municipal sources or surface water rights owners to lakes, impoundments, and streams from possibly 17 different locations. About half of the water would be from impoundments or lakes, and the rest may come from up to nine streams, including Coos River,	These numbers do not align with those provided in Pacific Connector's Response to May 4, 2018 Data Request filed on May 24, 2018. See Attachment FERC-PCGP-RR10-1. 17 locations should be revised to 14 different locations, and the number of potential discharge locations should be "32" rather than "3,084".	Suggest revising to the following: "The maximum amount of ~~Total~~ water used for hydrostatic testing would be about 64 million gallons. Pacific Connector would obtain its hydrostatic test water from commercial or municipal sources or surface water rights owners to lakes, impoundments, and streams from possibly ~~17~~ 14 different locations. ~~About half of the water would be from impoundments or lakes, and the rest may come from up to~~ Water may be withdrawn from nine streams, including Coos River, East and Middle Fork Coquille Rivers, Olalla Creek, South Umpqua

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			East and Middle Fork Coquille Rivers, Olalla Creek, South Umpqua River, Rogue River, Lost River, and Klamath River. Pacific Connector estimates it would withdraw just over 39 million gallons from 12 source locations within six construction spreads along the length of the pipeline route. Pacific Connector would obtain all necessary appropriations and withdrawal permits, including from the OWRD, prior to use. All the streams identified as potential test water sources include anadromous salmonids or resident trout. About 3,084 potential discharge locations for the test water have been identified.		River, Rogue River, Lost River, and Klamath River. ~~Pacific Connector estimates it would withdraw just over 39 million gallons from 12 source locations within six construction spreads along the length of the pipeline route~~. Pacific Connector would obtain all necessary appropriations and withdrawal permits, including from the OWRD, prior to use. All the streams identified as potential test water sources include anadromous salmonids or resident trout. About 32 ~~3,084~~ potential discharge locations for the test water have been identified.”
4.6 -Threatened, endangered species					
4.6.1	4-311	Table 4.6.1-1	Jordan Cove terminal, navigation reliability improvements dredge area	Column heading asks where species may occur. Martens are terrestrial vertebrate.	Jordan Cove terminal, ~~navigation reliability improvements dredge area~~
4.6.1	4-311	Table 4.6.1-1, All whale species	LNG carrier transit in the waterway	Column heading asks <u>where</u> species may occur	<u>Waterways in the area of</u> LNG carrier transit

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4.6.1	4-311	Table 4.6.1-1 Gray whale	LNG carrier transit in the waterway, navigation reliability improvements dredge area	Column heading asks where species may occur	Waterways in the area of LNG carrier transit ~~LNG carrier transit in the waterway, navigation reliability improvements dredge area~~
4.6.1	4-311	Table 4.6.1-1 short-tailed albatross	LNG carrier transit in the waterway	Column heading asks where species may occur	~~LNG carrier transit in the waterway~~ Ocean in the area of LNG carrier transit
4.6.1	4-311	Table 4.6.1-1 marbled murrelet	LNG carrier transit in the waterway Jordan Cove terminal" navigation reliability improvements dredge area	Column heading asks where species may occur	Waterways in area of LNG carrier transit ~~in the Waterway~~ ~~Jordan Cove terminal, navigation reliability improvements dredge area~~ Pacific Connector pipeline
4.6.1	4-311	Table 4.6.1-1 northern spotted owl	Jordan Cove terminal Pacific Connector pipeline	Column heading asks where species may occur	~~Jordan Cove terminal~~ Pacific Connector pipeline
4.6.1	4-311	Table 4.6.1-1 coho South OR/North CA Coast ESU	LNG carrier transit in the waterway Pacific Connector pipeline	Column heading asks where species may occur	~~LNG Carrier transit in the waterway, Jordan Cove terminal~~ Waterways in area of LNG carrier transit, Stream crossings Pacific Connector pipeline
4.6.1	4-311	Table 4.6.1-1 eulachon	LNG carrier transit in the waterway Jordan Cove terminal Pacific Connector pipeline	Column heading asks where species may occur	~~LNG carrier transit in the waterway~~ ~~Jordan Cove terminal~~ ~~Pacific Connector pipeline~~

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					Waterways in area of LNG carrier transit, Stream crossings Pacific Connector pipeline
4.6.1	4-311	Table 4.6.1-1 coho Oregon Coast ESU	LNG carrier transit in the waterway Jordan Cove terminal Pacific Connector pipeline	Column heading asks where species may occur	~~LNG carrier transit in the waterway Jordan Cove terminal,~~ Waterways in area of LNG carrier transit, Pacific Connector Pipeline
4.6.1	4-311	Table 4.6.1-1 All turtles	LNG carrier transit in the waterway	Column heading asks where species may occur	~~LNG carrier transit in the waterway~~ Waterways in area of LNG carrier transit
4.6.1	4-311	Table 4.6.1-1	Table 4.6.1-1 North American green sturgeon		Include reference to "Pacific Connector Pipeline" in column 4
4.6.1.1	4-316	Paragraph 6	Currently, there are two documented populations of fisher in southern Oregon, one in the northern Siskiyou Mountains and one in the southern Cascade Range, that were believed to be genetically isolated from each other (FWS 2014b). However, recent research shows that the two populations are not genetically isolated (Barry et al. 2018).	This last sentence is not supported by the reference cited, Barry et al. 2018.	Suggest deleting the unsupported language: "Currently, there are two documented populations of fisher in southern Oregon, one in the northern Siskiyou Mountains and one in the southern Cascade Range, that were believed to be genetically isolated from each other (FWS 2014b). ~~However, recent research shows that the two populations are not genetically isolated (Barry et al. 2018)."~~
4.6.1.2	4-323	Paragraph 4	Through a combination of GIS data provided by the BLM and private timber companies, and field surveys conducted between 2007 and 2018, Pacific Connector identified 175 occupied and presumed occupied MAMU stands within 0.25 mile of the proposed	Recent habitat surveys (conducted March/April 2018 and provided in Appendix 1 to Attachment A) determined that three presumed occupied stands on private lands (G133, G134, and G58) do not contain suitable nesting structures for MAMU; therefore, these stands	Suggest revising to the following: "Through a combination of GIS data provided by the BLM and private timber companies, and field surveys conducted between 2007 and ~~2018~~ 2019, Pacific Connector identified ~~175 occupied~~ 172 occupied and presumed occupied MAMU stands within 0.25 mile of the proposed action, or within 0.5 mile of

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			action, or within 0.5 mile of federally-designated critical habitat that would be affected by the proposed action.	should be removed from consideration.	federally-designated critical habitat that would be affected by the proposed action."
4.6.1.2	4-324	Paragraph 1	Construction of the Project would remove a total of about 806 acres of MAMU habitat (suitable, recruitment, capable), including about 78 acres of suitable habitat removed from 37 stands (18 occupied MAMU stands and 19 presumed occupied stands). There is the potential that effects could extend over a total of about 7,145 acres of suitable nesting habitat in the terrestrial nesting analysis area...	Approximately 2.46 acres of habitat within the three presumed occupied stands (G133, G134, and G58) would not be affected because no longer considered habitat. 2 acres should be removed from the acreage. The APDBA indicates 39 stands, 19 occupied and 20 presumed occupied. Based on removal of G133, G134, and G58, the following numbers for MAMU stands should be included. Applying the changes above will also affect numbers / acres provided in the Determination of Effect section for MAMU.	Suggest revising to align with the information provided in the APDBA: "Construction of the Project would remove a total of about 806 acres of MAMU habitat (suitable, recruitment, capable), including about ~~78 acres~~ 76 acres of suitable habitat removed from ~~37 stands~~ 36 stands (18 occupied 19 occupied MAMU stands and ~~19 presumed~~ 17 presumed occupied stands). There is the potential that effects could extend over a total of about ~~7,145 acres~~ 7,143 acres of suitable nesting habitat in the terrestrial nesting analysis area..."
4.6.1.2	4-324	4th Bullet	MAMU: Disturbance associated with Pacific Connector Pipeline Project activities and construction of the Kentuck project would	As shown in Appendix 1 to Attachment A , this stand (PO-4) was visited on May 18, 2018 and determined to not provide suitable nesting structures for	Delete bullet.

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			occur within the critical breeding season and within 0.25 mile of known MAMU stands.	MAMU and is no longer a "presumed occupied stand" in the MAMU count. This statement was inadvertently left in the APDBA revisions provided to FERC in September 2018.	
4.6.1.2	4-328	Paragraph 2	For operations and maintenance activities, Pacific Connector would not conduct vegetation maintenance activities within 0.25 mile of NSO activity centers during the entire breeding season (March 1–September 30) to minimize disturbance and disruption to NSO. Other operations and maintenance activities may occur within the breeding season. Mitigation projects such as snag creation projects proposed by the Forest Service to meet LRMP objectives would benefit NSO.	As written, the timing restriction could prevent Jordan Cove from conducting required safety inspections during the growing season. Furthermore, herbicides, should be they be needed to control unwanted vegetation, would be ineffective outside of the growing season. Even mechanical vegetation maintenance would be challenging if limited to the rainy season.	Revise language to: ~~For operations and maintenance activities,~~ Pacific Connector would limit the number of site visits ~~not~~ to conduct vegetation maintenance activities and safety inspections to those that are essential and required within 0.25 mile of NSO activity centers during the ~~entire~~ breeding season (March 1-September 30) to minimize disturbance and disruption to NSO.
4.6.1.2	4-327	Paragraph 2	The Project would affect habitat within 97 NSO home	Revise to align with APDBA.	Suggest revising to the following:

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			ranges and 9 nest patches. About 37 miles of pipeline route would cross 7 designated critical habitat sub-units.		"The Project would affect habitat within 97 NSO home ranges and ~~9~~ 8 nest patches. About 37 miles of pipeline route would cross 7 designated critical habitat sub-units (only 35 miles would cross NSO forested habitat)."
4.6.1.2	4-329	Paragraph 4	Given the anticipated avoidance of disturbance and disruption to NSO….(i.e., implementation of the distance and timing restrictions, without exception), …	"without exception" would apply to timing operations and maintenance timing restriction on p. 4-328. Without exception could prevent required safety inspections and make certain management activities infeasible.	Revise language to: "Given the anticipated ~~avoidance~~ minimization of disturbance and disruption to NSO during the breeding season per inclusion of the recommendation above into the proposed action (i.e., implementation of distance and timing restrictions, unless a written exception is provided for a specific seasonally required activity by the appropriate land management agency)"
4.6.1.3	4-332	5th Bullet	approximately 17 acres of native riparian vegetation (forest, wetlands, unaltered, and nonforested habitats) and altered habitat would be removed during construction within riparian zones associated with designated critical habitat. Adverse effects on riparian zones associated with critical habitat would be long term or permanent depending on whether mid-seral riparian	Table 3.5.3-34a in APDBA includes critical habitat *and* assumed coho habitat. The DEIS does not accurately calculate the acreage from the table.	Suggest revising the language to the following: "approximately ~~17 acres~~ 8.9 acres of native riparian vegetation (forest, wetlands, unaltered, and nonforested habitats) and altered habitat would be removed during construction within riparian zones associated with designated critical habitat. Adverse effects on riparian zones associated with critical habitat would be long term or permanent depending on whether mid-seral riparian forests (~~7 acres~~ 2.1 acres) or LSOG riparian forests (~~2 acres~~ 1.6 acres) are removed.

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			forests (7 acres) or LSOG riparian forests (2 acres) are removed.		
4.6.1.3	4-335	4th Bullet	approximately 88 acres of native riparian vegetation (forest, wetlands, and nonforested habitats) and altered habitat would be removed during construction within riparian zones associated with designated critical habitat associated with waterbodies within range of Oregon Coast coho ESU. Adverse effects on riparian zones associated with critical habitat would be long term or permanent depending on whether mid-seral riparian forests (14 acres) or LSOG riparian forests (4 acres) are removed.	Table 3.5.4-39a in APDBA includes critical habitat *and* assumed coho habitat. The DEIS does not accurately reflect the acreage from the table.	Suggest revising the language to the following: "approximately ~~88 acres~~ 64 acres of native riparian vegetation (forest, wetlands, and nonforested habitats) and altered habitat would be removed during construction within riparian zones associated with designated critical habitat associated with waterbodies within range of Oregon Coast coho ESU. Adverse effects on riparian zones associated with critical habitat would be long term or permanent depending on whether mid-seral riparian forests (~~14 acres~~ 11 acres) or LSOG riparian forests (~~4 acres~~ 2 acres) are removed."
4.6.1.3	4-340	4th List	However, the Project is not likely to adversely affect designated critical habitat for the shortnose sucker because:	The DEIS inadvertently duplicated the "shortnose sucker", and this section should reference the "Lost River sucker."	Suggest revising to the following language: "However, the Project is not likely to adversely affect designated critical habitat for the <u>Lost River</u> sucker because:"
4.6.1.5	4-346	Paragraph 1	Suitable vernal pool habitat occurs within and adjacent to Project facilities, some of which has not been surveyed.	No potentially suitable habitat has been surveyed for vernal pool fairy shrimp.	Suggest revising to the following language:

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					"Suitable vernal pool habitat occurs within and adjacent to Project facilities (habitat has not yet been surveyed)."
4.6.1.6	4-347	Last Paragraph	A botanical analysis area applies to the extent of Project-related effects on listed plant species. The botanical analysis area for this Project extends to 98 feet (30 meters) each side of the pipeline project (i.e., construction ROW, TEWAs, UCSAs, rock source and disposal sites, proposed storage yards, and aboveground facilities) as well as the footprint for the Jordan Cove LNG Project.	This paragraph should include a statement for vernal pool-dependent ESA species. From the APDBA: For the large-flowered woolly meadowfoam, the analysis area was extended 250 feet from the perimeter of four proposed pipe storage areas that are located within the Vernal Pool Complex – Agate Desert, Jackson County, Oregon and shown in figure 3.7.3-1, as well as along the Pipeline right-of-way where Agate-Winlo soil complex occurs. This is a distance within which indirect effects from the Proposed Action could occur to vernal pools supporting this species (FWS 2011h).	Suggest revising to the following language: "A botanical analysis area applies to the extent of Project-related effects on listed plant species. <u>For most listed plant species,</u> the botanical analysis area for this Project extends to 98 feet (30 meters) each side of the pipeline project <u>and for vernal pool dependent species, the analysis area was extended 250 feet in certain instances</u> (i.e., construction ROW, TEWAs, UCSAs, rock source and disposal sites, proposed storage yards, and aboveground facilities) as well as the footprint for the Jordan Cove LNG Project."
4.6.1.6	4-349	3rd bullet	Construction activities would occur in the fall and winter outside the critical growing, flowering, and seeding periods.	Winter construction has not been proposed for this current project.	Suggest deleting the bullet point.

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4.6.1.6	4-349	4th bullet	Wetland mats would be used in travel areas in saturated soil areas to minimize soil rutting and soil compaction and protect existing plants that may be present	The bullet is a conservation measure proposed specifically in the area of Applegate's milkvetch and should be removed from general mitigation discussion for plants.	Suggest deleting the bullet point.
4.6.1.6	4-351	Paragraph 3	The FWS will require two-year protocol surveys in unsurveyed, potentially suitable habitat and in suitable habitat where surveys are older than 10 years.	Pacific Connector began resurveying areas in 2017 that surveys would be 10 years or older by Pipeline construction. Survey efforts on federal lands focusing on two-year surveys, per BLM direction (and FWS), and one-year on private unless surveys have documented plants (per FWS protocol).	Suggest revising to: “Per FWS’ request, Pacific Connector is conducting additional surveys where prior surveys are older than 10 years and will survey federal and private lands in accordance with existing FWS protocols.”
4.6.1.6	4-351	Paragraph 1	Since 2007, survey efforts have identified Gentner’s fritillary individuals in five locales: (1) approximately 0.38 mile north of MP 128.0 near Indian Creek and 50 feet below a four-wheel drive road; (2) 21 feet from TEWA 128.01-W; (3) 100 feet from proposed access road EAR-128.05; (4) near MP 129.1 approximately 54 feet from TEWA 128.96-N; and (5)	The sites were located in 2008 and again in 2010, but the roads in which they were located are no longer proposed for Pipeline project use, as indicated in the APDBA. The roads listed in (1) and (3) are no longer proposed for Pipeline use.”	Revise to: “Since 2007, survey efforts have identified Gentner’s fritillary individuals in <u>three</u> locales: ~~(1) approximately 0.38 mile north of MP 128.0 near Indian Creek and 50 feet below a four-wheel drive road;~~ (1) 21 feet from TEWA 128.01-W; ~~(3) 100 feet from proposed access road EAR-128.05;~~ (2) near MP 129.1 approximately 54 feet from TEWA 128.96-N; and (3) within 21 feet of TEWA 142.07-N near MP 142.1.

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			within 21 feet of TEWA 142.07-N near MP 142.1.		
4.6.1.6	4-353	1st Bullet	The Project **may affect the** Western lily: • known populations occur within 1 mile of the botanical analysis area.	This should be "10 miles"; and the closest known location is 5.5 miles.	Suggest revising the language to the following: "known populations occur within <u>10</u> miles of the botanical analysis area."
4.6.1.6	4-354	2nd Bullet in second list	the 0.48-acre of unsurveyed potential habitat within the Avenue F and 11th and WC Short pipe storage yards consists of low-quality vernal pool habitat within active industrial sites or previously disturbed industrial areas and is unlikely to contain large-flowered woolly meadowfoam;	This should not be listed as a bullet for NLAA because Pacific Connector would avoid using portions of the pipe storage yards within 250 feet of potentially suitable vernal pool habitat (which is actually next bullet under NLAA).	Delete bullet.
4.6.1.6	4-355	Paragraph 3	Surveys have not been conducted within the Avenue F & 11th Street and WC Short pipe storage yards because access has not been granted; however, based on aerial photography and offsite observation in April 2018, Avenue F and 11th and WC Short pipe storage yards do not appear to contain suitable habitat for Cook's lomatium. A	Potentially suitable habitat discussion should be the same as large-flowered woolly meadowfoam, i.e., 0.48-acre of low quality vernal pool habitat near both Avenue F and 11th and WC Short pipe storage yards.	Suggest revising the language to the following: ~~Surveys have not been conducted within the Avenue F & 11th Street and WC Short pipe storage yards because access has not been granted; however, based on aerial photography and offsite observation in April 2018, Avenue F and 11th and WC Short pipe storage yards~~ ~~**do not appear to contain suitable habitat for Cook's lomatium**~~. ~~A long drainage ditch running along the northern edge of the Avenue F and 11th pipe storage yard, which could~~

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			long drainage ditch running along the northern edge of the Avenue F and 11th pipe storage yard, which could provide low-quality habitat for Cook's lomatium, was observed during these off-site surveys.		~~provide low-quality habitat for Cook's lomatium, was observed during these off-site surveys.~~ The 0.48-acre of unsurveyed potential habitat within the Avenue F and 11th and WC Short pipe storage yards consists of low-quality vernal pool habitat within active industrial sites or previously disturbed industrial areas and is unlikely to contain Cook's lomatium.
4.6.1.6	4-357	Paragraph 1	Additionally, the population between MP 96.48 and 96.90 was burned during the 2015 Stouts Creek fire. Although no plants were relocated along the construction ROW between MP 96.48 and 96.90 in 2016, it is possible that construction of the pipeline and use of access roads could affect this population if plants resprout in this area. Pacific Connector would conduct additional surveys within the Stouts Creek fire area (MP 96.48 to 96.9) prior to ground disturbance.	To clarify that there will not be any plants located in this area.	Suggest revising the language to the following: "In 2015, the population between MPs 96.48 and 96.90 was burned during the Stouts Creek fire." "~~Although~~ No plants were observed along the construction ROW between MPs 96.48 and 96.90 in 2016, and during the 2018 monitoring efforts indicated that landowner activities at this site would most likely preclude any plants reestablishing (i.e., timber activities, herbicide use, road expansion, slash piles) ~~it is possible that construction of the pipeline and use of access roads could affect this population if plants resprout in this area.~~ Pacific Connector would conduct additional surveys within the Stouts Creek fire area (MP 96.48 to 96.9) prior to ground disturbance."

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4.6.2	4-363 4-365 4-367 4-369		ORBIC 2006a	ORBIC 2006a citations should be changed to ORBIC 2017 throughout section 4.6.2 (pages 4-363, 4-365, 4-367, 4-369).	ORBIC 2006a should be changed to ORBIC 2017.
4.6.2.3	4-366	Paragraph 1	In 2012, surveys conducted by the BLM documented approximately 1,300 plants within and adjacent (within 100 meters) to the Project, with approximately 300 plants occurring in the construction ROW (BLM 2017c). However, modifications have been made to the pipeline route subsequent to these surveys. In 2018, surveys for Cox's mariposa lily were conducted during the flowering season on approximately 65 acres between MPs 74 and 75 of the revised pipeline route. The 2018 survey data are currently under review by the BLM.	Correct to reflect the current route and timing and location of surveys.	Revise to the following: "BLM has been monitoring a population of Cox's mariposa lily since 2011 which occurs within the vicinity of the Project between MPs 74 and 75. In 2012, BLM documented approximately 13,865 plants within that population, of which 1,300 plants occur within and adjacent (within 100 meters) to the Project, with approximately 300 plants occurring in the construction right-of-way (BLM 2017c). In 2018, PCGP conducted surveys for Cox's mariposa lily during the flowering season on approximately 65 acres between MPs 74 and 75 of the ~~revised~~ proposed pipeline route; plants were documented within and adjacent to the Project. ~~The 2018 survey data are currently under review by the BLM.~~"
4.6.4.2	4-376	Paragraph 5	Approximately 20 acres of the ROW near known populations of two Forest Service sensitive terrestrial invertebrates (Mardon skipper and short-horned grasshopper) on the Dead Indian Plateau would be	Include scientific names for the species listed here. The "short-horned grasshopper" should be referred to as the "Siskiyou short-horned grasshopper".	Suggest revising to: "Approximately 20 acres of the ROW near known populations of two Forest Service sensitive terrestrial invertebrates (Mardon skipper (*Polites mardon*) and ~~short-horned~~

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			restored with grasses (including Festuca sp.) preferred by these species in addition to the rehabilitation required under BMP guidelines. This mitigation on the Rogue River National Forest has the potential to increase the habitat and local range for these two species.		~~grasshopper~~) Siskiyou short-horned grasshopper (*Chloealtis aspasma*)) on the Dead Indian Plateau would be restored with grasses (including Festuca sp.) preferred by these species in addition to the rehabilitation required under BMP guidelines. This mitigation on the Rogue River National Forest has the potential to increase the habitat and local range for these two species."
4.6.4.2	4-376	Paragraph 6	Three BLM and Forest Service sensitive mollusk species were located during surveys for the Project: Siskiyou hesperian, traveling sideband, and Oregon shoulderband.	Include scientific names for Siskiyou Hesperian, Traveling sideband, and Oregon shoulderban.	Please revise to include the scientific names for the following species: "Three BLM and Forest Service sensitive mollusk species were located during surveys for the Project: Siskiyou Hesperian (*Vespericola sierranas*), Traveling sideband (*Monadenia fidelis celeuthia*) Oregon shoulderband (*Helminthoglypta talmadgei*)."
4.6.4.2	4-379	Paragraph 5	Rogue Canyon rockcress (Arabis modesta), Bensonia (Bensoniella oregana), Cox's mariposa lily, Umpqua mariposa lily, bristly sedge (Carex comosa), coastal lip fern (Cheilanthes intertexta), pine woods cryptantha (Cryptantha simulans), clustered lady's	Include scientific name.	Please include the scientific names for the following species: "Bellinger's meadowfoam (*Limnanthes floccosa* ssp. *bellingeriana*)."

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			slipper (Cypripedium fasciculatum), California globe-mallow (Iliamna latibracteata), and Bellinger's meadowfoam.		
4.6.4.2	4-381	Paragraph 3	In 2010, 30,000 plants within less than one acre were documented between MPs 154.8 and 154.7, near Heppsie Mountain (SBS 2011a), also within the Rogue River National Forest.	Include name of plant species.	Revise to include "Belinger's meadowfoam" as the type of plant in the area: "In 2010, 30,000 Belinger's meadowfoam plants within less than one acre were documented between MPs 154.8 and 154.7, near Heppsie Mountain (SBS 2011a), also within the Rogue River National Forest."
4.6.4.3	4-392	Table 4.6.4.3-6	Sites on NFS Lands in NSO Range b/ = 1540	Revise typographical error based on Appendix F.5, Section 4.1.	Sites on NFS Lands in NSO Range b/ = ~~1540~~ 540
4.6.4.3	4-393	Table 4.6.4.3-7	Remaining Sites on NFS Lands in NSO Range = 1,539	Sites identified in Table 4.6.4.3-7 are not consistent with the data provided in Appendix F.5.	The following numbers should be revised: Change 1,539 to 539 Change 1,390 to 1,391 (one site affected, 1,392 minus 1)
4.6.4.3	4-397	Table 4.6.4.3-8	Total Sites in NSO Range a/ *Arborimus longicaudus* = 34,946	Total sites of *Arborimus longicaudus* in Table 4.6.4.3-11 indicate 34,946; however Table ARLO-1 in Appendix F.5 and related text identifies 4,946 sites. Number should be revised.	Revise to the following: Total Sites in NSO Range a/ *Arborimus longicaudus* = ~~34,946~~ 4,946

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4.6.4.3	4-397	Table 4.6.4.3-11	Sites in NFS Reserves in NSO Range - *Arborimus longicaudus* -624 (34%)	Total sites of *Arborimus longicaudus* in Table 4.6.4.3-11 indicate 624 sites in NFS Reserves; however this number should be 539 which differs from the number 524 included in text below Table ARLO-3 in Appendix F.5 (505 in LSRs, 8 in LSR3, 14 in LSR4, 11 in CR, and 1 RR).	Revise to the following: Sites in NFS Reserves in NSO Range - *Arborimus longicaudus* ~~-624~~ 539 (~~34%~~ 35.4%)
4.6.4.3	4-397	Table 4.6.4.3-11	Sites in NFS Reserves in NSO Range – *Strix nebulosi* – 16 (12%)	Total sites of *Strix nebulosi* in Table 4.6.4.3-11 indicate 16; however, Table STNE-3 in Appendix F.5 and related text identifies 6 sites. Number should be revised from 16 to 6. Additionally, Table 4.6.4.3-11 indicates 55 sites on NFS in NSO Range, which would be 11%; however, data in Tables STNE-2 and STNE-3, respectively identify either 55 or 51 sites on NFS lands. Using 51 sites and 6 on reserves, the percent on reserves would be 12% (which is also what text says below Table STNE-3 in Appendix F.5).	Number of *Strix nebulosi* sites on NFS lands should be revised in both Appendix F.5 and the DEIS to rectify numbers and update appropriately.

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4.6.4.3	4-398	Table 4.6.4.3-12	Vertebrate Sites Potentially Affected by the Project	Reconcile the amounts in the tables.	Table 4.6.4.3-12 identifies that 525 habitat areas (or 55 sites) would be affected by the Pipeline; footnote b/ identifies that 55 sites were converted to 25 habitat areas). The number of habitat areas (25) also correlates with text included in Appendix F.5. Number in the table should be changed from 252 to 25.
4.7 -Land Use					
4.7.1.1	4-400	Table 4.7.1.1-1	Boxcar Hill Staging Area Oregon Dunes Sand Park, LLC; North Bank Site Fort Chicago Holdings II US LLC	Align with Supplemental Resource Report filed with FERC November 2, 2018.	Add: "and Fort Chicago Holdings II US LLC" after "Oregon Dunes Sand Park, LLC" for ownership of the Boxcar Hill site; Add "and private" after "Fort Chicago Holdings II US LLC" for ownership of the North Bank Site.
4.7.1.1	4-400	Table 4.7.1.1-1	Please see table.	Align with Supplemental Resource Report filed with FERC November 2, 2018.	Add: "Pile Dike Rock Apron" owned by "Fort Chicago Holdings II US LLC, State of Oregon (easement) Oregon International Port of Coos Bay, State of Oregon (easement)"
4.7.1.1	4-400	Table 4.7.1.1-1	Please see table.	The table does not identify the COE easement on land owned by Fort Chicago Holdings II US LLC and Roseburg Forest Products.	For the LNG Terminal entries under both "Construction and Operation" and "Temporary Construction," revise the ownership text to state "Fort Chicago Holdings II US LLC, COE (easement)." For the Roseburg Laydown Site entry under "Temporary Construction," revise the

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					ownership text to state "Roseburg Forest Products Company; COE (easement)."
4.7.1.1	4-409	Table 4.7.1.1-2	Table on Land Uses Affected by Construction and Operation of Aboveground Jordan Cove Project Area Facilities.	The acreages listed in Table 8.1-2 of the Supplemental Resource Report filed with FERC November 2, 2018 do not match those displayed in DEIS Table 4.7.1.1-2 for certain areas, and some data is omitted (see, e.g., the row for the Pile Dike Rock Apron).	Consider updating the 4.7.1.1-2 and references in DEIS text to match acreages and "Project Facility/Activity" rows listed in Table 8.1-2 of the Supplemental Resource Report filed with FERC November 2, 2018.
4.7.1.3	4-410	Bullet Point List	N/A	Update to align with Table 8.2-1 of the Supplemental Resource Report filed with FERC on November 2, 2018.	Add to the bullet point list: "One structure (disused building) on Eastern South Dunes that would be removed".
4.7.1.3	4-410	Paragraph 3	With the exception of the shed that would be removed from the construction work area for the Boxcar Hill site, none of these structures would be affected and no mitigation is proposed.	Revise to align with Sections 5.2.3 & 8.2.2 of the Supplemental Resource Report filed with FERC November 2, 2018.	Replace with: "None of the above listed structures would be affected with the following exceptions: 1) the shed would be removed from the construction work area for the Boxcar Hill site; 2) two structures within the construction work area for the Roseburg Laydown site would be removed; and 3) a disused structure would be removed on the Eastern South Dunes area. No mitigation is proposed."
4.7.1.4	4-414	Paragraph 2	The dune areas at the LNG terminal site currently contain non-merchantable timber.	DEIS Section 4.7.1.4 says that timber will be selectively processed for commercial	Suggest changing "non-merchantable timber" to "low-grade timber" as stated in section 1.5.3 of Resource Report 1.

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				timber, so it must be at least partially merchantable.	
4.7.2.2	4-416	Table 4.7.2.2-2	Table on Acres of Land Affected by Construction and Operation of the Pacific Connector Pipeline Project	FERC should use acreages from the November 2, 2018 FERC Data Request response which included an updated Table 8.4-1: Update impact of disturbance (Klamath CS) to 21.39 and subsequent totals and operation disturbance to 17.4.	Update acreage of disturbance associated with Klamath Compressor Station and subsequent table totals.
4.7.2.2	4-419	Table 4.7.2.2-3	Table on Acres Affected by Operation of Pacific Connector Proposed Aboveground Facilities	FERC should use acreages from the November 2, 2018 FERC Data Request response, which included an updated Table 8.3-4: Updated impact 21.40 acres, subtotal 25.40, grand total 27.01	Update acreage of disturbance during construction for Klamath Compressor station and subsequent table totals.
4.7.2.3	4-419	Coastal Zone Management	Therefore, Pacific Connector would need to obtain a finding from the ODLCD that the portion of its pipeline within the coastal zone (MPs 1.5 R to 53)…	1.5 R is a carryover from 2015. The current number is 0 R.	Revise to current numbers: "(MPs 0 to 53)".
4.7.3.1	4-425	Section 4.7.3.1	Land Requirements on Federal Lands.	The title of the DEIS section implies that all Project Land Requirements on Federal Lands should be discussed within the section; however, only Pipeline	Add the following: "With the exception of a COE easement at the LNG Terminal site and BLM land crossed by the industrial wastewater pipeline (within an

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				requirements are discussed. The Terminal requirements need to be added consistent with Section 5.1.7 of the DEIS.	existing utility corridor), no federal lands would be affected at the LNG terminal site." In addition, language should be added to clarify how these lands would be affected. For the industrial wastewater pipeline, for example, the land is currently used as a utility corridor, and elsewhere, the DEIS notes minimal and temporary impacts (disturbance of less than 0.2 acre as discussed at page 4-405, less than 0.1 acre of temporary wetland impacts as discussed at page 4-127, and no permanent effects anticipated as discussed at page 4-405.
4.7.3.3	4-437	Table 4.7.3.3-2	Table on Forest Service NWFP Land Allocations – Acres Impacted by the Pipeline	Table matches Table 8.5-3a in Resource Report 8 in some cells but not in others. Specifically, Off-site Source/Disposal in Umpqua added 15.87 acres for Peavine Quarry, but because the quarry is categorized as a TEWA, it is already included in the 30.66 acres.	Revise to be consistent with Table 8.5-3a in Pacific Connector Resource Report 8.
4.7.3.3	4-441	Table 4.7.3.3-3	Table on BLM RMP Land Allocations – Acres Impacted by the Pacific Connector Pipeline	Table matches Table 8.5-4a in Resource Report 8 for BLM Medford and Lakeview districts but not for Coos Bay and Roseburg.	Revise to be consistent with Table 8.5-4a submitted in Pacific Connector Resource Report 8.

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4.8 -Recreation and visual resources					
4.8.1.1	4-538	Paragraph 1	"An estimated average of 802 non-local workers are expected to be employed over the 53-month-long construction phase, with the number of non-local workers expected to peak at 1,568 workers during month 30."	This information is not consistent with the data on Page 4-588 of the DEIS.	Jordan Cove to reconcile data. Consider revising to: "An estimated average of 802 non-local workers are expected to be employed over the 53 month-long construction phase, with the number of non-local workers expected to peak near 1,557 workers during month 30."
4.8.1.1	4-540,4-541	Last Paragraph	Excavation of the berm and the four submerged areas as part of the Navigation Reliability Improvements would occur during a single in-water work period.	Correct timing for excavations for the Navigation Reliability Improvements from one in-water period to four in-water periods	Consider revising the wording to: "Excavation of the berm and the four submerged areas as part of the Navigation Reliability Improvements would occur during <u>four</u> in-water work periods."
4.9 -Socioeconomic					
4.9.1.1	4-588	Paragraph 3	…with projected employment expected to peak in month 30 with an estimated 1,996 workers employed on site (ECONorthwest 2017a).	Update to be consistent with identification of the pipeline's peak employment month.	Suggest revising to: "…with projected employment expected to peak in December of <u>Year 3</u> ~~(month 30)~~ with an estimated 1,996 workers employed on site (ECONorthwest 2017a)."
4.9.11	4-589	Paragraph 1	At the peak of construction, an estimated total of 1,752 people would temporarily relocate to	Revise to reflect that the estimate provided is for the LNG terminal only.	Suggest revising to: "At the peak of <u>terminal</u> construction, an estimated total of 1,752 people could

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			the Project vicinity (ECONorthwest 2017a).		temporarily relocate to the Project vicinity (ECONorthwest 2017a)."
4.9.1.2	4-590	Paragraph 3	In 2015, Coos County had an estimated total of 30,482 housing units[166], with a rental vacancy rate of 6.7 percent and 660 housing units available for rent.	Data should reflect Table 11 on page 16 of ECONorthwest 2017a, which states that Rental Housing vacancy rate is 8.1%.	Suggest correcting percent of housing units available and revising to: "In 2015, Coos County had an estimated total of 30,482 housing units[166], with a rental vacancy rate of <u>8.1</u> percent and 660 housing units available for rent."
4.9.1.2	4-590	Paragraph 4	A housing analysis and action plan completed for Coos County in 2018 (czbLLC 2018) found limited affordable housing units available for rent or purchase in Coos County, with very little new construction over the past decade and existing units being converted to vacation and seasonal use. The study identified a deficit of affordable rental units for almost all income groups, including low income households. In addition, the study noted that anecdotal examples exist of newcomers being unable to find quality housing at a reasonable price (czbLLC 2018).	See pages 6, 12, 13, 18, 28 and 29 of the CZB Housing Study. Housing challenges are not due to a static growth in population but rather a large portion of the population is choosing to age in place. (see page 6). The study simply states that a growth in population is not a cause for the increased prices of properties. An increase in population would not going to necessarily address the issue. The current population would need additional income level in the $35,000 to $50,000 rage to afford rent when there is a slight rent surplus.	Suggest replacing paragraph with: "A housing analysis and action plan completed for Coos County in 2018 (czbLLC 2018) found <u>that, due to a significant portion of the county's population choosing to age in place, a loss of employment opportunities, and stagnant incomes within the county, there has been little new residential construction in Coos County over the past decade. In addition, many existing home ownership units have been converted to rental units, especially for vacation and/or seasonal use. The study concluded that there is a shortage of quality rental units in Coos County for households earning less than $35,000 annually and a shortage of affordable home ownership options for households with annual incomes below $75,000.</u> In addition, the study noted that anecdotal examples exist of

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					newcomers being unable to find quality housing at a reasonable price (czbLLC 2018)."
4.9.1.1	4-588	Paragraph 3	…with projected employment expected to peak in month 30 with an estimated 1,996 workers employed on site (ECONorthwest 2017a).	Update to be consistent with identification of the pipeline's peak employment month.	Suggest revising to: "…with projected employment expected to peak in December of Year 3 ~~(month 30)~~ with an estimated 1,996 workers employed on site (ECONorthwest 2017a)."
4.9.1.2	4-591	Paragraph 2	Units would be added in phases beginning with approximately 200 units in the fall of year 2, and peaking at up to 700 units (depending on demand) in early year 3, with the number of units on-site gradually reduced starting in the latter half of year 4.	The units discussed in this section relate to workforce housing	For clarity, suggest revising to: "<u>Workforce housing units</u> would be added in phases beginning with approximately 200 units in the fall of year 2, and peaking at up to 700 units (depending on demand) in early year 3, with the number of units on-site gradually reduced starting in the latter half of year 4."
4.9.1.2	4-591	Paragraph 3	Potential housing options for relocating workers include rental housing (houses, apartments, and mobile homes), hotels and motels, and RV parks and campgrounds, as discussed above.	Clarify that this paragraph applies to potential housing options for construction workers.	Suggest revising to: "Potential housing options for relocating <u>construction</u> workers include rental housing (houses, apartments, and mobile homes), <u>and short-term housing accommodations, including</u> hotels and motels, and RV parks and campgrounds, as discussed above."

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4.9.1.2	4-591	Paragraph 4	These estimates also assume, as described above, that about one-third of the workers temporarily relocating to the area would be housed at the workforce housing facility, thereby reducing demand for other types of housing in the Project vicinity.	Given that 802 workers will temporarily relocate (see DEIS 4-588, Paragraph 4) and that 311 workers will utilize worker housing (EcoNorthwest 2017a. Table 12 p18), 39 percent of the workers will use the workforce housing facility during an average month. Given that 1752 people will relocate to the Project vicinity (EcoNorthwest 2017a) and 693 will use the workforce housing facility (EcoNorthwest 2017a, Table 12, page 18) during the peak at the LNG terminal, 40 percent of the workers would be at the temporary workforce housing facility.	Suggest revising to: "These estimates also assume, as described above, that around 39 percent of the workers would temporarily relocate to the area and be housed at the workforce housing facility, thereby reducing demand for other types of housing in the Project vicinity, (during both peak and average months of construction)."
4.9.1.4	4-593	Paragraph 2	State and local government and retail trade were the two largest sectors in the county in 2015 based on employment (U.S. Bureau of Economic Analysis 2016a). The median household income in Coos County in 2015 was $38,934 (U.S. Census Bureau 2016).	Update to include the comparisons of local versus state wages in dollars.	Suggest revising to: "In 2016, annual wages in Coos County averaged $37,083, compared to a statewide average annual wage rate of $49,452 (Oregon Employment Department 2017). State and local government and retail trade were the two largest sectors in the county in 2015 based on employment (U.S. Bureau of Economic

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					Analysis 2016a). The median household income in Coos County in 2015 was $38,934, compared to a statewide median household income of $51,243 (U.S. Census Bureau 2016)."
4.9.1.5	4-594	Paragraph 5	The LNG terminal would contribute to the fiscal health of local communities through a local Community Enhancement Plan (CEP) in Coos County. Construction and operation of the Jordan Cove LNG Project would also generate state and local tax revenues, including revenues from payroll taxes.	Clarify the components of the CEP by noting that it includes $40 million (See Resource Report 5, page 12) per year for initial 15 years (See Resource Report 5, page 16) of operation and that that equates to 76.5 percent of Coos County's total revenue in fiscal year 2016 (Resource Report 5, page 9).	Suggest revising to: "The LNG terminal would contribute to the fiscal health of local communities through a local Community Enhancement Plan (CEP) in Coos County. The cities of Coos Bay and North Bend, along with Coos County and the Port of Coos Bay, would oversee a community fund to implement the CEP, which, once operational, would amount to approximately $40 million per year, on average, during the initial 15 years of operation. Approximately $40 million per year equates to 76.5 percent of Coos County's total revenues in fiscal year 2016. Construction and operation of the Jordan Cove LNG Project would also generate local, state, and federal tax revenues, including revenues from payroll taxes."
4.9.1.6	5-595	Paragraph 2	Jordan Cove would also be responsible for funding additional security measures outlined in the Coast Guard's WSR and LSR to protect LNG carrier marine traffic to and from the terminal within the	Correct acronym from LSR to LOR (Letter of Recommendation).	Suggest revising to: "Jordan Cove would also be responsible for funding additional security measures outlined in the Coast Guard's WSR and LOR to protect LNG carrier marine traffic to and from the

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			waterway; this would include escort boats operated by the County Sheriff's department.		terminal within the waterway; this would include escort boats operated by the County Sheriff's department."
4.9.1.6	4-597	Paragraph 5	During LNG carrier transit in the waterway to the terminal, fishermen would be required to move out of the security zone, which would result in delays in transit.	Update to more clearly define USCG safety and security zone.	Suggest revising to: "During LNG carrier transit in the waterway to the terminal, a non-exclusionary USCG safety and security zone would be implemented. Other vessels would be allowed to transit through the safety zone and would also be allowed in the safety zone during LNGC passage provided that the other vessels do not impede the safe navigation of the LNG carriers in the restricted channel, and that the other vessels do not pose a security threat or concern to the LNG carriers in transit. The timing and constraints associated with LNG carrier transit through the channel entrance bar area would be similar to existing constraints on chip ships and log carriers calling at the port.
4.9.1.6	4-598	Paragraph 4	Also, two warehouses located on the Roseburg Forest Products site would be removed during site preparation.	Add a description of the structures that will be removed on Boxcar Hill and South Dunes.	Suggest added the following to the end of the paragraph: "On the Boxcar Hill site, one structure, a small shed, would be removed. A disused structure would be removed on the Eastern South Dunes area."

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4.9.1.9	4-600	Paragraph 3	The data also indicate that the share of the population considered low income by EJSCREEN in the city of Coos Bay, within 3 miles of the site, and in Coos County is higher than the statewide average.	Data includes city of North Bend.	Suggest revising to: "The data also indicate that the share of the population considered low income by EJSCREEN in the city of North Bend, city of Coos Bay, within 3 miles of the site, and in Coos County is higher than the statewide average."
4.9.1.9	4-603	Paragraph 1	Additionally, the combined demand for housing from LNG terminal and pipeline workers would result in a significant impact on housing in Coos County.	Clarify that the impacts on housing will be temporary.	Suggest revising to: "Additionally, the combined demand for housing from LNG terminal and pipeline construction workers would result in a significant temporary impact on housing in Coos County."
4.9.2.1	4-604	Paragraph 1	The construction workforce ….	Clarify that the construction worker estimates are for the pipeline.	Suggest revising to: "The pipeline construction workforce …"
4.9.2.1	4-604	Paragraph 2	Based on Pacific Connector's initial estimates, monthly employment for pipeline construction is assumed to average 241 workers in Coos County,…	Clarify that the numbers of workers are estimates.	Suggested revising to: "Based on Pacific Connector's initial estimates, monthly employment for pipeline construction is estimated to average 241 workers in Coos County,…"
4.9.2.1	4-604	Paragraph 3	Peak construction workforces…	Clarify that the construction worker estimates are for the pipeline	Suggested revising to: "Peak pipeline construction workforces…"

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4.9.2.1	4-604	Paragraph 4	Construction of the Pacific Connector pipeline in Coos County would coincide with Jordan Cove LNG Project construction. Based on the above analyses, the combined temporary increase in population (workers and family members) associated with both projects would average 1,076 workers over the life of the Project. Assuming LNG terminal and pipeline construction activities in Coos County begin at the same time, construction workforces could potentially peak at the same time, resulting in a temporary combined increase in population of approximately 2,555 workers. These potential additions would be equivalent to approximately 1.7 percent (average) and 4.0 percent (peak) of the total estimated population in Coos County in 2017.	The numerical updates are not significant enough to necessarily warrant change. Although the DEIS paragraph states that the terminal and pipeline workforces would peak at the same time, ECONorthwest's analysis assumes that the terminal and pipeline workforces would peak at different periods. The suggested text revisions more accurately reflect the underlying analysis behind the DEIS' workforce estimates while preserving FERC's "worst case" scenario of peak employment impacts in Coos County.	Suggested revisions to paragraph: "Construction of the Pacific Connector pipeline in Coos County would coincide with Jordan Cove LNG Project construction. Based on the above analyses, the combined temporary increase in population (workers and family members) associated with both projects would average 1,177 people over the life of the Project. Although the LNG terminal construction workforce is expected to peak in December of Year 3 and the pipeline construction workforce in Coos County is expected to peak in June of Year 3, scheduling changes and other contingencies could result in the two construction workforces potentially peaking at the same time, leading to a temporary combined increase in population (workers and family members) of approximately 2,544 people. This upper-bound estimate of the potential short-term increase in Coos County's population due to terminal and pipeline construction would be equivalent to approximately 1.7 percent (average) and 4.0 percent (peak) of the total estimated population in the county in 2017."
4.9.2.2	4-605	Paragraph 3	Estimated average and peak housing demand by non-local construction workers is shown	Update to reflect the czbLLC 2018 study.	Suggest revising to: "Estimated average and peak housing demand

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			by housing type and county in table 4.9.2.2-2. Estimated average and peak demand is compared with estimated supply by housing type and county in table 4.9.2.2-3. Viewed as a portion of available rental housing, peak demand for rental housing would range from 6 percent (Klamath county) to 24 percent (Coos County) and 25 percent (Douglas County) of estimated available units. As discussed in section 4.9.2.1, the 2018 Coos County housing analysis and action plan identified a shortage of affordable rental housing (czbLLC 2018). Similarly, despite Census estimates that almost 1,000 housing units in Klamath County are currently available for rent, a recent newspaper editorial indicated that Klamath Falls and Klamath County are also facing a housing shortage (H&N View 2019).		by non-local pipeline construction workers are shown by housing type and countyin table 4.9.2.2-2. Estimated average and peak demand are compared with estimated supply by housing type and county in table 4.9.2.2-3. Viewed as a portion of the available supply of rental housing units, peak demand for rental housing by pipeline construction workers would range from 6 percent (Klamath County) to 24 percent (Coos County) and 25 percent (Douglas County) Anecdotal evidence suggests that some construction workers could find it difficult to obtain suitable rental housing in Coos County (czbLLC 2018). Similarly, a recent newspaper editorial noted a housing shortage in Klamath Falls and Klamath County (H&N View 2019), which could affect the ability of pipeline construction workers to find rental housing in that county.”
4.9.2.2	4-606	4.9.2.2-3	a/ Percentages represent estimated demand as a share of	Clarify that the percentages are based on seasonal occupancy	Suggest revising footnote to:

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			the total estimated supply of hotel and motel rooms and RV sites, not the share that would normally be available for rent.	rates. See DEIS at 4-606, with sentence starting with "Total supply …."	a/ Percentages represent estimated demand as a share of the total estimated supply of hotel and motel rooms and RV sites, not the share that would normally be available for rent, based on seasonal occupancy rates.
4.9.2.2	4-606 4-607	Paragraphs 1, 2 Paragraphs 1, 2, 3	During peak tourist season (July to September), short-term accommodations in some communities, especially those in Coos, Douglas, and Jackson Counties, would experience lower vacancy rates and upward pressure on rental rates. The availability of short-term housing, especially at hotels, motels, and RV parks, could become limited in the immediate pipeline vicinity, and workers and others seeking temporary accommodation in those areas may pay higher rents or have to commute farther than desired. Additionally, during peak construction worker demand, tourists would likely be displaced, particularly during summer weekends. Visitors seeking outdoor recreational opportunities do, however, have	Replace July to September with July to August in accordance with page 16 of ECONorthwest. 2017b. Further update numbers to align with EcoNorthwest 2017b. The remainder of changes are for clarification.	Suggest revising to: "During peak tourist season (July to August), short-term accommodations in some communities, especially those in Coos, Douglas, and Jackson Counties, would experience lower vacancy rates and upward pressure on rental rates. The availability of short-term housing, especially at hotels, motels, and RV parks, could become limited in the immediate pipeline vicinity, and workers and others seeking temporary accommodation in those areas could pay higher rental rates for rooms or RV sites, or have to commute farther than desired. Additionally, during the period of peak demand for short-term housing by pipeline construction workers, tourists would likely be displaced, particularly during summer weekends. Visitors seeking outdoor recreational opportunities do, however, have a wide range of destination choices in southern Oregon and would be likely to recreate elsewhere in the region if they were interrupted by pipeline construction at a

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			a wide range of destination choices in southern Oregon and would be likely to recreate elsewhere in the region if they were interrupted by pipeline construction at a particular location. These potential issues would be exacerbated in Coos County, where the Pacific Connector Pipeline Project construction would coincide with Jordan Cove LNG Project construction, resulting in higher levels of demand for temporary housing. The following discussion addresses the combined demand from both projects and assumes that housing demand would peak for both projects during the same month. Combined, estimated average and peak demand for hotel and motel rooms, RV or campground spaces, or individual room rentals would be for 429 and 1,212 units, respectively, equivalent to 11 percent and 31		particular location. These potential housing issues would be exacerbated in Coos County, where the Pacific Connector Pipeline construction would coincide with Jordan Cove LNG terminal construction. The following discussion addresses the combined demand for housing in Coos County from construction workers on both projects, and assumes that housing demand would peak for both projects during the same month. If this occurred, the estimated average and peak demand for short-term housing accommodations (hotel and motel rooms, RV and campground spaces, and individual room rentals) would be for 484 and 1,190 units, respectively, equivalent to 12.5 percent and 30.8 percent of the total supply of hotel and motel rooms and RV spaces in Coos County (3,862). The peak level of demand would exceed the number of hotel and motel rooms and RV spaces in Coos County that are usually vacant and available for rent during the summer, and would result in increased competition for temporary housing among terminal and pipeline construction workers, as well as the potential displacement of tourists and other visitors who would be unable to find temporary

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			percent of the total supply of hotel and motel rooms and RV spaces in Coos County. These peak levels of demand would exceed the share of hotel and motel rooms and RV spaces that are usually vacant and available for rent during the summer, resulting in increased competition for temporary housing among workers, as well as the potential displacement of tourists and other visitors who would be unable to find temporary accommodation in Coos County. For rental housing, the combined estimated average and peak demand would be for 207 and 432 units, respectively, equivalent to approximately 31 percent and 65 percent of the total 660 units estimated to be available for rent in Coos County. As noted in section 4.9.2.1, potential shortages of rental housing have been identified in Coos County		accommodation in Coos County. The combined estimated average and peak demand for rental housing in Coos County would be for 241 and 426 units, respectively, equivalent to approximately 36.5 percent and 64.5 percent of the total 660 units estimated to be available for rent in the county. The increased demand for rental housing from coincident peak construction workforce levels would be likely to further reduce vacancy rates and place upward pressure on residential rental rates in Coos County, resulting in the potential displacement of other existing or potential residents seeking rental accommodations. The 15 permanent employees required for pipeline operation would have no noticeable effect on local housing markets."

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			(czbLLC 2018). Increased demand from Project-related construction workers would likely reduce vacancy rates and place upward pressure on rental rates, resulting in the potential displacement of other existing or potential residents seeking rental accommodation. Operation of the pipeline would require 15 permanent employees and would have no noticeable effect on the local housing markets.		
4.9.2.4	4-609	Paragraph 1	Constructing the Project would also support an estimated total of 4,102 indirect and 6,344 induced FTE jobs, with an estimated average of 2,051 indirect and 3,172 induced FTE jobs supported each year. In addition, Project construction would support total (direct, indirect, and induced) output, value added, and labor income of $2.8 billion, $1.3 billion, and $1.1 billion, respectively (table 4.9.2.4-2).	Clarify that this paragraph relates to the pipeline.	Suggest revising to: "Constructing the Pipeline Project would also support an estimated total of 4,102 indirect and 6,344 induced FTE jobs, with an estimated average of 2,051 indirect and 3,172 induced FTE jobs supported each year. In addition, Pipeline Project construction would support total (direct, indirect, and induced) output, value added, and labor income of $2.8 billion, $1.3 billion, and $1.1 billion, respectively (table 4.9.2.4-2)."

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4.9.2.4	4-609	Paragraph 2	Annual Project operation is estimated to support total…	Clarify the paragraph relates to the pipeline.	Suggest revising to: "Annual Pipeline Project operation is estimated to support total…"
4.9.2.5	4-610	Paragraph 1	Local tax revenues would be generated from property taxes.	Revise to show that tax revenues include city lodging taxes.	Suggest revising to: "Local tax revenues would be generated from property taxes and city lodging taxes."
4.9.2.5	4-611	First Paragraph	Property tax payments would vary over time due to pipeline depreciation and changing tax rates.	Suggest including state assessor methodologies as a variable to property tax payments	Suggest revising to: "Property tax payments would vary over time due to pipeline depreciation, state assessor methodologies, and changing tax rates."
4.9.2.9	4-618	Paragraph 3	The impacts of constructing and operating the Project on the natural and human environments are identified and discussed throughout the environmental analysis section of this document.	Clarify that the paragraph relates to the pipeline.	Suggest revising to: "The impacts of constructing and operating the Pipeline Project on the natural and human environments are identified and discussed throughout the environmental analysis section of this document."
4.9.4	4-621	Paragraph 2	Construction and operation of the Project would result in impacts on socioeconomic resources as described in the preceding sections. Temporary impacts during construction would include increased demand for law enforcement	Insert additional numerical values to offer a more thorough conclusion. The numerical values can be found in Table 4.9.1.4-1 and Table 4.9.2.4-2 of the DEIS.	Suggest revising to: "Construction and operation of the Project would result in impacts on socioeconomic resources as described in the preceding sections. Project construction would provide direct employment and income for local workers, and support jobs and income

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			and fire protection, and medical services. These potential construction-related impacts would be temporary and short term. In addition, constructing the Project would provide direct employment for local workers, support jobs and income elsewhere in the local and state economies, and generate tax revenues for local, state, and federal agencies. However, when the combined effects of the Jordan Cove LNG Project and Pacific Connector Pipeline Project are taken into consideration collectively, construction of the Project has the potential to cause significant affects to short-term housing in Coos County. These impacts could include potential displacement of existing and potential residents, as well as tourists and other visitors. Tourists and other visitors could also be displaced during peak construction in Douglas and Jackson counties as Project-related demand for		elsewhere in the local and state economies. Over the 53 month (4.4 years) construction period, Jordan Cove LNG Project construction would create an average of 1,023 direct jobs per year, 798 of which are expected to be filled by Oregon residents. In addition, terminal construction would support an average of 6,236 indirect and induced jobs per year for Oregon residents. Constructing the Pipeline Project would also support an estimated total of 4,102 indirect and 6,344 induced FTE jobs, with an estimated average of 2,051 indirect and 3,172 induced FTE jobs supported each year. These impacts to employment and personal income would be temporary and would end with construction completion. Purchases of supplies and materials and the use of service providers would generate revenue for local and Oregon businesses. Project construction would also generate tax revenues for local, state, and federal agencies. Additional temporary impacts during construction would include increased demand for law enforcement, fire protection, and medical services. These potential construction-related impacts would be temporary and short term. When the combined workforces of the Jordan Cove LNG Project and Pacific Connector Pipeline Project are taken into

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			hotel and motel rooms would likely exceed the normally available supply. With the applicant's proposed construction and operations procedures and mitigation measures in place, construction and operation of the LNG terminal and pipeline facilities are not expected to result in significant impacts on socioeconomic resources or services, with the exception of housing availability.		consideration collectively, construction of the Project has the potential to cause significant effects to short-term housing in Coos County. The Project could stimulate troubled housing markets, especially in Coos and Klamath counties, by improving local economic conditions through increased job opportunities and earning potential that would allow local residents to advance to an income bracket offering more affordable housing choices. In the event that rental rates for housing and short-term accommodations were to increase, additional housing impacts could include the potential displacement of existing and potential residents as well as tourists and other visitors. However, Oregon's recently-passed rent control legislation restricts annual rent increases to keep living costs affordable for lower-income residents and protects residents from displacement in the short term as a result of fast rising rent prices. Tourists and other visitors could also be displaced during peak construction in Douglas and Jackson counties as Project-related demand for hotel and motel rooms could exceed the normally available supply. With the applicant's proposed construction and operations procedures and mitigation measures in place, construction and operation of the LNG terminal and pipeline facilities are not expected to result in

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					significant impacts on socioeconomic resources or services, with the exception of housing availability. <u>Potential impacts to housing would be temporary and would end with construction completion.</u> <u>Permanent employment associated with the Jordan Cove LNG terminal and Pacific Connector Pipeline projects would include 200 workers at the LNG terminal in Coos Bay, 20 workers at Jordan Cove's offices in Portland, six pipeline technicians in Coos Bay, five employees in the Medford pipeline office in Jackson County, and four employees at the Pacific Connector compressor station in Klamath County. Project operations would also contribute to local and state business revenues; as well as revenues to local, state and federal agencies, largely through property, sales and income taxes</u>."
4.11 -Cultural Resources					
4.11	All	Throughout	N/A	Derr *et al.* 2018b (Survey Addendum 2 report) has not been incorporated throughout the entire section.	Revise and update the tables and text throughout this section using the current site status table using Derr *et al.* 2018b, as shown in Appendix 3 and Appendix 4 (filed separately under seal as privileged).
4.11.2.1	4-646	Paragraph 1	The consultants concluded that no historic properties would have a view of the aboveground components of the LNG	Jordan Cove recommends the text be revised to more clearly reflect the consultant's conclusion.	Revise the sentence to the following: "As such, the indirect APE was recommended to be the same as the direct APE because the

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			terminal. As such, the indirect APE was recommended to be the same as the direct APE.		new visual elements, auditory additions, and potential cumulative impacts to the environment appear to be in scale with the existing environment."
4.11.3.3	4-651	Table 4.11.3.3-1	Row 4 of Table, Column (Subsurface Detail) Test Units	This report included shovel probes and test units.	Consider revising to: "Test units and shovel probes"
4.11.3.3	4-652	Paragraph 2	Surveys have not been conducted at the following five locations in the indirect APE…...West side of the Kentuck Slough	A survey has been conducted at the West Kentuck Slough location and the results are reported in Bowden et al. 2017.	Consider revising to: "at the following four locations" and remove: "West Kentuck Slough"
4.11.4	4-653	Paragraph 7	Pacific Connector included a copy of its August 2017 draft UDP as Appendix B.4 of Resource Report 4,…..	Text should align with Appendix E.4	Revise text to: "Pacific Connector included a copy of its August 2017 draft UDP as Appendix E.4 of Resource Report 4..."
4.12 -Air and noise					
4.12.1.1	4-657	Paragraph 4	Nonattainment NSR (NNSR), which applies to "major" stationary sources located in nonattainment areas, and PSD, which applies to "major" stationary sources located in attainment or unclassifiable areas. Because existing air quality is classified as	Language is potentially misleading because the Jordan Cove LNG Project is not a PSD project.	Suggest changes to second and third sentences: "… and NSR/PSD, which applies to "major" stationary sources located in attainment or unclassifiable." "… only NSR/PSD regulations are applicable to Jordan Cove LNG Project."

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			"attainment" or "unclassifiable" for all NAAQS pollutants, only PSD regulations are applicable to the Jordan Cove LNG Project.		
4.12.1.1	4-657	Paragraph 4	The Project as originally designed was considered a "major" PSD source, and a PSD permit application was submitted to ODEQ in March 2013. However, the current Project design no longer includes the previously proposed South Dunes Power Plant facility, and as a result it no longer qualifies as a major PSD source.	The Project refers to both the LNG Terminal and the Pipeline.	"The Project" should be replaced with "The Jordan Cove LNG Terminal."
4.12.1.1	4-657	Paragraph 4	A Type B state-only NSR application was submitted to ODEQ in September 2017.	Both the Klamath Compressor Station and Jordan Cove LNG Project applied for a Standard ACDP by submitting a Type B state-only NSR application. There is no mention of the Type B state-only NSR permit application submitted to ODEQ in May 2015 for the Pacific Connector Pipeline Klamath Compressor Station; or that a	Recommend revising this sentence to: "A Type B state-only NSR application was submitted to ODEQ in September 2017 <u>for the Jordon Cove LNG project and in May 2015 for the Pacific Connector Pipeline Klamath Compressor Station</u>."

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				draft ACDP permit was issued and completed the public hearing process in April 2016. Additionally, an application for a modification to the ACDP permit was to be submitted in September 2017 to change the make/model of the three turbines from Solar Titan 130 gas turbines to GE PGT25/DLE 1.5 gas turbines.	
4.12.1.3	4-663	Second paragraph under heading “Visible Emission and Nuisance Requirements”	The LNG Project site is within three miles of North Bend, Oregon,…	Current language does not include Coos Bay, Oregon.	Suggest including Coos Bay, Oregon, which is located within three miles of the LNG Project with a population of approximately 16,000.
4.12.1.3	4-672	Table 4.12.1.3-3	PM2.5 maximum cumulative impact + background value of 18.2 micrograms/cubic meter.	Jordan Cove believes the 18.2 value in Table 4.12.1.3-3 is a typo and the proper value is 17.2.	Suggest changing value to 17.2 micrograms/cubic meter.
4.12.1.3	4-672	Table 4.12.1.3-3	Third column title – “Maximum Cumulative Impact”	Clarify that the figures shown in the “Maximum Cumulative Impact” column are obtained from two different sources. Some are the modeled results	Replace Table 4.12.1.3-3 with updated table provided in Appendix 5.

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				for comparison to NAAQS, and some are the results for comparison to the increment. Reconstructing the value in the "Maximum Cumulative Impact + Background" column by starting with the values in the "Maximum Cumulative Impact" column results in an erroneously high value for pollutants and averaging periods for which an increment result is shown. The footnote would clarify that the values shown in the "Maximum Cumulative Impact" column are not necessarily the values to be used for comparison to the NAAQS.	
4.12.1.5	4-676	Paragraph 3	If modeled impacts at all of the 50 km receptors were below the significant impact level (SIL)…	Suggest clarifying the type of SIL.	Suggest revising the language to: "If modeled impacts of all of the 50 km receptors were below the <u>Class I</u> significant impact <u>level</u> (SIL)…"
4.12.1.5	4-676	Paragraph 3	…Jordan Cove LNG Project at all Class I areas would be well below the SILs.	Suggest clarifying the type of SIL.	Suggest revising the language to: "…Jordan Cove LNG Project at all Class I areas would be well below the <u>Class</u> I SILs."

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4.12.2.2	4-681	Paragraph 5	which collected data for approximately 30 minutes per measurement.	Sound level data from the 2017 survey was collected over three days.	Consider revising the sentence to state: "for several days at each measurement location."
4.12.2.2	4-681	Last paragraph of page	over a period of greater than 24 hours	The survey took place over three days.	Consider revising the sentence to state: "over a period of greater than 72 hours"
4.12.2.2	4-682	Paragraph 3	Pacific Connector monitored the ambient noise levels at those NSAs over a period of greater than 24 hours, and the results are presented in table 4.12.2.2-2.	According to Appendix B of the Klamath Compressor Station Noise Study (September 2017) in Appendix C.9 of the Pacific Connector Pipeline Resource Report 9, the ambient noise levels were collected in two (2) 10-minute intervals, one in the daytime and one in the nighttime.	Recommend replacing the sentence as follows: "Pacific Connector monitored the ambient noise levels at those NSAs and the results are presented in table 4.12.2.2-2."
4.12.2.3	4-683	Paragraph 2	Noise levels from the construction equipment are expected to range from 71 dBA L_{eq} to 81 dBA L_{eq} at 50 feet.	The low end of the construction equipment level range had been incorrectly identified. The correct number is 68 dBA (for the manlift), not 71 dBA.	Consider revising the sentence to state: "...from 68 dBA L_{eq} to 81 dBA L_{eq} at 50 feet."
4.12.2.3	4-684	Last paragraph	Based on the noise levels provided in table 4.12.2.3-2, it is predicted that pile-driving operations could result in an	This is clearly a non-continuous source. It is not appropriate to use 48.6 dBA Leq (equivalent to 55 dBA Ldn for a continuous	Consider deleting the last sentence and revising the first sentence to the following:

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			increase greater than 3 dB Ldn on the ambient noise level at two NSAs. Additionally, using the Lmax values, pile-driving activities would result in noise impacts at all NSAs at or greater than our noise criterion of 48.6 dBA Leq 188.	source as noted in footnote 188) as a comparison to the Lmax sound levels from pile-driving. These are two entirely different metrics that describe two different properties of sound pressure and it therefore does not make logical sense to compare them. In addition, there is not an increase of greater than 3 dB at two NSAs, rather at one NSA (NSA 1) and at one receptor point (REC 1).	"Based on the noise levels provided in table 4.12.2.3-2, it is predicted that pile-driving operations could result in an increase greater than 3 dB Ldn on the ambient noise level at NSA 1 and at REC 1."
4.12.2.3	4-684	Paragraph 2	The pipe pile diameters would range from 24 to 72 inches, and the maximum sound pressure level data were analyzed.	Clarify the source of the impact pile driving data.	Consider revising the sentence to: "The pipe pile diameters would range from 24 to 72 inches, and the maximum sound pressure level data from the equipment manufacturer were used in the impact pile driving analysis."
4.12.2.3	4-686	Table 4.12.2.3-4	Values in the column titled "Increase Over Existing Ambient"	The values in Table 4.12.2.3-4 show the difference between the "2017 Nighttime Measured 1-hour L_{eq}/L_{50}" and the "Predicted Project Sound Levels (L_{eq})" The increase in sound level should show the difference between the combined ambient and project sound level, so the "2017	Consider changing the values in the "Increase Over Existing Ambient" column to read 4, 0, 5, and 4 for NSAs 1, 2, 3, and REC 1, respectively.

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
				Nighttime Measured 1-hour L_{eq}/L_{50}" and the "Predicted Project Sound Levels (L_{eq})" should be logarithmically summed and then the "Predicted Project Sound Level (L_{eq})" should be subtracted from that value.	
4.12.2.3	4-686	Paragraph 4	Project demonstrates compliance with the OAR anti-degradation standard as there are no expected increases greater than 10 dBA relative to the measured nighttime 1-hour Leq/L50 sound level.	The proposed site of the Jordan Cove LNG Terminal is a previously used industrial site, therefore the anti-degradation standard does not apply.	Consider deleting this paragraph
4.12.2.3	4-688	Table 4.12.2.3-5	Values in "Increase Over Existing Ambient"	The values in the "Increase Over Existing Ambient" are not correct. As an example, see the row for REC 1 for the Process Flare condition, the increase is listed as "<1" even though the flare contribution is 51 and the ambient is 48. The increase should be logarithmic sum of (51+48) – 48 or 5.	Consider updating the table to show the values in Appendix 6.
4.12.2.3	4-688	Table 4.12.2.3-5	Values in "Predicting Flaring Sound Level (Adjusted for Event Duration), L_{eq}"	The predicted L_{eq} sound levels for flaring in the table have been calculated from the L_{dn} values presented in the Resource	Consider updating the table to show the values in Appendix 6.

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				Report 9 by subtracting 6.4 decibels. This does not correctly calculate the one-hour L_{eq} for flaring events. The 24-hour L_{dn} as presented in the Resource Report 9 included 30-minutes of nighttime operation for the Cold Process Flare, 2 hours of nighttime operation for the Warm Process Flare, and 9 hours of night and 5 hours of daytime operation for the marine flare. By subtracting 6.4 dB from the L_{dn} values presented in the Resource Report 9, the DEIS table presents the sound level for a continuous (24-hours per day) source that would have the same L_{dn} as the flaring events. To accurately predict the 1-hour flaring L_{eq} for comparison with the 1-hour ambient, the flaring should be broken out by flaring type. The "Flaring Sound Level (Adjusted for Event Duration), L_{eq}" for the Cold Process Flare will be 3 decibels less than the sound	

DEIS Section	Page No.	Paragraph Table Figure No.	Text	Comment	Suggested Resolution
				level contribution L_{eq} of that flare (because it only takes place for one-half of the hour, the 1-hour L_{eq} is 3 decibels lower than the flare contribution, because a 3 decibel decrease represents one-half of the sound level energy), while the 1-hour L_{eq} (adjusted for event duration) for the other two flares will be equal to their sound level contribution L_{eq} (because the event duration is longer than one hour).	
4.12.2.3	4-689	First paragraph	"process flaring is substantially louder than marine flaring and therefore dominates the combined case, with process flaring as the only even with an increase over ambient levels being greater than 1 Ldn."	The meaning of the second half of the sentence is not clear.	Consider ending sentence with "the combined case" and deleting the remainder of the sentence.
4.12.2.4	4-690	Paragraph 3	HDD operations are expected to last up to 4 weeks at each site.	According to Pacific Connector Resource Report 1, Request 3 response on page 131 of the Jordan Cove and Pacific Connector Response to Commission Staff's January 3, 2018 Data Request (submitted	Recommend replacing sentence with: "HDD/DP operation durations are dependent upon HDD length and geology, among other factors. For Pacific Connector, HDD/DP duration ranges from 30 days to 130 days."

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				January 26, 2018), the HDD and DP estimated construction durations range from 30 days to 100 days. Additionally, current planning indicates that the duration range should updated to 130 days.	
4.12.2.4	4-694	Table 4.12.2.4-3	The "Predicted Increase Over Existing L_{dn} (dBA)" for NSA 4	Typographical error.	Consider changing the "Predicted Increase Over Existing L_{dn} (dBA)" for NSA 4 from 6 dB to 5 dB.
4.12.2.4	4-694	1st Bullet	The turbine intake and/or exhaust systems should be equipped with silencers having greater insertion losses than the standard Solar Titan 130 silencers in order to reduce the noise contribution at the nearest NSA (NSA 1) to a level below Ldn 55 dBA.	According to page 35 of Pacific Connector Resource Report 9, the turbine air intake and/or exhaust systems will be equipped with silencers having greater insertion losses than the standard GE silencers.	Replace "standard Solar Titan 130 silencers" with "standard silencers".
4.12.2.4	4-694	3rd Bullet	The turbine lube oil coolers should have noise levels approximately equal to Solar's 85 dBA cooler. The cooler noise level at a horizontal distance of 50 feet from the center of each cooler will be about 54 dBA.	No need to be vendor specific on this element and recommend deleting the reference to Solar and making it generic.	Consider replacing as follows: "The turbine lube oil coolers should have noise levels approximately equal to <u>85 dBA, which are available.</u> The cooler noise level at a horizontal distance of 50 feet from the center of each cooler will be about 54 dBA."

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4.12.2.4	4-696	Table 4.12.2.4-5	Values under "Distance", column 3	Incorrect distances were provided in Attachment FERC-PCGP-RR9-4 to Pacific Connector's response to the January 3, 2018 data request, filed with FERC on January 26, 2018. The table should be revised to match Table 9.8-12 of Resource Report 9.	Suggest revising distances to the following: Correct the table to include the following distances: BVA#2 – 727 feet; BVA#5 - 1,114 feet; BVA#6 - 1,096 feet; BVA#8 – 205 feet; BVA#10 - 896 feet; BVA#15 - 1,092 feet; BVA#16 - 604; BVA#17 - 743 feet.
4.13 -Reliability and safety					
4.13.1.5	4-716	Paragraph 2	A diesel storage tank would be provided to supply two standby diesel generators that would support the black start and power backup capability. The diesel storage tank would also supply three diesel firewater pumps.	Please revise DEIS description to align with the Supplemental Information submitted to FERC on May 2, 2019.	Consider replacing with: "A diesel storage tank would be provided to supply the three diesel firewater pumps. Black start power supply for the STGs will be available from the grid. However, during the detail design phase of the Project, Jordan Cove will consider installing one standby diesel generator to provide redundant black start power supply. The diesel storage tank will supply diesel to this standby generator if included in the final design."
4.13.1.5	4-723	Paragraph 2	Jordan Cove would design for overpressures in accordance with API 753, ASCE 41088, and other recommended and	Alignment of applicable codes and standards for overpressure design. Jordan Cove will follow API RP 752, API RP 753 and	Consider changing to:

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			generally accepted good engineering practices	ASCE 41088 design methodology and levels of protection as indicated in the Overpressure Design Criteria (J1-000-STR-BOD-KBJ-50015-00) included in Appendix H.13.3 in Resource Report 13.	"Jordan Cove would design for overpressures in accordance with API RP 752, API RP753 and ASCE 41088."
4.13.1.5	4-723 and 4-728	Paragraph 3	…a fire from the tank outer walls would result in less than 4,000 Btu/ft2-hr in most other areas of the plant with the exception of the LNG Flash Drum and the Auxiliary Boiler	The Equipment referenced in these paragraphs are within the 10,000 Btu/ft2-hr heat flux zone.	Consider changing to: "…a fire from the tank outer walls would result in less than 10,000 Btu/ft2-hr in most other areas of the plant with the exception of the LNG Flash Drum and the Auxiliary Boiler."
4.13.1.5	4-732	Paragraph 2	The subsurface data from the geotechnical soil borings and CPT soundings indicate that the subsurface conditions are relatively consistent across the site. Generally, the profile consists of existing sand fill from the ground surface near EL 20 feet to EL 9.5 feet. Near approximately EL 9.5 feet, an up to 2 feet thick layer of peat is present in many locations across the site.	Alignment of DEIS description for the west side of Ingram Yard with the Geotechnical Report (J1-000-GEO-RPT-KBJ-50001-00) description included in Resource Report 13 Appendix J.13.4. This DEIS paragraph describes the conditions on the west side of the Ingram Yard portion of the site. This is not representative of the eastern portion of the Ingram Yard site	Suggest modifying this text as: "The subsurface data from the geotechnical soil borings and CPT soundings indicate that the subsurface conditions on the west side of Ingram Yard are relatively consistent with existing sand fill from the ground surface near EL 20 feet to EL 9.5 feet. Near approximately EL 9.5 feet, and up to 2 feet thick organic/peat layer is present in many locations below the fill, with native sand below the peat as discussed in the previous paragraph."

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				where there is a dune overlying the site and no peat is present.	
4.13.1.5	4-732	Paragraph 2	Below EL −30 feet is dense to very dense, native sand that extends to about EL −135 feet. From EL −135 feet to below EL −260 feet. A clayey silt material identified as poorly indurated silty shale was found below about EL −235 feet.	Incomplete statement. This paragraph should to be updated to include the subsurface conditions at the west side of Ingram Yard as described in the Geotechnical Report (J1-000-GEO-RPT-KBJ-50001-00) included in Appendix J.13.4 of Resource Report 13.	Revise this paragraph to provide the complete context for "From EL -135 feet to below EL -260 feet".
4.13.1.5	4-732	Paragraph 4	Measured groundwater elevations have varied from a high of approximately 18 feet to 1 foot NAVD 88 below grade.	Remove reference to "below grade" depths. The groundwater elevations values presented in this paragraph are elevations not depths.	Consider changing to: "Measured groundwater elevations have varied from a high of approximately 18 feet to -1 foot NAVD 88."
4.13.1.5	4-733	Paragraph 1	At Ingram Yard, the potential total settlement was estimated to approximately 11.5 inches. Along the Access and Utility Corridor, the potential total settlement was estimated to be approximately 0.8 to 9.5 inches. At the South Dunes, the potential total settlement was estimated to be approximately 0.5 inch up to 7 inches.	Alignment of DEIS description of liquefaction settlement with the Geotechnical Report (J1-000-GEO-RPT-KBJ-50001-00) included Appendix J.13.4 in Resource Report 13.	Consider changing to: "At Ingram Yard, the potential total settlement due to liquefaction was estimated to be approximately 11.5 inches. Along the Access and Utility Corridor, the potential total settlement due to liquefaction was estimated to be approximately 0.8 to 9.5 inches. At the South Dunes, the potential total settlement due to liquefaction was estimated to be approximately 0.5 inch up to 7 inches."

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4.13.1.5	4-733	Paragraph 1	Due to the wide range of settlement values, we recommend in section 4.13.1.6 that Jordan Cove file an upper limit for total settlement for large flexible foundations and the maximum total edge settlement for equipment and structures consistent with applicable codes, including but not limited to API 620, API 625, API 653, and ACI 376.	Alignment of description between DEIS Section 4.13.1.5 (Page 4-733) and DEIS Section 4.13.1.6 and Recommendation No. 109. The referenced industry standards are applicable to the foundations of the LNG storage tanks only.	Consider changing to: "Due to the wide range of settlement values, we recommend in section 4.13.1.6 that Jordan Cove file the settlement results during hydrostatic tests of the LNG storage containers and periodically thereafter to verify the settlement is as expected and does not exceed the applicable criteria in API 620, API 625, API 653 AND ACI 376."
4.13.1.5	4-734	Paragraph 2	Jordan Cove states that FERC and NEPA 59A… Thus, the final design would be intended to satisfy the FERC, NEPA 59A...	Please correct typo on the NFPA 59A standard references in this paragraph.	Consider replacing with: "Jordan Cove states that FERC and NFPA 59A (2001)…" and "Thus, the final design would be intended to satisfy the FERC, NFPA 59A (2001),…"
4.13.1.5	4-737	Paragraph 3	Based on the design ground motions for the site and the importance of the facilities, the facility seismic design is assigned Seismic Design Category D in accordance with the IBC (2006) and ASCE 7-05.	Update this paragraph to be consistent with the site seismic design categories described in the Seismic Ground Motion Hazard Study (J1-000-GEO-RPT-KBJ-50002-00) included in Appendix I.13.1 of Resource Report 13.	Consider changing to: "Based on the design ground motions for the site and importance of the facilities, the facility seismic design is assigned Seismic Design Category E for all Risk Category I, II or III structures and Seismic Design Category F for all Risk Category IV structures in accordance with the IBC (2006) and ASCE 7-05."
4.13.1.5	4-738	Paragraph 2	FERC staff has identified the Project as a Seismic Design	Update this paragraph to be consistent with the site seismic	Consider changing to:

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			Category D based on the ground motions for the site and an Occupancy Category (or Risk Category) of II or III or IV, this seismic design categorization would appear to be consistent with the IBC (2006) and ASCE 7-05 (and ASCE 7-10).	design categories described in the Seismic Ground Motion Hazard Study (J1-000-GEO-RPT-KBJ-50002-00) included in Appendix I.13.1 of Resource Report 13.	"FERC staff has identified the Project as a Seismic Design Category E and Category F based on the ground motions for the site and an Occupancy Category (or Risk Category) of II or III or IV, this seismic design categorization would appear to be consistent with the IBC (2006) and ASCE 7-05 (and ASCE 7-10)."
4.13.1.5	4-740	Paragraph 3	Jordan Cove stated that the design wind speed using ASCE 7-10 Load and Resistance Factor Design (LRFD) and Allowable Stress Design (ASD) for the LNG facilities and hazardous structures, which would be categorized as Risk Category III and IV (Occupancy Category in ASCE 7- 05).	Consider re-wording to make the statement clearer.	“”Consider changing to: "Jordan Cove stated that the design wind speed would be used in conjunction with ASCE 7-10 Load and Resistance"
4.13.1.5	4-740 to 4-741	Paragraph 4	Jordan Cove indicated that non-hazardous buildings and structures would be designed to satisfy the design win[d] speed requirements of the OSSC, rather than the requirements of USDOT regulations. Moreover, Jordan Cove confirmed that all facilities, including those	Jordan Cove has confirmed that all facilities within the LNG Terminal will be designed for wind loads in accordance with Chapters 26-31 of ASCE 7-10 using the wind speed in accordance with 49 CFR 193.2067 (b)(2)(ii) and Exposure Category D. Refer to the August 6, 2019	Consider changing to: "Jordan Cove confirmed that all facilities, including those containing LNG or other hazardous fluids (and associated safety systems), will be designed for wind loads in accordance with Chapters 26-31 of ASCE 7-10 using the wind speed in accordance with 49

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			containing LNG or other hazardous fluids (and associated safety systems), would be designed for wind loads in accordance with Chapters 26 through 31 of ASCE 7-10 using the site specific wind speed in accordance with 49 CFR 193.2067 and code-based wind directionality factor,…	supplemental response to the July 17, 2018 FERC staff Engineering Information Request and email from Sentho White (PHMSA) to G. Patel (FERC) (Accession No. 20190508-3022).	CFR 193.2067 (b)(2)(ii) and Exposure Category D."
4.13.1.5	4-741	Paragraph 1	However it is unclear whether some of the non-hazardous buildings and structures would qualify as LNG facilities under USDOT regulations, and, if so, whether a 10,000 year return period (123 mph 3-second gust, Exposure Category D) would meet USDOT requirements.	The correct wind speed is 127 mph as noted in paragraph 4 in Page 4-740 in Section 4.13.1.5 of the DEIS.	Consider replacing with: "However, it is unclear whether some of the non-hazardous buildings and structures would qualify as LNG facilities under USDOT regulations, and, if so, whether a 10,000 year return period (127 mph 3-second gust, Exposure Category D) would meet USDOT requirements".
4.13.1.5	4-742	Paragraph 2	Jordan Cove discussed storm surge expected at the site based on the NAVD 88 using a Federal Emergency Management Agency (FEMA) conversion factor, indicating a storm surge elevation of 24.62 feet at the Project site.	The +24.62 feet storm surge elevation at the LNG Terminal site in this paragraph is incorrect. Jordan Cove provided in Section 6.4.4.4.2 of Resource Report 6 the flood elevations in accordance with the FEMA flood insurance studies, which indicate flooding at the project site for the 500 yr	Consider replacing with: "Storm surge expected at the entrance of Coos Bay is based on the NAVD 88 using a Federal Emergency Management Agency (FEMA) conversion factor, indicating a storm surge elevation of +24.62 feet. Flood elevations in accordance with the FEMA flood insurance studies indicate flooding at the project site for the 500 yr event including storm surge to be

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				event including storm surge to be +12.6' NAVD88 at Ingram Yard and +12.8' NAVD88 at South Dunes.	+12.6 feet NAVD88 at Ingram Yard and +12.8 feet NAVD88 at South Dunes. The LNG Terminal site elevations of all above ground facilities are higher than the maximum coastal flooding elevations estimated."
4.13.1.5	4-743	Paragraph 1	Jordan Cove stated the storm surge expected at the site based on the NAVD 88 using a FEMA conversion factor, indicating a coastal flooding (storm surge) elevation of 24.62 feet at the Project site. The Project site elevations of pipeline and all above ground facilities are higher than the maximum coastal flooding elevations estimated.	The +24.62 feet storm surge elevation at the LNG Terminal site in this paragraph is incorrect. Jordan Cove provided in Section 6.4.4.4.2 of Resource Report 6 the flood elevations in accordance with the FEMA flood insurance studies, which indicate flooding at the project site for the 500 yr event including storm surge to be +12.6' NAVD88 at Ingram Yard and +12.8' NAVD88 at South Dunes.	Consider replacing with: "Storm surge expected at the entrance of Coos Bay is based on the NAVD 88 using a Federal Emergency Management Agency (FEMA) conversion factor, indicating a storm surge elevation of +24.62 feet. Flood elevations in accordance with the FEMA flood insurance studies indicate flooding at the project site for the 500 yr event including storm surge to be +12.6 feet NAVD88 at Ingram Yard and +12.8 feet NAVD88 at South Dunes. The LNG Terminal site elevations of all above ground facilities are higher than the maximum coastal flooding elevations estimated."
4.13.1.5	4-743	Paragraph 3	Adding the 500-year storm surge, wave crest elevations, relative sea level rise and subsidence results in a total elevation of 42 feet.	The total elevation of 42 feet is incorrect. Please revise the total elevation cited in this paragraph to be in-line with the FEMA elevations provided in Section	Update the FERC calculated elevation cited in this paragraph in accordance with the comment on Paragraph 2 of page 4-742, above.

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				6.4.4.4.2 of Resource Report 6. Refer to comments provided on Page 4-742 and 4-743 of the DEIS.	
4.13.1.5	4-750	Paragraph 2	Two mixed use aviation airports, Southwest Oregon Regional Airport and Lakeside Municipal Airport, would be located 0.6 mile southeast and 10.9 miles northeast of the LNG terminal site, respectively. The one general aviation airport is the Sunnyhill- North Bend Airport located 4.7 miles northeast of the LNG terminal site. These are all farther than the 0.25-mile distance referenced in USDOT regulations.	The last sentence in this paragraph refers to compliance with a USDOT regulation based on distance from the airport to the nearest point to the LNG terminal, But the USDOT requirement is based on distance from the ends of the runway or nearest point of a runway to the LNG storage tanks; refer to cited USDOT regulation in paragraph 1 of Page 4-750, 49 CFR 193.2155(b), Subpart C.	Consider replacing with: "Two mixed use aviation airports, Southwest Oregon Regional Airport and Lakeside Municipal Airport, would be located 0.6 mile southeast and 10.9 miles northeast of the LNG terminal site, respectively. The one general aviation airport is the Sunnyhill- North Bend Airport located 4.7 miles northeast of the LNG terminal site. The <u>LNG storage tanks</u> are <u>located</u> farther than the <u>1.0 mile distance from the ends, or</u> <u>0.25 miles</u> <u>from the nearest point of a runway</u> referenced in USDOT regulations."
4.13.1.5	4-751	Paragraph 6	In addition, the Project would install a 100-feet tall impervious barrier that would located between the process equipment and the heliport.	The final height of vapor barriers will be finalized during detail engineering based on a final design siting analysis verification.	Consider replacing with: "In addition, the Project would install an impervious barrier that would be located between the process equipment and the heliport."

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4.13.1.5	4-752	Paragraph 1	FERC staff determined that the full containment LNG storage tanks could withstand general aviation impacts without perforation of the outer tank wall from aircraft impacts that exceed frequencies of 3e-5 per year. However, FERC staff also determined that the LNG storage tanks may not withstand commercial aviation impacts without perforation of the outer tank wall from aircraft impacts that exceed frequencies of 3e-5 per year. As discussed above, potential fire hazard distances from aircraft impacts to the LNG storage tank could extend beyond the property lines, however, these fire hazards would not impact the public. Therefore, we conclude that with the implementation of our recommendations, the Project would not pose a significant risk or increase risk to the public from aircraft impacts to either the LNG	The probability of an accident involving a commercial jet is below the credible threshold of 3e-5, as determined in the Air Safety Study (J1-000-ADM-RPT-KBJ-50140-00) included in Appendix G.13.6 of Resource Report 13.	Consider replacing with: "FERC staff determined that the full containment LNG storage tanks could withstand general aviation impacts without perforation of the outer tank wall from aircraft impacts that exceed frequencies of 3e-5 per year. FERC staff also determined that the LNG storage tanks may not withstand commercial <u>jet</u> aviation impacts without perforation of the outer tank wall from aircraft impacts that exceed frequencies of 3e-5 per year. <u>However, the probability of an accident involving a commercial jet was below the credible event threshold of 3e-5 per year.</u> Therefore, we conclude <u>that</u>, with the implementation of our recommendations, the Project would not pose a significant risk <u>of</u> aircraft impacts <u>with</u> the LNG storage tanks or the process <u>areas. The incident data, distance,</u> and position of aircraft operations relative to the populated areas in the North Bend <u>communities lead us to conclude the Project would not pose a significant risk</u>."

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			storage tanks or the process areas due to the potential consequences, incident data, and the distance and position of aircraft operations relative to the populated areas in the North Bend community.		
5.0					
5.1.3.2	5-3	Paragraph 2	The pipeline would be constructed across or in close proximity to 352 waterbodies; 270 intermittent streams and ditches, 69 perennial waterbodies, and several ponds and other surface water features.	Revise number to align with November 2018 DSL filing.	Suggest revising to: "The pipeline would be constructed across or in close proximity to 342 ~~352~~ waterbodies; 263 ~~270~~ intermittent streams and ditches, 66 ~~69~~ perennial waterbodies, and several ponds and other surface water features."
5.1.3.3	5-4	Paragraph 1	Constructing and operating the pipeline would temporarily affect about 112.2 acres of wetlands and result in long-term impacts on about 5.8 acres of wetlands.	It appears that 0.91 acres of permanent conversion acres may have been added to the 4.82 acres of long-term impacts (arrived at by adding impacts from right-of-way and TEWA to PSS and PFO wetlands) to arrive at the 5.8 acres shown.	Suggest revising to: "Constructing and operating the pipeline would temporarily affect about 112.2 acres of wetlands and result in long-term impacts on about 4.9 acres of wetlands."
5.1.9	5-7	Paragraphs 3-4	In the Coos Bay area, constructing both the LNG terminal and the pipeline would significantly impact demand for housing and could result in rent	Insert additional text to reflect the recent legislation passed in Oregon regarding rent control.	Suggest revising to: "In the Coos Bay area, constructing both the LNG terminal and the pipeline could impact the demand for housing and could result in rent

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			increases and displacement. …we conclude that constructing and operating the LNG and pipeline facilities are not expected to result in significant impacts on socioeconomic resources or services, with the exception of temporary housing availability during construction.		increases and tenant displacement, although Oregon's recent rent control legislation attempts to mitigate against this (Senate Bill 608).…we conclude that constructing and operating the LNG and pipeline facilities are not expected to result in significant impacts on socioeconomic resources or services, with the exception of temporary housing availability during construction. Potential impacts to housing are likely to be mitigated by the increased job opportunities and increased personal incomes associated with the Project, along with Oregon's recent rent control legislation."
5.1.10	5-8	Paragraph 1	We have recommended that Jordan Cove entered into traffic development agreements with ODOT, Coos County, and the City of North Bend, as recommended in the Traffic Impact Analysis report.	Revise text to include a period at the end of the sentence, ending in "as recommended in the *Traffic Impact Analysis* report". Include an enter after "report" and before "Furthermore,".	Suggest revising to: "We have recommended that Jordan Cove enter into cooperative improve agreement with ODOT and traffic development agreements with, Coos County, and the City of North Bend, as recommended in the Traffic Impact Analysis report."
Appendices					
App. F.7	34	Paragraph 1	Exceptions to this timeline would occur where adherence to seasonal restrictions for federally endangered or threatened species is expected	Pacific Connector will comply with seasonal restrictions as required, and, instream construction windows as required, yet Pacific Connector	Suggest revising to: "Exceptions to this timeline would occur where adherence to seasonal restrictions for

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			and in Spread 5 (MP 170 – 229) where winter construction is scheduled in part to comply with Oregon Department of Fish and Wildlife (ODFW) instream construction windows.	may desire to perform construction outside of the winter in Klamath, as allowed by timing and instream windows.	federally endangered or threatened species is expected and adherence to Oregon Department of Fish and Wildlife (ODFW) instream construction windows."
App. F.7	40-49	Table 7	**Table 7**: Effects to Acres of Johnson & O'Neil Habitat Type by National Forest - **TOTALS**	The total acres affected do not match what was provided in Appendix G of Resource Report 3; i.e., total subtotals of forest and non-forest - acres do not add up to what is included in Table 7. The tables in Appendix B are tables updated and included in Appendix G of Resource Report 3.	Suggest updating Table 7 based on the tables in Appendix B.
App. F.9	Throughout	Throughout	Throughout	Appendix F.9, including the tables, figures, and alignment sheets, reflect the 2015 FEIS Blue Ridge Variation, rather than the modified FEIS route (Blue Ridge Variation) to the Blue Ridge Route.	Update to reflect the modified FEIS route. Pacific Connector will provide updated alignment sheets and tables for Appendix F.9.
App. L		Table L-8	N/A	There are sites listed that are outside of the PCGP APE.	Remove from Table L-8 35CS36, 35CS50, 35CS317

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				There are also additional previously recorded sites within the APE – but since the text of paragraph 1 discusses those reported in Bowden et al. 2009.	
App. L	L-98	Table L-11	Table Rows with Sites 35CS264, 35CS265, 35CS268	These sites are located on a previous pipeline route and are now outside of the APE	Remove from Table L-11 35CS264, 35CS265, 35CS268

Attachment C

Comments on Recommended Mitigation Conditions

Comments on Recommended Mitigation Conditions

FERC No.	Condition	Applicant Response
16	**Prior to construction**, Pacific Connector shall file with the Secretary, for review and written approval by the Director of OEP, revised alignment sheets that incorporate the Blue Ridge Variation into its proposed route between MP 11 and 25. (section 3.4.2.2)	Please see the discussion regarding the Blue Ridge Alternative in Attachment A for Pacific Connector's comments on Recommendation No. 16.
21	**Prior to the end of the draft EIS comment period**, Pacific Connector shall consult with the ODEQ regarding existing soil and groundwater contamination at the sites listed in appendix G, and file the results of this consultation, along with any proposed site-specific soil or groundwater handling, management, and disposal procedures. (section 4.2.2.2)	Applicants submitted a letter on May 28, 2019, with additional information to consult with ODEQ regarding the environmental cleanup site information and leaking underground storage tank sites located within 0.25 mile of the proposed Project activities to determine if there are any ODEQ-required soil or groundwater handling, management, and disposal procedures for those areas. By letter dated June 12, 2019, and filed with the Commission on June 17, 2019, ODEQ agreed with the conclusions of the May 28 letter. Applicants' May 28 letter and ODEQ's June 17 response are provided in Appendix 1.
27	**Prior to construction**, Pacific Connector shall file with the Secretary its commitment to adhere to FWS-recommended timing restrictions within threshold distances of MAMU and NSO stands during construction, operations, and maintenance of the pipeline facilities. (section 4.6.1.2)	Please see the discussion regarding recommended Recommendation No. 27 in Attachment A. Recommendation No. 27 should be revised to read as follows: ***Prior to construction**, Pacific Connector shall file with the Secretary its commitment to adhere to <u>timing restrictions identified in BLM's right-of-way grant regarding</u> threshold distances of MAMU and NSO stands during construction, operations, and maintenance of the pipeline facilities <u>that</u>*

FERC No.	Condition	Applicant Response
		have been recommended by FWS following formal consultation.
28	**Prior to the end of the draft EIS comment period**, Pacific Connector shall file with the Secretary revised alignment sheets that eliminate or relocate TEWA 128.01-W, TEWA 128.96-N, TEWA 142.07-N, and EAR-128.05. (section 4.6.1.6)	TEWAs 128.01-W and 128.96-N have been adjusted and 142.07-N has been removed in the revised Environmental Alignment Sheets included in Appendices 2 and 3; Appendix 3 has been provided under seal as privileged information. EAR 128.05 was not part of the Pacific Connector application filed in September 2017 (see Sheet 36 of 55 in Appendix G.1/General Location Maps).
30	Jordan Cove and Pacific Connector **shall not begin construction** of the Project **until** they file with the Secretary a copy of the determination of consistency with the Coastal Zone Management Plan issued by the State of Oregon. (section 4.7.1.2)	Suggest revising Recommendation No. 30 to the following: *Jordan Cove and Pacific Connector **shall not begin construction** of the Project **until** they file with the Secretary a copy of the determination of consistency with the Coastal Zone Management Plan issued by the State of Oregon (or evidence of waiver thereof). (section 4.7.1.2)*
32	**Prior to construction** of facilities and/or use of any staging, storage, temporary work areas, or new or to-be-improved access roads, Jordan Cove and Pacific Connector shall file with the Secretary a revised Ethnographic Report describing sites of religious and cultural significance to Indian Tribes and other tribal information as outlined in the FERC staff's October 23, 2018 environmental information request No. 14, for the	Please see the discussion regarding the Ethnographic Study in Attachment A for Jordan Cove's and Pacific Connector's comments on Recommendation No. 32.

FERC No.	Condition	Applicant Response
	review of interested Indian tribes and the FERC staff, and for written approval by the Director of OEP. (section 4.11.3.1)	
34	**Following the start of pile-driving activities**, Jordan Cove shall monitor daytime pile- driving and file weekly noise data reports with the Secretary that identify the noise impact on the nearest NSAs. If any measured daytime noise impacts (Lmax) at the nearest NSAs are greater than 10 dBA over the Leq ambient levels, Jordan Cove shall: a. cease pile-driving activities and implement noise mitigation measures; and b. file with the Secretary evidence of noise mitigation installation and request written notification from the Director of OEP that pile driving may resume. (section 4.12.2.3)	Jordan Cove conducted an analysis of the existing baseline one-hour L_{max} and L_{eq} sound levels at the NSAs using the full set of data collected in May 2017, provided as Appendix 4, JCEP LNG Terminal Baseline Environmental Survey – L_{max} Addendum, J1-000-RGL-TNT-SLR-00008 (L_{max} Report). The analysis indicates that current existing sound levels would only achieve compliance with the proposed Recommendation No. 34 criterion approximately 6% of the time at NSA 1. In other words, the FERC proposed Recommendation No. 34 limitation on L_{max} levels of 10 dBA over the ambient L_{eq} was exceeded in 94% of the hours during the survey of the existing sound levels. Under this Recommendation, any type of construction work (even without pile driving) would exceed the goal. In fact, days with no construction activity at all would be in violation under this constraint because the existing local environmental sound levels are already above the criterion almost all of the time. As the FERC 55 dBA L_{dn} noise requirements are more stringent than the Oregon day and night L_{50} requirements, the Project has been using the FERC 55 dBA L_{dn} requirements as the standard for operations and other long-term continuous noise. However, there is no specific FERC sound level limit for short-term impulsive noises. Given that this proposed L_{max} limit is impractical and unachievable, the State of

FERC No.	Condition	Applicant Response
		Oregon noise regulations would represent a reasonable and a locally-acceptable noise guideline for consideration as construction noise goals for daytime and nighttime. The Oregon noise regulations are outlined in Oregon Administrative Rule (OAR) 340-0035-0035. The OAR noise regulations include a specific exemption for "Sounds that originate on construction sites" and therefore do not apply to pile driving and other Project construction activities. Nonetheless, the Project proposes to adopt the OAR L1 standard for use in evaluating the effects of daytime and nighttime pile driving and other impulsive noises from Project construction at the nearby NSAs. The Oregon OAR L1 limit is 75 dBA and 60 dBA for daytime and nighttime, respectively. An analysis of the existing baseline one-hour L1 data from the May 2017 data set, included in the L_{max} Report, shows that the OAR one-hour L1 limits were not exceeded during any hour of the baseline measurement period at NSA 1, the closest NSA. The levels were exceeded for 40% and 3% of the measurement period for NSAs 2 and 3, respectively. This indicates that an hourly L1 limit would be appropriate for evaluating the Project impulsive noise impacts at NSAs 1 and 3, but would be difficult to implement for NSA 2. As NSAs 1 and 3 are the closest NSAs to the construction area, the Project proposes to apply the L1 limit at these two NSAs. Consider replacing Recommendation No. 34 with the following:

FERC No.	Condition	Applicant Response
		Prior to construction of the Terminal, *Jordan Cove shall file with the Secretary a noise mitigation plan, for review and written approval by the Director of OEP, that includes the measures it will implement to reduce the projected noise levels to an hourly L1 at or below 75 dBA during daytime hours and 60 dBA during nighttime hours at NSA 1 and 3. The noise mitigation plan will include details of the noise monitoring program to be implemented by the Project.*
35	Jordan Cove shall conduct all pile-driving activities between the hours of 7 a.m. and 7 p.m. **throughout the duration of construction**. (section 4.12.2.3)	Jordan Cove's recommendation on Recommendation No. 34 proposes the use of the Oregon L1 guideline for daytime and nighttime construction noise. In addition, Jordan Cove has offered to develop a noise management plan for the Project that will include noise mitigations and construction activity controls to monitor and limit day and night sound levels from the Project. With these modified guidelines and a noise management plan for the Project, Jordan Cove believes that noise-related concerns for nighttime work are adequately addressed and Recommendation No. 35 can be removed.
36	Jordan Cove shall file a full power load noise survey with the Secretary for the LNG terminal **no later than 60 days after each liquefaction train is placed into service**. If the noise attributable to operation of the equipment at the LNG terminal exceeds an Ldn of 55 dBA at the nearest NSA, within 60 days Jordan Cove shall modify operation of the liquefaction facilities or install additional noise controls until a noise level below an Ldn of 55 dBA at the NSA is achieved. Jordan Cove	Jordan Cove requests that Recommendation No. 36 be removed and the noise survey for the LNG Terminal be performed in accordance with Recommendation No. 37. In accordance with Resource Report 13, Appendix A.13.5 – Project Management and unlike other LNG export terminals currently under construction in the United States, Jordan Cove will construct and commission all the LNG trains concurrently and therefore demonstration of compliance

FERC No.	Condition	Applicant Response
	shall confirm compliance with the above requirement by filing a second noise survey with the Secretary no later than 60 days after it installs the additional noise controls. (section 4.12.2.3)	with the full power noise requirements will be based on an overall terminal noise survey.
39	Pacific Connector shall file a noise survey with the Secretary **no later than 60 days after placing the Klamath Compressor Station in service**. If a full load condition noise survey is not possible, Pacific Connector shall provide an interim survey at the maximum possible horsepower load and provide the full load survey within six months. If the noise attributable to the operation of all of the equipment at the Klamath Compressor Station under interim or full horsepower load conditions exceeds an Ldn of 55 dBA at any nearby NSAs, Pacific Connector shall file a report on what changes are needed and shall install the additional noise controls to meet the level within one year of the in-service date. Pacific Connector shall confirm compliance with the above requirement by filing a second noise survey with the Secretary no later than 60 days after it installs the additional noise controls. (section 4.12.2.4)	The full load condition noise survey cannot be completed until all of the Jordan Cove liquefaction trains are placed in service. Jordan Cove suggests revising the second sentence to the following: *If a full load condition noise survey is not possible, Pacific Connector shall provide an interim survey at the maximum possible horsepower load and provide the full load survey ~~within six months~~ no later than 60 days after all liquefaction trains at the LNG Terminal are fully in service*.
40	**Prior to end of the draft EIS comment period**, Jordan Cove shall file with the Secretary documentation of consultation with USDOT PHMSA staff as to whether the design wind speed for other non-hazardous buildings and structures would be subject USDOT PHMSA requirements. (section 4.13.1.6)	Jordan Cove consulted with USDOT PHMSA on the applicability of the 49 C.F.R. § 193.2067 design wind speed requirements. In response to this consultation, Sentho White, (PHMSA) provided a response to Ghanshyam Patel (FERC) in an email dated May 6, 2019. See Accession No. 20190508-3022 in Docket No. CP17-495.

FERC No.	Condition	Applicant Response
41	**Prior to the end [of the] draft EIS comment period**, Jordan Cove shall file with the Secretary an analysis that demonstrates the flammable vapor dispersion from design spills would be prevented from dispersing underneath the elevated LNG storage tanks, or the LNG storage tanks would be able to withstand an overpressure due to ignition of the flammable vapor dispersion cloud that disperses underneath the elevated LNG storage tanks. (section 4.13.1.6)	Jordan Cove will prepare an analysis to demonstrate that flammable vapor dispersion from design spills would be prevented from dispersing underneath the elevated LNG storage tanks, or the LNG storage tanks would be able to withstand an overpressure due to ignition of the flammable vapor dispersion cloud that disperses underneath the elevated LNG storage tanks. The methodology for completing this analysis will be consistent with that followed in the Facility Siting Hazard Analysis (J1-000-ADM-RPT-KBJ-50132-00) provided to FERC on November 16, 2018 (49 C.F.R. Part 193, Subpart B, Siting Review). Jordan Cove has commenced the analysis and will submit the analysis to FERC **prior to construction of final design**. FERC has previously accepted a similar condition. *See, e.g.*, FEIS for Annova LNG Brownsville Project at Recommendation No. 81.
42	**Prior to initial site preparation**, Jordan Cove shall file with the Secretary documentation demonstrating it has received a determination of no hazard (with or without conditions) by USDOT FAA for all permanent structures, temporary construction equipment, and mobile objects that exceed the height requirements in 14 CFR 77.9. (section 4.13.1.6)	Jordan Cove requests that Recommendation No. 42 be broken into two conditions, as described below: ***Prior to initial site preparation**, Jordan Cove shall file with the Secretary documentation demonstrating it has received a determination of no hazard (with or without conditions) by USDOT FAA for all permanent structures that exceed the height requirements in 14 CFR 77.9.* ***Prior to construction of final design**, Jordan Cove shall file with the Secretary documentation demonstrating it has received a determination of no hazard (with or without conditions) by USDOT FAA for all temporary construction*

FERC No.	Condition	Applicant Response
		equipment, and mobile objects that exceed the height requirements in 14 CFR 77.9. In accordance with the FAA 7460-1, Form 7460-1 must be submitted at least 45 days before the start date of the proposed construction or alteration or the date an application for a construction permit is filed, whichever is earliest. Consistent with the typical execution of an EPC project, details of the temporary construction equipment subject to FAA review will not be available prior to initial site preparation, as such details are developed at advanced stages of the final design. In addition, this request is consistent with the timeline for implementation of the same condition recommended by FERC Staff in the final environmental impact statement for Eagle LNG, issued on April 12, 2019.
43	Prior to construction of final design, Jordan Cove shall file with the Secretary the following information, stamped and sealed by the professional engineer-of-record, registered in Oregon: a. site preparation drawings and specifications; b. LNG terminal structures, LNG storage tank, and foundation design drawings and calculations (including prefabricated and field constructed structures); c. seismic specifications for procured Seismic Category I equipment prior to the issuing of request for quotations; d. quality control procedures to be used for civil/structural design and construction; and	Jordan Cove requests that Recommendation No. 42 be modified as described below: ***Prior to construction of final design**, Jordan Cove shall file with the Secretary the following information, stamped and sealed by the professional engineer-of-record, registered in Oregon:* *a. site preparation drawings and specifications;* *b. LNG terminal structures, LNG storage tank, and foundation design drawings and calculations (including prefabricated and field constructed structures);*

FERC No.	Condition	Applicant Response
	e. a determination of whether soil improvement is necessary to counteract soil liquefaction. In addition, Jordan Cove shall file, in its Implementation Plan, the schedule for producing this information. (section 4.13.1.6)	*c. seismic specifications for procured Seismic Category I equipment ~~prior to the issuing of request for quotations~~; <u>and</u>* *d. quality control procedures to be used for civil/structural design and construction~~; and~~* *e. ~~a determination of whether soil improvement is necessary to counteract soil liquefaction~~* *In addition, Jordan Cove shall file, in its Implementation Plan, the schedule for producing this information.* Recommendation No. 43(c): Seismic specifications for procured Seismic Category I equipment will be provided prior to construction of final design as the schedule for obtaining equipment quotations is independent from the requirements on this recommendation. Jordan Cove will ensure that seismic specifications for procured Seismic Category I equipment is included in the purchase orders for the respective equipment. Recommendation No. 43(e): The Geotechnical Report (Doc. No. J1-000-GEO-RPT-KBJ-50001-00) included in Resource Report 13 Appendix J.13.4 confirms that soil improvement is necessary to counteract soil liquefaction. Section 2.4.1.3 Page 2-47 and Section 4.13.1.5 page 4-732 of the DEIS confirm that soil improvement will be performed to counteract liquefiable soil.

FERC No.	Condition	Applicant Response
53	**Prior to construction of final design**, Jordan Cove shall file information/revisions pertaining to Jordan Cove's response numbers 8c, 13, 15, 21, 22, 23, 24, 26, 27, 28, and 31 of its December 20, 2018 filing and 6, 9, 10, 11, 17, 19, 32, 34, and 36 of its February 6, 2019 filing which indicated features to be included or considered in the final design. (section 4.13.1.6)	In response to FERC's Engineering Information Request dated December 20, 2018, Jordan Cove confirmed that the PCGP Jordan Cove Meter Station is not part of the LNG Terminal and is not under the jurisdiction of 49 C.F.R. Part 193. Therefore, Jordan Cove requests that Item No. 13 from the December 20, 2018 filing be removed from Recommendation No. 53. Jordan Cove also requests that Item No. 10 from the February 6, 2019 filing be removed from Recommendation No. 53. Jordan Cove's response to Item No. 10 does not specify features that will be included or considered in the final design.
59	**Prior to construction of final design**, Jordan Cove shall file a plot plan of the final design showing all major equipment, structures, buildings, and impoundment systems. This lighting plan shall also be in compliance with recommendation 23. (section 4.13.1.6)	Jordan Cove requests that Recommendation No. 59 be modified as described below: ***Prior to construction of final design**, Jordan Cove shall file a plot plan of the final design showing all major equipment, structures, buildings, and impoundment systems.* ~~*This lighting plan shall also be in compliance with recommendation 23.*~~ The second sentence of Recommendation No. 59 should be part of Recommendation No. 58.
60	**Prior to construction of final design,** Jordan Cove shall file three-dimensional plant drawings to confirm plant layout for maintenance, access, egress, and	Jordan Cove requests that Recommendation No. 60 be modified as described below:

FERC No.	Condition	Applicant Response
	congestion. (section 4.13.1.6)	***Prior to construction of final design****, Jordan Cove shall file ~~three-dimensional~~ plant drawings to confirm plant layout for ~~maintenance,~~ access and egress for emergency response~~, and congestion.~~* Section 4.13.1.5 Page 4-754 of the DEIS indicates that FERC's recommendation for Jordan Cove to provide three dimensional drawings is to demonstrate that there is a sufficient number of access and egress locations for emergency response; these are independent from accessibility for maintenance provisions or congestion. Jordan Cove will provide two-dimensional (plan and elevation) drawings to demonstrate that adequate access and egress provision for emergency response are considered in the final design layout. Two-dimensional drawings provide the necessary dimensions and information to verify equipment spacing, three-dimensional drawings are not necessary for this purpose.
62	**Prior to construction of final design**, Jordan Cove shall file P&IDs, specifications, and procedures that clearly show and specify the tie-in details required to safely connect subsequently constructed facilities with the operational facilities. (section 4.13.1.6)	Jordan Cove requests that Recommendation No. 62 be modified as described below: ***Prior to construction of final design****, Jordan Cove shall file P&IDs and specifications~~, and procedures~~ that clearly show and specify the tie-in details required to safely connect subsequently constructed facilities with the operational facilities.*

FERC No.	Condition	Applicant Response
		Tie-in details for each of the trains and supporting units will be provided in the final design P&IDs. Tie-in procedures will be provided prior to commissioning per Recommendation No. 117.
64	**Prior to construction of final design**, Jordan Cove shall file information to demonstrate the EPC contractor has verified that all FEED HAZOP and LOPA recommendations have been addressed. (section 4.13.1.6)	Jordan Cove requests that Recommendation No. 64 be modified as described below*:* ***Prior to construction of final design**, Jordan Cove shall file information to demonstrate ~~the EPC contractor has verified~~ that all FEED HAZOP and LOPA recommendations have been addressed.*
67	**Prior to construction of final design**, Jordan Cove shall specify how Mole Sieve Gas Dehydrator support and sieve material would be prevented from migrating to the piping system. (section 4.13.1.6)	Jordan Cove requests that Recommendation No. 67 be removed. Information detailing Jordan Cove's provisions for preventing migration of mole sieve material from the mole sieve dehydrators to the piping system was included in the response to Item No. 16 to FERC's Engineering Information Request dated November 30, 2018.
68	**Prior to construction of final design**, Jordan Cove shall specify how the regeneration gas heater tube design temperature would be consistent with the higher shell side steam temperatures. (section 4.13.1.6)	Jordan Cove requests that Recommendation No. 68 be removed. The information requested in this recommendation was provided in response to Item No. 19 to FERC's Engineering Information Request dated November 30, 2018. The DEIS does not provide additional technical basis, nor a reference

FERC No.	Condition	Applicant Response
		to a published lesson learned, applicable code, or an industry standard to support this recommendation.
69	**Prior to construction of final design**, Jordan Cove shall specify a cold gas bypass around the defrost gas heater to prevent defrost gas heater high temperature shutdown during low flow and startup conditions. (section 4.13.1.6)	Jordan Cove requests that Recommendation No. 69 be removed. Jordan Cove's response to Item No. 20 to FERC's Engineering Information Request dated November 30, 2018 provides the technical basis for the proposed design of the defrost gas system. The DEIS does not provide additional technical basis, nor a reference to a published lesson learned, applicable code, or an industry standard to support this recommendation.
70	**Prior to construction of final design**, Jordan Cove shall demonstrate that the differential pressure (dp) level transmitters on the LNG flash drum would not result in an excess number of false high-high-high level shutdowns. (section 4.13.1.6)	Jordan Cove requests that Recommendation No. 70 be removed. Jordan Cove's response to Item No. 29 to FERC's Engineering Information Request dated November 30, 2018 provides the justification for use of differential pressure level transmitters. The DEIS does not provide additional technical basis, nor a reference to a published lesson learned, applicable code, or an industry standard that requires the use of switches in-lieu of transmitters for this service.
71	**Prior to construction of final design**, Jordan Cove shall specify a means to stop LNG flows to the BOG suction drum when the BOG compressor is shutdown to	Jordan Cove requests that Recommendation No. 71 be removed.

FERC No.	Condition	Applicant Response
	prevent filling the BOG suction drum with LNG. (section 4.13.1.6)	Jordan Cove's response to Item No. 37 to FERC's Engineering Information Request dated November 30, 2018 provides the technical basis for the proposed design of the BOG system. The DEIS does not provide additional technical basis, nor a reference to a published lesson learned, applicable code, or an industry standard to support this recommendation.
72	**Prior to construction of final design**, Jordan Cove shall specify a low instrument air pressure shutdown to prevent loss of control to air operated valves. (section 4.13.1.6)	Jordan Cove requests that Recommendation No. 72 be removed. Jordan Cove's response to Item No. 38 to FERC's Engineering Information Request dated November 30, 2018 provides the technical basis for the proposed instrument air system and means considered to prevent loss of control to air operated valves. The DEIS does not provide additional technical basis, nor a reference to a published lesson learned, applicable code, or an industry standard to support this recommendation.
73	**Prior to construction of final design**, Jordan Cove shall evaluate and, if applicable, address the potential for cryogenic feed gas back flow in the event relief valve 30-PSV-01002A/B is open. (section 4.13.1.6)	Jordan Cove requests that Recommendation No. 73 be removed. Jordan Cove's response to Item No. 42 to FERC's Engineering Information Request dated November 30, 2018 provides the results of technical evaluation for the scenario described in this recommendation. The DEIS does not provide additional technical basis, nor a reference to a published lesson learned, applicable code, or an industry standard to support this recommendation.

FERC No.	Condition	Applicant Response
74	**Prior to construction of final design**, Jordan Cove shall include LNG tank fill flow measurement with high flow alarm. (section 4.13.1.6)	Jordan Cove requests that Recommendation No. 74 be removed. Section 4.13.1.6 of the DEIS does not provide The DEIS does not provide additional technical basis, nor a reference to a published lesson learned, applicable code, or an industry standard in support of this recommendation. The proposed design of the LNG storage tanks include the necessary instrumentation for safe operations and shutdown.
75	**Prior to construction of final design**, Jordan Cove shall specify a discretionary vent valve on each LNG storage tank that is operable through the Distributed Control System (DCS). In addition, a car sealed open manual block valve shall be provided upstream of the discretionary vent valve. (section 4.13.1.6)	Jordan Cove requests that Recommendation No. 75 be removed. The proposed design for the LNG Terminal includes a vent valve (refer to valve 60-PV-00007 detailed in P&ID Doc. J1-120-PRO-PID-KBJ-50129-02) that allows operators to manually vent BOG from the LNG storage tanks to the Marine Flare. CSO valves are also included upstream and downstream of 60-PV-00007. In addition, each LNG storage tank is equipped with a remote operated valve, HV-00049 and HV-00099, that allows the operator to manually vent BOG to a safe location.

FERC No.	Condition	Applicant Response
79	**Prior to construction of final design**, Jordan Cove shall file a list of all codes and standards and the final specification document number where they are referenced. (section 4.13.1.6)	Jordan Cove requests that Recommendation No. 79 be modified as described below to align with the DEIS Section 4.13.1.5 page 4-718 to 4-719: ***Prior to construction of final design****, Jordan Cove shall file a list of all codes and standards* ~~*and the final specification document number where they are referenced*~~ <u>*required by regulation and those recommended and generally accepted as good engineering practice that will be considered for the final design. In addition, Jordan Cove shall file equipment specifications referencing the specific codes and standards applicable to the equipment covered in the specifications*</u>*.* In the response to Item No. 50. to FERC's Engineering Information Request dated November 30, 2018, Jordan Cove confirmed that all applicable codes and standards required by regulation will be followed and those recommended and generally accepted as good engineering practice by the industry would be followed to the extent applicable. Including cross-references for all codes and standards and project documents is not practical for a large-scale project due to the extensive number of mandatory and recommended codes and standards that are considered in the final design, including those incorporated by reference. The stand-alone list of all codes and standards, and equipment specifications with applicable codes and standard references, satisfies the intent of this recommendation as detailed on Section 4.13.1.5, Page 4-719 of the DEIS.

FERC No.	Condition	Applicant Response
82	**Prior to construction of final design**, Jordan Cove shall file an evaluation of dynamic pressure surge effects from valve opening and closure times and pump startup and shutdown operations. (section 4.13.1.6)	Jordan Cove requests that Recommendation No. 82 be modified as described below: ***Prior to construction of final design****, Jordan Cove shall file an evaluation of dynamic pressure surge effects from valve opening and closure times and pump startup and shutdown operations <u>for the LNG loading system</u>.* This modification will provide context to clarify that the evaluation of the dynamic pressure surge effects referenced in DEIS Section 4.13.1.6 is applicable to the LNG loading system only.
84	**Prior to construction of final design**, Jordan Cove shall clearly specify the responsibilities of the LNG tank contractor and the EPC contractor for the piping associated with the LNG storage tank. (section 4.13.1.6)	Jordan Cove requests that Recommendation No. 84 be removed. There is no technical basis or published lesson learned referenced in the DEIS to support this recommendation. The coordination between the EPC contractor and the LNG tank contractor is no different than the coordination required with any other sub-contractor or equipment supplier to engineer and construct the LNG Terminal. In addition, this recommendation cannot be fulfilled when the EPC contractor and LNG tank contractor are the same entity.

FERC No.	Condition	Applicant Response
		Jordan Cove should not be required to obtain FERC's approval to modify the responsibilities between contractors during the execution phase as these are project execution driven decisions that will not change the final design reviewed and approved by FERC.
109	**Prior to construction of final design**, Jordan Cove shall file the settlement results during hydrostatic tests of the LNG storage containers and periodically thereafter to verify settlement is as expected and does not exceed the applicable criteria in API 620, API 625, API 653, and ACI 376. (section 4.13.1.6)	Jordan Cove requests that Recommendation No. 109 be modified as described below which reflects the timeline in Recommendation No. 116 for the identical activity: ***Prior to ~~construction of final design~~ commissioning****, Jordan Cove shall file the settlement results during hydrostatic tests of the LNG storage containers and periodically thereafter to verify settlement is as expected and does not exceed the applicable criteria in API 620, API 625, API 653, and ACI 376. (section 4.13.1.6)* The timeline proposed by FERC for implementation of Recommendation No. 109 is incorrect. Foundation settlement results for the LNG storage tanks can only be determined during and after the hydrostatic tests.
116	**Prior to commissioning**, Jordan Cove shall file settlement results from the hydrostatic tests of the LNG storage containers and shall file a plan to periodically verify settlement is as expected and does not exceed the applicable criteria set forth in API 620, API 625, API 653, and ACI 376. The program shall specify what actions would be taken after various levels of seismic events. (section 4.13.1.6)	Jordan Cove requests that Recommendation No. 116 be removed and LNG storage tank foundation settlement monitoring plan requirements be incorporated into Recommendation No. 109. Recommendation Nos. 116 and 109 are the same with the exception of the LNG storage tank foundation monitoring plan requirements included in Recommendation No. 116.

Jordan Cove LNG℠

Project Impacts on Salinity Memo

A	01/22/18	Issued for Information	Moffatt & Nichol	DEA	DEA	
REV	**DATE**	**DESCRIPTION**	**BY**	**CHKD**	**APPVD**	**COMPANY APPROVAL**

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Jordan Cove LNG[SM]	Project Impacts on Salinity Memo		DAVID EVANS AND ASSOCIATES INC.
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TECHNICAL MEMORANDUM

DATE:	November 29, 2017
ATTENTION:	Mick Rowlands, P.E.
COMPANY:	Jordan Cove LNG, LLC (JCLNG)
ADDRESS:	5615 Kirby Drive, Suite 500, Houston, TX 77005
FROM:	William Gerken, P.E., Thomas McCollough, P.E., Cheng-Feng Tsai, P.E. – Moffatt & Nichol
SUBJECT:	Project Impacts on Salinity
DEA PROJECT NAME:	Hydrodynamic Studies
DEA PROJECT NO:	JLNG0000-0015, Service Order 1179
M&N PROJECT NO:	9929-02, Task Order MN-1179-001
DOCUMENT NO:	J1-000-MAR-TNT-DEA-00009-00
COPIES TO:	DEA (Sean Sullivan, Derik Vowels)

1. INTRODUCTION

Jordan Cove Energy Project, LP (“JCEP”) is seeking authorization from the Federal Energy Regulatory Commission (“FERC”) under Section 3 of the Natural Gas Act (“NGA”) to site, construct, and operate a natural gas liquefaction and liquefied natural gas (“LNG”) export facility (“LNG Terminal”), located on the bay side of the North Spit of Coos Bay, Oregon. The LNG Terminal, related facilities, temporary construction sites, and other sites/actions associated with LNG Terminal construction are collectively referred to as the “JCEP Project Area” as shown on Figure 1-1

The JCEP Project Area is made up of the following selected components, among others not listed here because they are not relevant to the scope of this memorandum:

- Slip – a permanent facility between Ingram Yard and the Access Channel. LNG carriers will enter the Slip via the Access Channel, get loaded with LNG, and leave for export. The Slip will include an LNG carrier loading berth and LNG loading facilities, a tug berth, and an emergency lay berth to safely moor a temporarily disabled LNG carrier.
- Access Channel – the Access Channel will be dredged north of the Federal Navigation Channel (“FNC”) to provide LNG carriers with access from the FNC to the Slip.
- Material Offloading Facility (“MOF”) – a permanent facility east of the Slip where fill will be placed to construct a barge berth.
- Navigation Reliability Improvements – four permanent dredge areas adjacent to the FNC that will allow for navigation efficiency and reliability for vessel transit under a broader weather window.

The effect on estuarine salinity due to proposed JCEP Project elements is one issue that must be evaluated.

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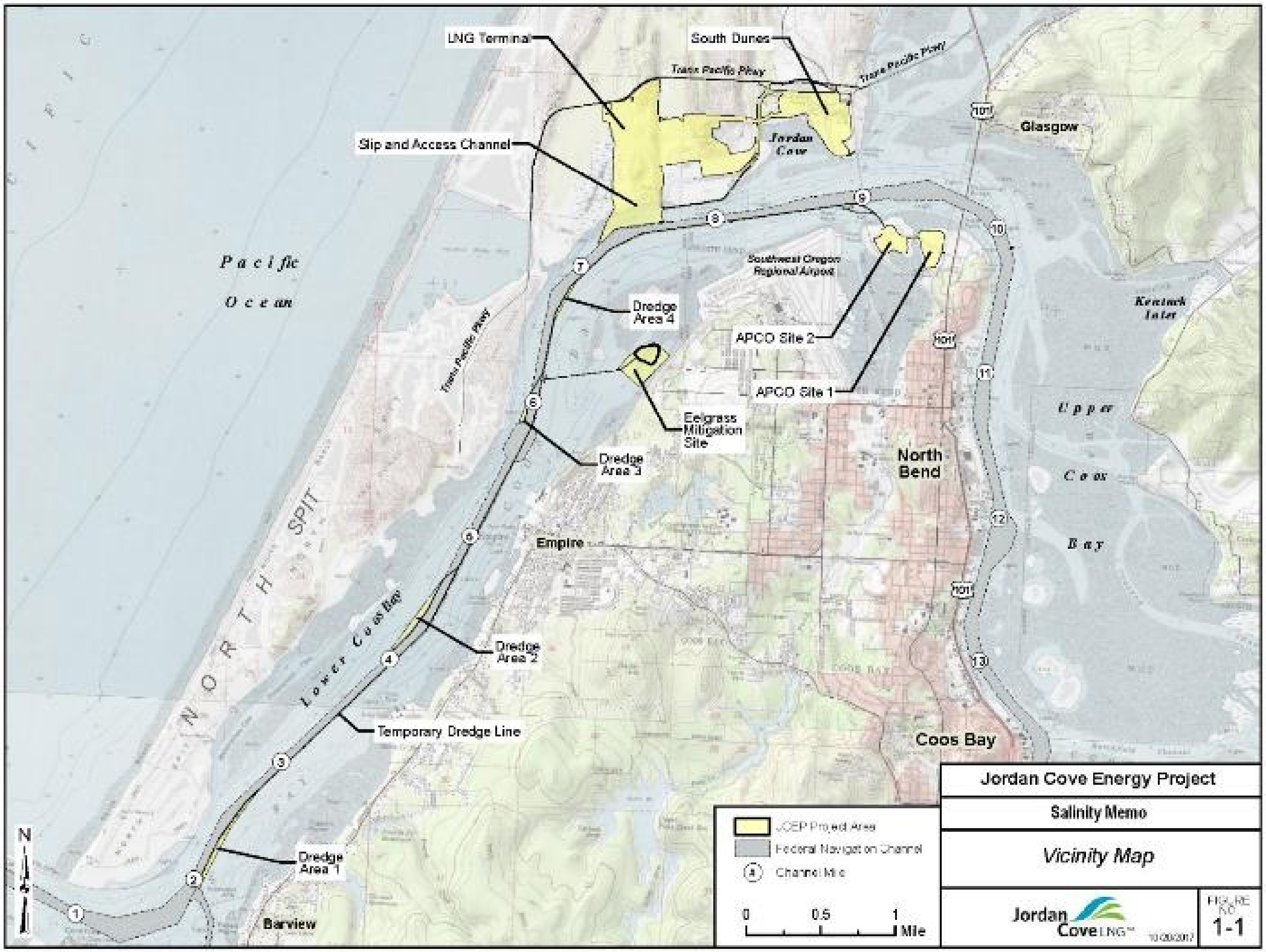

Figure 1-1: Vicinity Map

In a separate action, Oregon International Port of Coos Bay (Port) proposes to widen and deepen the FNC from nominally 35 feet in depth by 300 feet in width to nominally 45 feet in depth by 450 feet in width, plus additional widening and/or deepening at the ocean entrance and channel bends as necessary (referred to as the Proposed Alteration). The improvements constituting the JCEP Project's Slip, Access Channel, and MOF have been included in the Port Project's Without-Project Conditions (WOP).

The JCEP Project's NRI dredge areas fall within the limits of the Port Project's Proposed Alteration (PA) condition. The NRI dredge areas are comprised of four relatively small submerged areas lying adjacent to the FNC. These areas are referred to individually as Dredge Areas 1 through 4 as shown on Figure 1-1. Navigation depth of the four NRI dredge areas will be the same as the adjacent FNC at -37' MLLW.

The Port has performed extensive numerical modeling of hydrodynamic conditions, including salinity, on the Coos Bay Estuary for Existing, WOP, and PA Conditions. This memorandum uses the work performed by the Port (OIPCB 2017) to address the issue of effects of the JCEP Project on estuarine salinity.

2. PURPOSE

This memorandum provides a summary of potential effects on estuarine salinity of the JCEP Slip, Access Channel, MOF and NRI based on potential effects of the much larger Port PA. The document relies on work performed for the Port project, but it does not report the full details of the Port's hydrodynamic modeling since such detailed reporting is beyond the scope required for analyzing the effects of the JCEP Project.

3. CONCLUSIONS

The modeling results for the Port Project indicate that the salinity variability (spatial and temporal distributions) is primarily influenced by fluvial inflow volume and not by channel depth and width. The salinity in the estuary is similar to the salinity levels at the open coast under low flow conditions and is very stratified under high fluvial storm flow conditions. Port Project channel improvements (deepening and widening) have minimal effects on salinity patterns and values, and the scale of change due to the PA condition is negligible compared to background changes due to freshwater inflow during storm events. Hence, effects of the proposed Port Project on salinity levels and variability are very limited and are not expected to adversely affect water quality conditions in the estuary.

The NRI modifications constitute a very small percentage of the PA, and thus the changes in salinity that may be attributed to the JCEP Project are even less significant than those attributable to the PA. Additional information on salinity modeling for the Port Project, and the results that support this conclusion are contained in the sections that follow.

4. SALINITY MODELING

Coos Bay is an estuary, where salt water from the ocean mixes with fresh water from rivers. Depending on the intensity of river inflow, the estuary can be in well-mixed (low freshwater flow) to stratified (high freshwater flow) conditions. Deeper navigation channels may introduce more salt water into the estuary, which has a potential to influence the estuarine environment.

Given the differences in salinity with freshwater inflow, it was necessary to model salinity in Coos Bay for a variety of inflow conditions and channel configurations.

In each of the various inflow conditions, the sources of salinity are identical over all the channel configurations (i.e., varying channel configurations do not modify the sources and sinks of salinity), and changes to salinity are a reflection of changes to greater circulation patterns. Therefore, salinity can also serve as a proxy for other water quality constituents (OIPCB, 2017). If the project effects on salinity are small, then the effects on other water quality constituents are also likely to be small.

Three inflow scenarios have been considered:

- A low freshwater inflow condition (10^{th} percentile)
- A median freshwater inflow condition (50^{th} percentile)
- A high freshwater inflow condition (90^{th} percentile).

These scenarios were applied to the Coos Bay system from the inner bays to the ocean. Modeling was performed for the Existing Condition, Port's WOP Condition, the National Economic Development (NED) Plan, and the PA. Variation in model salinity results was basically indiscernible between the Existing Condition and the WOP Condition therefore the Existing Condition will not be discussed in this memorandum. The NED Plan will not be discussed in this memorandum because it is lesser in scale than the PA.

4.1 MODEL OVERVIEW

Salinity was modeled using the MIKE-3 FM model with linked hydrodynamic and salinity modules. In the hydrodynamic model, water density varies with salinity, which is computed with additional transport equations (DHI 2014). As a result, horizontal gradients in water density and buoyancy cause density driven flows, such as freshwater flow over sea water and propagation of sea water further into the estuary. While density may have some dependence on water temperature as well, in this study density depended on the salinity only.

4.2 GATHERED INFORMATION

4.2.1 Boundary Conditions

The offshore boundary conditions, both tidal levels and currents, were extracted from the OSU Tidal Database. The model simulations for comparison were conducted for a duration of two months for which representative steady-state inflow conditions were recorded. For the upstream freshwater boundary conditions, a two-month running average inflow was analyzed based on available data from the Port for water years 2007 and 2012. The water year is defined as the period between October 1st and September 30th of the following year. Then the data was used to compute 10th, 50th, and 90th percentile values. The two-month running average was used to represent the steady-state conditions for the freshwater inflow. Table 4-1 and Figure 4-1 provide the constant inflow discharges used in the model.

For the salinity boundary conditions, a constant value of 33 practical salinity units (PSU) was used at the offshore boundaries, and a constant value of 1 PSU was used at the upstream fresh water boundaries. Both values were selected to represent typical sea water and fresh water conditions and were applied as constants for all simulation cases.

Table 4-1: Summary of Inflow Discharges Used in the Salinity Model

Discharge (cfs)	Two-Month Running Average Inflow				
	Isthmus Slough	K&W Sloughs	South Slough	North Slough	Coos River
10th Percentile	8.8	12.5	15.5	20.4	70.1
50th Percentile	88.5	123.9	153.2	200.6	1033.5
90th Percentile	214.2	294.5	364.2	476.6	3519.0

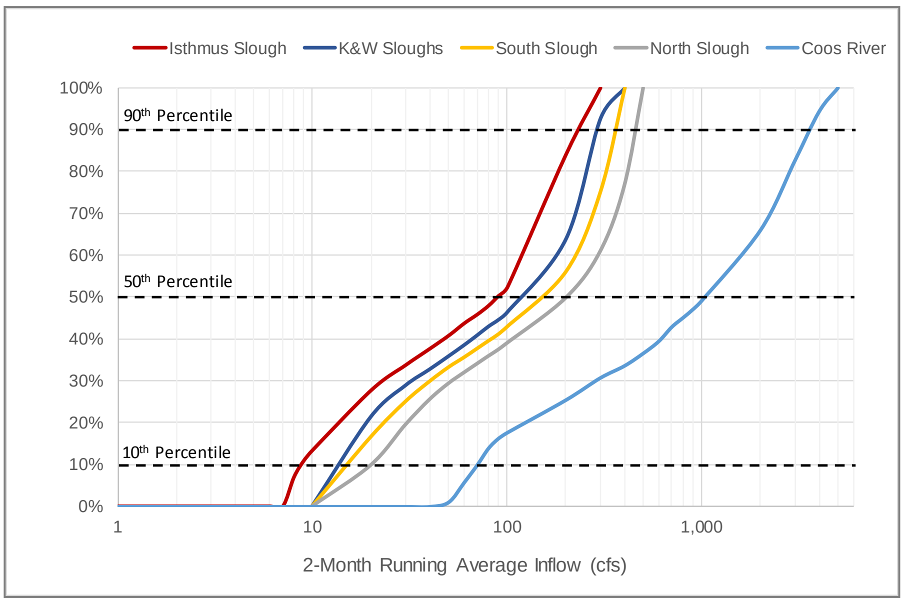

Figure 4-1: Statistics of Two-Month Running Average Inflows

4.2.2 Salinity Measurements (O'Neill 2014)

O'Neill conducted a series of along-channel salinity sampling during a 21-month period (O'Neill 2014). Figure 4-2 shows the sampling transects.

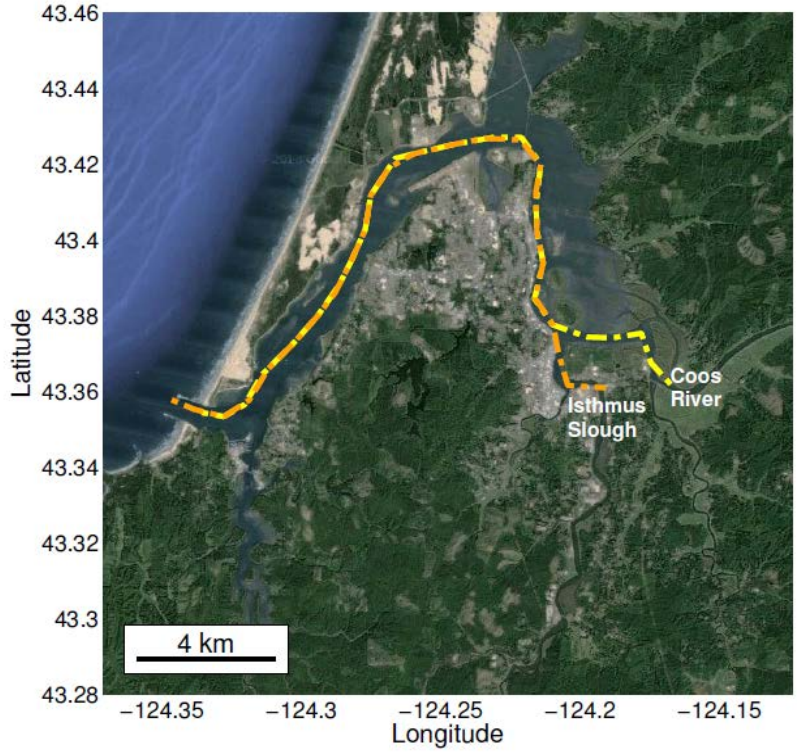

Figure 4-2: Salinity Sampling Transects (excerpted from O'Neill 2014)

4.3 MODEL ASSUMPTIONS AND INPUT PARAMETERS

Table 4-2 lists the parameters used in the salinity module. The dispersion coefficient was determined by calibration, as opposed to direct measurement. Dispersion quantifies the scattering of constituent by the combined effects of shear and transverse diffusion.

Table 4-2: Input Parameters for Salinity Module

Parameter	Value	Comment
Horizontal/Vertical Dispersion	A constant scaled eddy viscosity of 0.1	Selected from three types of formulations: 1) No dispersion 2) Scaled eddy vicosity 3) Dispersion coefficient
Initial Condition	A constant of 33 PSU	Well-mixed sea water

4.4 MODEL RESULTS

Salinity modeling was conducted for a two-month period with steady river inflows. The simulation period was arbitrarily selected from November 16, 2011 to January 19, 2012 to represent typical tidal conditions. Three inflow scenarios were simulated for each bathymetric case: the WOP Condition, the NED Plan (not discussed in this memorandum), and the PA. For each flow scenario, constant discharges were applied at the model boundaries over the two-month simulation period. Statistics (50th, 75th, and 90th percentile) for salinity contour lines of 20 PSU and 30 PSU over the two-month simulation period were calculated at the top layer, bottom layer, and for the entire water column for each simulation. The 50th percentile is defined as 50% of the time the salinity is less than 20 or 30 PSU. The resultant figures were prepared to show the differences of salinity between three different bathymetric cases and flow conditions.

In general, the following findings are seen in the salinity results:

- As would be expected in a stratified estuary, the less inflow of the fresh water, the further intrusion of the salt wedge into the estuary;
- Difference in position of contour lines for 50th and 90th percentile between the modeled configurations is marginal, indicating that effect of Ports major channel widening and deepening project on salinity is small to negligible. Plots depicting all salinity scenarios can be seen in Attachments A through C.

4.4.1 Low Inflow Scenario

Results for the low inflow scenario are provided in Attachment A. Because the fresh water inputs are very low, the 30 PSU salinity contours are very close to the river mouths (river boundaries). Therefore, most of the estuary has a salinity value over 30 PSU. There are negligible differences in salinity between the three channel configurations; hence, it is concluded that there are negligible effects on salinity for the low inflow scenario. Figure 4-3 and Figure 4-4 show 50th percentile for top and bottom layer, respectively.

4.4.2 Median Inflow Scenario

Results for the median inflow scenario are provided in Attachment B. Similarly, the differences between bathymetric cases are minor. A typical trend shows that the WOP Condition has similar contours as the PA. There are practically no differences between the three channel configurations for the salinity contour of 20 PSU. Overall, results indicate that the project effects on salinity for the median inflow scenario are negligible.

4.4.3 High Inflow Scenario

Results for the high inflow scenario are provided in Attachment C. The differences in salinity between bathymetric cases are only slightly more compared to the low and medium flow conditions, and the salinity contour patterns are still very similar. For the worst case, in terms of contour line shift (see Figure C-5 in Attachment C), the shift is less than a mile. In addition, it should be noted that a continuous high river inflow for two months will be very rare.

5. PROJECT EFFECTS

Salinity modeling results show that the Port's Project effects on both salinity spatial extent and salinity values are expected to be very small.

More generally, salinity can be interpreted to represent circulation and tidal exchange within Coos Bay. Salinity is sourced from the ocean; limiting changes to salinity within the estuary indicates that tidal flushing and mixing is not expected to change as a result of the JCEP Project. Therefore, circulation and flushing of other water quality constituents are unlikely to be effected by the JCEP Project.

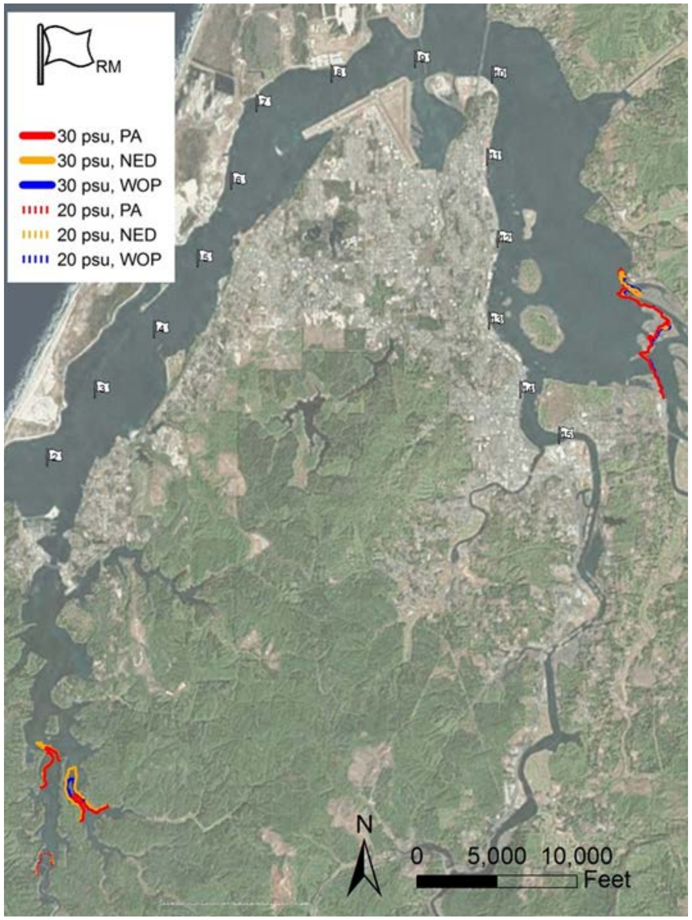

Figure 4-3: Low Inflow Scenario, Top Layer, 50th Percentile for Selected Salinity Contours

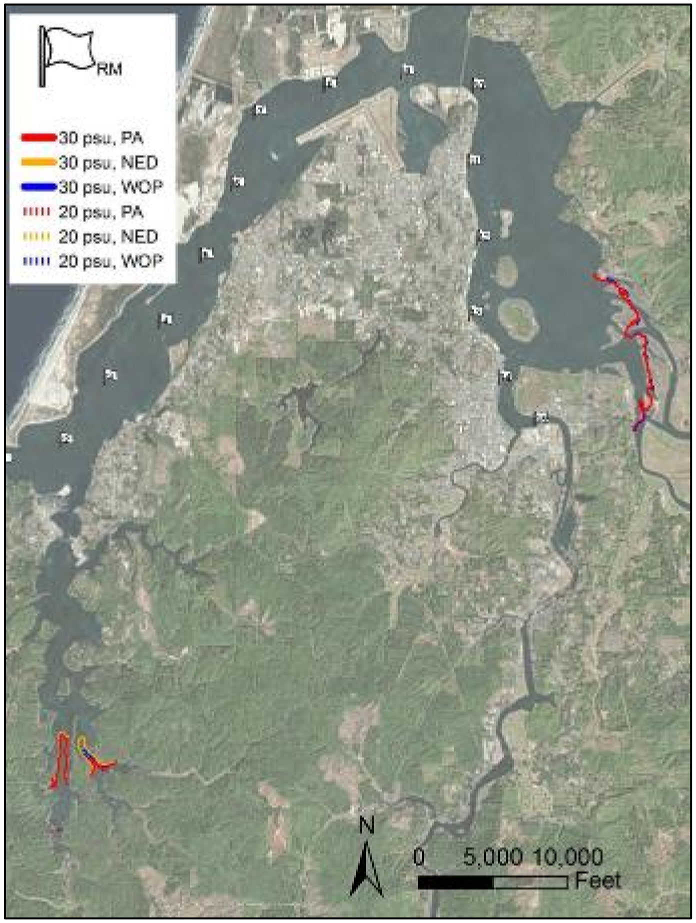

Figure 4-4: Low Inflow Scenario, Bottom Layer, 50th Percentile for Selected Salinity Contours

6. REFERENCES

Danish Hydraulic Institute (DHI). 2014. MIKE 3 Flow Model FM - Hydrodynamic Module User Guide. JCLNG Document No. J1-000-GEO-PCD-DHI-00001-00.

O'Neill, M.A. 2014. Seasonal Hydrography and Hypoxia of Coos Bay, Oregon. Master Thesis. Submitted to the Department of Geological Sciences, University of Oregon. JCLNG Document No. J1-000-GEO-RPT-UOO-00001-00.

Oregon International Port of Coos Bay (OIPCB). 2017. Draft Section 204 (f) Channel Modification Project Estuarine Dynamics. Prepared by M&N: September 15, 2017. JCLNG Document No. J1-000-MAR-RPT-PCB-00004-00.

ATTACHMENT A: SALINITY RESULTS FOR LOW INFLOW SCENARIO

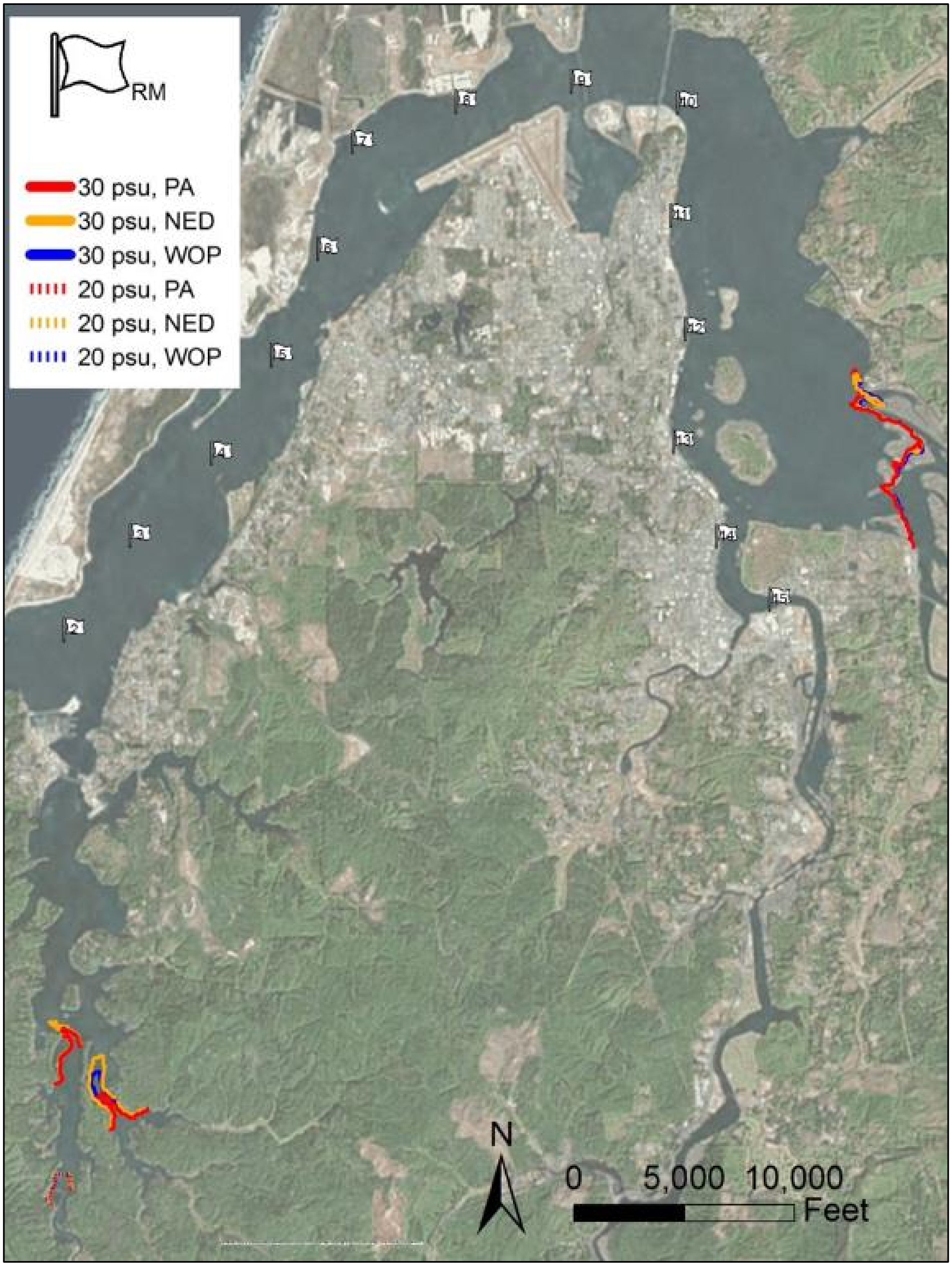

Figure A-1: Low Inflow Scenario, Top Layer, 50th Percentile for Selected Salinity Contours

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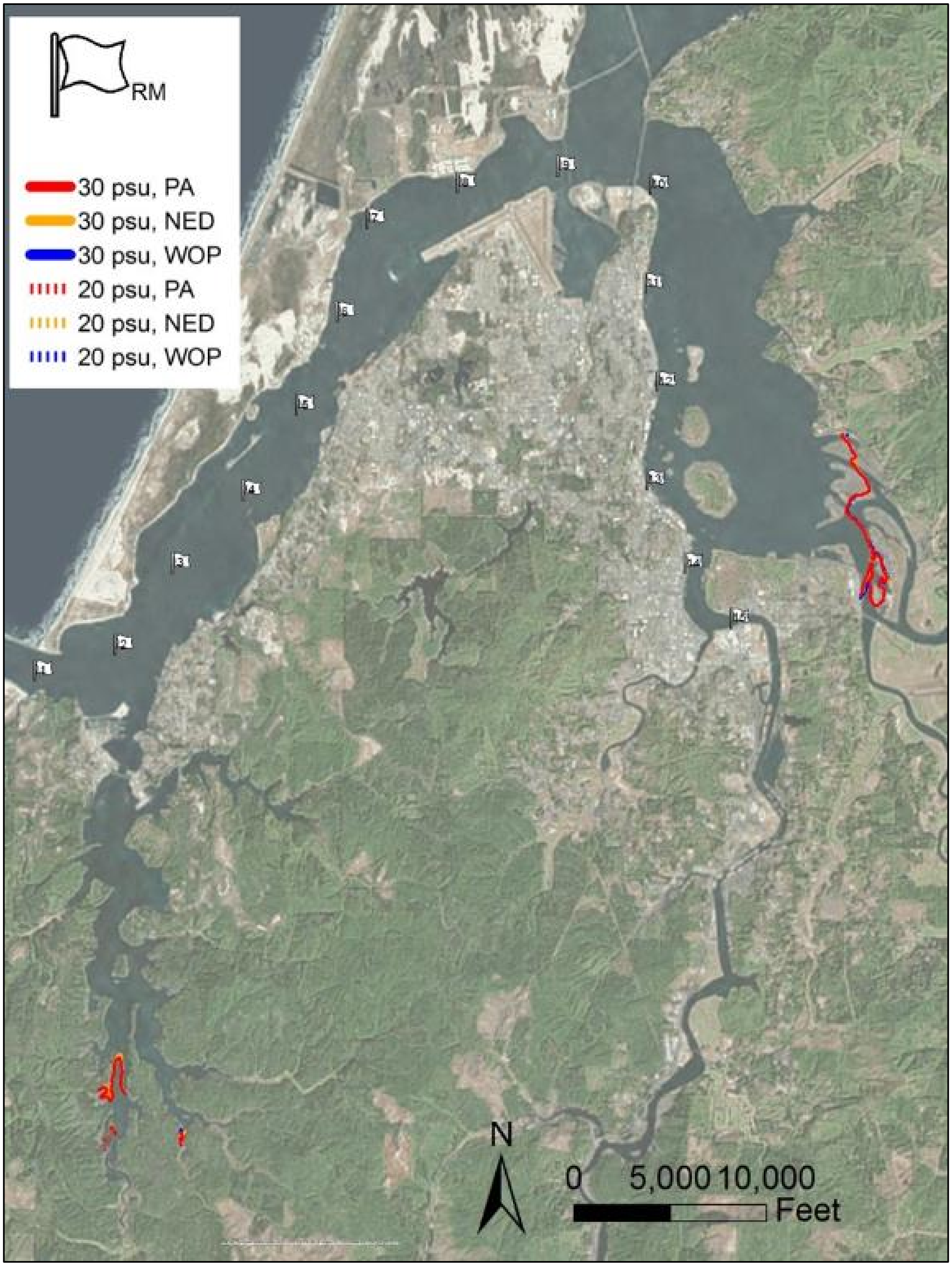

Figure A-2: Low Inflow Scenario, Top Layer, 75th Percentile for Selected Salinity Contours

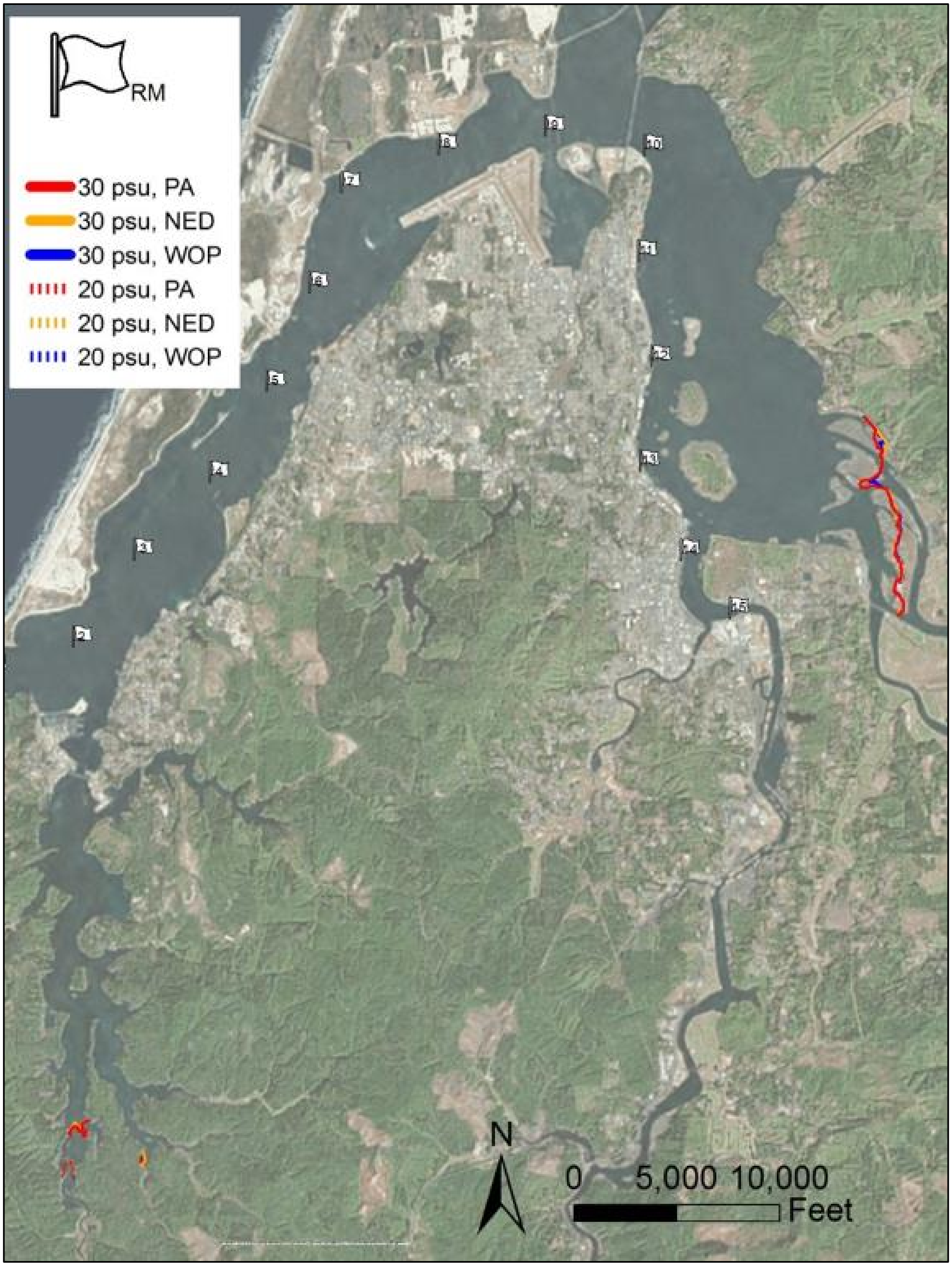

Figure A-3: Low Inflow Scenario, Top Layer, 90th Percentile for Selected Salinity Contours

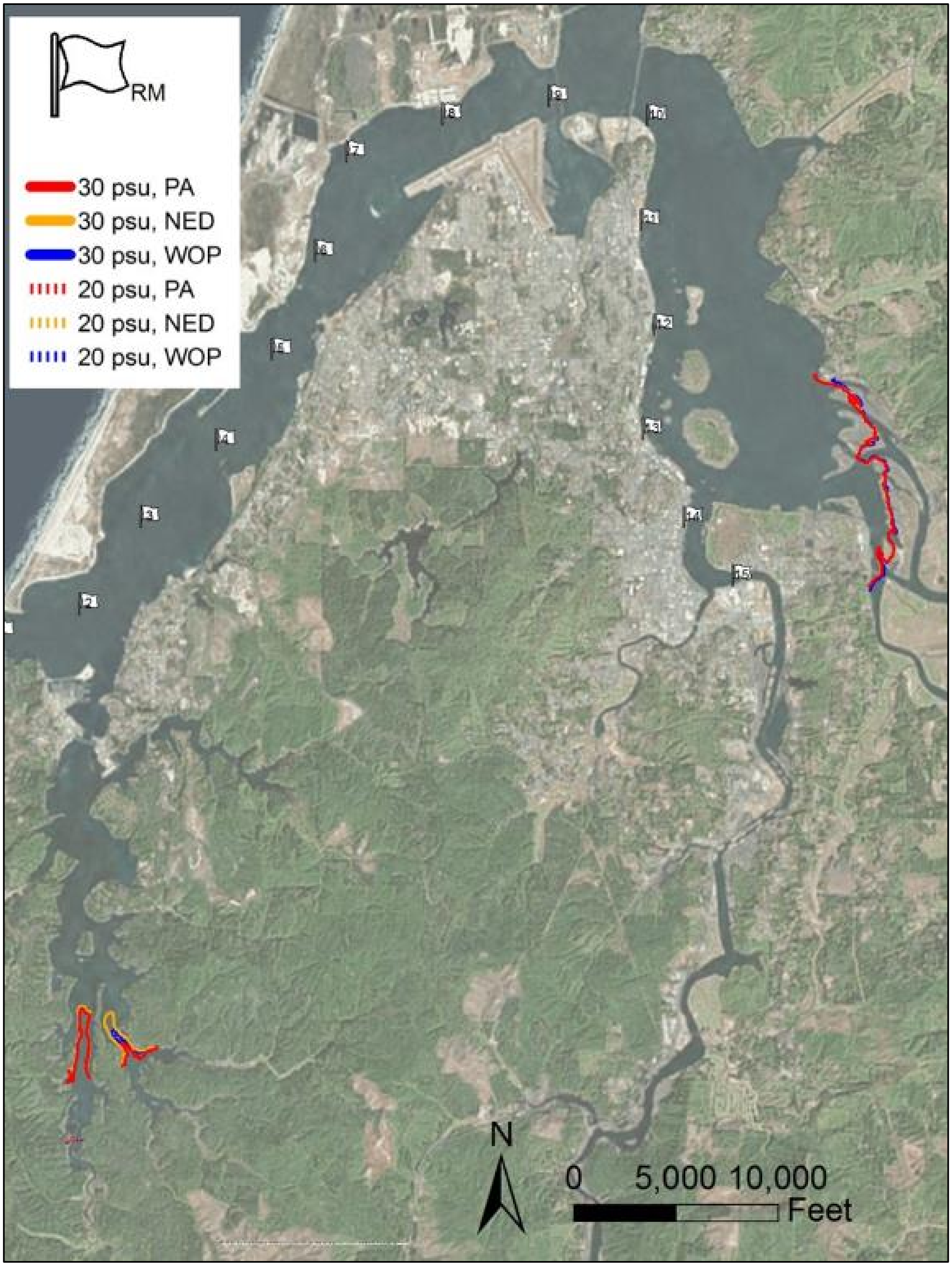

Figure A-4: Low Inflow Scenario, Bottom Layer, 50th Percentile for Selected Salinity Contours

Jordan Cove LNG	Project Impacts on Salinity		moffatt & nichol
	Document Number: J1-000-MAR-TNT-DEA-00009-00		
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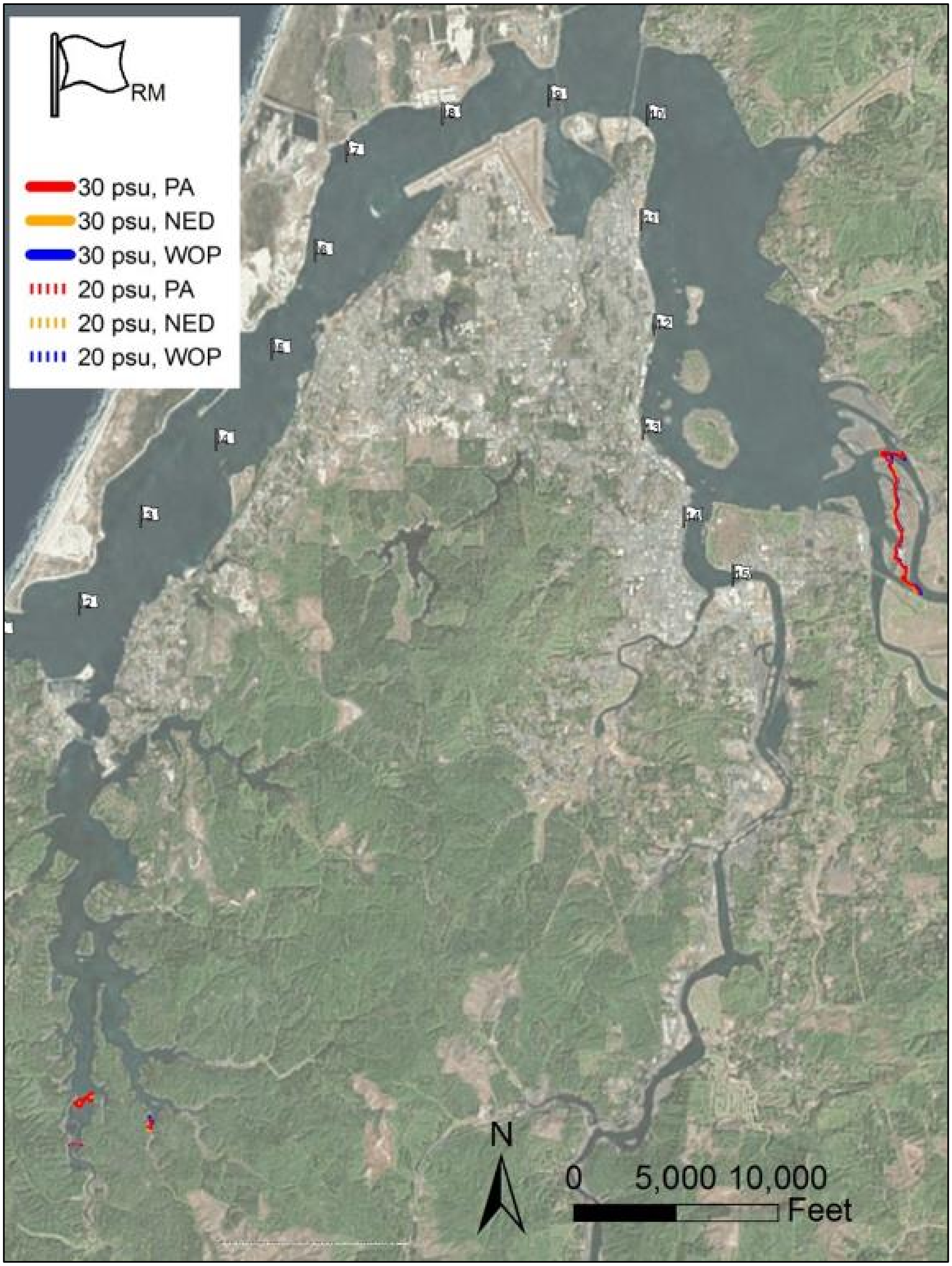

Figure A-5: Low Inflow Scenario, Bottom Layer, 75th Percentile for Selected Salinity Contours

Jordan Cove LNG	Project Impacts on Salinity		moffatt & nichol
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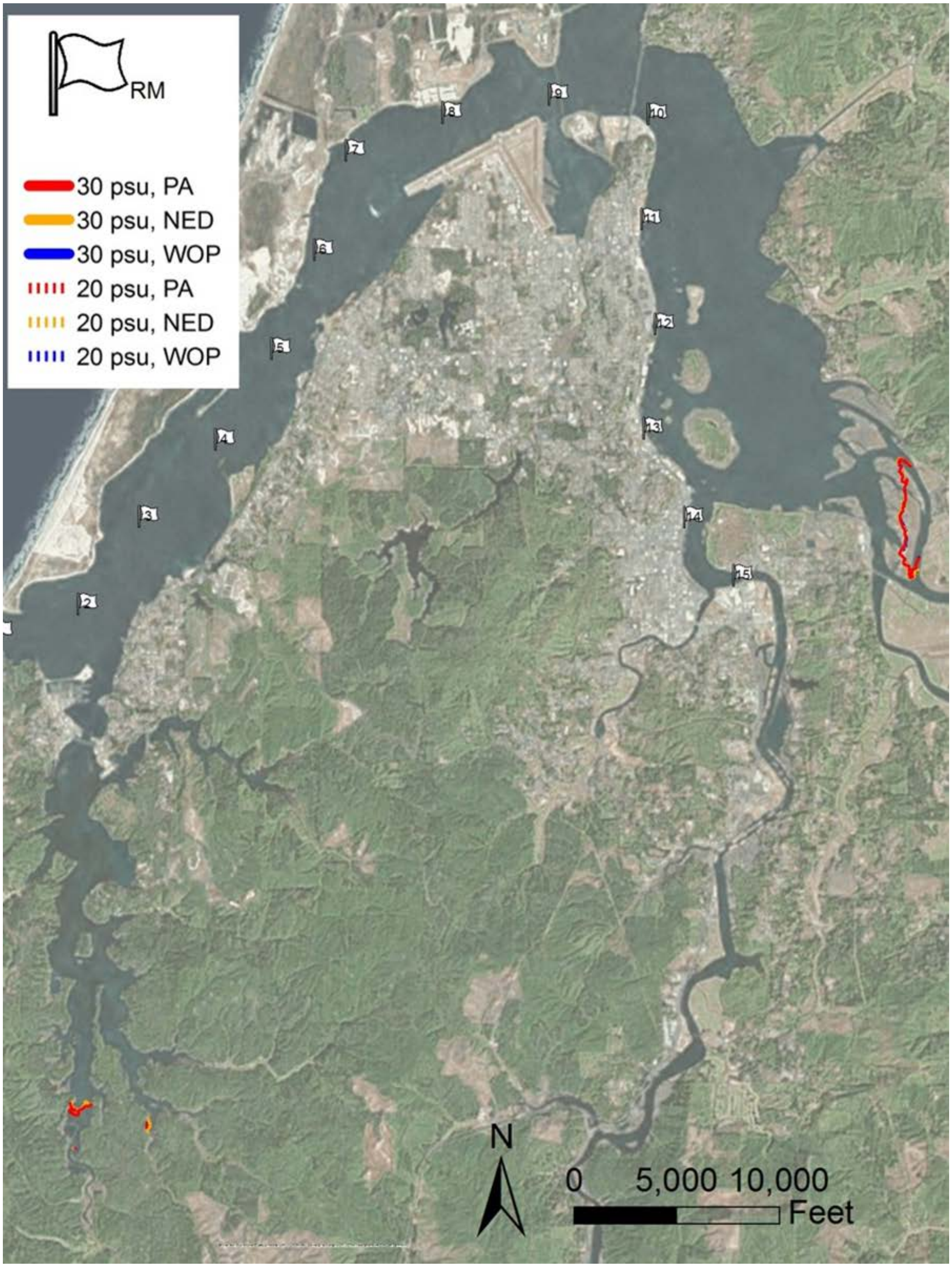

Figure A-6: Low Inflow Scenario, Bottom Layer, 90th Percentile for Selected Salinity Contours

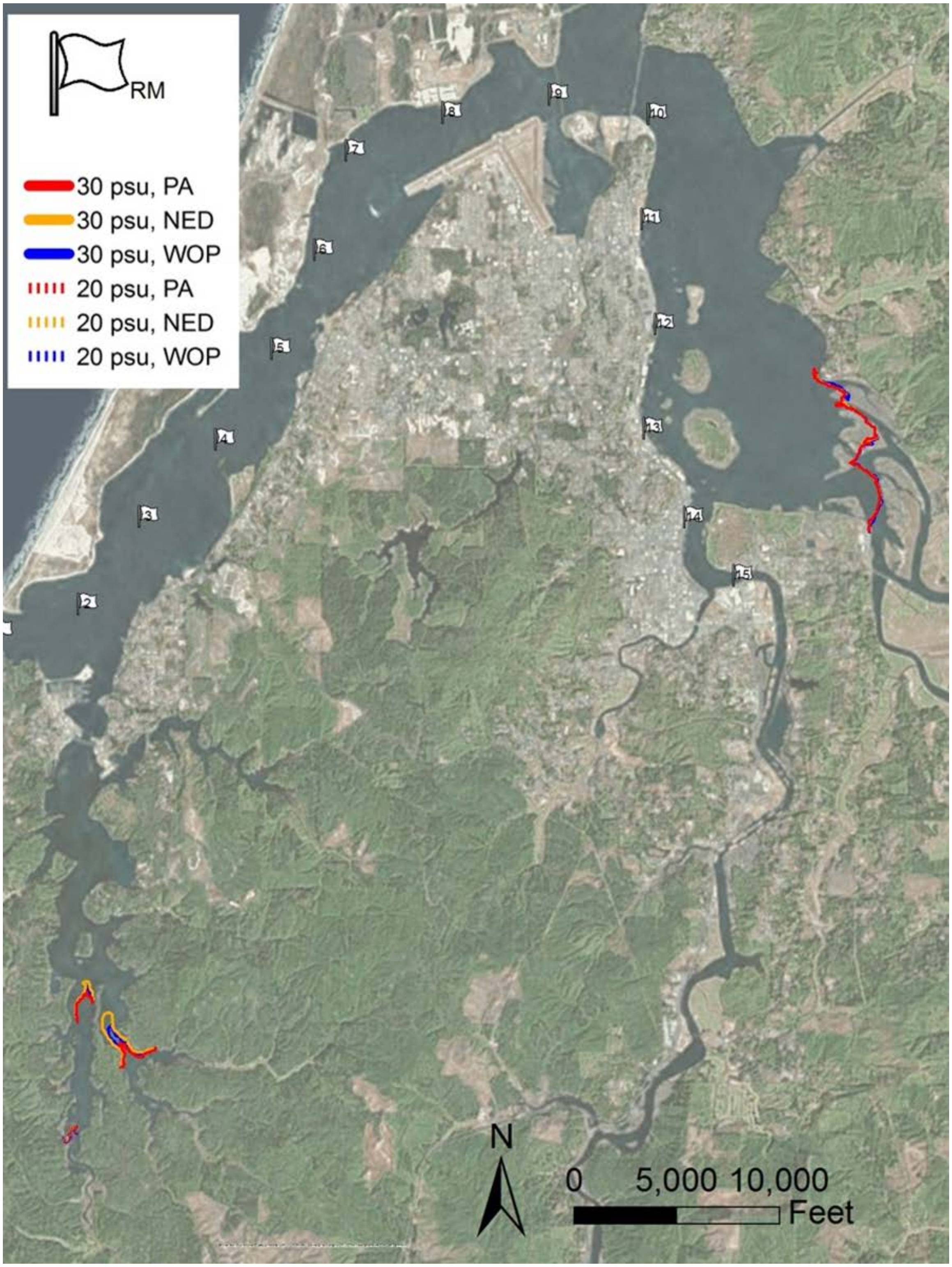

Figure A-7: Low Inflow Scenario, Depth Average, 50th Percentile for Selected Salinity Contours

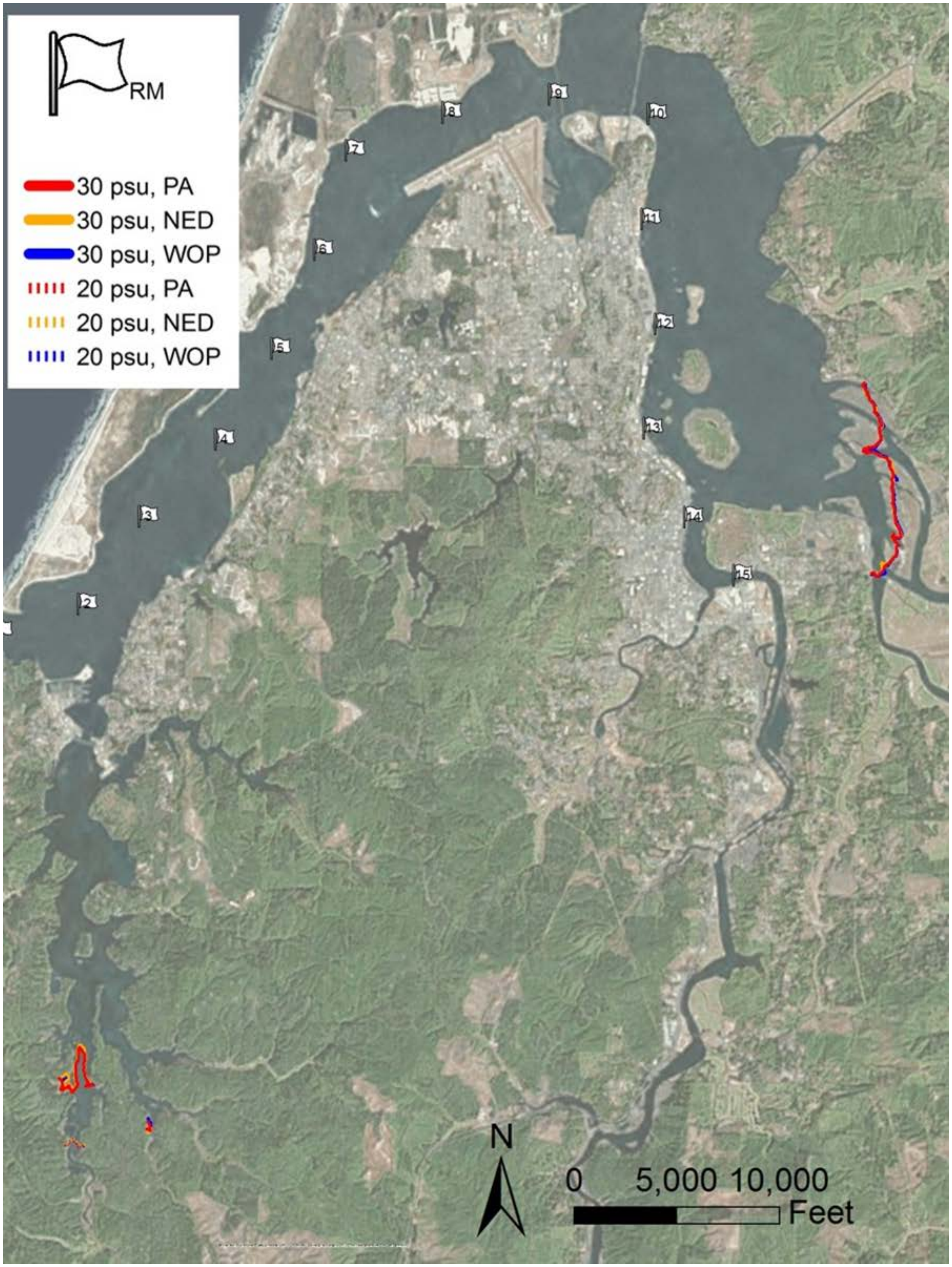

Figure A-8: Low Inflow Scenario, Depth Average, 75th Percentile for Selected Salinity Contours

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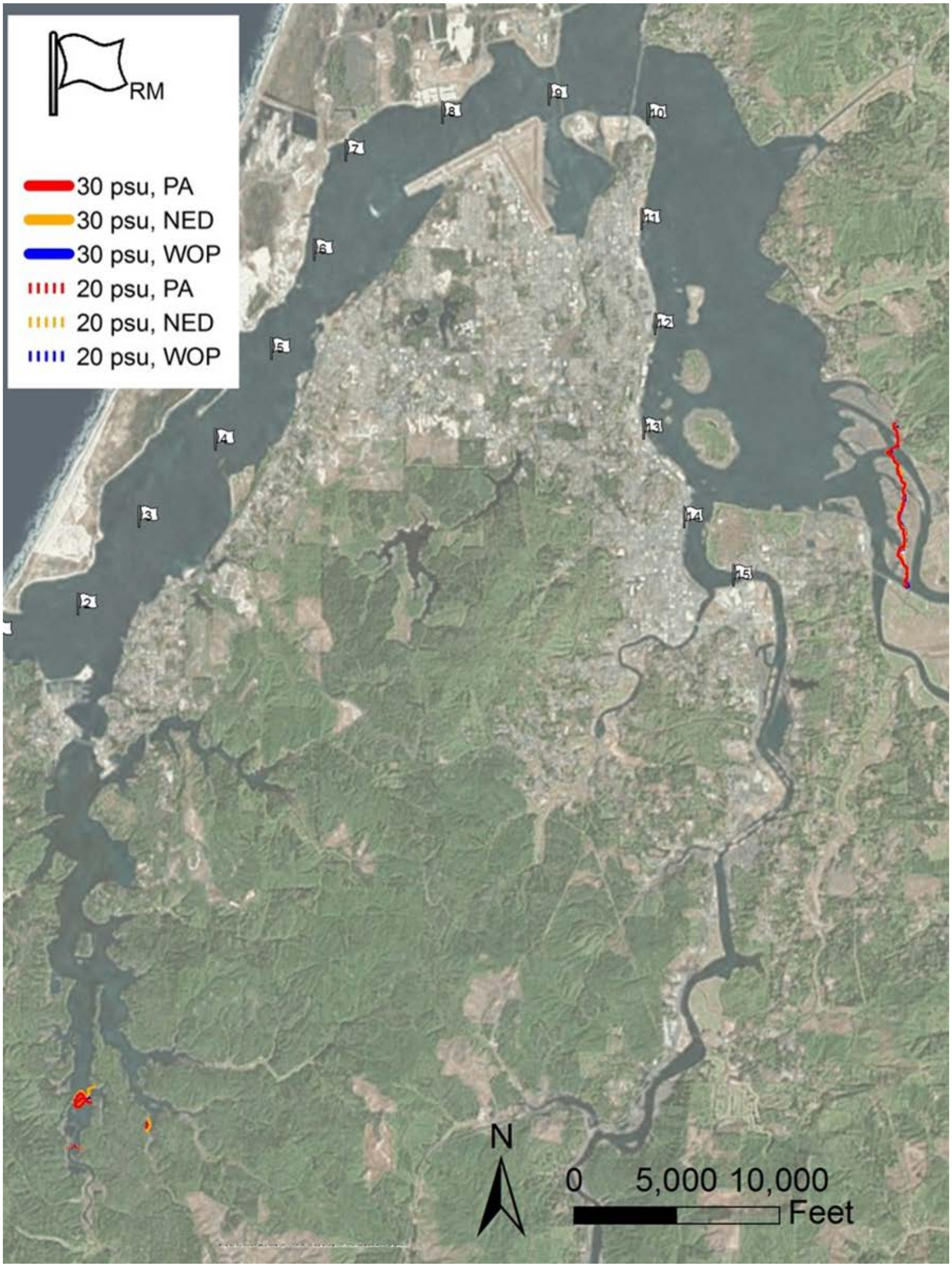

Figure A-9: Low Inflow Scenario, Depth Average, 90th Percentile for Selected Salinity Contours

ATTACHMENT B: SALINITY RESULTS FOR MEDIAN INFLOW SCENARIO

Jordan Cove LNG	Project Impacts on Salinity		moffatt & nichol
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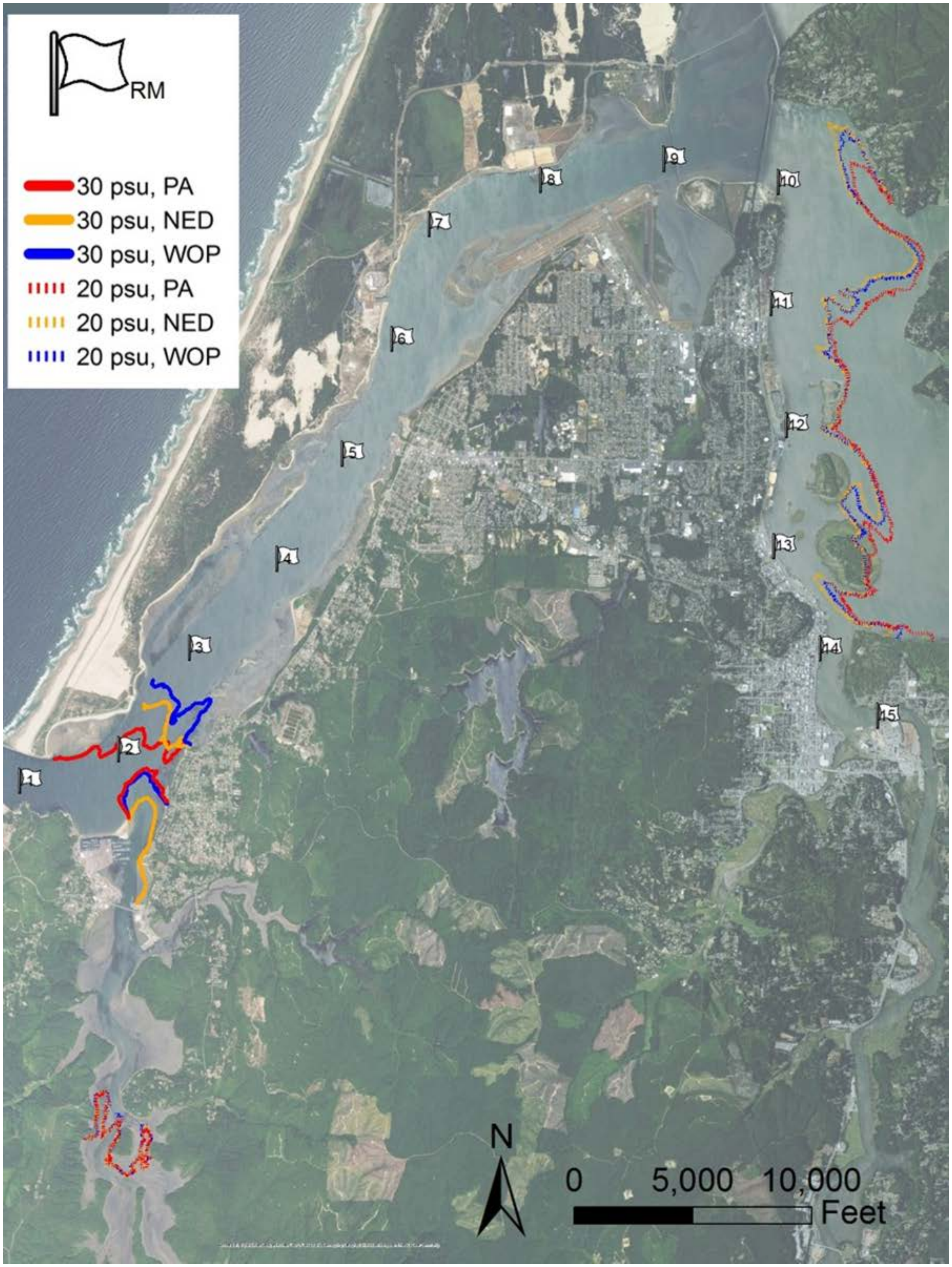

Figure B-1: Median Inflow Scenario, Top Layer, 50th Percentile for Selected Salinity Contours

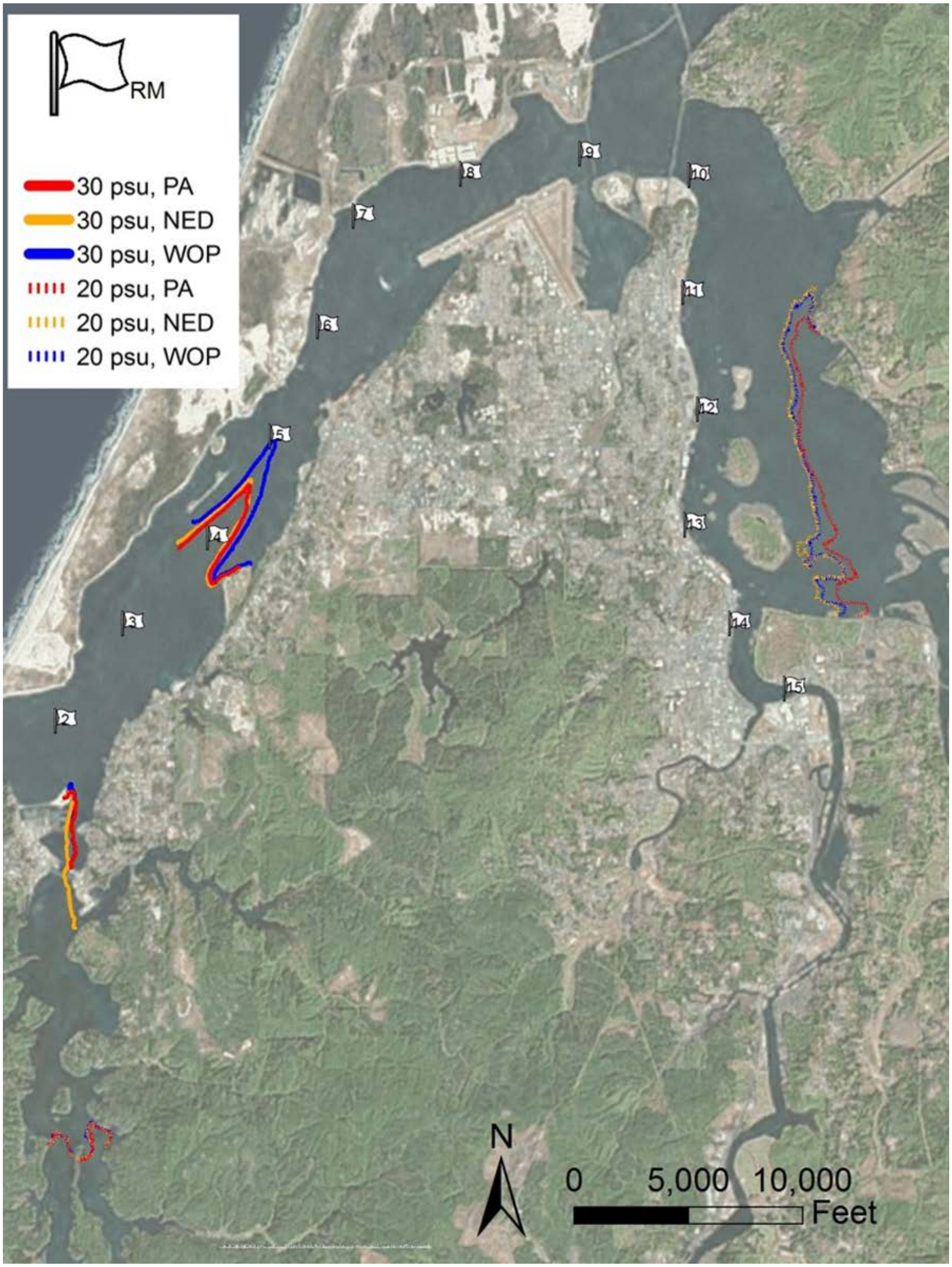

Figure B-2: Median Inflow Scenario, Top Layer, 75th Percentile for Selected Salinity Contours

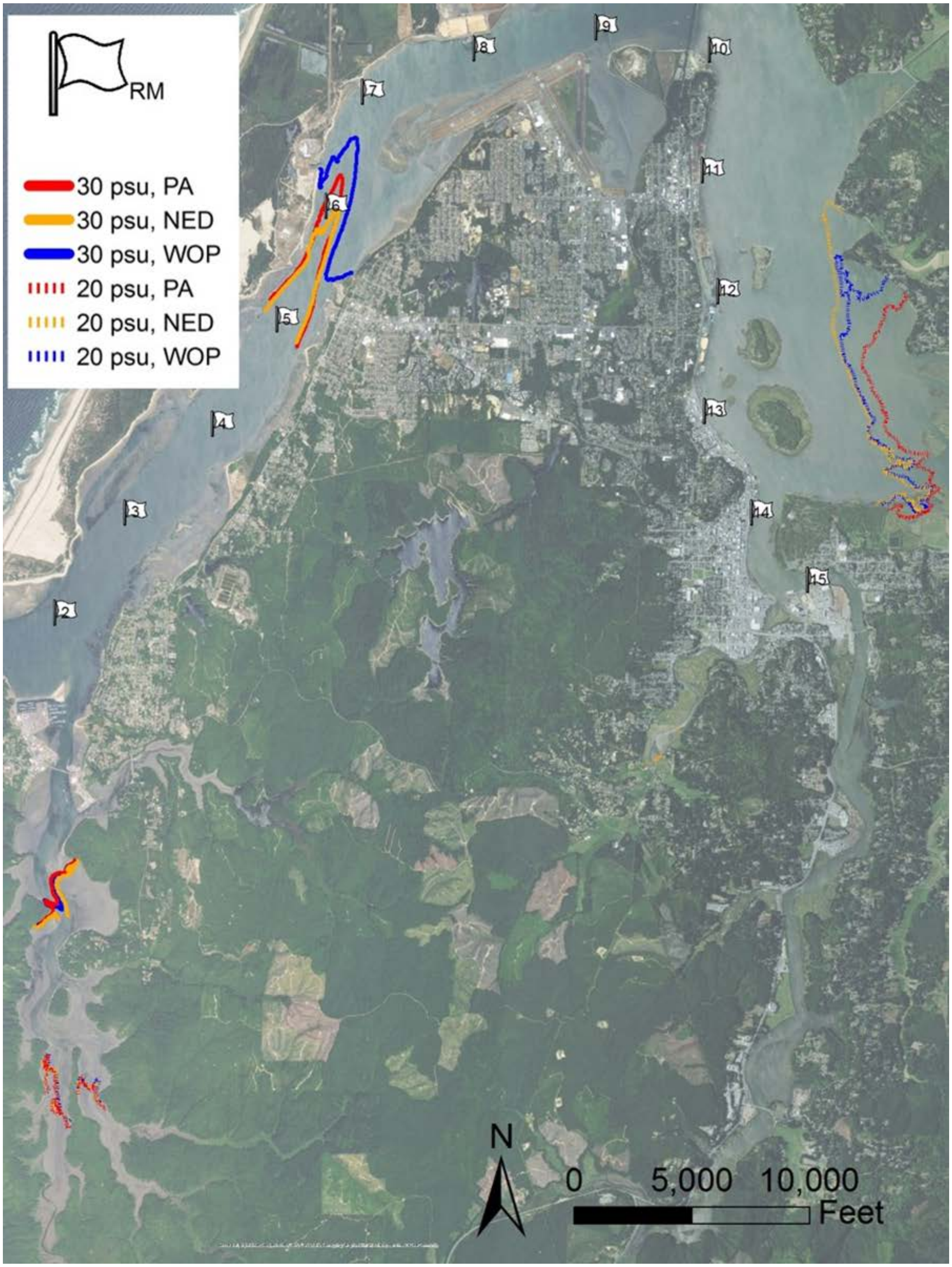

Figure B-3: Median Inflow Scenario, Top Layer, 90th Percentile for Selected Salinity Contours

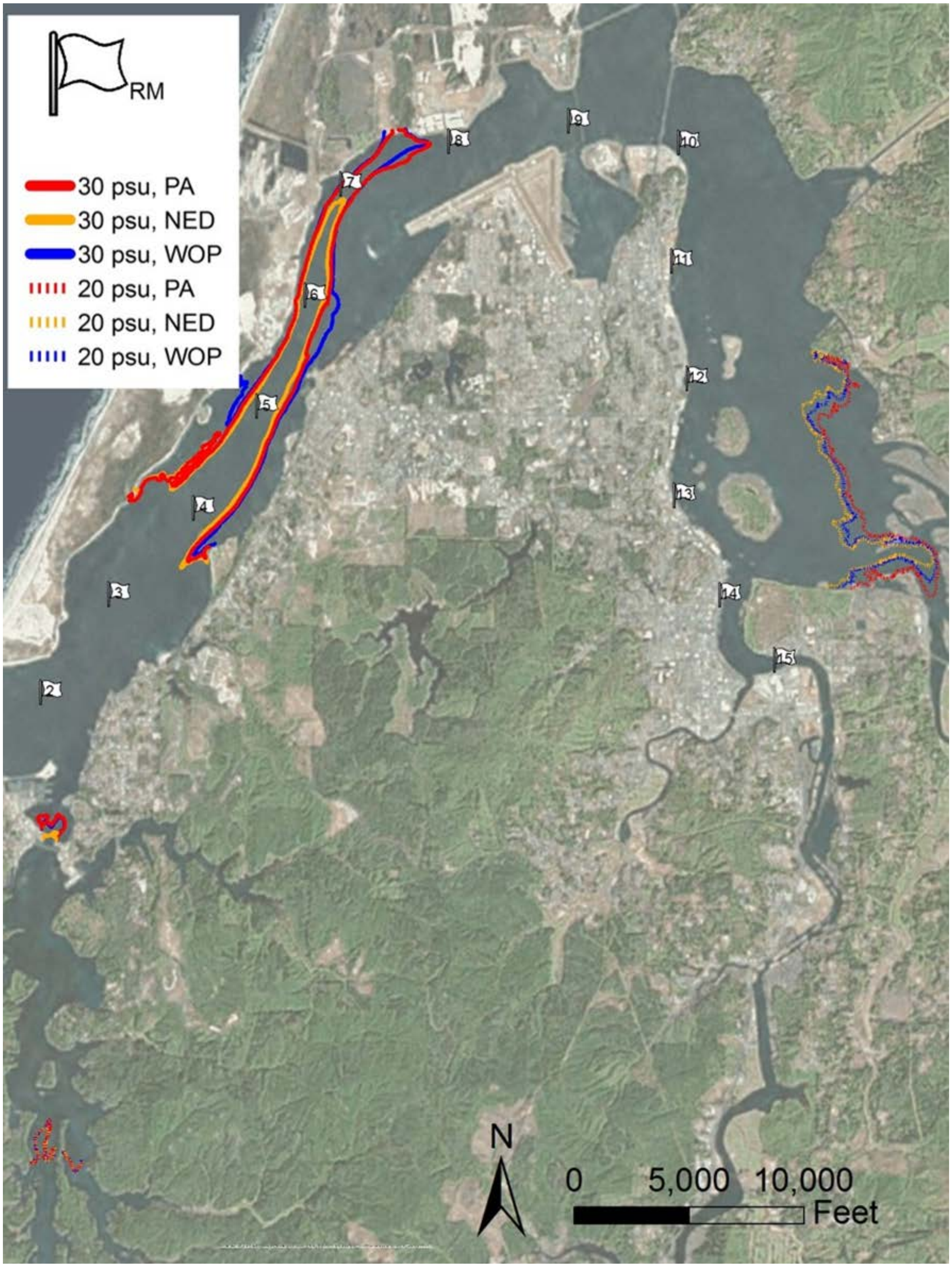

Figure B-4: Median Inflow Scenario, Bottom Layer, 50th Percentile for Selected Salinity Contours

Jordan Cove LNG	Project Impacts on Salinity		moffatt & nichol
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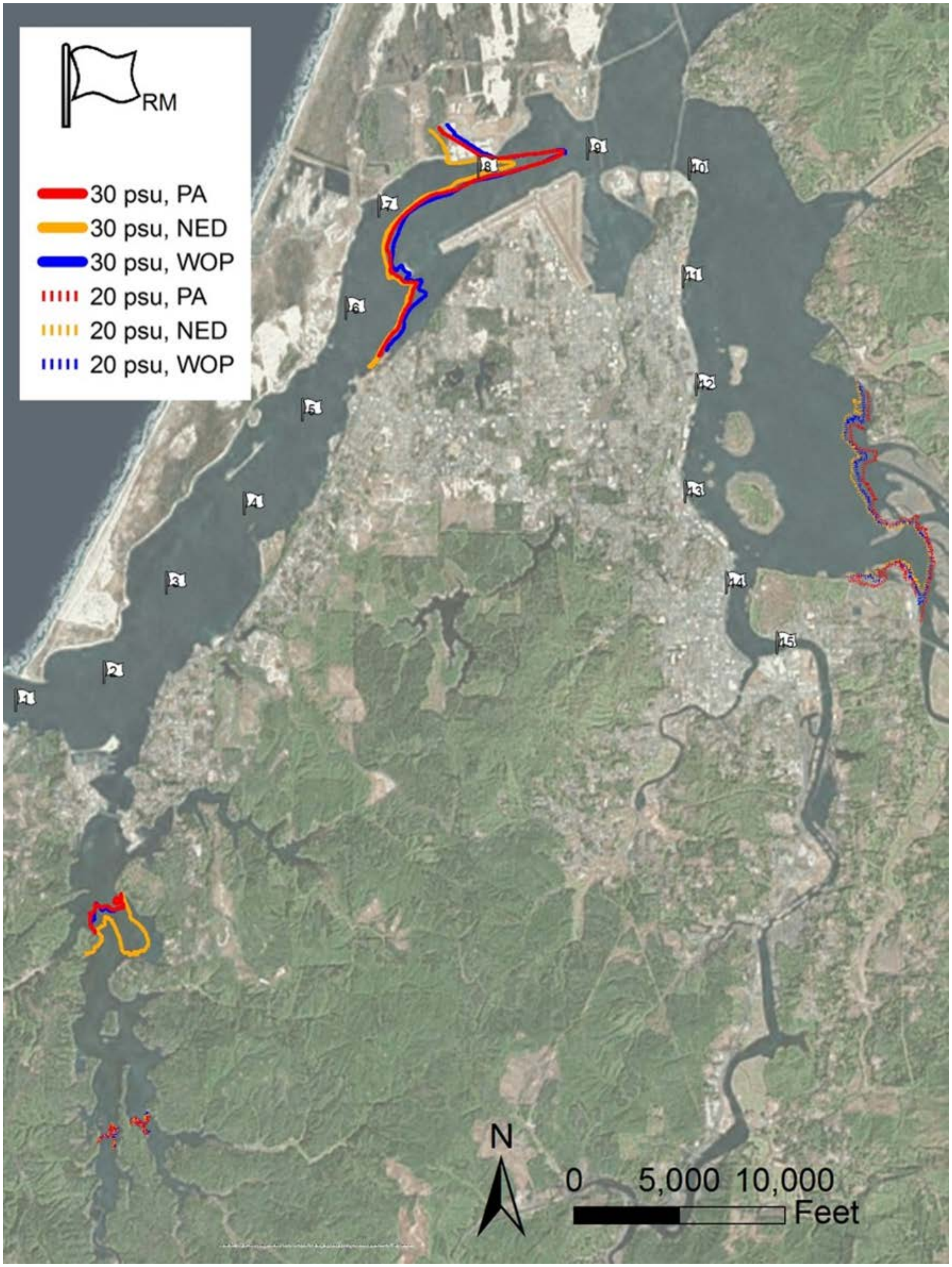

Figure B-5: Median Inflow Scenario, Bottom Layer, 75th Percentile for Selected Salinity Contours

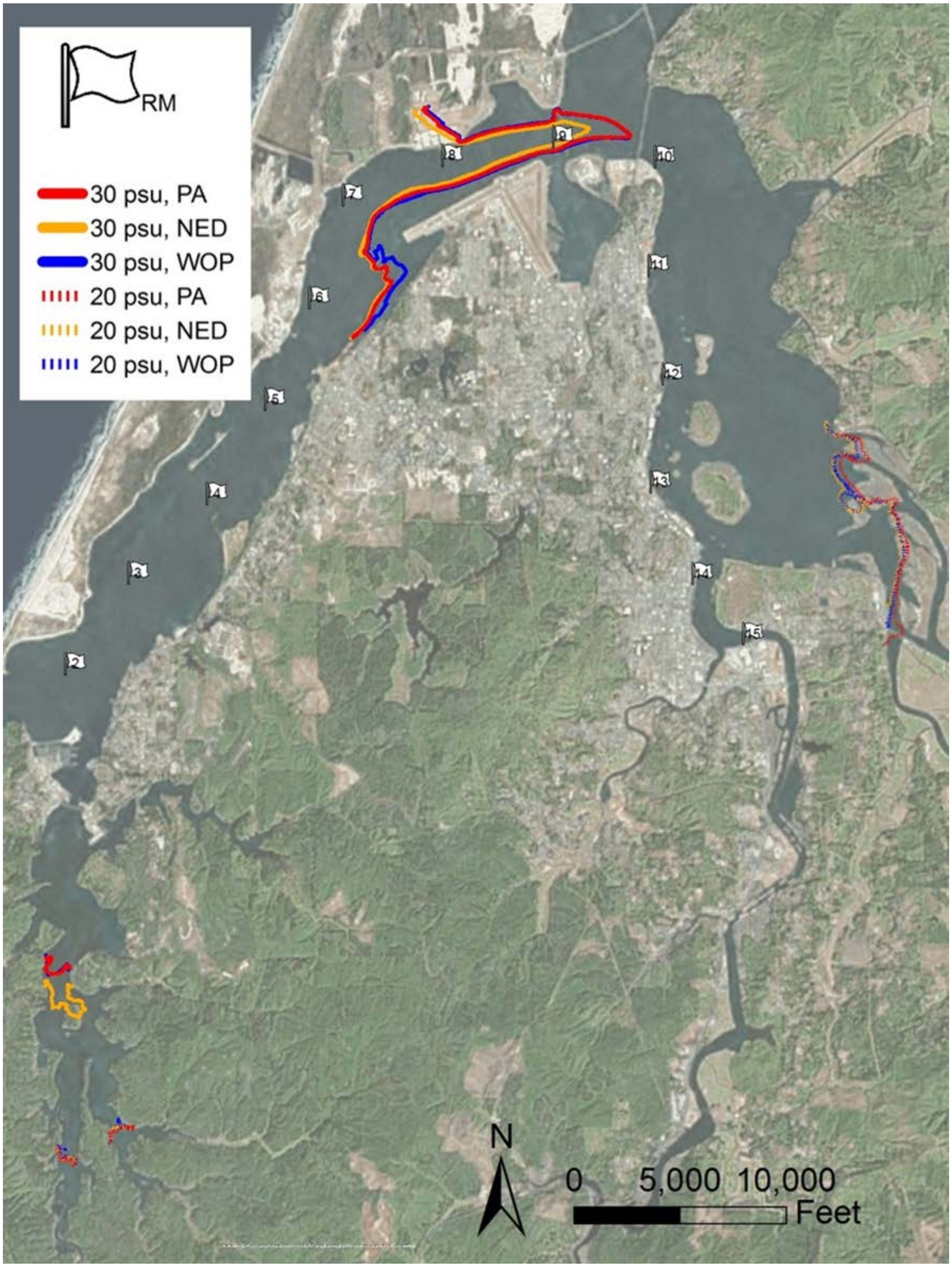

Figure B-6: Median Inflow Scenario, Bottom Layer, 90th Percentile for Selected Salinity Contours

Jordan Cove LNG	Project Impacts on Salinity		moffatt & nichol
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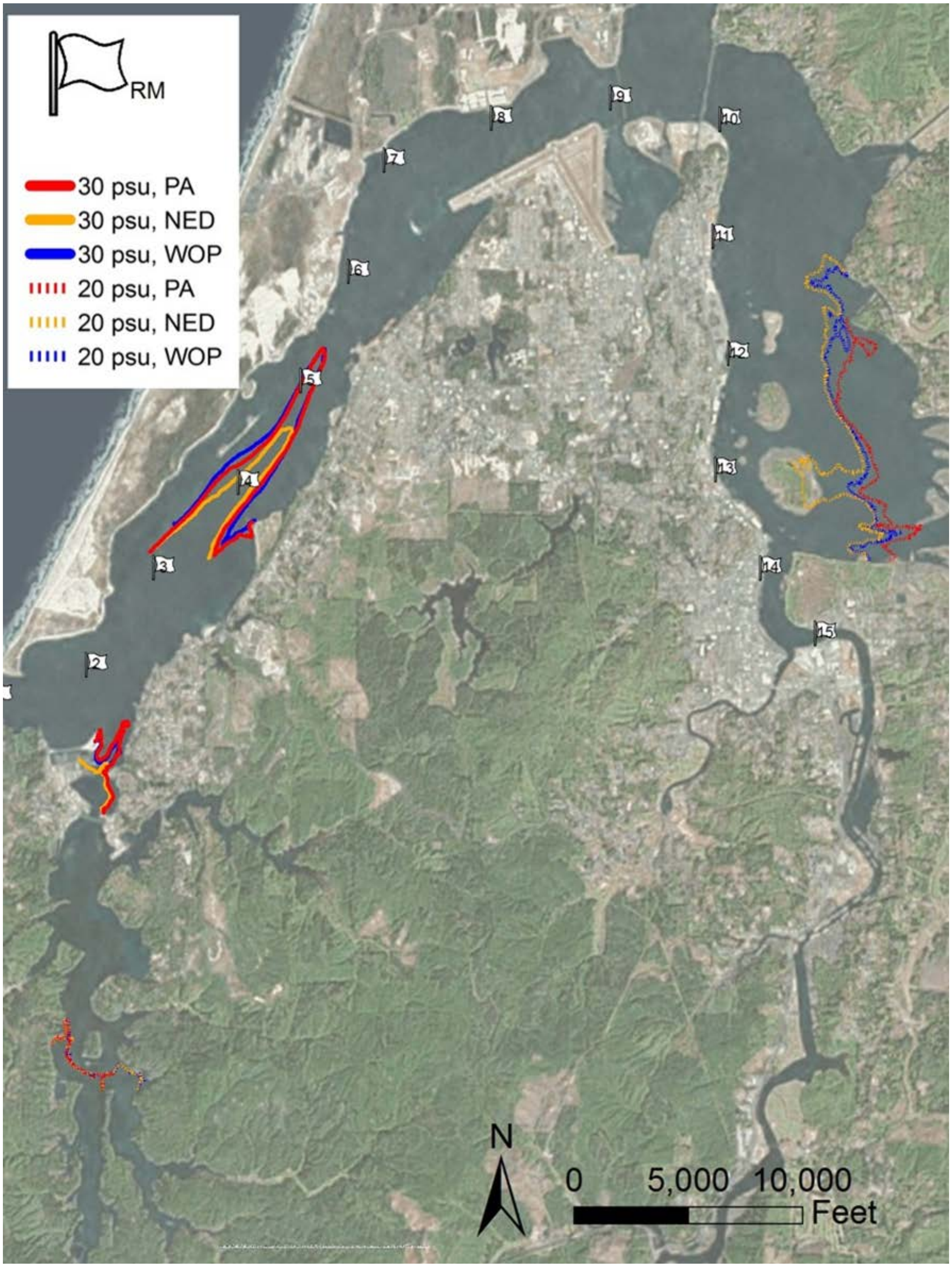

Figure B-7: Median Inflow Scenario, Depth Average, 50th Percentile for Selected Salinity Contours

Jordan Cove LNG	Project Impacts on Salinity		moffatt & nichol
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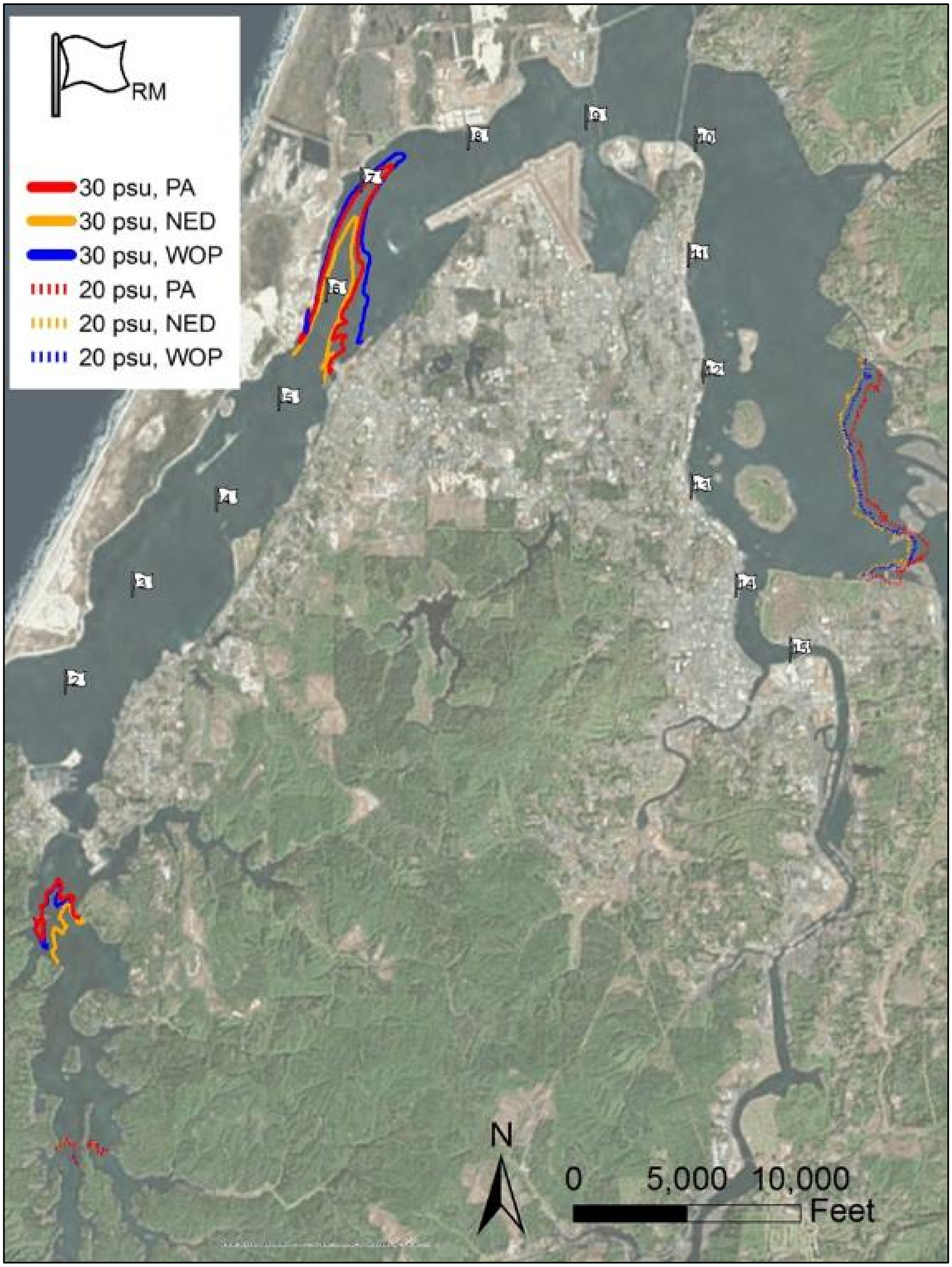

Figure B-8: Median Inflow Scenario, Depth Average, 75th Percentile for Selected Salinity Contours

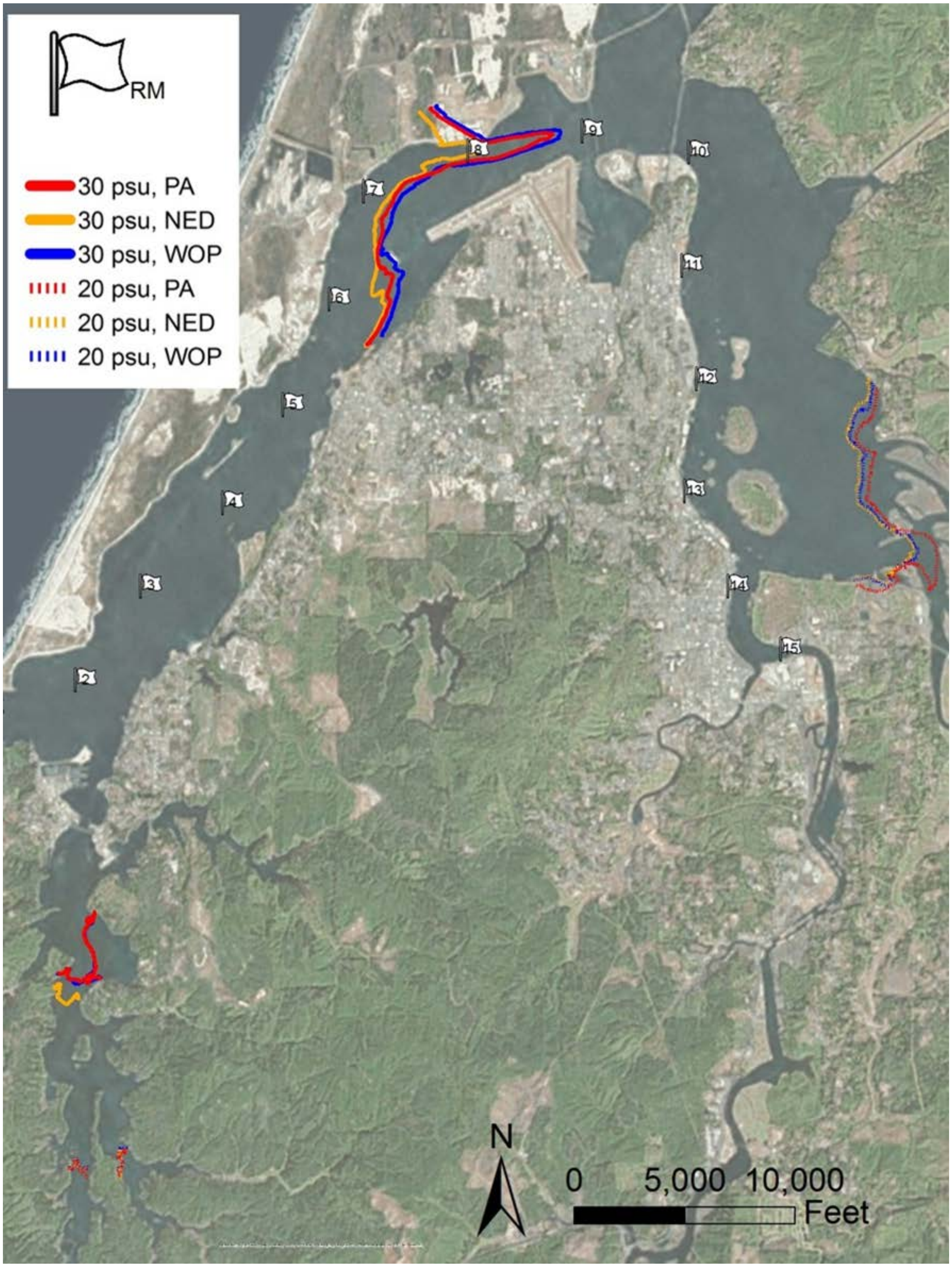

Figure B-9: Median Inflow Scenario, Depth Average, 90th Percentile for Selected Salinity Contours

ATTACHMENT C: SALINITY RESULTS FOR HIGH INFLOW SCENARIO

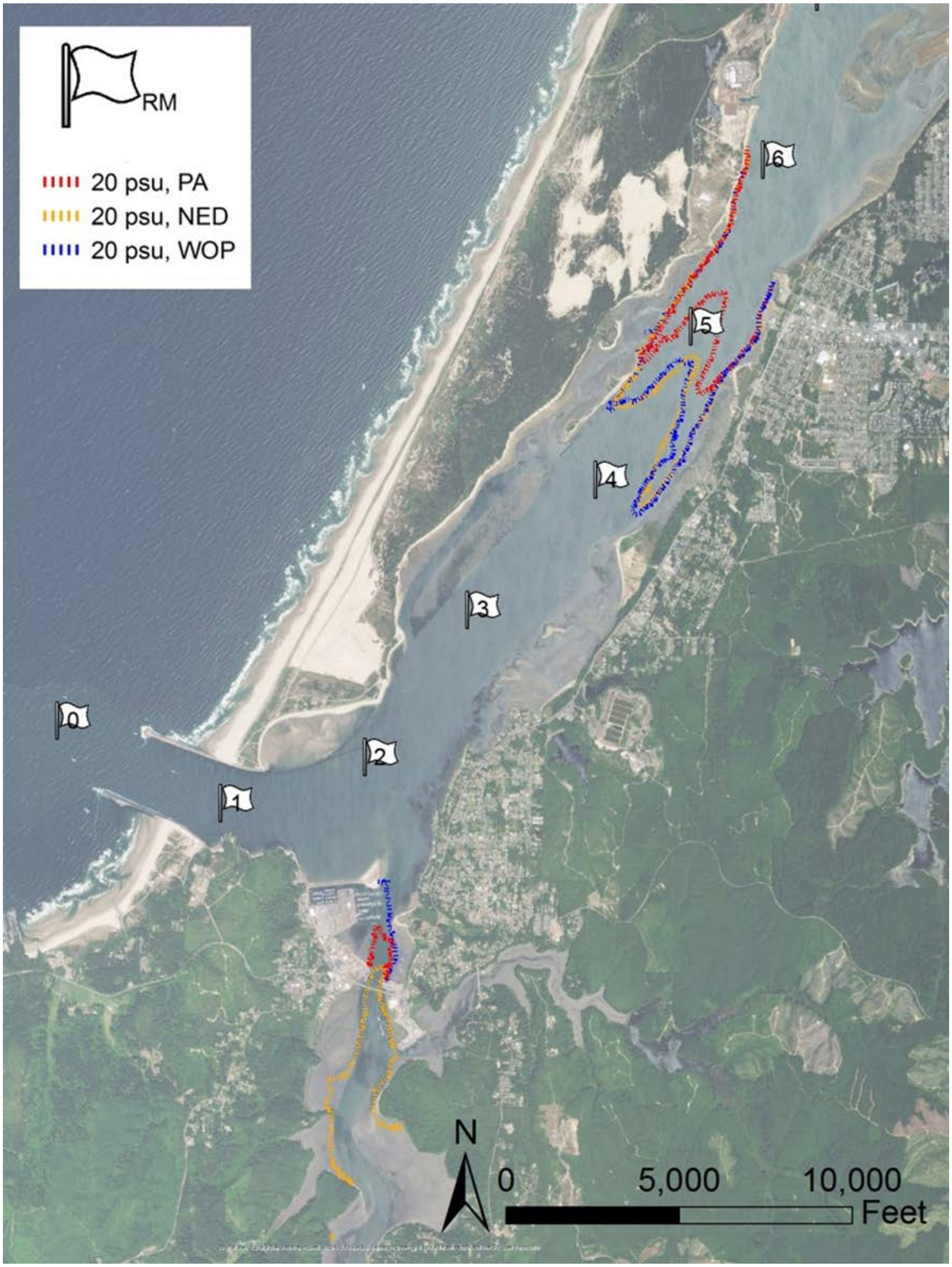

Figure C-1: High Inflow Scenario, Top Layer, 50th Percentile for Selected Salinity Contours

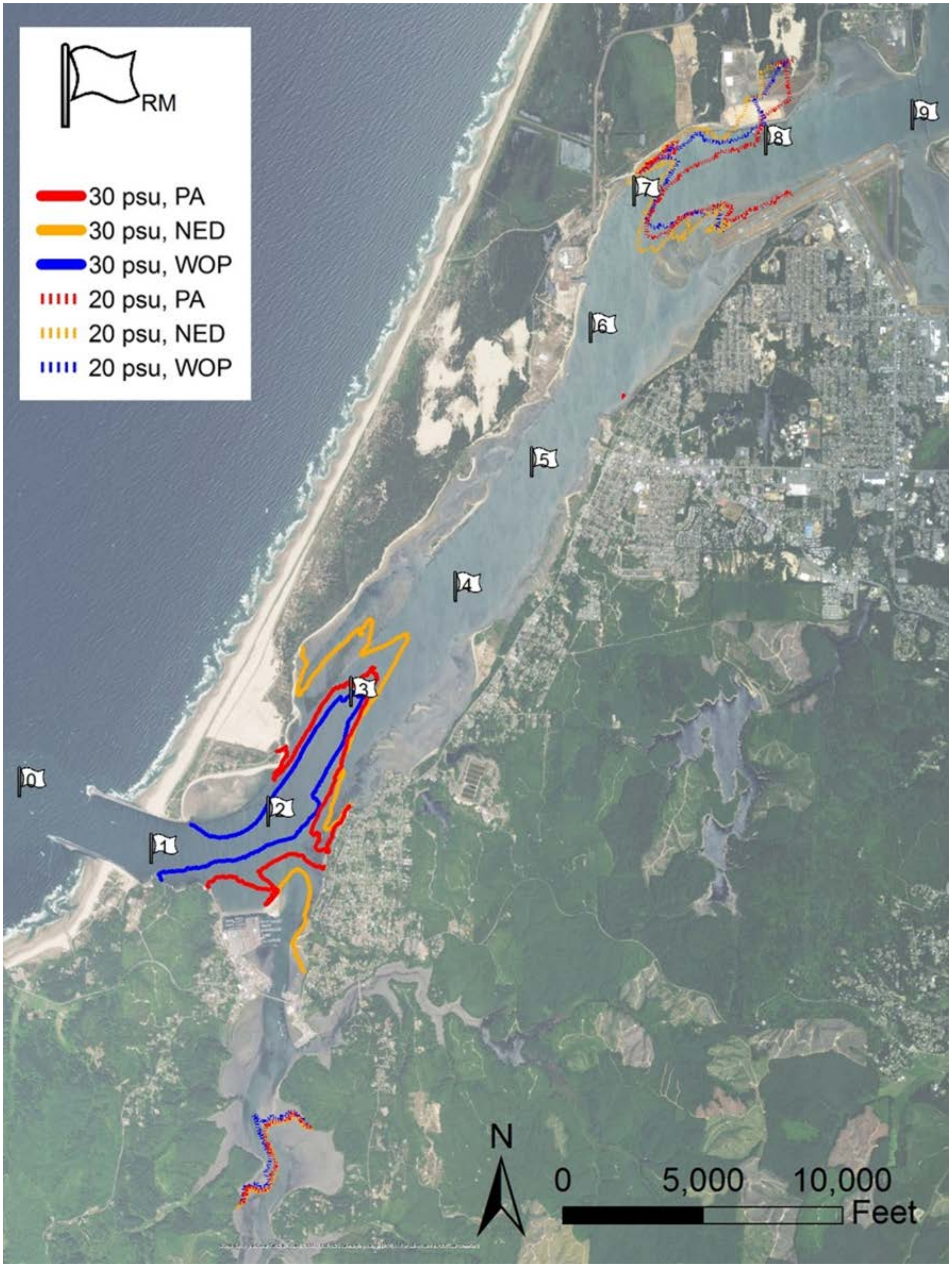

Figure C-2: High Inflow Scenario, Top Layer, 75th Percentile for Selected Salinity Contours

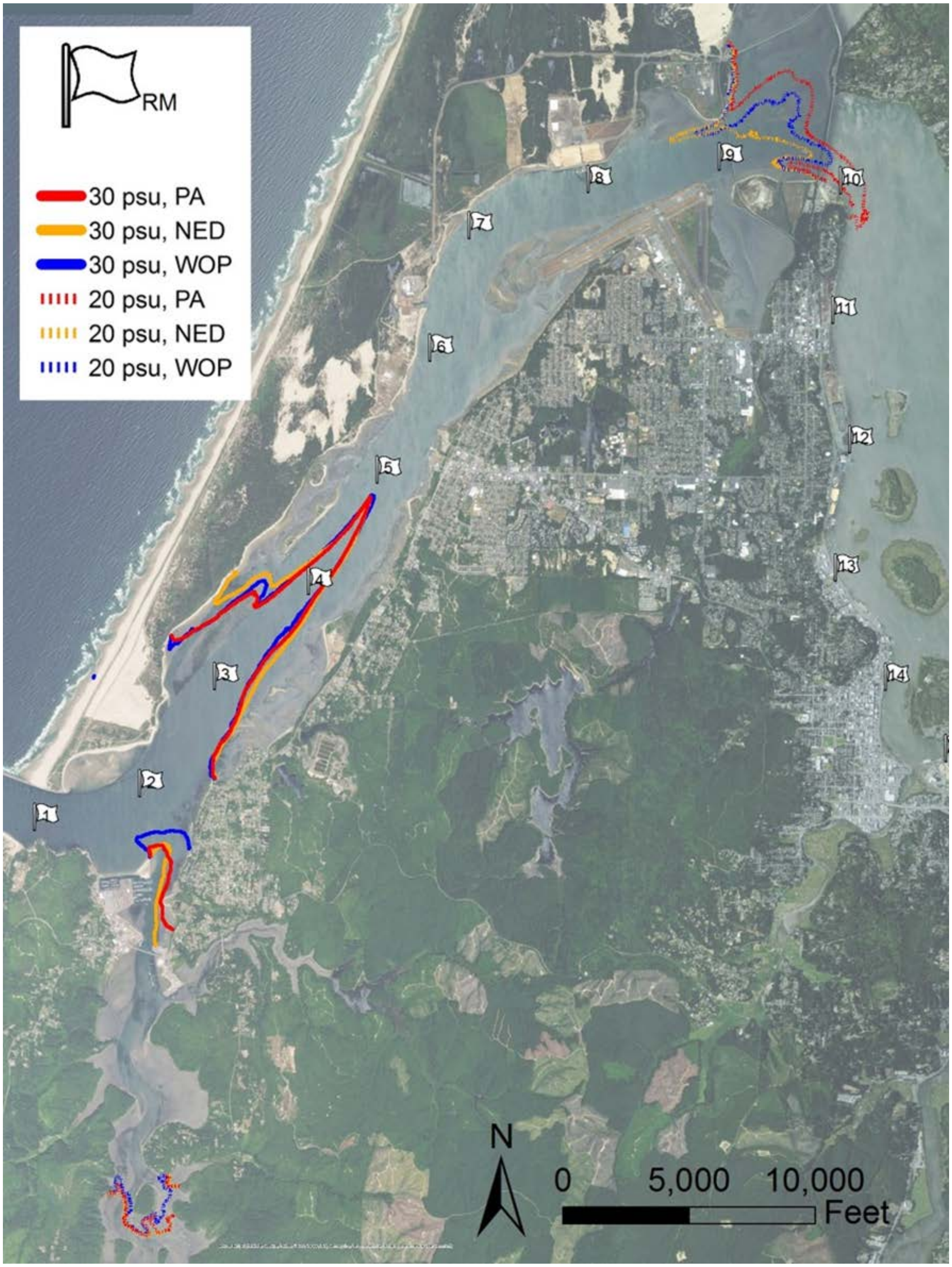

Figure C-3: High Inflow Scenario, Top Layer, 90th Percentile for Selected Salinity Contours

Jordan Cove LNG	Project Impacts on Salinity		moffatt & nichol
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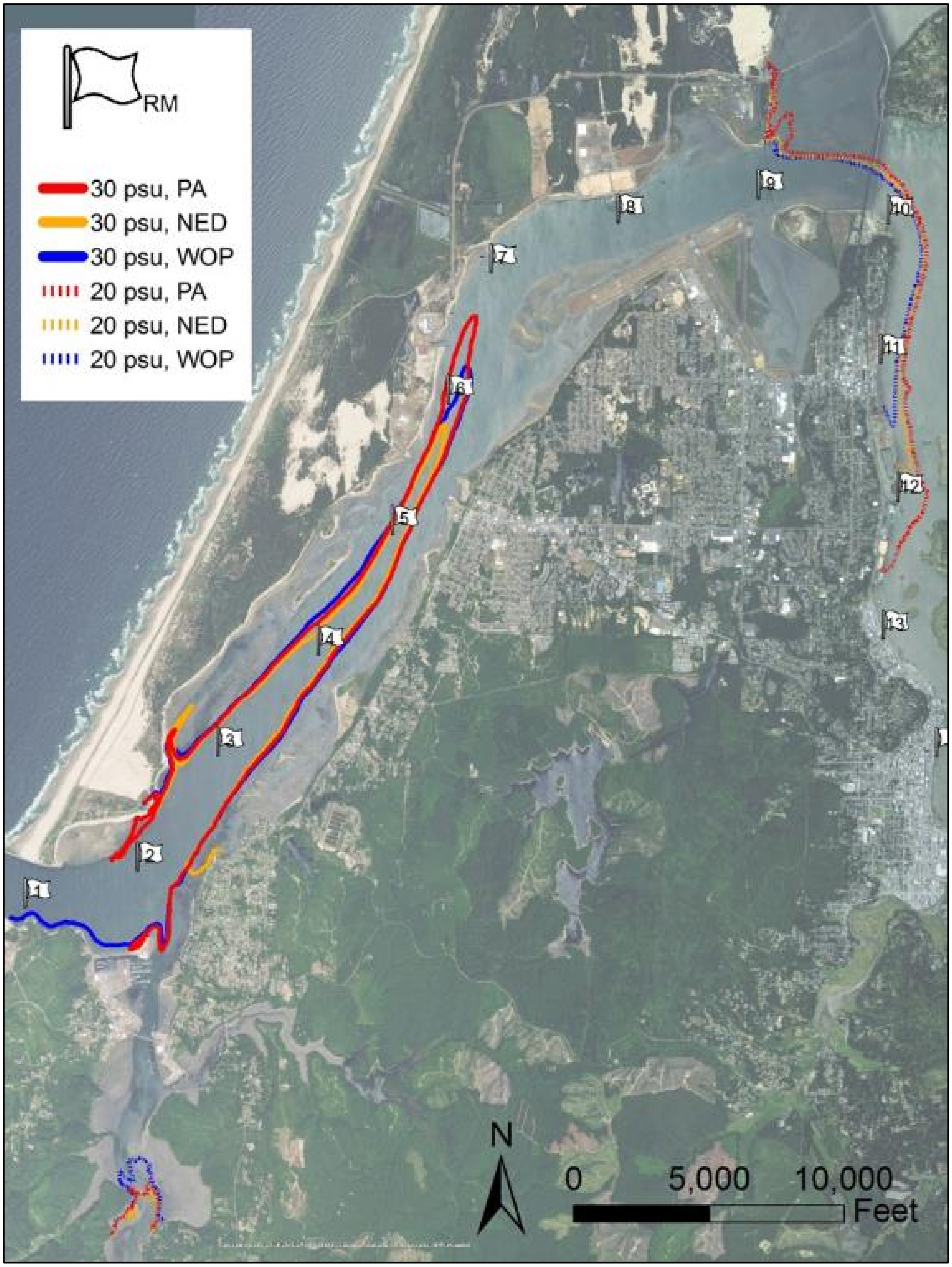

Figure C-4: High Inflow Scenario, Bottom Layer, 50th Percentile for Selected Salinity Contours

Jordan Cove LNG	Project Impacts on Salinity		moffatt & nichol
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	Rev.: A	**Rev. Date: November 29, 2017**	

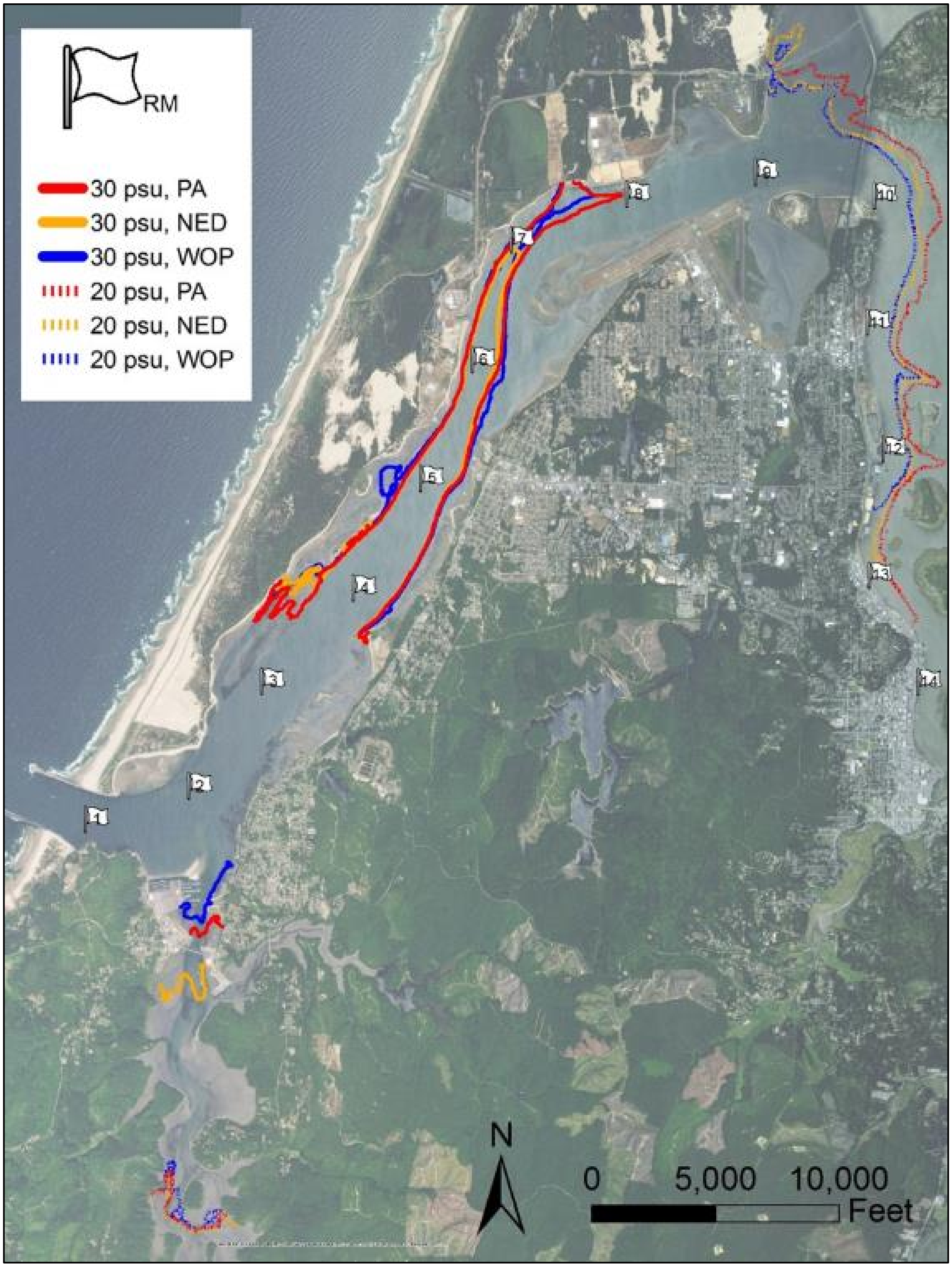

Figure C-5: High Inflow Scenario, Bottom Layer, 75th Percentile for Selected Salinity Contours

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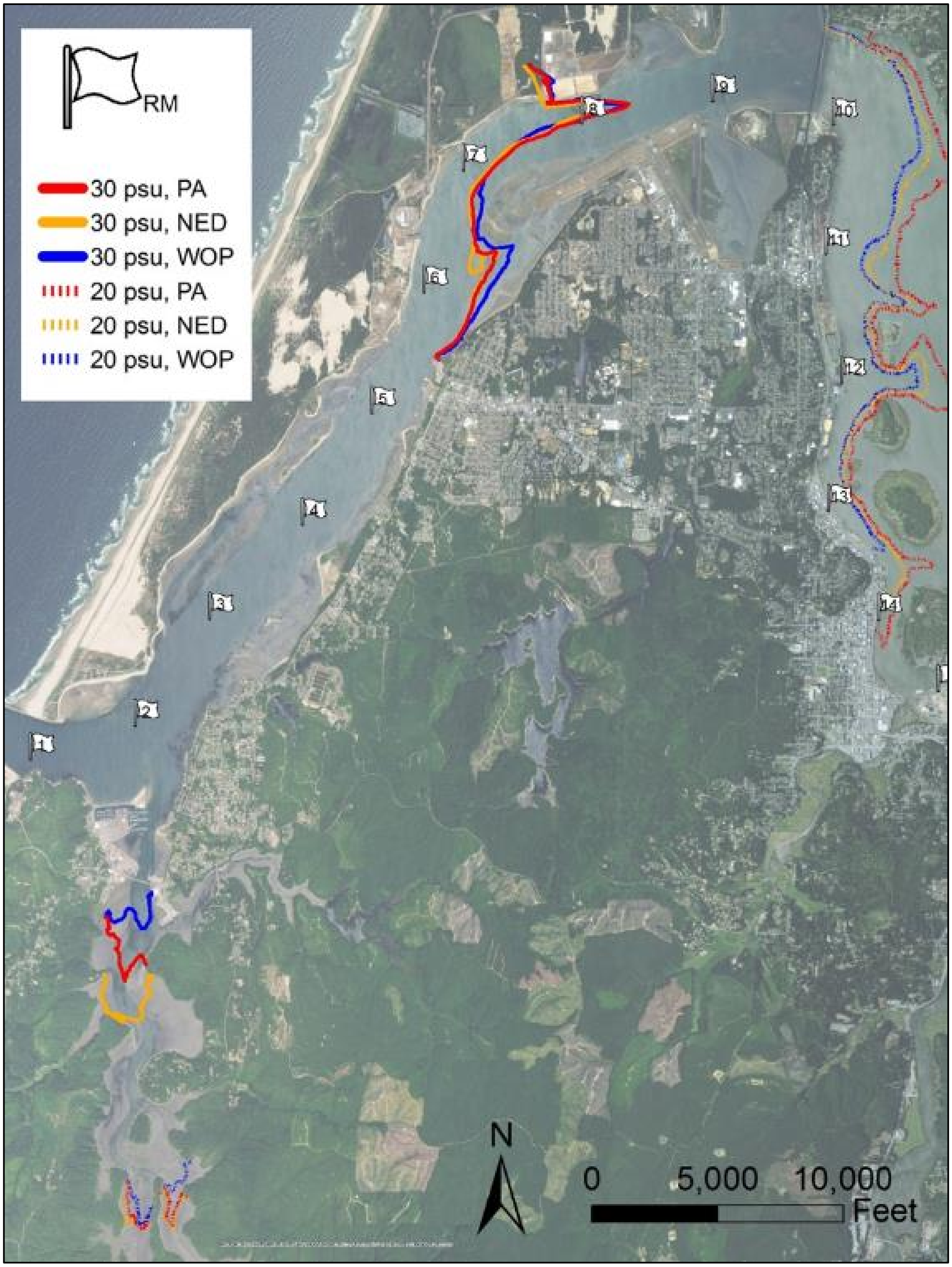

Figure C-6: High Inflow Scenario, Bottom Layer, 90th Percentile for Selected Salinity Contours

Jordan Cove LNG	Project Impacts on Salinity		moffatt & nichol
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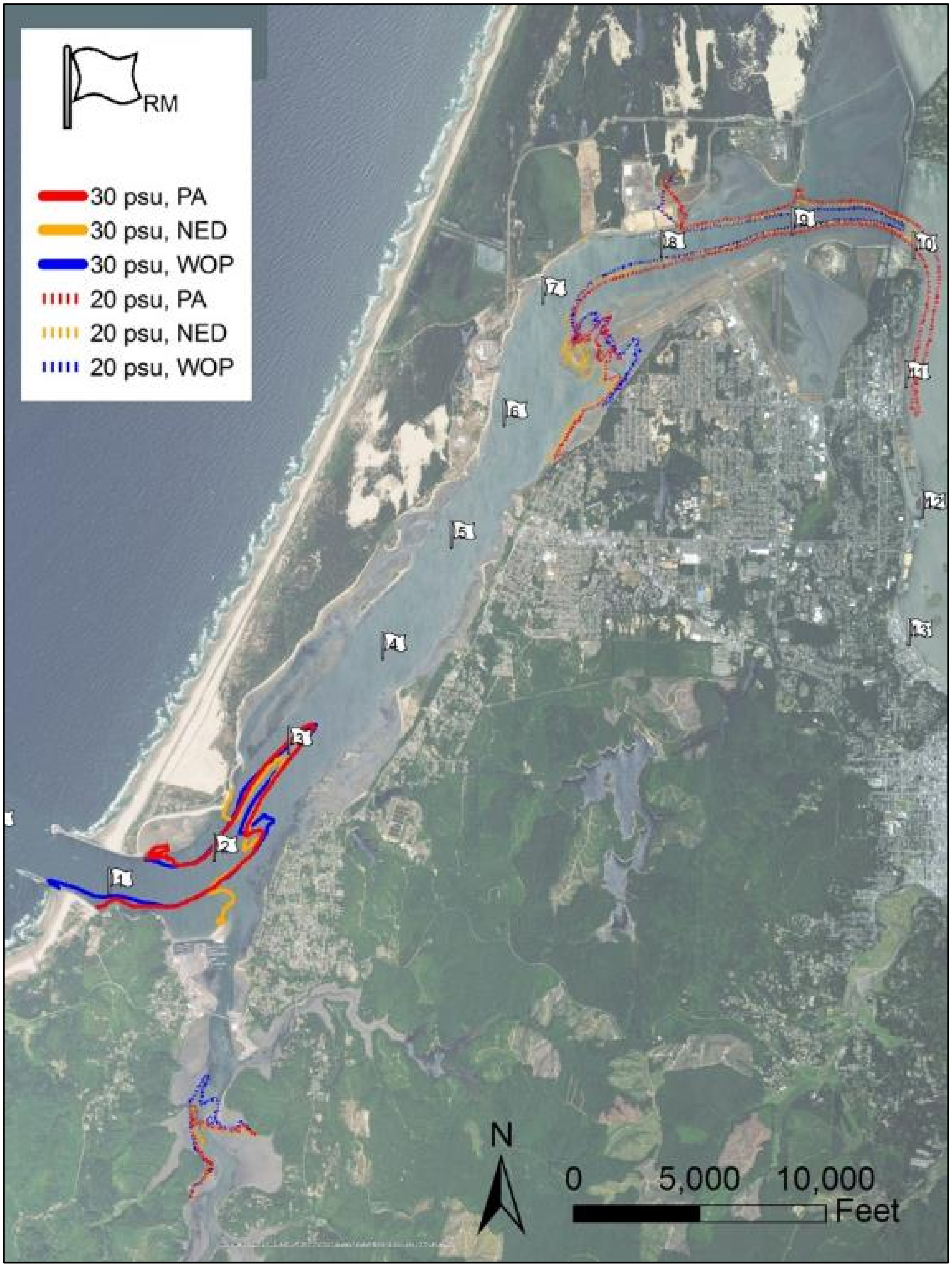

Figure C-7: High Inflow Scenario, Depth Average, 50th Percentile for Selected Salinity Contours

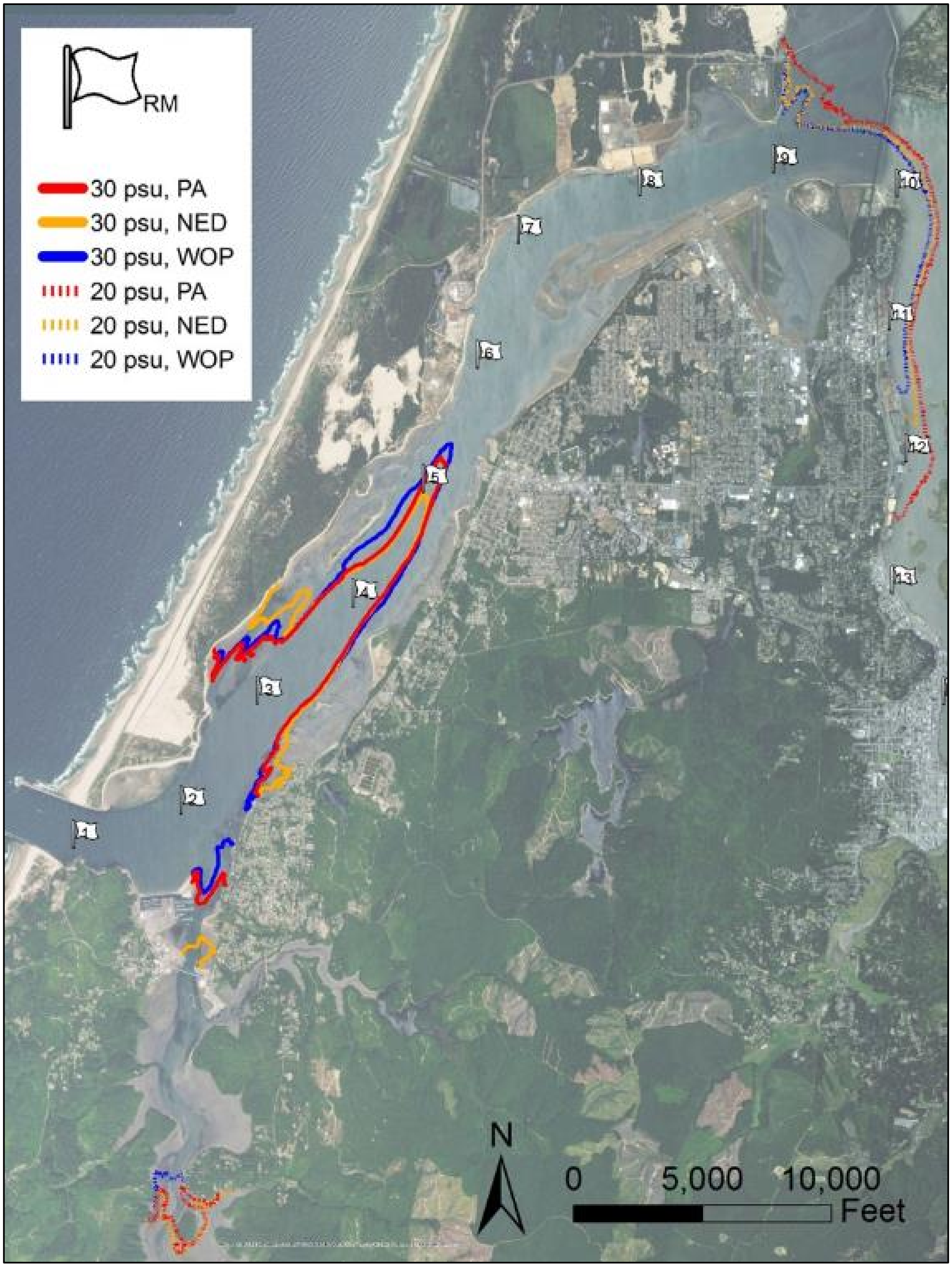

Figure C-8: High Inflow Scenario, Depth Average, 75th Percentile for Selected Salinity Contours

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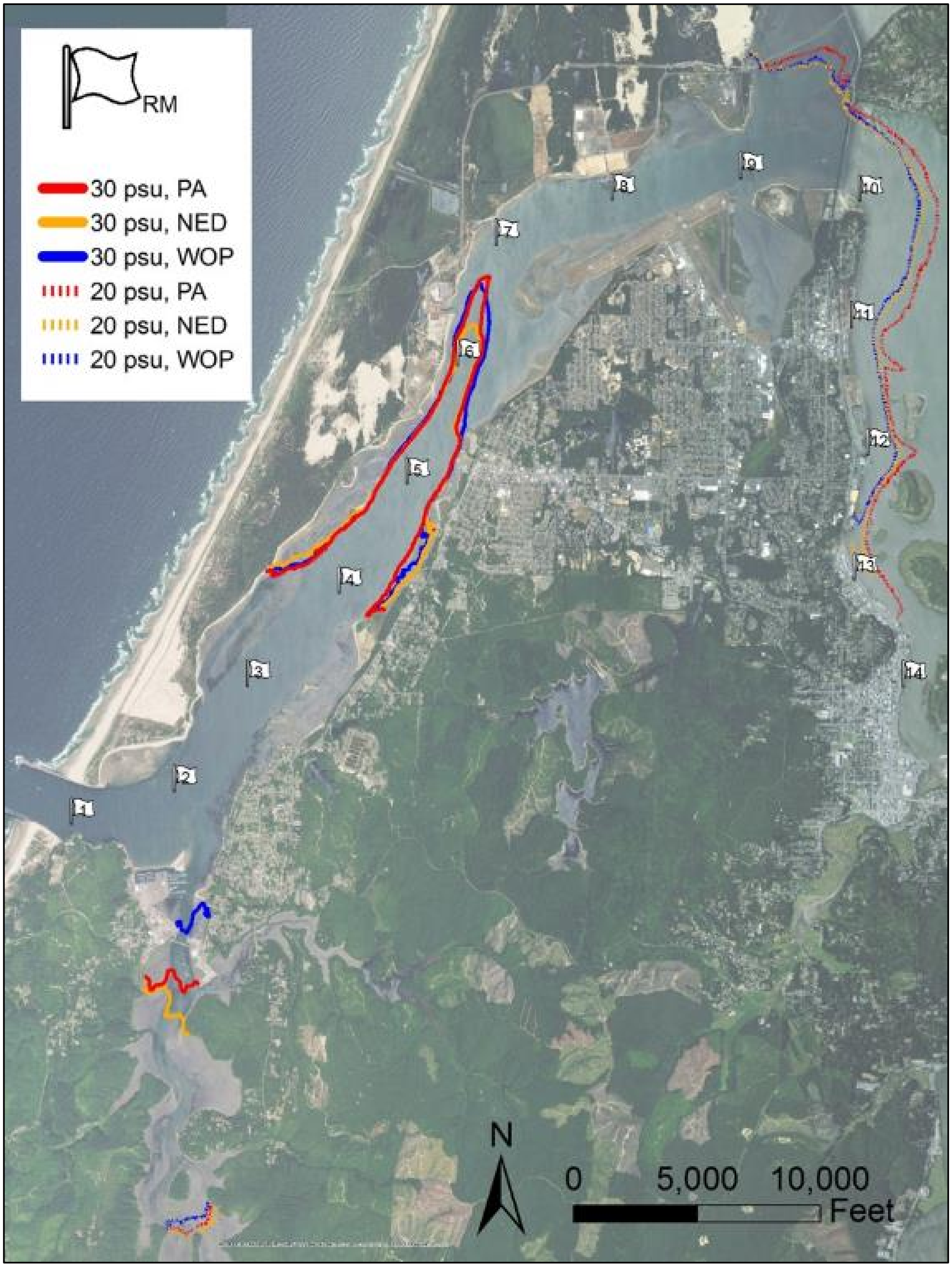

Figure C-9: High Inflow Scenario, Depth Average, 90th Percentile for Selected Salinity Contours

Turbidity Analysis Memo

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REV	DATE	DESCRIPTION	BY	CHKD	APPVD	COMPANY APPROVAL

IP SECURITY	☐ Confidential		Total amount of pages including coversheet:				38
FOR CONTRACTOR DOCUMENTS	Contract No.		Contractor Document No.				Contractor Rev.
	DEA-041, SO 1179		117				0
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TECHNICAL MEMORANDUM

DATE:	November 29, 2017
ATTENTION:	Mick Rowlands, P.E.
COMPANY:	Jordan Cove LNG, LLC (JCLNG)
ADDRESS:	5615 Kirby Drive, Suite 500, Houston, TX 77005
FROM:	Mads Jorgensen, William Gerken, P.E. – Moffatt & Nichol
SUBJECT:	Turbidity Analysis
DEA PROJECT NAME:	Hydrodynamic Studies
DEA PROJECT NO:	JLNG0000-0015, Service Order 1179
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DOCUMENT #	J1-000-MAR-TNT-DEA-00006-00
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1. INTRODUCTION

Jordan Cove Energy Project, LP ("JCEP") is seeking authorization from the Federal Energy Regulatory Commission ("FERC") under Section 3 of the Natural Gas Act ("NGA") to site, construct, and operate a natural gas liquefaction and liquefied natural gas ("LNG") export facility ("LNG Terminal"), located on the bay side of the North Spit of Coos Bay, Oregon. The LNG Terminal, related facilities, temporary construction sites, and other sites/actions associated with LNG Terminal construction are collectively referred to as the "JCEP Project Area" as shown on

The JCEP Project Area is made up of the following selected components, among others not listed here because they are not relevant to the scope of this memorandum:

- Slip – a permanent facility between Ingram Yard and the Access Channel. LNG carriers will enter the Slip via the Access Channel, get loaded with LNG, and leave for export. The Slip will include an LNG carrier loading berth and LNG loading facilities, a tug berth, and an emergency lay berth to safely moor a temporarily disabled LNG carrier.
- Access Channel – the Access Channel will be dredged north of the Federal Navigation Channel ("FNC") to provide LNG carriers with access from the FNC to the Slip.
- Material Offloading Facility ("MOF") – a permanent facility east of the Slip where fill will be placed to construct a barge berth. Dredging will occur to provide access the MOF.
- Navigation Reliability Improvements – four permanent dredge areas adjacent to the FNC that will allow for navigation efficiency and reliability for vessel transit under a broader weather window than the existing FNC.
- Kentuck Site - approximately 100-acre proposed mitigation site for unavoidable impacts associated with the LNG Terminal and the Pipeline.

- APCO Sites 1 and 2 – two sandy fill pads currently vacant to be used as a construction laydown area and dredge disposal site, at Site 1 and Site 2 respectively, with a new bridge to be constructed connecting the two areas over a tidal mudflat and estuarine wetlands.
- Eelgrass Mitigation Site - approximately 9.3-acre proposed mitigation site for unavoidable eelgrass impacts associated with dredging of the Access Channel.

As part of the hydrodynamic studies for the JCEP project, Moffatt & Nichol (M&N) has prepared this technical memorandum concerning turbidity associated with dredging activities. The purpose of this study is to assess turbidity plume dispersion associated with planned capital dredging/excavation and maintenance dredging activities.

Figure 1-1 provides an overview of the JCEP dredging locations, which include the Slip, Access Channel, MOF, Navigation Reliability Improvement (NRI) areas, and Eelgrass Mitigation Site. Details of the Slip, Access Channel, and MOF dredging/excavation areas are provided in Figure 1-2. In the figure, the USACE and DSL regulatory boundary is delineated as the Highest Measured Tide (HMT) line.

The extent of dredging needed for establishment of the Eelgrass Mitigation Site is indicated Figure 1-3.

Discharge water management at the APCO Site 2 and Kentuck Site are also discussed. Details of APCO Upland Disposal Sites 1 and 2 are provided in Figure 1-4, while a plan view of the proposed restoration at the Kentuck Site is provided in Figure 1-5 (note that minor design revisions are expected at the Kentuck Site based on forthcoming public comments). The LNG Terminal and Roseburg are confined upland dredge material disposal sites for the Slip and Access Channel, however, all decant water discharge will be directed back to the Slip and thus will not affect turbidity in Coos Bay.

The Dredge Material Management Plan (DMMP) developed by Moffatt & Nichol (M&N 2017d) provides detail about each of the dredging and upland disposal sites.

1.1 BASIS OF ANALYSIS

The numerical modeling of turbidity plume dispersal utilizes the updated hydrodynamics model (M&N 2017a) and information provided in the DMMP (M&N 2017d). The DMMP describes the anticipated means and methods for dredging, excavating and placing material for the project, which includes initial capital dredging and excavation, and subsequent maintenance dredging.

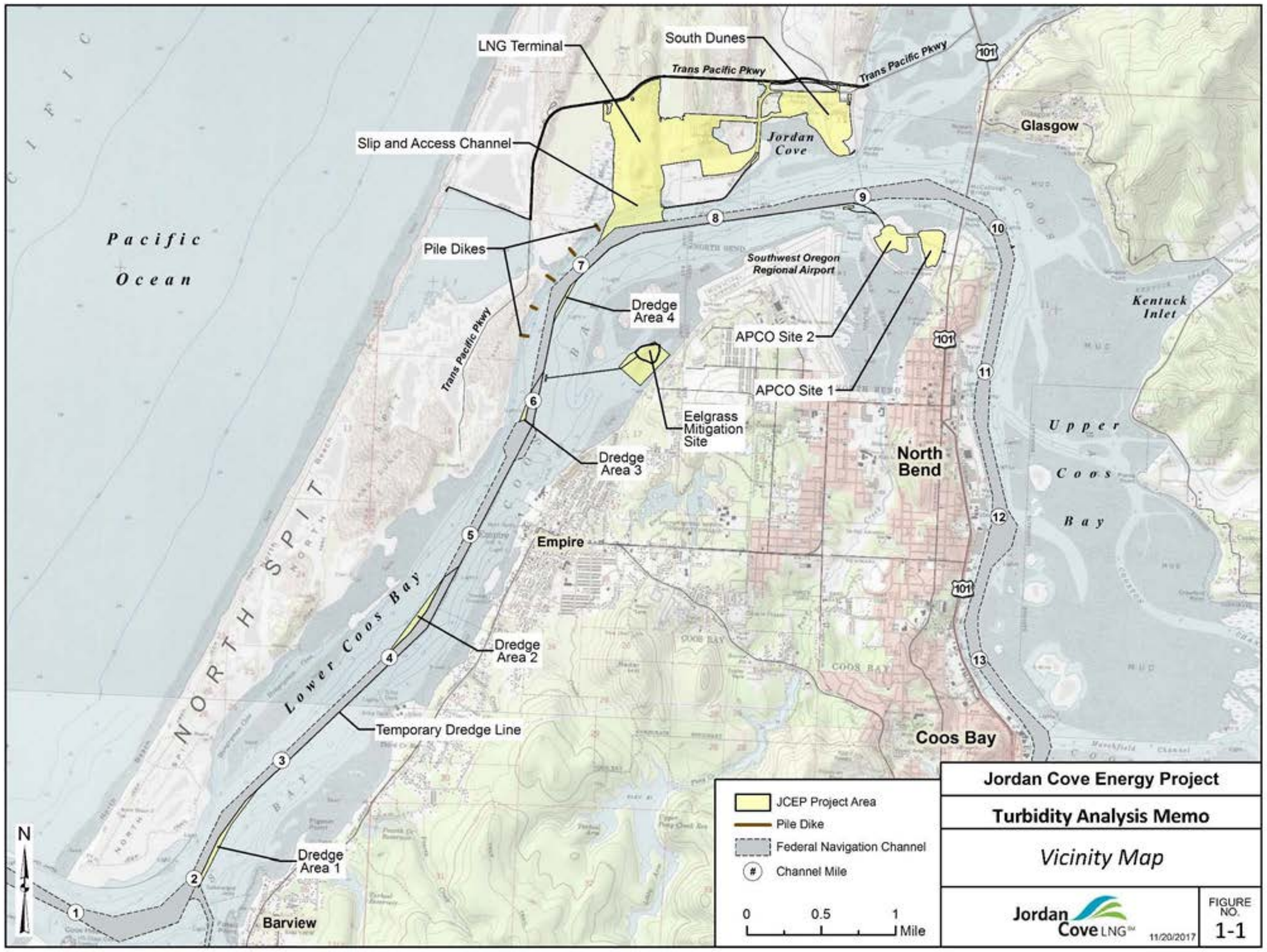

Figure 1-1: JCEP Project Area

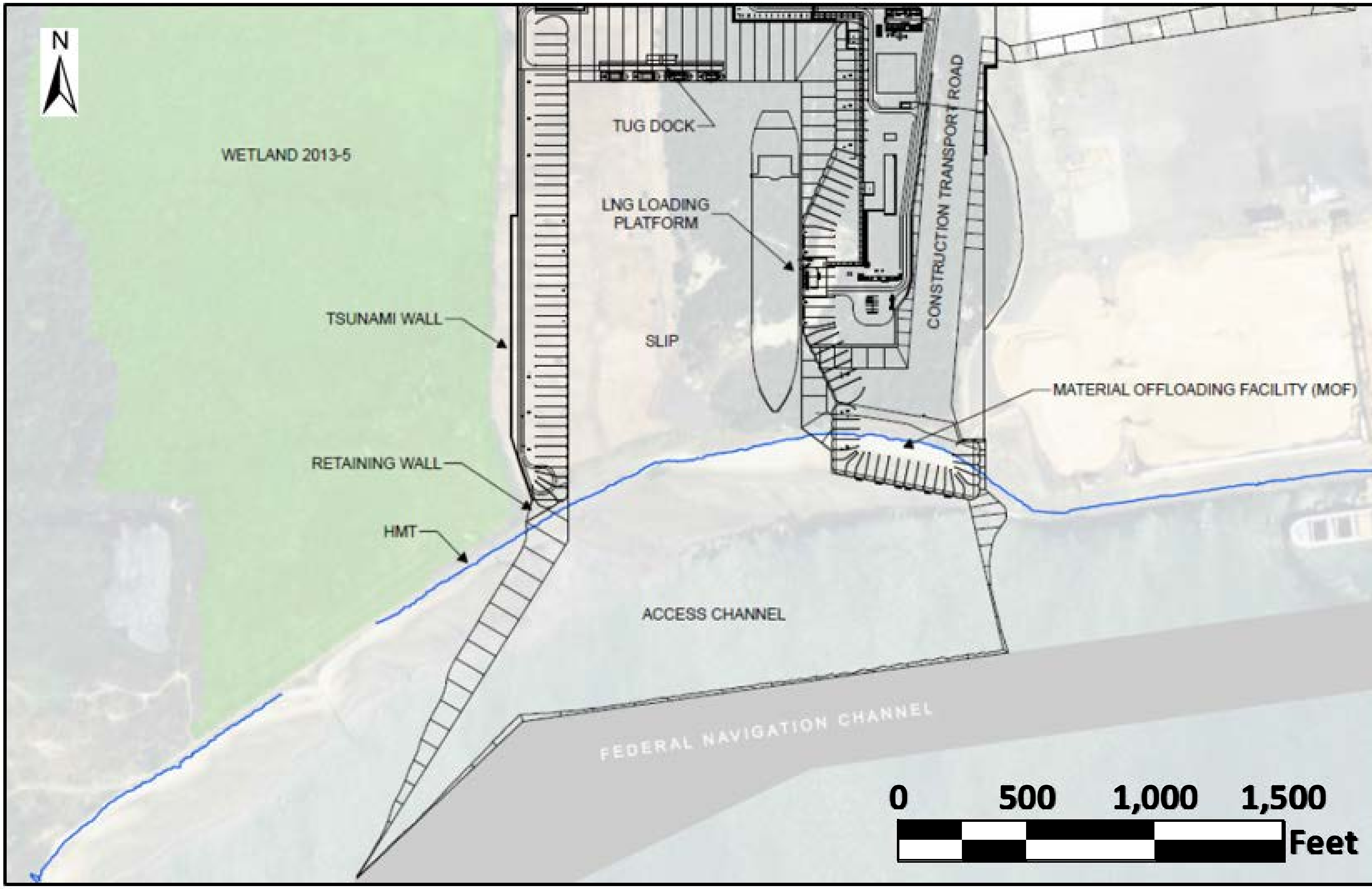

Figure 1-2: Marine Slip, Access Channel and MOF Dredging/Excavation Areas, reproduced from M&N (2017b)

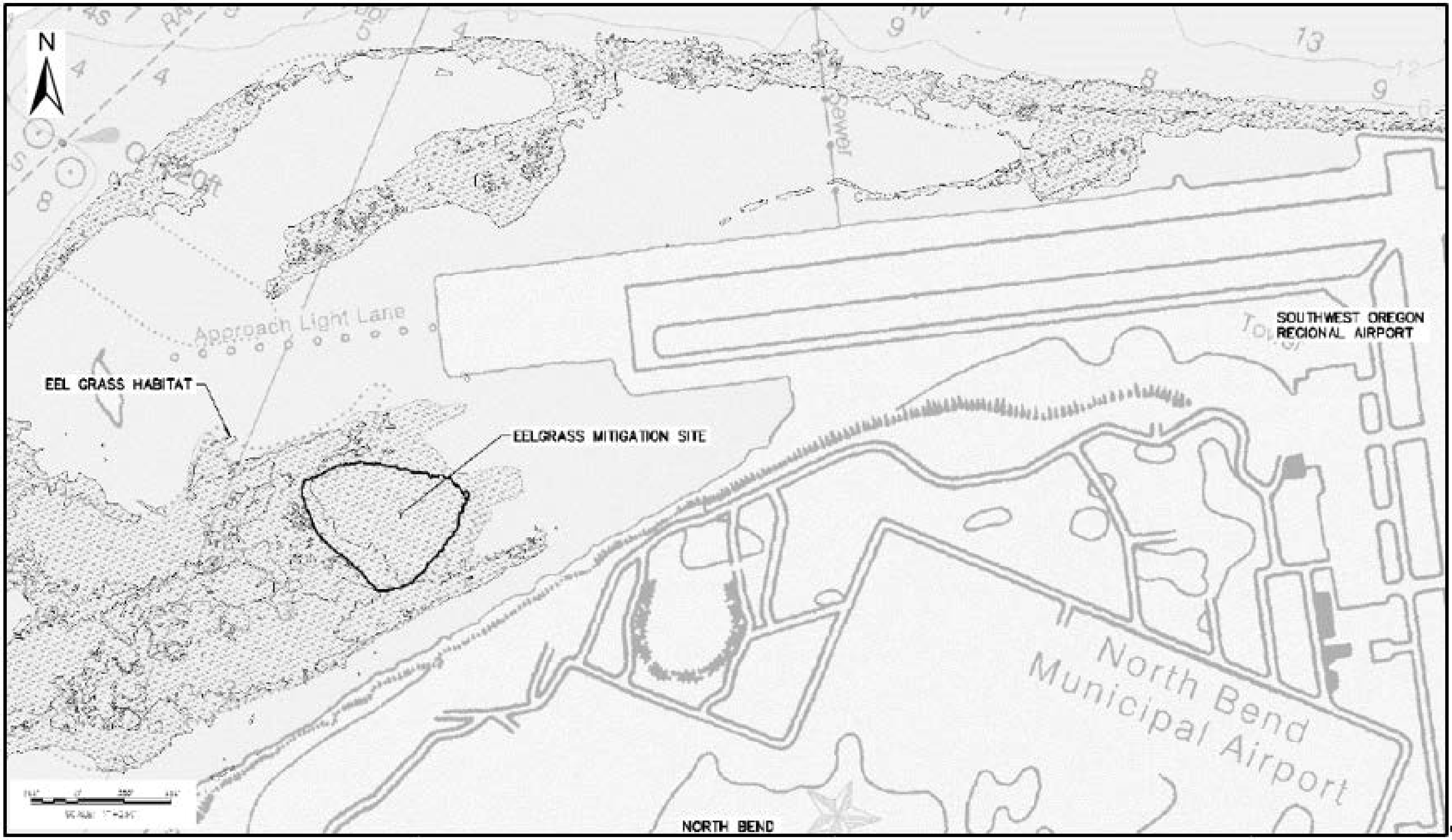

Figure 1-3: Dredging for Eelgrass Mitigation Site Enhancement

Figure 1-4: APCO Upland Disposal Area Sites 1 and 2, reproduced from M&N (2017b)

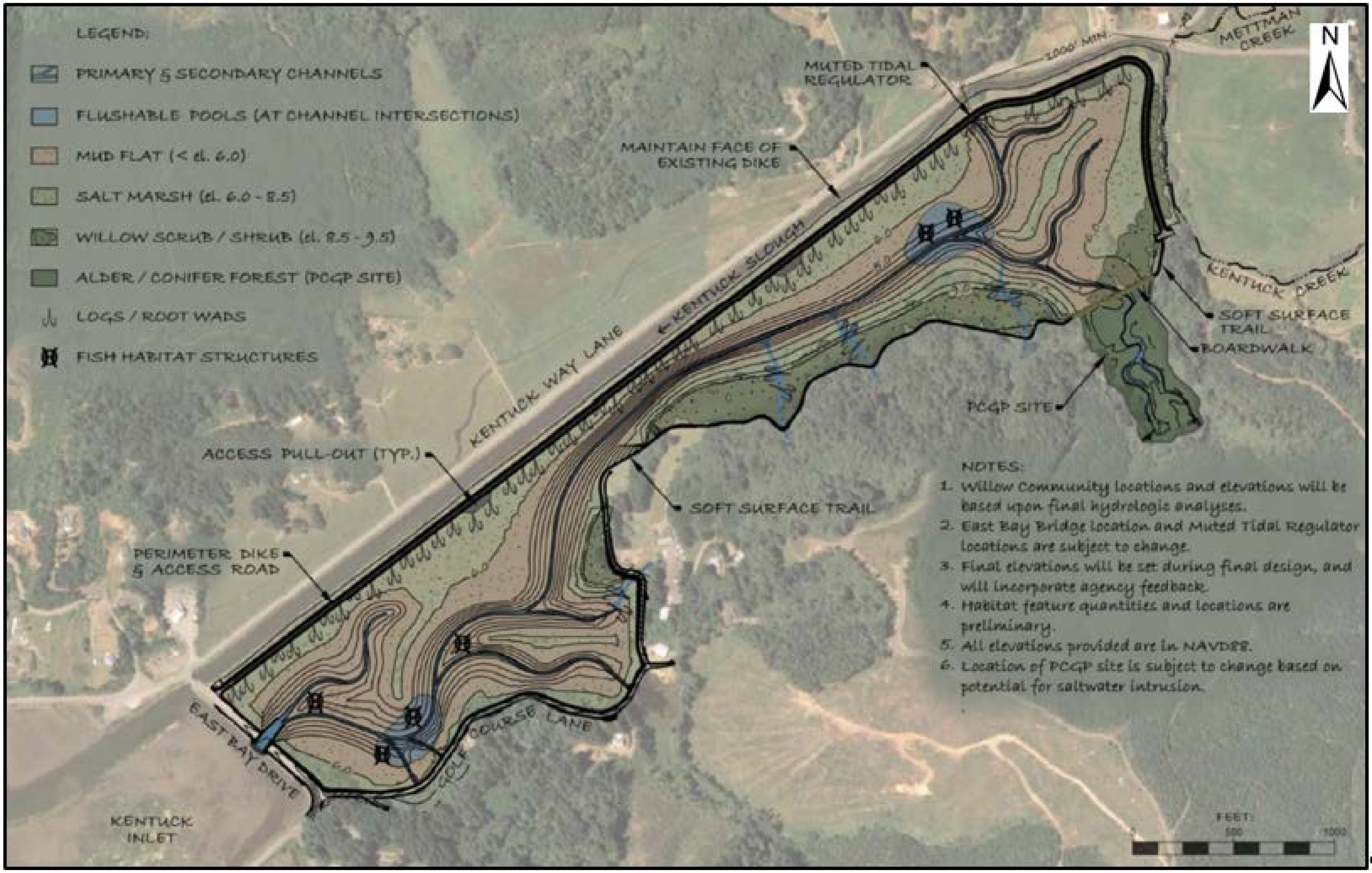

Figure 1-5: Kentuck Site, reproduced from M&N (2017b)

2. DREDGING/EXCAVATION MEANS AND METHODS

The DMMP (M&N 2017d) describes the anticipated means and methods for dredging, excavating and placing material for the project, which includes initial capital dredging and excavation, and subsequent maintenance dredging.

Table 2-1 summarizes construction areas requiring dredging or excavation at the project sites, composition of dredge/excavation materials, and material placement locations. Excavation denotes material removal with land-based equipment. Dredging indicates use of marine-based equipment to remove material below the water surface. Further details of dredging/excavation quantities are provided in the DMMP (M&N 2017d).

Table 2-1: Capital Dredging/Excavation Locations, Material Composition and Placement Locations

Location	Dredging/ Excavation	Dredge/Excavation Material Composition	Placement Location
Slip	Excavation behind berm	Natural earthen material. Medium to very dense sand, fine grained with some gravel and trace silt.	LNG Terminal site and Roseburg site
	Dredging in pocket behind berm		
	Dredging natural earthen berm		LNG Terminal site and Roseburg site, Kentuck Project site
Access Channel	Dredging		LNG Terminal site and Roseburg site
MOF	Excavation	Dune sand.	LNG Terminal site and Roseburg site
	Dredging	Dune sand. Densely packed fine-grained sand with traces of silt.	LNG Terminal site and Roseburg site
NRI Area 1	Dredging	Fine-to-medium grained, loose-to-dense sand with varying quantities of silt; underlain by a very soft and closely fractured siltstone and extremely soft-to-soft weathered sandstone with low fines content.	APCO Site 1 and 2
NRI Area 2			APCO Site 1 and 2
NRI Area 3		Fine to medium grained, loose to dense sand with varying quantities of silt.	APCO Site 1 and 2
NRI Area 4		Fine to medium grained, loose to medium dense sand with varying quantities of silt.	APCO Site 1 and 2
Eelgrass Mitigation Site	Dredging	Fine to medium grained, loose to medium dense sand with varying quantities of silt.	APCO Site 1 and 2

The anticipated construction sequence for the Slip is outlined in the DMMP and is based on using land based excavation equipment to perform the initial excavation of the upland area in the dry. A natural earthen berm is left in place at the entrance to the Slip to segregate excavation and dredge operations. Once the excavation reaches the water table, continued deepening of the Slip behind the natural earthen berm is completed with dredge equipment. The Slip is completed by removing the natural earthen berm.

Construction of the MOF requires the temporary placement of excavated dune (clean) sand in the water to facilitate pile-driving for the MOF waterfront structures. The temporarily placed dune material is then removed by dredging.

Remaining locations, including the Access Channel, NRI Areas, and Eelgrass Mitigation Site require dredging only.

Following capital dredging and excavation, subsequent maintenance will consist only of dredging. Maintenance dredging intervals, material composition, and material placement locations are summarized in Table 2-2. Once created, the Eelgrass Mitigation Site is not subject to maintenance dredging.

Table 2-2: Maintenance Dredging Interval, Material Composition and Material Placement Locations

Location	Dredging Interval	Dredge Material Composition	Placement Location
Slip	Every 3 years	Silt and silty/claey material, with some sand.	APCO Sites 1 and 2
Access Channel	Every 3 years		APCO Sites 1 and 2
MOF	Every 3 years		APCO Sites 1 and 2
NRI Area 1	Every 3 years	Sand	APCO Sites 1 and 2
NRI Area 2			
NRI Area 3			
NRI Area 4			
Eelgrass Mitigation Site	N/A	N/A	N/A

Table 2-3 summarizes equipment and methods anticipated for capital excavation and dredging. Mechanical operation implies handling of material with an excavator or clamshell bucket. The platform for the equipment can be either land-based or marine-based, i.e., mounted on a barge or vessel. Methods of hydraulic operation denotes hydraulic conveyance of materials in a slurry. This equipment is floating and refers to a cutter suction dredge or a hopper dredge.

Table 2-3: Capital Dredging/Excavation Methods and Equipment Types

Location	Dredging/Excavation Method	Equipment Type	Remarks
Slip	Mechanical	Land-based scrapers, excavator	No turbidity generated, decant water to Slip and isolated from Coos Bay
	Hydraulic	Cutter suction dredge	No turbidity generated, decant water to Slip and isolated from Coos Bay
	Mechanical, Hydraulic	Excavator, clamshell or cutter suction dredge	Work within Bay, potential for turbidity
Access Channel	Mechanical, Hydraulic	Clamshell or cutter suction dredge	Work within Bay, potential for turbidity
MOF	Mechanical	Land-based excavator	Work within Bay, potential for turbidity
	Mechanical, Hydraulic	Clamshell or cutter suction	
NRI Area 1	Hydraulic, Mechanical	Cutter suction or clamshell	Work within Bay, potential for turbidity
NRI Area 2			
NRI Area 3			
NRI Area 4			
Eelgrass Mitigation Site	Hydraulic, Mechanical	Small shallow water hydraulic dredge or Marine-based shallow water excavator	Work within Bay, potential for turbidity

Table 2-3 also indicates whether dredging/excavation has the potential to generate turbidity (work within the Bay). Operations that do not produce turbidity within Coos Bay are eliminated from further consideration.

The types of equipment anticipated for maintenance dredging are provided in Table 2-4.

Table 2-4: Maintenance Dredging Methods and Equipment Types

Location	Dredging Method	Equipment Type	Remarks
Slip	Mechanical, Hydraulic	Clamshell or cutter suction dredge	Work within Bay, potential for turbidity
Access Channel			
MOF			
NRI Area 1	Hydraulic, Mechanical	Cutter suction, clamshell, or hopper dredge	Work within Bay, potential for turbidity
NRI Area 2			
NRI Area 3			
NRI Area 4			
Eelgrass Mitigation Site	N/A	N/A	N/A

3. TURBIDITY PLUME MODELING

3.1 MODEL OVERVIEW

Turbidity plume dispersal was modeled using the two-dimensional MIKE-21 Flexible Mesh model, with linked hydrodynamics and transport modules. The transport module considers sediment suspension, transport, and dispersal under the action of currents and/or waves. The period between December 19, 2011 and January 2, 2012 was used as the basis of analysis to model turbidity plume dispersal. This period is representative of conditions within the in-water work period, which is from Oct. 1st through Feb. 15th. The actual turbidity plume simulation shown over 2 tidal cycles (one tidal day). The tides are mixed semi-diurnal, so there are two high and two low tides of different size each lunar day. The turbidity modeling therefore covers two tidal cycles to capture the pattern of two differing high and low tides each tidal day. Based on the two-week period, the tidal cycle with the largest amplitude (greatest difference between high and low tide) was selected to provide a conservative analysis.

Tide levels within this period reach a low of -2.5 feet MLLW and a high of +8.8 feet MLLW. This period includes tide cycles ranging from spring tide to neap tide. Spring tides occur twice a month, approximately at the full and new moon when the sun and the moon are in line. The combined gravitational pull of the sun and the moon produces the greatest difference between high and low tide. Neap tide occurs approximately two weeks after spring tide during the first and third quarters of the moon. This is when the gravitational pull of the sun counteracts the pull of the moon, and the difference between high and low tide is the least.

3.2 DREDGE MATERIAL GRAIN SIZE DISTRIBUTION

Information regarding grain size within the Coos Bay estuary is provided in (M&N 2017d). Figure 3-1 from (M&N 2017d) shows sediment sampling locations from (GRI 2010), (SHN 2007), and (USACE 2005), and the grain size used in the sediment transport simulation distribution. The figure shows that finer sediments originating from the Coos River and other tributaries settle out above RM 12. Grain size at the planned dredge locations (Figure 1-2) ranges from 0.32 to 0.44 mm diameter. The Eelgrass Mitigation Site has slightly finer sediment with grain sizes ranging from 0.26 mm to 0.32 mm. Sediment at all the dredge locations, including the Eelgrass Mitigation Site, are classified as medium sand on the Wentworth Classification scale.

3.3 TURBIDITY GENERATION PARAMETERS

Table 3-1 lists the Turbidity Generation Units (TGU) that have been compiled based on (TeA 1996) and (Nakai 1978), and verified with data from (HRW 1996). The TGU denotes the amount of material (kg) brought into suspension per volume (m3) of material dredged, and combined with the production rate (volume per day) produces a rate of suspended material release. The TGU values vary depending on the type of dredge equipment and the type of material dredged. The table provides typical values for dredging in sand using standard equipment (without controls to reduce turbidity), and using equipment that has been outfitted with properly functioning environmental controls. Environmental controls are discussed in section 3.4.

Comparison of the TGU values in the table shows that turbidity rates in many cases can be reduced by at least 50% when using equipment with functioning environmental controls. In order to produce conservative estimates for turbidity plume extent, the TGU values without environmental controls have been used in the model.

Table 3-1: Dredge Equipment, Production Rates and Turbidity Modeling Parameters

Operation	Dredge Equipment	Production Rate (m^3/day)	TGU (kg/m^3)	
			Without Environmental Controls	With Environmental Controls
Capital Dredging	Cutter Suction	5,900	0.3 [1, 2)]	0.1 [2)]
	Clamshell	3,600	15.8 [2)]	7.1 [8)]
	Excavator	3,100	54.0 [1, 3, 5)]	21.0 [1, 4)]
Maintenance Dredging	Hopper	7,400	14.0 [1, 6)]	3.0 [1, 7)]
	Clamshell	3,600	15.8 [2, 3)]	7.1 [8)]

[1)] *TeA (1996).*
[2)] *Nakai (1978).*
[3)] *Open bucket.*
[4)] *Closed bucket.*
[5)] *Resuspension rate typically 2-3 times greater than clamshell.*
[6)] *With Lean Mixture Overboard (LMOB).*
[7)] *Without Lean Mixture Overboard (LMOB).*
[8)] *Environmental bucket, Sato (2004).*

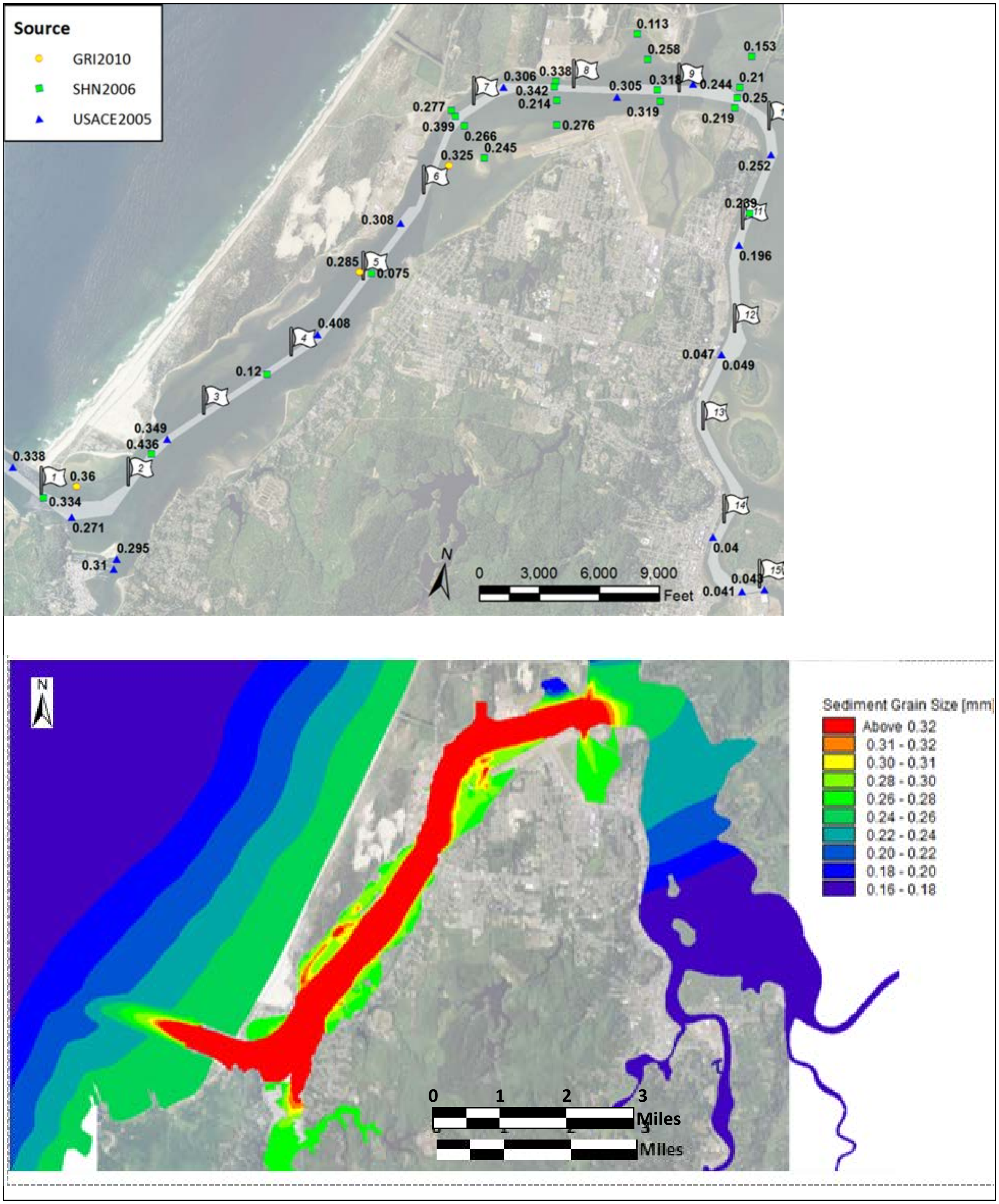

Figure 3-1: Grain Size Map, Measured (upper), Simulated (lower)

3.4 ENVIRONMENTAL CONTROLS FOR DREDGING OPERATIONS

A wide range of environmental controls have evolved to achieve significant reductions in turbidity generation. These are discussed in the following paragraphs. The DMMP (M&N 2017d) provides information on dredge equipment, including cutter suction, hopper, clamshell, and excavator dredges.

3.4.1 CUTTER SUCTION DREDGES

Cutter suction dredges generally have low rates of turbidity production compared to other conventional dredge methods. Most of the turbidity produced by cutter suction dredges occurs in the near-field around the cutter head. Improvements in turbidity generation may be achieved by reducing the swing velocity, dredge cut thickness, and/or rate of advance. Lower production rates would likely result from using these practices.

A shield around or above the cutter head or suction head can also aid in reducing turbidity generation. However, if most of the dredge material is composed of coarse fragmented rock down to medium-sized sand particles, a shield may have limited effect on reducing turbidity because its primary function is to reduce release of fine material to the water body.

3.4.2 HOPPER DREDGES

Significant increases in turbidity production from hopper dredges are often associated with using Lean Mixture Overboard (LMOB) discharge of water. When a hopper dredge is in operation, material excavated from the seabed is conveyed hydraulically (pumped) up into the cargo hold of the hopper dredge in the form of a slurry (mixture of water and solids). One method of operation is to discharge the excess water overboard and retain the dredge material within the hopper dredge. However, fine sediment may remain in suspension and be released with the discharge water, termed a lean mixture. The larger the proportion of fine sediment, the greater the amount of dredge material suspended in the discharge water. Turbidity generation can be mitigated by limiting LMOB discharge. If the dredge material has a low fines content, the use of LMOB may be feasible. For the JCLNG project, LMOB discharge may be reasonable as the dredge material classifies as medium sand and has a low fines content.

Reduction of the intake water at the suction head can also be a way to reduce release of turbidity. Reducing the water intake results in a denser payload and consequently less need for LMOB discharge.

There are additional treatment options that some hopper dredges employ to further reduce turbidity associated with LMOB. One method is to discharge the LMOB below the keel of the hopper dredge instead of at the water surface. This reduces the settling distance to the seafloor and thereby limits potential excursion of entrained sediment. Another effect that has been observed is that air bubbles entrained with the LMOB increase sediment suspension times because of the upward rise of bubbles through the water column. Modern hopper dredges utilize Green valves that prevent air entrainment in the overflow mixture in combination with LMOB discharge at the keel. The net effect is that entrained sediment discharged with the overflow water has a relatively short settlement path to the seafloor, and is uninterrupted by air bubbles ascending to the surface.

3.4.3 CLAMSHELL DREDGES

A significant contribution to turbidity associated with clamshell dredging comes from the use of conventional (open top) clamshell buckets. These have the potential for dredge material to wash and/or spill out as the bucket is being raised through the water column and swung over the water to the material barge. Ways to reduce turbidity generation include, slowing the bucket lift speed, pausing the bucket at the water surface to allow water to drain, limit bucket swing time and extent over open water, and insure bucket empties completely in material barge.

A closed clamshell bucket (environmental bucket) can reduce turbidity generation, but can also result in a larger quantity of water being retained in the bucket with the dredge material (if the bucket does not have vents/drains). The decant water can be handled by filtering through geotextile, straw bales, or other media prior to discharge back to receiving waters.

3.4.4 EXCAVATOR DREDGES

Excavator (backhoe) dredges outfitted with open buckets are prone to turbidity generation due to discharge of sediment-laden water and spillage of dredge material as the bucket is raised (similar to open clamshell bucket). Practices to reduce turbidity generation are similar to those for an open clamshell bucket.

Some excavator dredges are outfitted with hydraulic clamshell (environmental) buckets, similar to environmental buckets used on clamshell dredges.

4. TURBIDITY PLUME MODELING

4.1 SIMULATION CASES

Dispersion of the suspended sediment concentration originating at the dredge was modeled using MIKE-21 for a range of dredging scenarios as summarized in Table 4-1. The simulation scenarios were compiled from Table 2-3 (capital dredging), Table 2-4 (maintenance dredging), and Table 3-1 (turbidity generation parameters).

A cutter suction dredge was modeled for capital dredging in the NRI areas. A cutter suction dredge has a relatively high production rate, and if appropriately equipped can dredge the soft rock that will be encountered within NRI 1 and 2. A clamshell dredge was also modeled for capital dredging in the NRI areas (areas 3 and 4).

The dispersal/extent of a cutter suction dredge and clam shell dredge could be considered similar over a tidal day period. A cutter suction dredge has a higher production rate and a lower spillage per cubic yard value, while a clamshell dredge has a lower production rate and a higher spillage per cubic yard value. The resulting time rate of spillage is similar, so the tidal exchange/current governs the turbidity plume dispersal/extent, not the sediment concentrations which are similar.

Maintenance dredging of the NRI areas is likely more suitable for a clamshell dredge but could also be done with a cutter suction or hopper dredge. Maintenance dredging with a clamshell or cutter suction dredge is considered similar to capital dredging.

Capital and maintenance dredging within the Slip, Access Channel, and at the MOF is likely more suitable for a clamshell dredge, but capital dredging of the Access Channel could also be done with a cutter suction dredge.

Dredging with a barge-mounted excavator is anticipated for the Eelgrass Mitigation Site, a small, self-propelled hydraulic dredge that can work very shallow water and/or grounded could also be used. No meaningful difference between hydraulic and mechanical dredge turbidity would be anticipated due to exceptionally shallow backwater nature of the Eelgrass Mitigation Site.

The actual dredging equipment and methods utilized will depend to a great extent on the selected construction contractor.

Table 4-1: Turbidity Plume Modeling Cases

Operation	Dredge Equipment	NRI Areas				Slip	Access Channel	MOF	Eelgrass Mitigation
		NRI 1	NRI 2	NRI 3	NRI 4				
Capital Dredge	Cutter Suction	X	X	X	X				
	Clamshell			X	X	X	X	X	
	Excavator								X
Maintenance Dredge	Hopper	X	X	X	X				
	Clamshell					X	X	X	

Output from the MIKE-21 numerical model was post-processed to convert the suspended sediment concentration reported as total suspended solids (TSS) to turbidity in Nephelometric Turbidity Units (NTU). The following equation relates TSS concentration in units of mg/L to turbidity in NTU.

$$ln(TSS) = 1.32 \times ln(NTU) + c$$

Where $ln()$ is the natural logarithm, TSS is the total suspended sediment concentration, NTU is the level of turbidity, and c is a constant that is approximately equal to zero. The relationship is plotted in Figure 4-1.

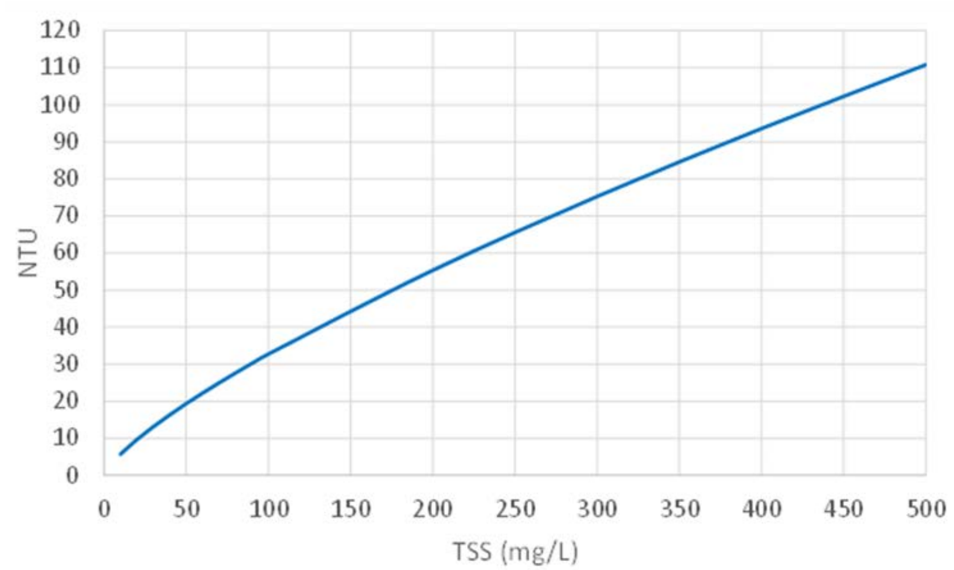

Figure 4-1: Relationship between Total Suspended Solids (TSS) and Turbidity (NTU)

5. RESULTS

5.1 NRI AREAS

Turbidity plume simulation results for capital dredging at the NRI Areas are shown in Figure 5-1 to Figure 5-4. Dredge areas are indicated with a red outline. Dredge location is marked, results are shown for dredging at a fixed location. The highest turbidity levels occur at the dredge location. The simulated turbidity values represent depth averaged values; the values near the channel bed are expected to be somewhat greater; the values at the water surface are expected to be somewhat less.

Dredging with a clamshell at NRI Areas 3 and 4 are shown in Figure 5-5 and Figure 5-6. These simulation results are representative of both capital dredging and subsequent maintenance dredging, and show the similarity of plume configuration with a cutter suction dredge.

Results for maintenance dredging using a hopper dredge are shown in Figure 5-7 to Figure 5-10. With this type of dredge equipment, higher turbidity levels/larger plume extents are possible. For maintenance dredging with a clamshell or cutter suction dredge, turbidity levels/plume extents will be similar to capital dredging.

Potential turbidity plume extents, defined by the simulated 10 NTU above background contour, reaches beyond the dredging location in the downstream, upstream, and transverse (crosswise) direction as summarized in Table 5-1.

Table 5-1: Turbidity Plume Extent beyond Dredging Footprint

Dredging	Area	Dredge Equipment	Distance Beyond Dredging Footprint (feet)			
			Downstream	Upstream	Transverse	Maximum
Capital Dredging	NRI 1	Cutter Suction	2,820	2,340	310	2,820
	NRI 2	Cutter Suction	3,350	2,280	320	3,350
	NRI 3	Cutter Suction	3,280	2,170	510	3,280
	NRI 4	Cutter Suction	3,060	2,640	340	3,060
Capital Dredging	NRI 3	Clamshell	3,315	2,180	557	3,315
	NRI 4	Clamshell	3,028	2,687	330	3,028
Maintenance Dredging	NRI 1	Hopper	4,600	2,420	310	4,600
	NRI 2	Hopper	3,400	2,610	390	3,400
	NRI 3	Hopper	3,780	2,220	660	3,780
	NRI 4	Hopper	3,150	2,880	380	3,150

Because of the elevated sediment concentrations associated with the dredging, both capital dredging and maintenance dredging of the NRI should be limited to the permitted in-water work windows.

5.2 SLIP, ACCESS CHANNEL, AND MOF

Representative results for capital dredging at the Slip, Access Channel, and the MOF are shown in Figure 5-11 through Figure 5-13.

Figure 5-11 represents use of a clamshell within the Access Channel, while Figure 5-12 provides turbidity levels for dredging with a cutter suction dredge. The turbidity plume extents again reach beyond the dredge footprints. The location represented is near the center of the Access Channel to represent an average condition. Dredging at the southern extent of the Access Channel adjacent to the FNC would generate a larger plume, similar to NRI 4, due to changes in hydrodynamic conditions.

Dredging within the Slip is shown in Figure 5-13. The results portray capital dredging to final grade within the Slip with a cutter suction dredge, and/or maintenance dredging within the Slip using a clamshell. The results show that sediment plume dispersal is limited within the Slip with no significant exchange to the Bay.

Potential turbidity plume extents, defined by the simulated 10 NTU above background contour, beyond the dredging location in the downstream, upstream, and transverse (crosswise) direction are summarized in Table 5-2. Where the dredging occurs near the shoreline, the distance to shore governs the plume extent.

Table 5-2: Turbidity Plume Extent (10 NTU above background) beyond Dredging Location

Dredging	Area	Dredge Equipment	10 NTU Above Background Distance Beyond Dredging Location (feet)			
			Downstream	Upstream	Transverse	Maximum
Capital and Maintenance Dredging	Access Channel & MOF	Clamshell	750	740	550	750
	Access Channel & MOF	Cutter Suction	780	730	550	780
	Slip	Clamshell	350	220	-	350

Because of the elevated sediment concentrations associated with the dredging, both capital dredging and maintenance dredging of the Slip, Access Channel, and MOF should be limited to the permitted in-water work windows.

5.3 EELGRASS MITIGATION SITE

Turbidity levels associated with dredging at the Eelgrass Mitigation Site using an excavator or small hydraulic dredge are shown in Figure 5-14. The suspended sediment plume is generally limited to the local area of excavation, and there is no significant dispersal of suspended sediment. This is because of the exceptionally shallow water conditions and limited tidal flow exchange (low current velocities) in this area.

Potential turbidity plume extents outside of the dredging footprints in the downstream, upstream, and transverse (crosswise) direction are summarizes in Table 5-3.

Table 5-3: Turbidity Plume Extent beyond Dredging Footprint

Dredging	Area	Dredge Equipment	Distance Beyond Dredging Footprint (feet)			
			Downstream	Upstream	Transverse	Maximum
Capital Dredging	Eelgrass Mitigation Site	Excavator	350	340	360	360

Because of the potential for elevated sediment concentrations associated with excavation/dredging at the Eelgrass Mitigation Site, the work should be limited to the permitted in-water work windows.

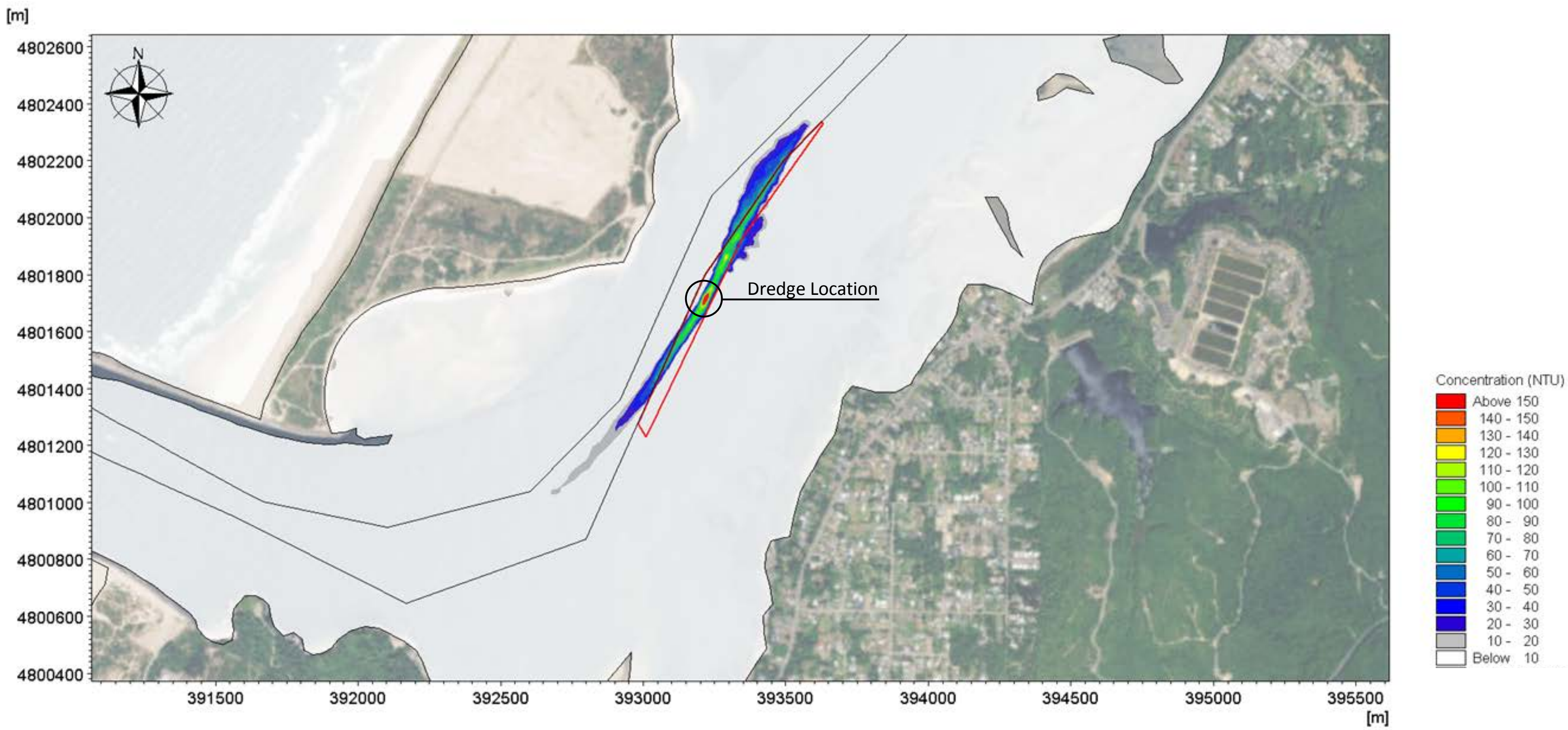

Figure 5-1: Capital dredging with cutter suction dredge, NRI 1

Jordan Cove LNG	Hydrodynamic Studies – Turbidity Analysis		moffatt & nichol
	Document Number: J1-000-MAR-TNT-DEA-00006-00		
	Rev.: A	Rev. Date: November 29, 2017	

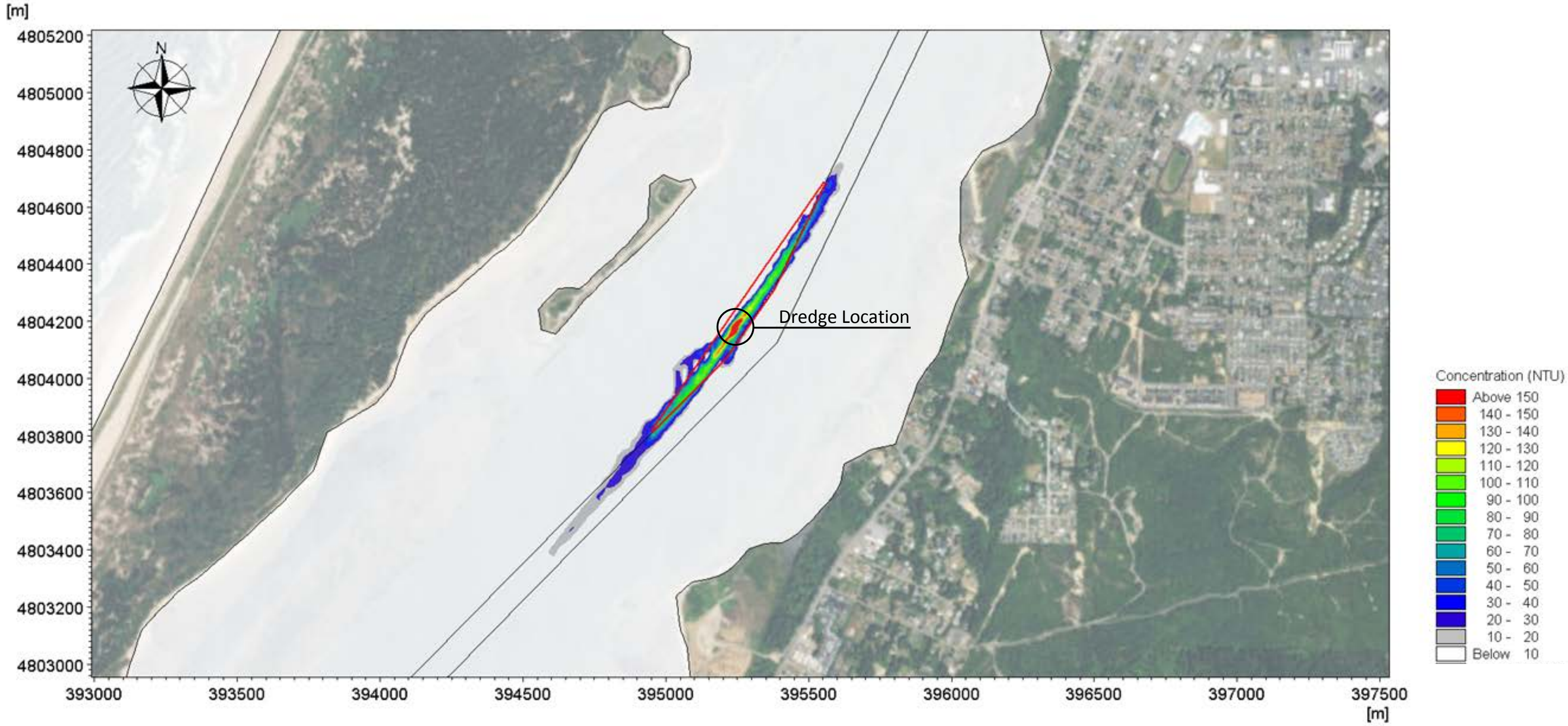

Figure 5-2: Capital dredging with cutter suction dredge, NRI 2

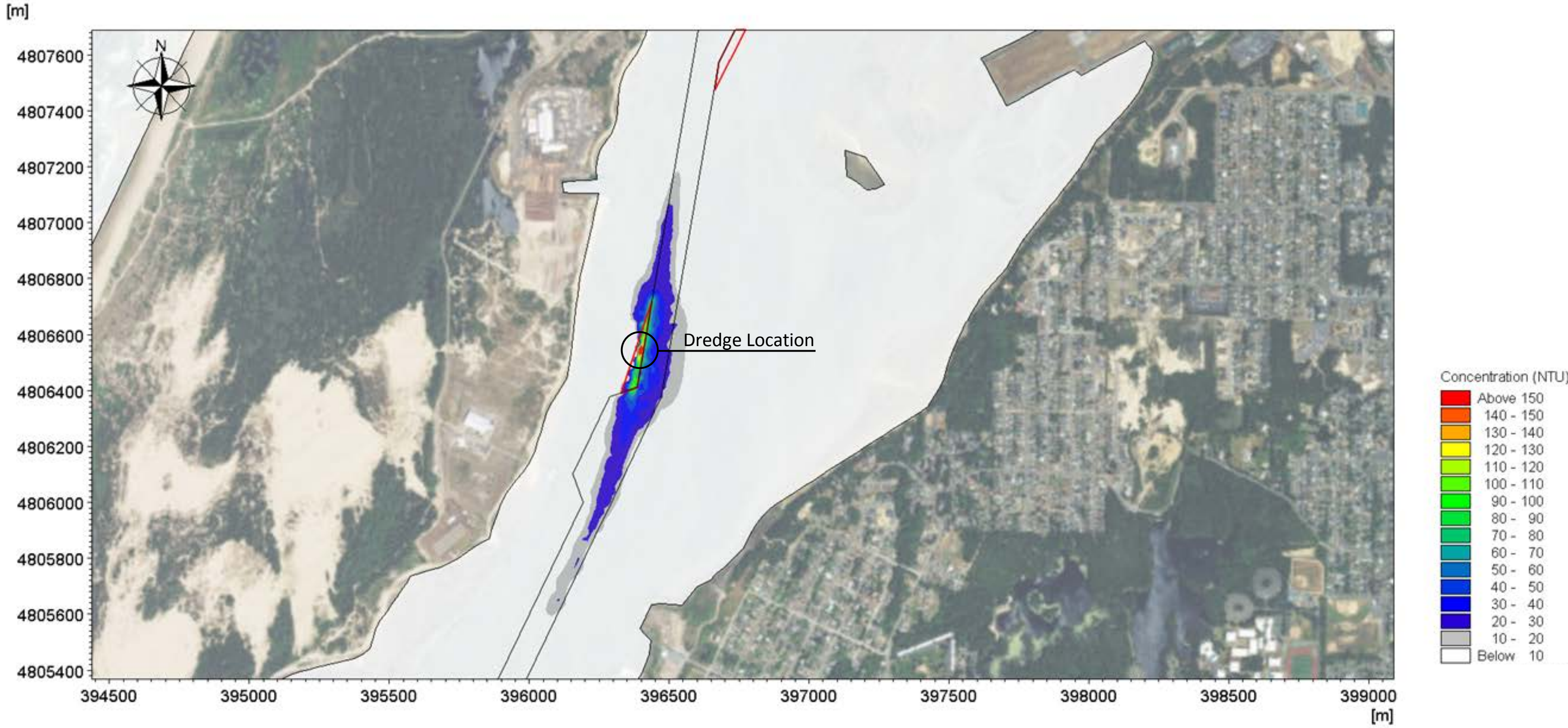

Figure 5-3: Capital dredging with cutter suction dredge, NRI 3

Jordan Cove LNG	Hydrodynamic Studies – Turbidity Analysis		moffatt & nichol
	Document Number: J1-000-MAR-TNT-DEA-00006-00		
	Rev.: A	Rev. Date: November 29, 2017	

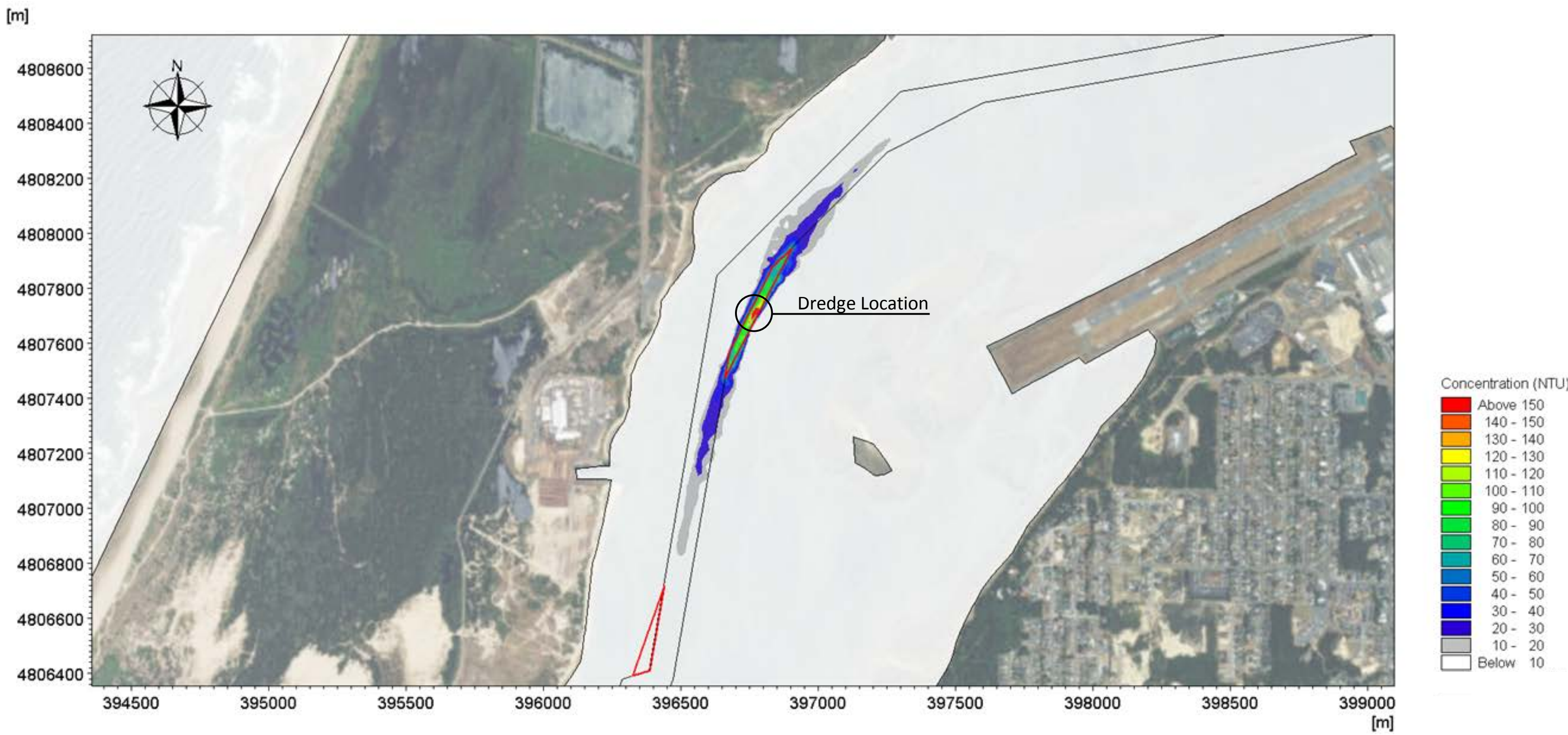

Figure 5-4: Capital dredging with cutter suction dredge, NRI 4

Jordan Cove LNG	Hydrodynamic Studies – Turbidity Analysis		moffatt & nichol
	Document Number: J1-000-MAR-TNT-DEA-00006-00		
	Rev.: A	**Rev. Date: November 29, 2017**	

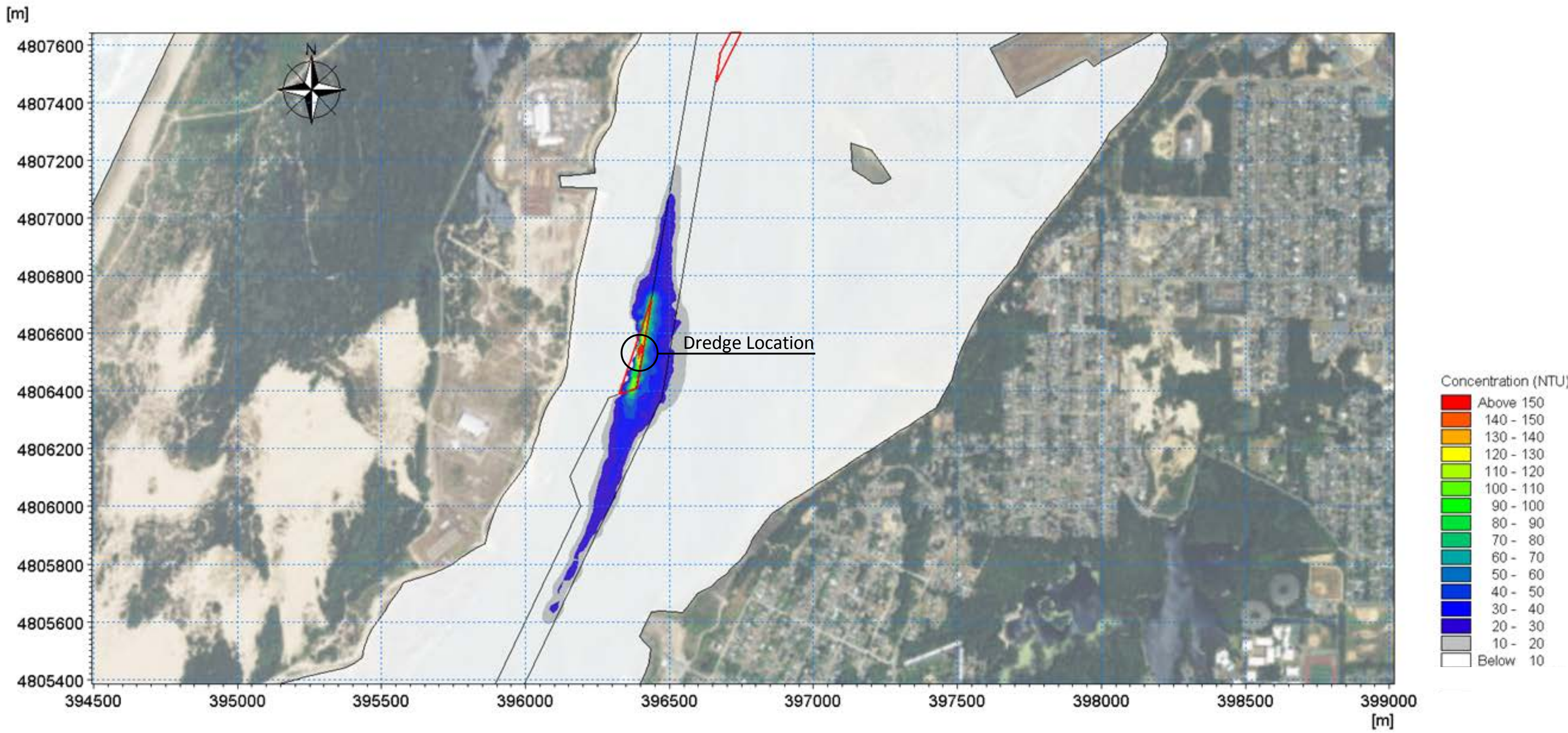

Figure 5-5: Capital/Maintenance dredging with clamshell, NRI 3

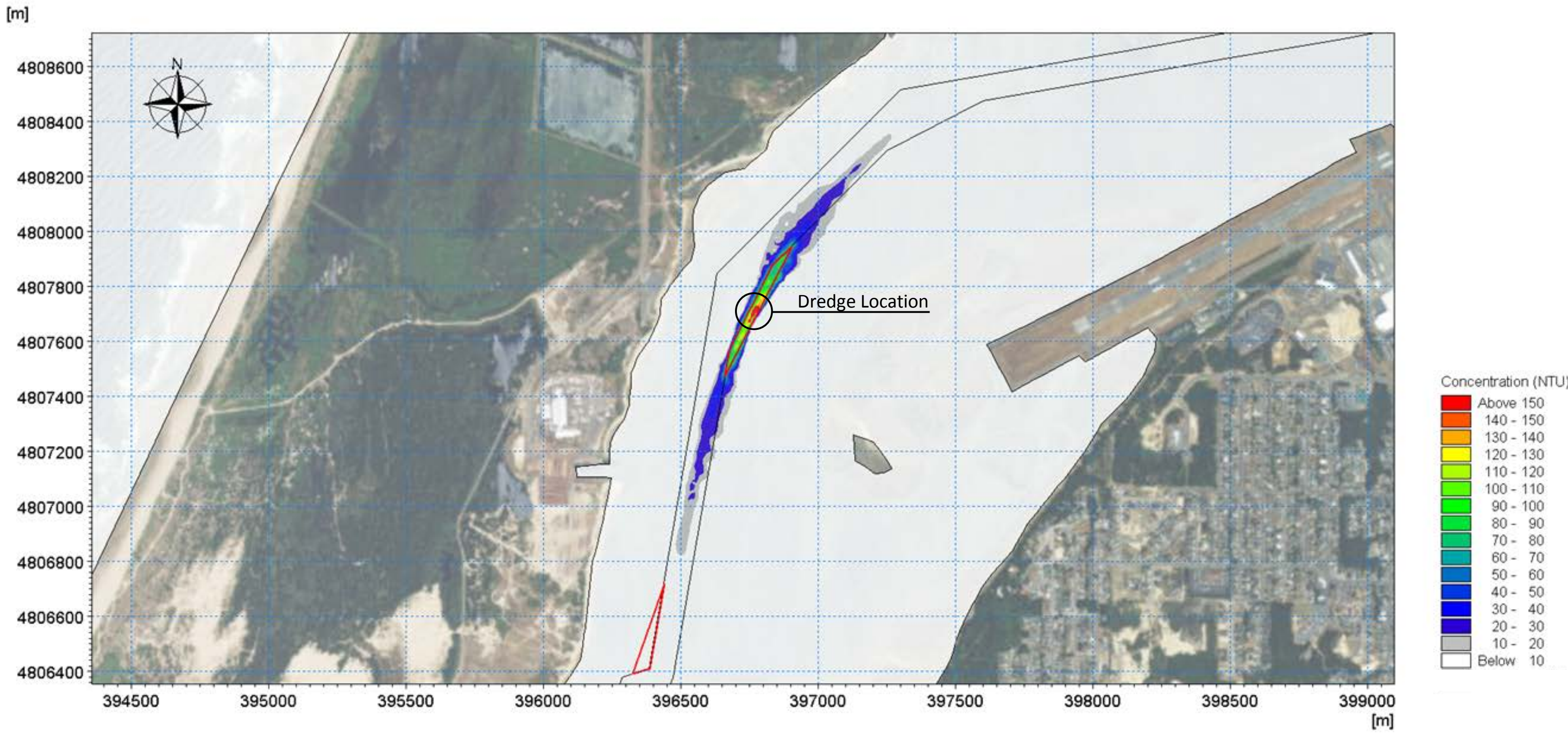

Figure 5-6: Capital/Maintenance dredging with clamshell, NRI 4

Jordan Cove LNG	Hydrodynamic Studies – Turbidity Analysis		moffatt & nichol
	Document Number: J1-000-MAR-TNT-DEA-00006-00		
	Rev.: A	Rev. Date: November 29, 2017	

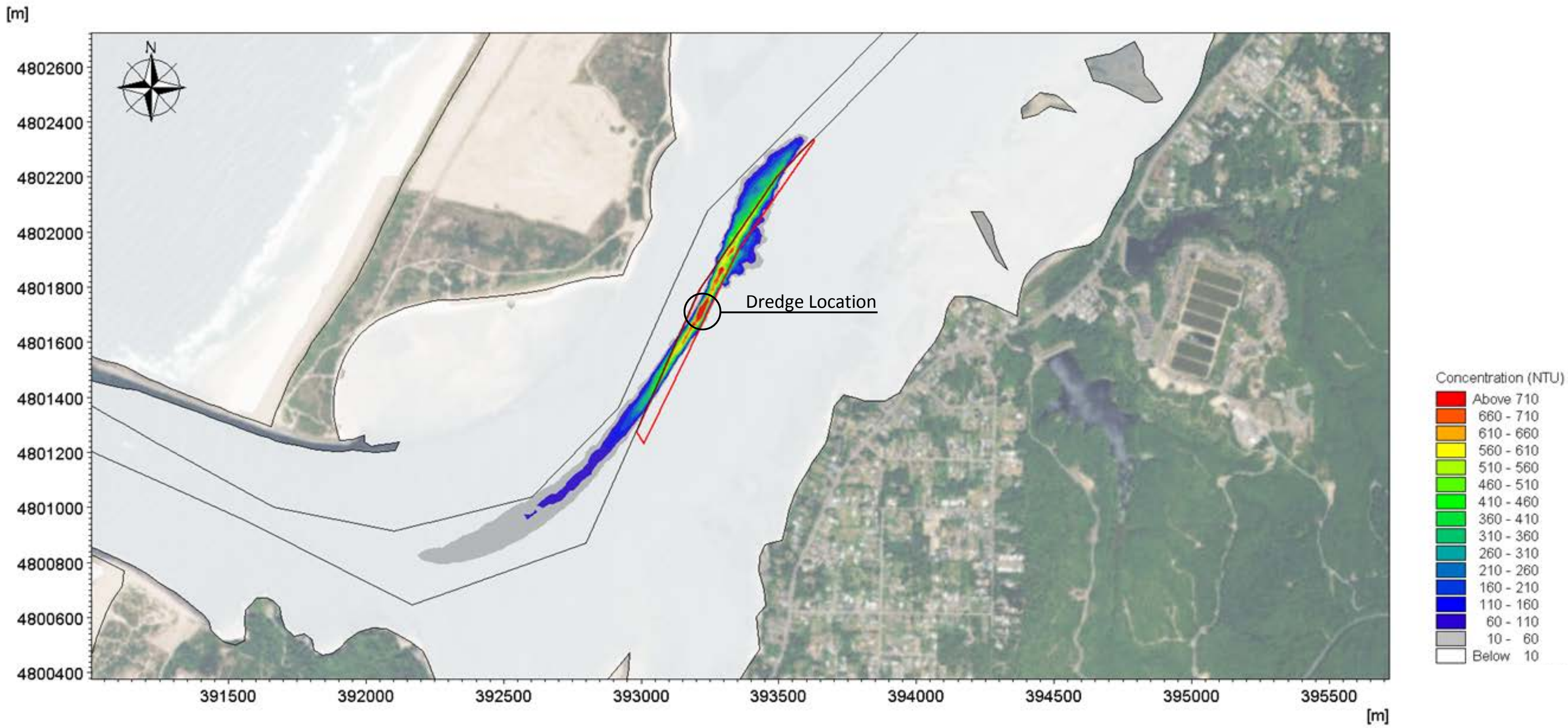

Figure 5-7: Maintenance dredging with hopper dredge, NRI 1

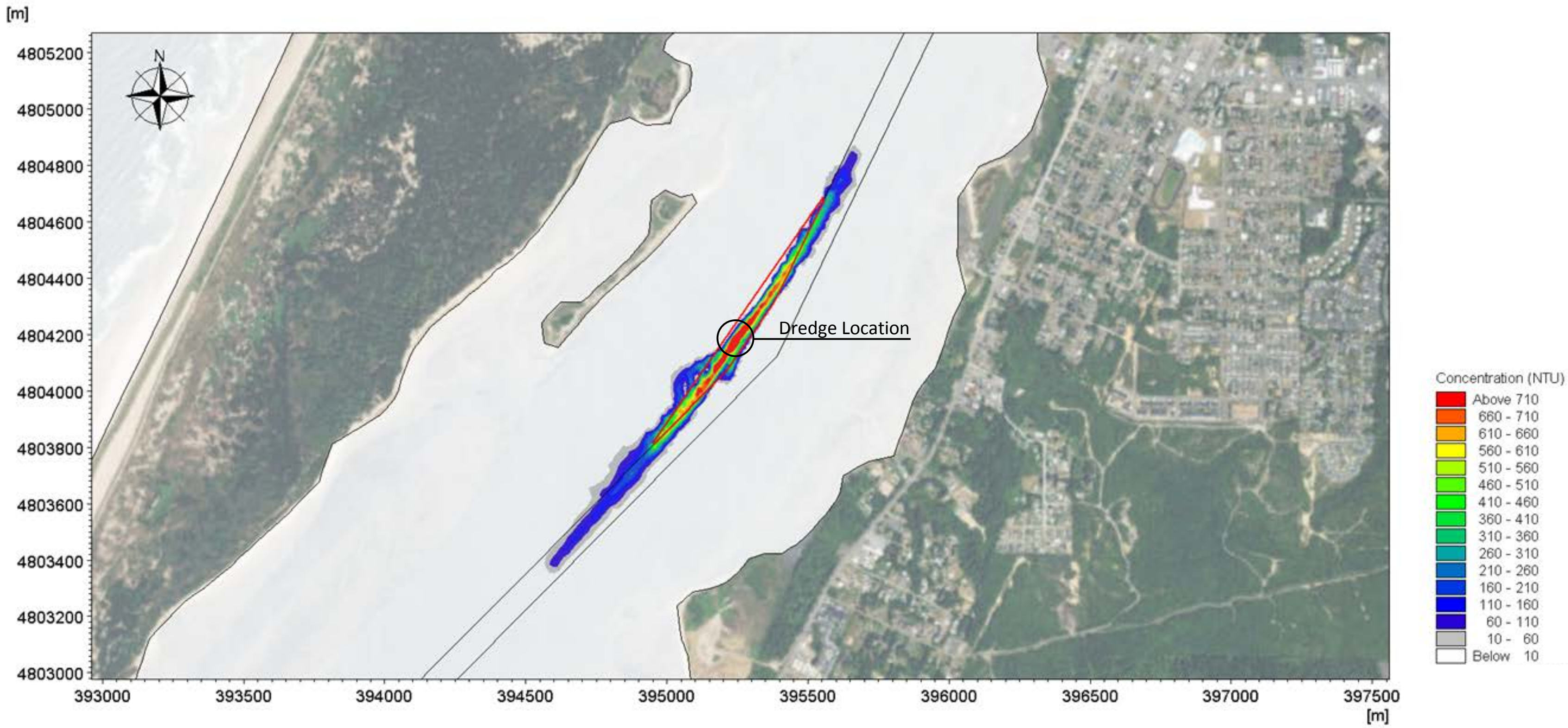

Figure 5-8: Maintenance dredging with hopper dredge, NRI 2

Jordan Cove LNG	Hydrodynamic Studies – Turbidity Analysis		moffatt & nichol
	Document Number: J1-000-MAR-TNT-DEA-00006-00		
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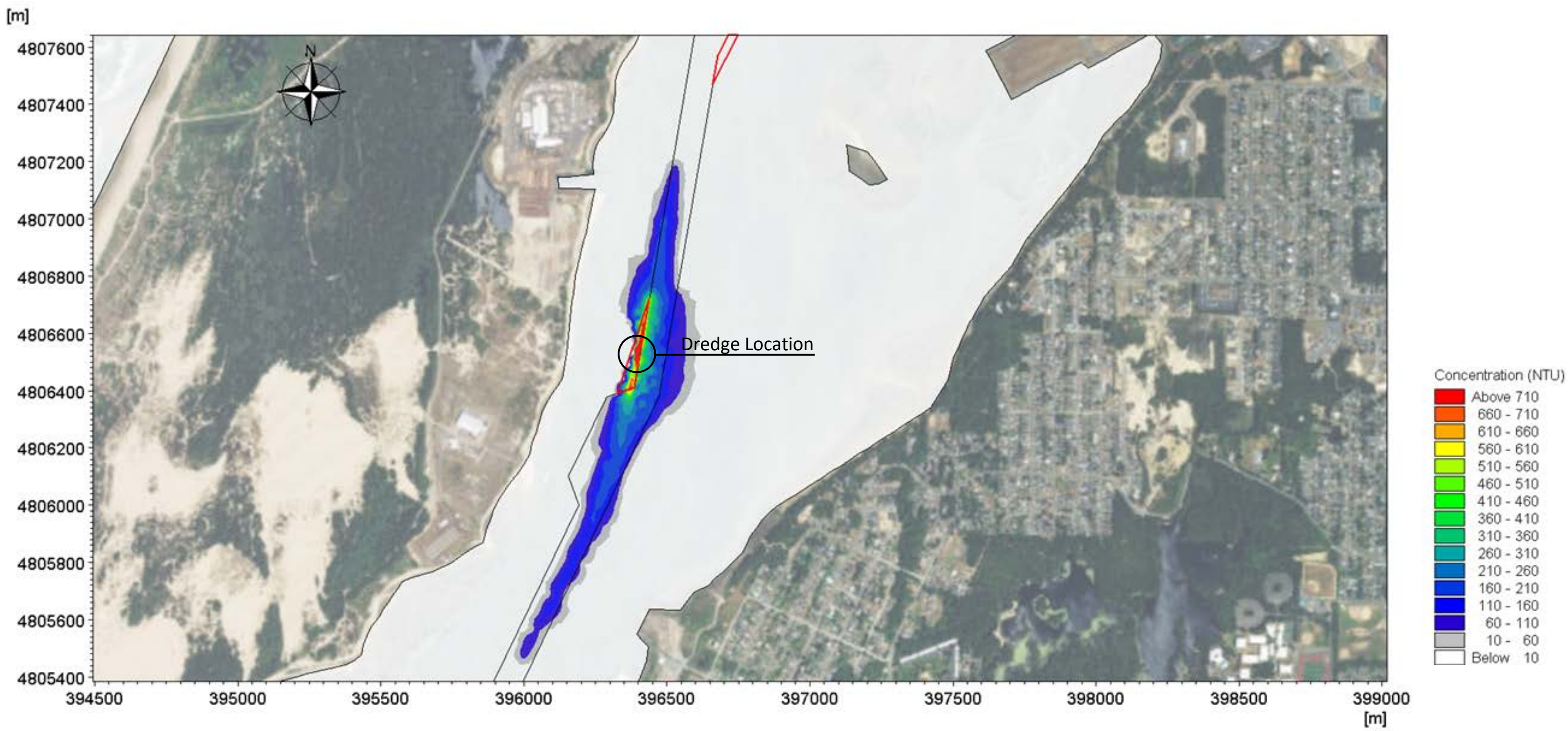

Figure 5-9: Maintenance dredging with hopper dredge, NRI 3

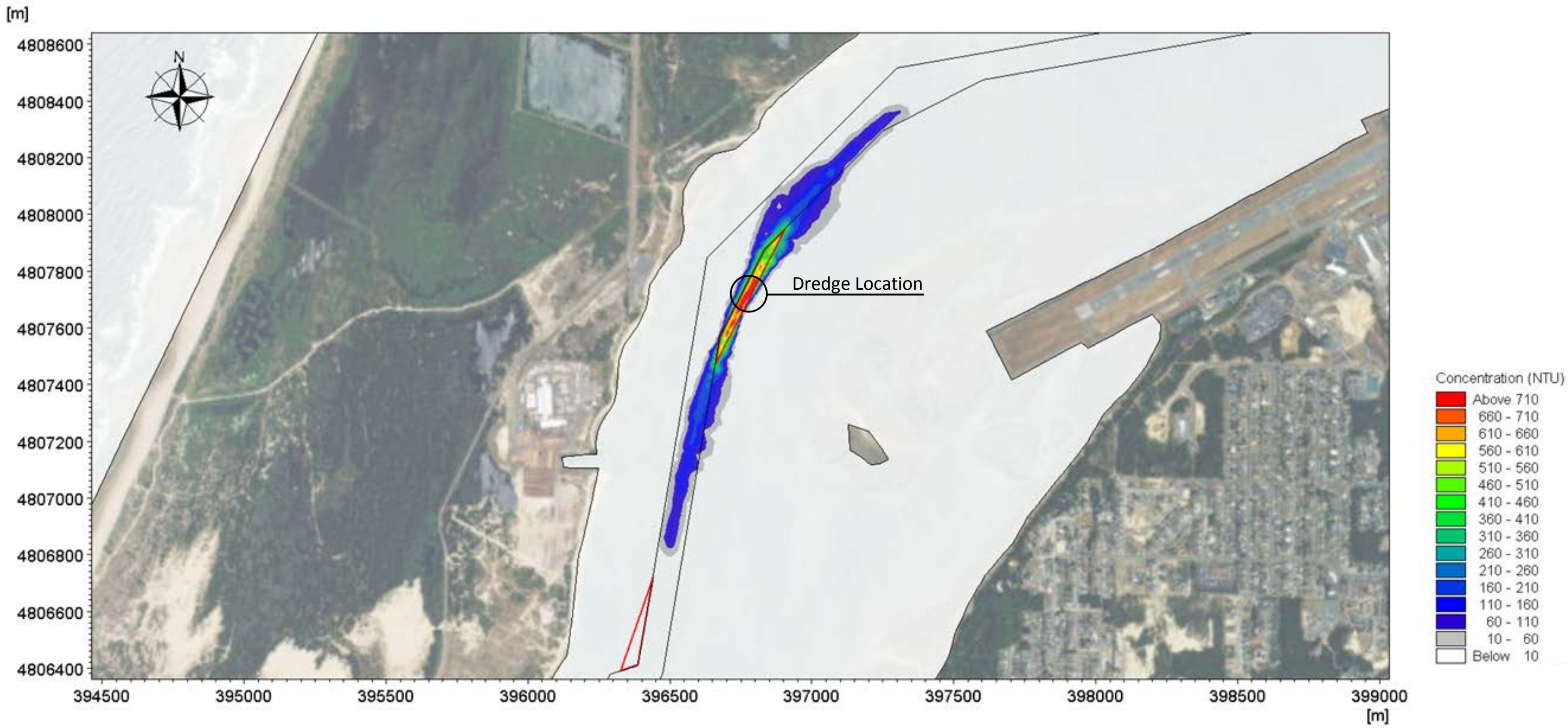

Figure 5-10: Maintenance dredging with hopper dredge, NRI 4

Jordan Cove LNG	Hydrodynamic Studies – Turbidity Analysis		moffatt & nichol
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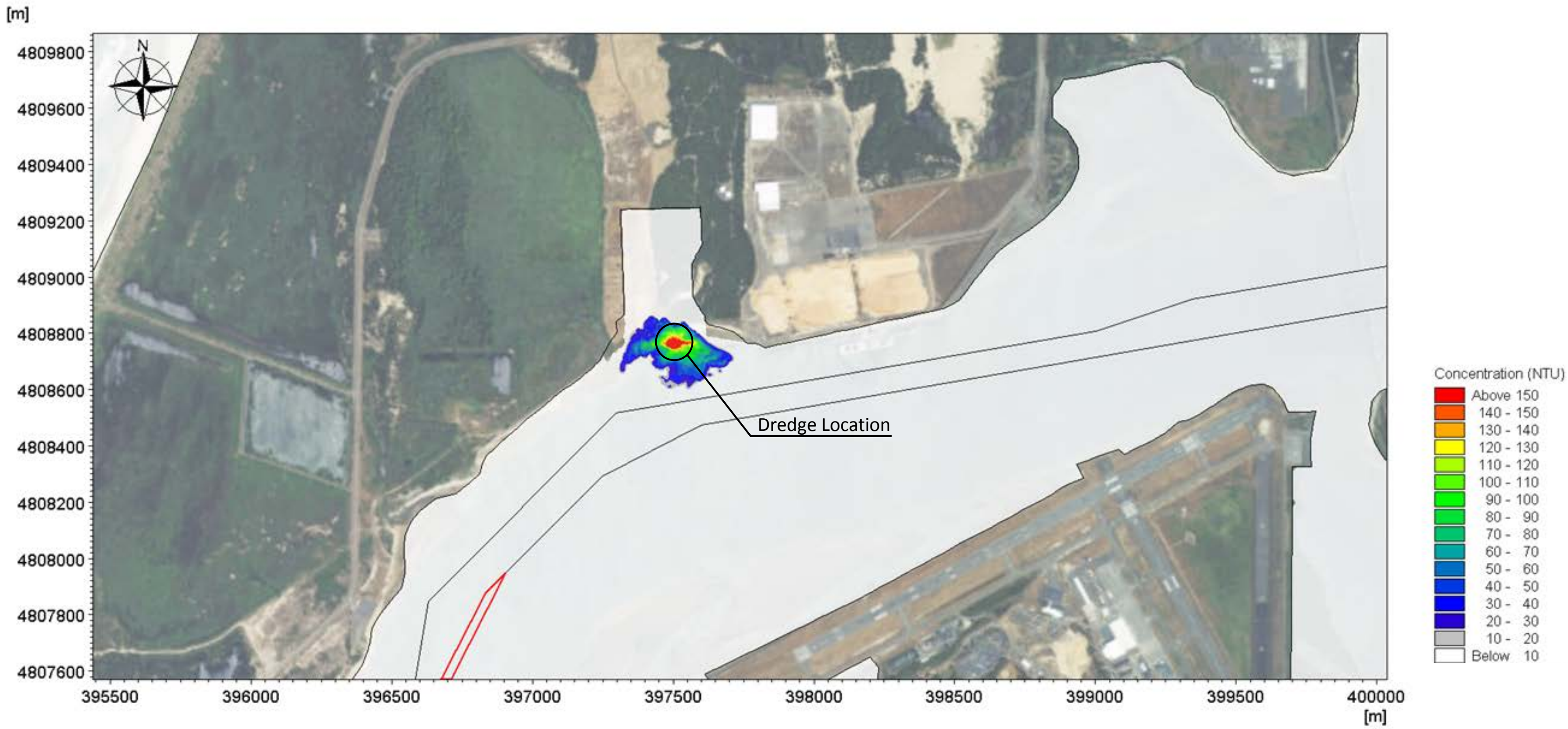

Figure 5-11: Capital dredging with clamshell, Access Channel and MOF

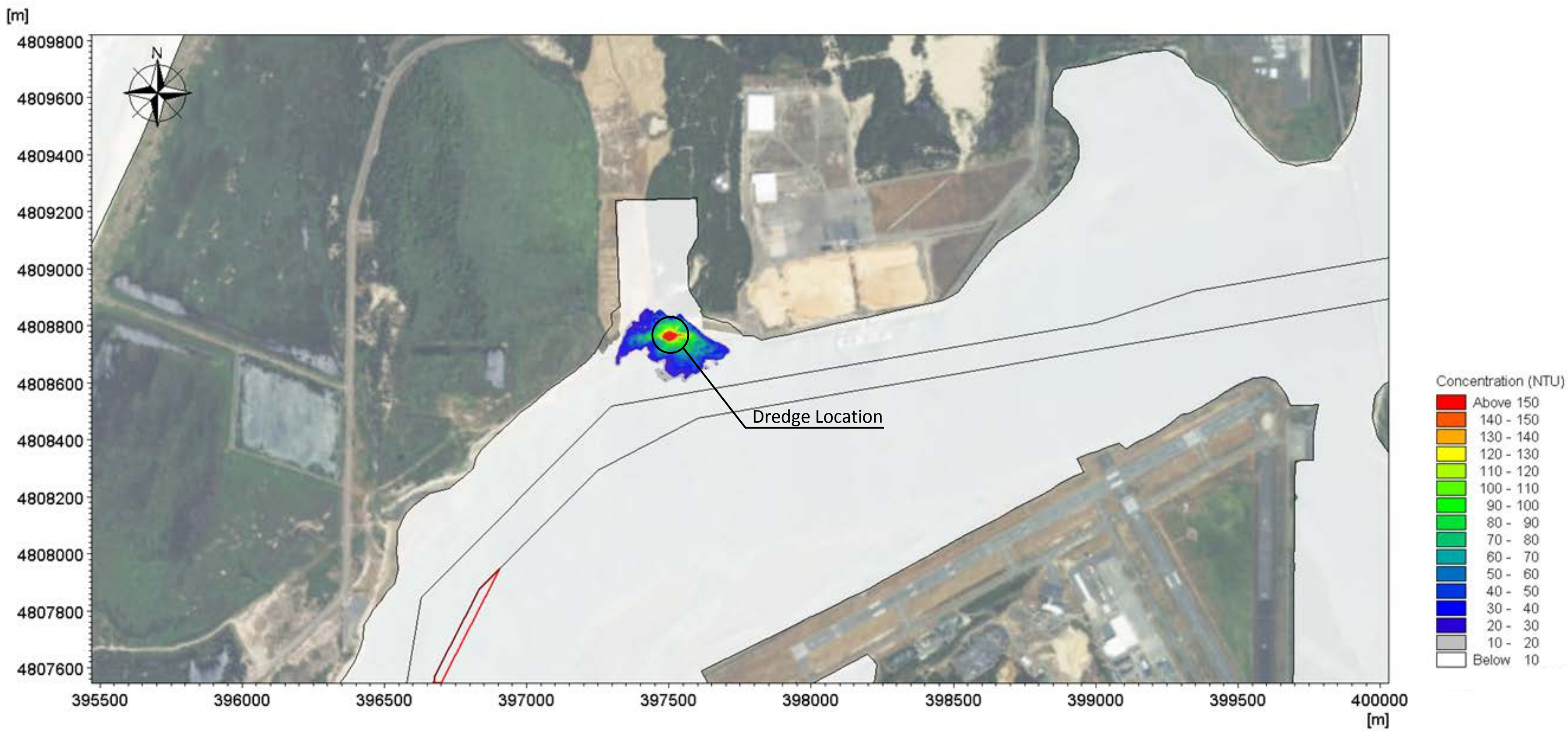

Figure 5-12: Capital dredging with cutter suction dredge, Access Channel and MOF

Jordan Cove LNG	Hydrodynamic Studies – Turbidity Analysis		moffatt & nichol
	Document Number: J1-000-MAR-TNT-DEA-00006-00		
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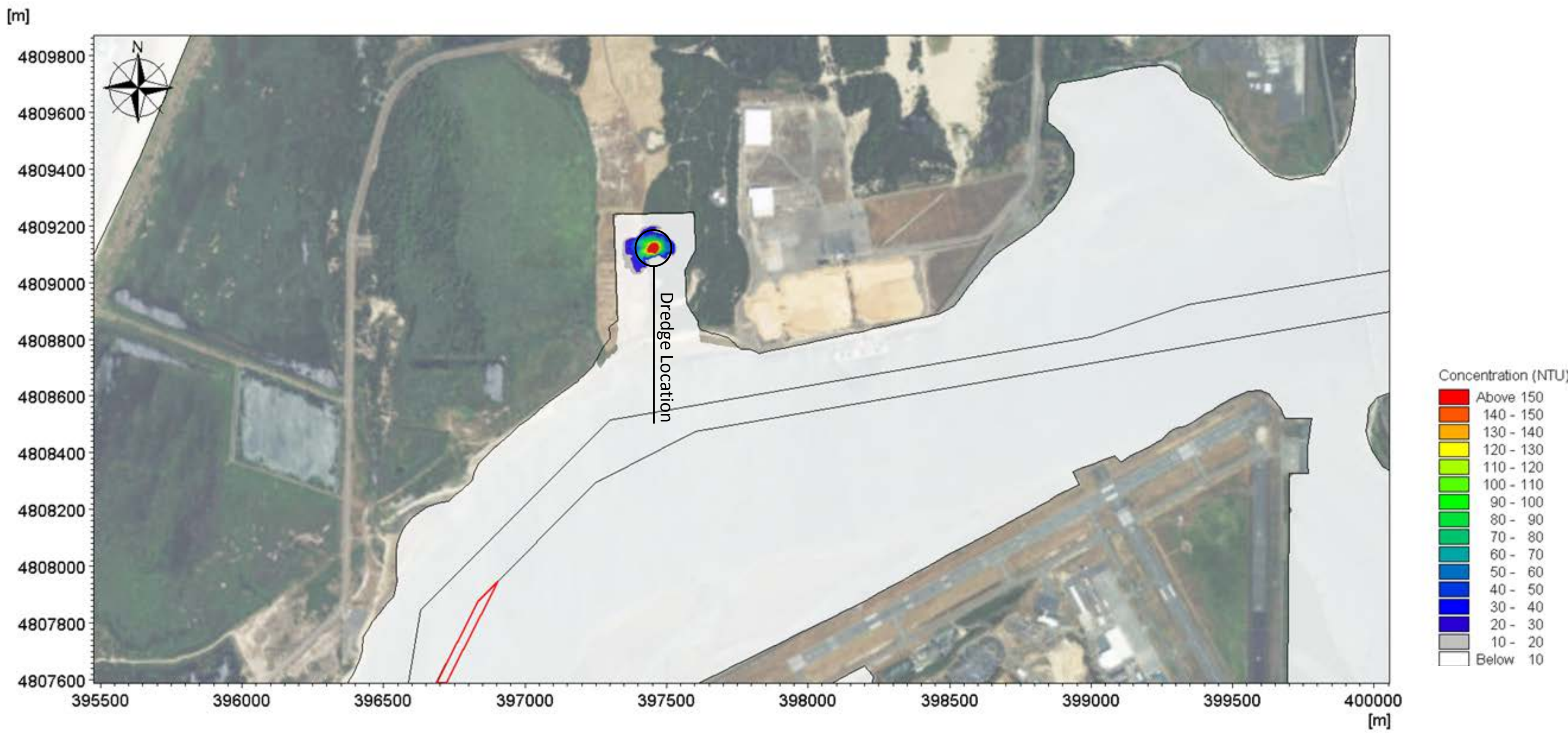

Figure 5-13: Dredging within Slip

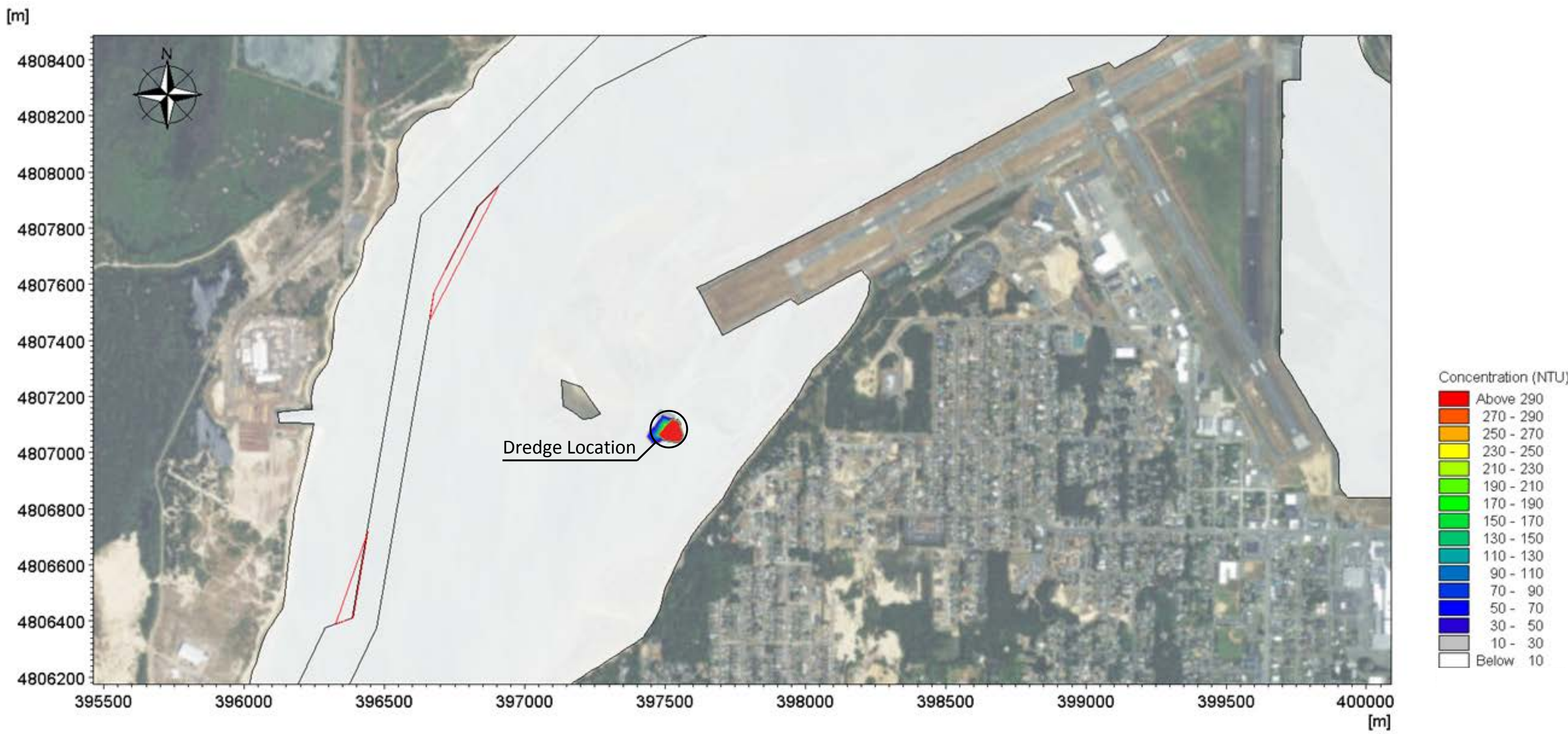

Figure 5-14: Capital dredging with excavator at Eelgrass Mitigation Site

6. UPLAND DISPOSAL DISCHARGE WATER MANAGEMENT

6.1 APCO SITES 1 AND 2

Material for upland storage at the APCO Site (Figure 1-4) is anticipated to be conveyed hydraulically to the site as a slurry via pipeline. Maximum capacity utilization is expected to raise existing grades by 37 to 49 feet (M&N 2017d).

Due to the amount of water conveyed with the hydraulically placed dredge material, management of discharge water will be employed at the APCO Site(s). Exterior containment berms along the circumference of the site would be constructed and maintained at a height to allow for sufficient settlement residence time. Interior berms and multiple slurry discharge points would be utilized within the site to produce longer and variable drainage paths. The intent is to increase the effectiveness of the area as a settling basin (or decant pond) by increasing the retention time. Discharge water from the basin would through a variable water level overflow weir to promote sediment trapping and limit suspended sediment discharge back to receiving waters.

6.2 KENTUCK RESTORATION SITE

Upland disposal of dredge material at the Kentuck Site is for Beneficial Use for Habitat Restoration. Elements of the restoration project are shown in Figure 1-5.

Upland placement of dredge material at the site will be via hydraulic offloading to the area. To prepare the site to receive dredge material, a perimeter berm should be constructed to contain the dredge material and discharge water.

Dredge material arriving on scows will be pumped hydraulically into the site using a hydraulic unloader and booster pumps as necessary. One or more booster stations may be needed to pump material from the point of offloading to the far end of the site. Dredge material placement/decant water management will employ interior berms, multiple slurry discharge points, and a variable water level overflow discharge weir to limit discharge to suspended sediment back to receiving waters.

Once upland placement of dredge material has been completed, final grading and restoration of the site can be initiated.

6.3 EELGRASS MITIGATION SITE

Dredging by means of an excavator dredge at the Eelgrass Mitigation Site is limited in quantity and duration. The limiting factor in terms of production rates may be moving scows to and from the site to transport the dredge material.

Dredging by means of a small shallow water hydraulic dredge is also limited in quantity and duration.

Environmental controls should consider the unique site conditions for the following reasons:

- Water depths within the area to be dredged are shallow, and portions of the site are above water at low tide.
- The area to be dredged is a backwater area that has limited flow exchange, which reduces dispersal of turbidity.
- Due to the shallow water depths in the area, suspended sediment settling times are very short, i.e. the material must only travel a limited distance before it settles back to the bed.

7. SUMMARY

Turbidity levels and suspended sediment plume dispersal associated with planned construction activities were simulated using the Hydrodynamic Model (M&N 2017a) coupled with sediment transport and particle tracking models.

The results provide conservative estimates of turbidity plume dispersal for dredging activities at the NRI areas, the Slip, Access Channel, and MOF; and the Eelgrass Mitigation Site.

Guidance on Best Management Practices (BMPs) to reduce turbidity generation during dredging is provided. Additionally, guidance is provided on BMPs for management of discharge water resulting from upland disposal of hydraulically placed dredge material at the APCO and Kentuck Sites.

Based on the turbidity simulation, it is recommended that both capital and maintenance dredging operations incorporate construction BMPs (active and adaptive) to reduce any potential effects related to the generation of short term localized turbidity during construction. The nature and extent of BMPs should be determined through coordination with the regulatory agencies.

8. REFERENCES

GRI. 2011. "Coos Bay Channel Modification Section 203 Feasibility Study / Environmental Impact Study". Geotechnical Data Report. Prepared for DEA. JCLNG Document No. (currently not available).

HRW, 1996. "Resuspension of Bed Material by Dredging. An Intercomparison of Different Dredging Techniques". Report SR 461, February 1996.

Moffatt & Nichol (M&N), 2017a "Hydrodynamic Studies – Hydrodynamic Analysis Technical Memorandum". Prepared for JCLNG, November 2017. JCLNG Document No. J1-000-MAR-TNT-DEA-00008-00.

—, 2017d "Jordan Cove Energy Project, Coos Bay, Oregon. Dredged Material Management Plan". Prepared for the JCLNG. September 2017. JCLNG Document No. J1-000-TEC-PLN-DEA-00001-00.

Nakai, O., 1978. "Turbidity Generated by Dredging Projects", Proceedings of the 3rd U.S./Japan Experts Meeting, US Army Engineer Water Resources Support Center.

Sato, M., 2004. "Field Survey of Turbidity During Environmental Dredging". Proceedings of Civil Engineering in the Ocean, Vol. 20, p. 1127-1132.

SHN, 2007. "Sediment Sampling and Analysis Report, Oregon Marine Gateway Terminal, Coos Bay, Oregon". Prepared for The Port of Coos Bay and Jordan Cove Energy Project, LP. JCLNG Document No. J1-000-RGL-RPT-SHN-00029-00.

TeA, 1996. "Turbidity Caused by Dredging; Viewed in Perspective." Terra et Aqua – Number 64, September 1996.

USACE, 2005. "Coos Bay Sediment Quality Evaluation Report". Prepared by Tim Sherman, Portland District Corps of Engineers, CENWP-EC-HR. March 2005. JCLNG Document No. (currently not available).

AN ABSTRACT OF THE THESIS OF

KATHARINE JEFFERTS for the degree of MASTER OF SCIENCE

in OCEANOGRAPHY presented on March 15, 1977

Title: THE VERTICAL DISTRIBUTION OF INFAUNA: A COMPARISON OF DREDGED AND UNDREDGED AREAS IN COOS BAY, OREGON.

Abstract approved: Redacted for Privacy

James E. McCauley

The vertical distribution of infauna was examined at eighteen stations in Coos Bay, Oregon. Twelve stations were located in the dredged shipping channel; six samples were taken in South Slough.

The faunal assemblages of South Slough (with the exception of one station) and the main dredged channel were found to be quite distinct. One hundred seventy three taxa were identified in the samples; forty five were common to the two areas. Faunal differences are postulated to be due to the more frequent disturbance in the dredged channel compared to the largely intertidal South Slough samples.

Phoronopsis harmeri was the only taxon consistently found to have a subsurface abundance maximum. All other taxa either showed a consistent decline in numbers with increasing depth in the sediment, or minor and isolated subsurface abundance maxima. South Slough faunas were consistently distributed to deeper levels in the sediment, probably due to the lower frequency of disturbance.

Multiple regression analysis of Shannon diversity on water con-

tent, grain size, and depth in the sediment accounted for 82% of the variation seen in diversity, when only the dredged channel stations were considered. Addition of the South Slough samples to the model resulted in a multiple R^2 of 0.63. This pejorative effect is postulated to be due to the difference in environment and frequency of disturbance in the two areas.

Dredging, shipping traffic, and industrial activity in the upper reaches of the dredged channel appear to have a deleterious effect on faunal diversity, due most probably to increased water and organic content, decreased grain size, and physical disturbance and removal of surface sediment layers. This area is depauperate in regard to species; those which do occur are generally cosmopolitan, opportunistic ones, restricted to the upper ten centimetres of the deposit. The lower reaches of the dredged channel, and all but one of the undredged stations exhibit a much more speciose fauna distributed to deeper levels in the sediment.

The Vertical Distribution of Infauna: A Comparison of Dredged and Undredged Areas in Coos Bay, Oregon

by

Katharine Jefferts

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed March 15, 1977

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APPROVED:

Redacted for Privacy

Associate Professor of Oceanography
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Dean of the Graduate School

Date thesis is presented March 15, 1977

Typed by Katharine Jefferts for Katharine Jefferts

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THE VERTICAL DISTRIBUTION OF INFAUNA: A COMPARISON OF DREDGED AND UNDREDGED AREAS IN COOS BAY, OREGON

INTRODUCTION

Study of the vertical distribution of infauna has heretofore been almost exclusively limited to examination of intertidal sandy beaches. Surprisingly little work has attempted to relate observed distribution patterns to various environmental parameters. The research described herein represents an attempt to compare vertical distribution to water and organic content of the sediment, grain size, and frequency of disturbance.

Terminology

The term "vertical distribution" has alternatively been used to describe the zonation of flora and fauna on a shoreline (eg., the surface of a beach, cf. Ricketts et al., 1968), to describe the stratification of organisms seen in the water column (eg., the stratification of fish faunas seen in the open ocean - mesopelagic vs. bathypelagic, cf. Wieser, 1960b, and Hardy, 1960), and to describe the distribution of organisms within a sediment deposit (Fenchel, 1971). It is the latter usage with which I shall be concerned. An attempt by investigators of any of these three phenomena to remove ambiguity in their terminology would be highly proficuous.

Infauna may be defined as those organisms which live within the sediment, as opposed to epifauna, which dwell at the sediment-water interface. Infauna generally includes three size classifications: microfauna, those organisms which pass the finest sieves and are generally sampled by culturing; meiofauna (Mare, 1942), those organisms passing a 0.5 to 1.0 mm sieve, but larger than microfauna; and macrofauna, the larger metazoans retained on a 0.5 to 1.0 mm sieve (McIntyre, 1969). As I utilized a sieve with meshes of 0.5 mm, my samples can probably be considered to quantitatively represent the macrofauna, and qualitatively represent the meiofauna (Reish, 1959, has stated that quantitative meiofaunal sampling requires a mesh size of 0.37 mm).

Previous Studies

Growing recognition of the importance of meioinfauna has prompted several ecological studies on small invertebrates (Jansson, 1966; Renaud-Debyser, 1963; Wieser and Kanwisher, 1961; Smidt, 1951; Muus, 1967; Renaud-Debyser and Salvat, 1963; Pennak, 1951; and Wieser, 1960a). Despite the rapidly enlarging literature on the vertical distribution of intertidal psammal organisms (Purasjoki, 1947; Delamare-Deboutteville, 1960; Swedmark, 1964; Bush, 1966; Fenchel and Jansson, 1966; Fenchel et al., 1967; Schmidt and Westheide, 1971; Salvat, 1964; and Johnson, 1967), information on vertical distribution of subtidal faunas remains scant (McIntyre, 1969; Mare, 1942; Molander, 1928; Moore, 1931; Bougis, 1946; McIntyre, 1961; and Thiel, 1966). Fenchel, Jansson, and Renaud-Debyser have contributed nearly all that is known about the vertical distribution of infauna, and most of their research has concerned the smaller members of the meiofauna, primarily the ciliates and nematodes of intertidal sandy beaches.

McIntyre (1964) provided data on biomass and production for infaunas as a whole. For intertidal faunas, the macrofauna to meiofauna biomass ratio may vary from 1:4 (Smidt, 1951) to 1:42458 (Rees, 1940), and for subtidal faunas, values ranging from 1:16 (Muus, 1967) to 1:770 (Wigley and McIntyre, 1964) have been recorded.

Vertical Distribution

Holme (1953, p. 9) has stated that "from observation on intertidal banks it is known that a majority of individuals are to be found in the top 15 cm or so" while McIntyre (1973, p. 3) has written "on sand the fauna is found in the interstitial space down to more than 30 cm... while on less porous mud it is restricted to about the top 6 cm." Holme (1964) later revised his estimate to the top 30 cm. MacGinitie (1935, 1939) has sampled certain animals at depths of two feet or more on intertidal flats, and believes that offshore faunas may penetrate to that depth as well. Meiofauna has been recorded at over one metre in sand (McIntyre, 1971, 1973; Renaud-Debyser, 1963), and is usually to be found throughout a sandy core if shallower than that (Ganapati and Rao, 1962; Bush, 1966; Fenchel and Jansson, 1966; and McIntyre, 1968). Many workers have noted that population maxima, while occurring near the surface at the low water line, move deeper in the sediment as one samples closer to the high water line (Schmidt and Westheide, 1971; McIntyre, 1968; Bush, 1966; and Ganapati and Rao, 1962). Animals have been detected at 52 cm in a tideless beach in the Øresund

(Fenchel et al., 1967). Bush (1966) noted the fauna extending downwards to the water table at 46 cm. The situation can be quite different in a muddy environment; Rees (1940) found the bulk of the fauna in the 0 to 1 cm section, with little life below 4 cm.

On a sandy beach in the Danish Waddensea, Smidt (1951) found 83% of the nematodes in the surface two centimetres; they extended to six centimetres, which was the deepest level sampled. Perkins (1958) took nematodes at the bottom of a seven centimetre thick lens of sand overlying stiff clay, but they were undetected in the clay. Teal and Wieser (1966) found nematodes to deeper than 14 cm, and Ganapati and Rao (1962) found maximum densities of nematodes between 10 and 20 cm, extending to 75 cm. Fenchel et al. (1967) found nematode maxima at 35 cm, extending to the deepest level sampled at 52 cm.

McIntyre (1971) stated that copepods were largely restricted to the top centimetre of mud in an estuarine environment. On an intertidal mud flat, Barnett (1968) found 95% of the harpacticoids in the 0.0 to 0.5 cm level, with only occasional individuals below one centimetre. Perkins (1958) found copepods to be restricted to a surface layer four millimetres thick. Pennak (1942) stated that copepods could be found at a depth of 25 cm in his study area. Renaud-Debyser (1963), in sampling an intertidal sandy beach to 65 cm, found Paraleptastacus spinicauda to 65 cm with a maximum density at 45 cm; Stenocaris pygmaea with a maximum at 35 cm; Psammotopa polyphylla only from 35 to 65 cm; and Arenopontica subterranea only from 45 to 65 cm.

Fenchel et al. (1967) recorded the oligochaetes Marionina preclitellochaeta and M. subterranea as surface forms, but Aktedrilus monospermatecus as occurring exclusively below 20 cm. They also listed the polychaetes Diurodrilus minimus as occurring from 12 to 24 cm, and Nerilla antennata at 48 cm.

Ciliates have been shown to exhibit a distinct zonation (Fenchel and Jansson, 1966); they may occur to more than 20 cm in clean sand, and to eight centimetres even in strongly reducing, although capillary, sediments (Fenchel, 1967). Maximum concentrations were found in sulphureta (Fenchel, 1967).

Ganapati and Rao (1962), on an intertidal sandy beach, considered the following groups to be generally restricted to the upper 20 cm: Hydrozoa, Turbellaria, Nemertea, Rotifera, Archiannelida, Polychaeta, Ostracoda, Halacaridae, and Nudibranchiata. They recorded kinorhynchs and isopods from 70 cm, and in their deepest samples, 75 cm, they identified a few ciliates, nematodes, oligochaetes, gastrotrichs, tardigrades, and crustaceans.

Johnson (1967) cored to 25 cm on an intertidal sand flat, finding 80% of the individuals in the upper 15 cm. The median depth for all species, except Phoronopsis harmeri, was 8 cm.

Fenchel and Jansson (1966) found the fauna in a tideless harbour (in 5 to 10 cm of water) to be restricted to the upper two centimetres, with only nematodes deeper in the sediment. They noted a condition of marked oxygen depletion and an Eh reduction at a depth in the sediment of only one centimetre.

There has been a debate in the literature for some fifty years concerning the depth to which organisms may be found in subtidal and offshore deposits (Holme, 1964; Thorson, 1957). Molander (1928) sampled to 15 cm in the Gullmar fjord and concluded that the majority of species and individuals were to be found in the upper five centimetres of sediment, with few occurring below ten centimetres. Wieser and Kanwisher (1961) have stated that the vertical distribution in sublittoral and some littoral deposits is restricted to eight centimetres, with the majority above four centimetres. Holme (1964) gave ten centimetres as the line of demarcation, animals below that depth being often large but infrequent. He went on to state that it may be necessary to sample to 30 cm to collect all individuals of certain species. Johansen (1927) wrote "invertebrates are not taken beyond about 12-25 cm down in the sea floor." However, Barnard and Hartman (1959) noted collections of Listriolobus made with an orange-peel grab that had penetrated at least 60 cm into the sediment. These echiuroids were frequently snagged by the bottom claws of the instrument, indicating the possibility of even deeper individuals.

There is a great paucity of published accounts of the vertical distribution of subtidal infaunas. Muus (1967) and Hopper and Meyers (1967), in examining sea grass communities in less than one metre of water, found most meiofauna to be restricted to the upper two centimetres. On a sandy bottom in eight metres of water, McIntyre (1969) found harpacticoids, turbellarians, gastrotrichs, and nematodes throughout 23 cm cores, but their numbers were much reduced below 16 cm. Molander (1928) investigated the vertical distribution of infauna in the Gullmar fjord. He stated that the majority of individuals occurred in the upper five or ten centimetres, only polychaetes being found to 15 cm, the maximum depth sampled. In examining the fauna of muddy bottoms at 20 to 40 m depth, Mare (1942), Moore (1931), and Bougis (1946) found copepods, ostracods, turbellarians, kinorhynchs, bivalves, and polychaetes primarily in the upper two centimetres, and at some sites only in the surface half centimetre. Nematodes were occasionally found with maximum concentrations in the one to two centimetre layer, and occurring deeper, but numbers below five centimetres were very low. In sediments in 73 to 166 m of water, Moore (1931) and McIntyre (1961) found the top four centimetres to contain the bulk of the fauna, only nematodes occurring continuously to seven or eight centimetres. At 5030 m, Thiel (1966) found harpacticoids and ostracods confined to the surface two centimetres. Nematodes occurred at seven centimetres depth, but 90% of the population was found in the zero to two centimetre layer.

Nematodes have been recorded to a depth of 50 cm in a peat bog (Kischke, 1956). Ohlmacher and Schlichting (1967) found higher populations of algae, bacteria, and protozoa in the hydrosol layer of a lake (mud-water interface) than in the first and subsequent sediment sections.

Environmental Factors Influencing Vertical Distribution

I should now like to consider the available information on the effects of various environmental factors on the vertical distribution of infaunal organisms. Purdy (1964, p. 238) has stated that grain size is generally a controlling factor in the distribution of benthic organisms:

> "Distribution patterns of aquatic benthos, for example, are correlated usually with the texture, or, more specifically, with the silt and clay content of the sediment rather than with its mineral composition. This relationship results from the fact that current velocities not only determine the proportion of silt and clay in the sediments, other factors being equal, but also control the ecologically important variables of substrate mobility and concentration of organic matter."

Pennak (1951), however, has stated that the grain size has "no constant relationship to either number or distribution of organisms." I think he has been adequately refuted in recent years (eg., Jansson, 1967a; Kinner et al., 1974).

Prenant (1960) has an exhaustive bibliography on the granulometric literature. It appears likely that rather than grain size, *per se*, it is the physiographic environment of which grain size is but an indicator, to which organisms react (Jones, 1950). Jansson (1967a) has given grain size preferences of an interstitial oligochaete and the harpacticoid *Parastenocaris vicesima*, which has a strong affinity for sediments with a median diameter of 125 to 250 μ. The copepod is incapable of movement when placed in sediments in the 500 to 1000 μ range. Kinner et al. (1974) have shown grain size correlations for several organisms; they list *Heteromastus filiformis* as being characteristic of sediments of greater than 50% silt and clay, and also record higher diversities for localities with less than 25% silt and clay. Prenant (1961) listed *Arenicola marina* and *Lanice conchilega* as tolerating a wide range of particle sizes, but Rullier (1959) stated that Arenicola marina, Lanice conchilega, and Capitella capitata were restricted to a narrow range of grain sizes, while Pygospio elegans and Cardium edule were more eurygranular. Interesting dichotomy! Jansson (1966) demonstrated preferences of the oligochaete Marionina for varying grain sizes.

The work of Chapman (1949) and Ekman (1947) has suggested that different degrees of packing may influence infaunal distribution or burrowable depth through thixotropic and dilatancic properties of the sediment. The work of O.S.U. (1977) has confirmed this in part.

Wieser (1959) has postulated a morphologic barrier at a median grain size of 200 μ, separating interstitial sliding organisms (grain size greater than 200 μ) from those which burrow (less than 200 μ). He has listed Spiochaetopterus costarum as an indicator of silt and fine sand. In his work in Puget Sound, Wieser (op. cit.) found Leptochelia dubia, Rhynchospio arenincola, and Cumella vulgaris females only in sediments with a median diameter of less than 200 μ. Cumella vulgaris males were found in sediments with a mean diameter of up to 300 μ. The males of this species are noticeably smaller than the females, of quite a different shape, and may well utilize a different mode of locomotion; King (1977) noted differences in swimming patterns between the sexes. Species of Boccardia were found in sediments of up to 250 μ mean diameter, while Corophium salmonis was found exclusively in deposits of less than 200 μ mean grain size. Jansson (1967c) stated that this critical grain size of 200 μ is related more to pore water content than to space restrictions, and that creeping and burrowing animals are less influenced by grain size than are interstitial sliders. The mode of locomotion apparently governs an organism's ability to remain in a sand layer of optimum humidity (Wieser, 1959). Boaden (1962) found graded sand to be differentially colonized by different infaunal organisms.

Temperature

Temperature may also play a significant role in determining vertical distribution. Jansson (1966) has correlated the vertical distribution of some metazoans with temperature; he has also demonstrated temperature preferences for the oligochaete *Marionina*. Salvat (1967) has studied the influence of air and sea water temperatures on sand temperature at different depths in the sediment. Jansson (1967d) examined vertical temperature gradients over 24-hour periods in several seasons; surface layers showed the largest fluctuations, especially in summer. Perkins (1958) has demonstrated a marked meiofaunal downward migration when the surface temperature falls below 4°C. Renaud-Debyser (1963) and Gray (1965) have also recorded vertical migrations of infauna in relation to temperature.

Salinity

Remane and Schulz (1934) have stressed the importance of the salinity of the interstitial water (*Küstengrundwasser*); Kinne (1964) has a comprehensive review of recent studies. Jansson (1966) has correlated vertical distribution of infauna with salinity, and has given salinity preferences for Paraleptastacus and Parastenocaris. Barnett (1968), on an intertidal mud flat, recorded 95% of the harpacticoids in the first half-centimetre of sediment even in a considerably diluted environment, and noted that they did not migrate downwards to the 1.5 to 2.0 cm level, where normal salinities were available. However, Bush (1966) has noted marked downward migrations during periods of heavy rains.

Light

Gray (1966) has described vertical migration of infauna (both positively and negatively phototactic) in response to light levels.

Oxygen

Oxygen availability may be a very important factor influencing the distribution of infauna. Many species are undetected in sediment layers lacking in oxygen. Very coarse sediments may be well oxygenated to at least 20 cm (Fenchel, 1971), but in finer deposits oxygen is often lacking below 1 cm (Wieser and Kanwisher, 1961). Oxygen tenor may limit the distribution of some species, but many can survive anoxically for long periods. Intertidal plants such as Spartina may furnish oxygen to deeper levels in the sediment than it is normally available, but only in a narrow zone around their roots (Wieser and Kanwisher, 1961). Nematodes especially are able to survive long periods without oxygen (Moore, 1931), and Wieser and Kanwisher (op.

cit.) have related their distribution to oxygen availability. Jansson (1966) has correlated the distribution of some metazoans with oxygen availability, and has given figures on the influence of oxygen on Derocheilocaris. Any group with species which can withstand anaerobic and reducing conditions may be represented in the deeper levels of a deposit (McIntyre, 1969).

Pore Water

Jansson (1967b) has noted the importance of water flow for oxygen availability in the interstitial water. He has also stated (1967c) that pore water content of a sediment is probably more important than grain size, *per se*, in influencing infaunal distributions (he is writing of the sandy intertidal environment). Salvat (1964) has proposed a four-fold classification system for sandy beaches based on interstitial water content and frequency of interchange. Wieser (1959) has noted a break in the curve of water holding capacity of variously sized sediments at 200 μ; Krogerus (1932) stated that sediments may vary from closely packed fine sand in which capillary forces are high (and, consequently, water content is high), to coarse sand in which a system of interstitial spaces is developed and capillary forces (and water content) are low. Jansson (1968) found harpacticoids to be most sensitive to decreasing amounts of pore water, turbellarians next, and oligochaetes relatively indifferent. He also (1966) has correlated the vertical distribution of some metazoans with water content of the sediment.

Tidal Variation

Johnson (1967) and Boaden (1968) have described migrations of infauna in relation to tidal fluctuations. Rieger and Ott (1971) recorded a turbellarian and nematode which moved to surface layers when the tide was high, and retreated to lower levels when the tide receded. They noted another nematode, lower on the shore, which exhibited precisely the opposite behaviour.

Seasonal Variation

Studies of seasonal fluctuations in vertical distribution are few; Renaud-Debyser (1963) found maximum densities as deep as 70 cm in a sandy beach in January, with the maximum moving to upper layers in the summer. MacCoy (1966), studying the tidal creeks of an estuary, noted a threefold change in population abundance from July to September in the zero to two centimetre layer, a sixfold change in the two to four centimetre layer, and a tenfold change in the four to six centimetre section. The upper layer constituted 69% of the total population, the middle section had 22%, and the bottom (four to six cm) level contained the remaining 9%. He postulated a downward migration of organisms over the season.

Dredging

The effects of dredging may be compared to conditions obtaining in a deposit characterized by high rates of biologic reworking. Unstable and reworked bottoms are primarily restricted to deeper subtidal areas (Rhoads and Young, 1970), for intertidal and shallow subtidal bottoms are frequently stabilized by benthic diatoms (VanStraaten and Kuenen, 1958), shallow water algal mats and grasses (Ginsburg and Lowenstam, 1958), and high densities of tubicolous polychaetes (Fager, 1964). Highly reworked bottoms, produced by high densities of infaunal deposit feeders, result in uncompacted surfaces of sand-sized biogenic particles of low bulk density (faecal pellets and clasts of semiconsolidated mud), high turnover rates of bottom muds through resuspension by weak tidal currents, high turbidity at the mud-water interface, water contents of greater than 60% at the surface (water contents of 30 to 50% and lower are more usual for areas with fewer deposit-feeding bivalves), and better oxygenation, to about six centimetres in the deposit (Rhoads and Young, 1970). Rhoads and Young have also noted the production of textural and compositional grading corresponding to the maximum depth of biologic reworking, which they were able to identify as an X-ray opaque zone. This physical instability can be stressful to filter feeding organisms by clogging filtering structures, resuspending and burying newly settled larvae, and discouraging settlement of suspension-feeding larvae. Rhoads and Young (op. cit.) have shown significantly lower growth rates (less than fifty per cent that of the upper) for juvenile bivalves at 10 cm above the surface of highly reworked sediments, than for those 45 and 75 cm above.

Muus (1966) pointed out that although many larvae of suspension feeders show high settling discrimination, some larvae do settle and metamorphose in areas where adult populations are rare or absent.

In cases where the instability of the bottom is not totally lethal to a population, surviving individuals may exhibit stunted growth (Hallam, 1965). McNulty et al. (1962) have noted that unstable bottoms do not affect all feeding types equally, and Rhoads and Young (1970) have defined the following three-part trophic-group division. In homogeneously suspension-feeding faunas, deposit feeders are excluded by an inadequate food source (eg., rocky bottoms). Sediment instability and water turbidity exclude suspension feeders in areas where the fauna is a deposit feeding one. However, Driscoll (1967) and Sanders (1958) consider that a limiting food supply is the controlling factor in the distribution of suspension feeders in Buzzard's Bay. A mixed fauna indicates a physically stable bottom, according to Rhoads and Young.

Dredged areas are frequently characterized by this physically unstable bottom condition, but water and sediment chemistry, as well as physical removal of organisms, appear to play a larger part. Highly organic sediments, rapid sedimentation rates, and low dissolved oxygen act in concert to produce faunal impoverishment in dredged silt-clay sediments (Taylor and Saloman, 1968). Kaplan et al. (1975) listed acute effects of dredging as siltation, changes in water chemistry, and physical removal of plankton and benthic organisms. Chronic effects of dredging are primarily changes in sediment deposition and current velocity regimes. In a small estuarine lagoon, Kaplan et al. (op. cit.) found that stations most diverse before dredging recovered least; one sandy habitat showed increased diversity following dredging. Reish (1962) found that dominant forms appeared within four months following dredging, and gradually increased in numbers. He also noted the presence of temporarily dominant, or opportunistic, species. Parr (1974), studying the upper reaches of the Coos Bay dredged channel, recorded a return of numerical abundance to pre-dredging levels within 28 days following dredging. He noted that dredge-induced changes were non-persistent, and postulated that the fauna was already well adapted to periodic disturbance.

In summary, it would appear that the physiographic environment, with concomitant factors of grain size, oxygen tenor, pore water content, and instability of the deposit, are most important in determining the vertical distribution of subtidal infaunas. Dredged deposits frequently exhibit what would seem to be limiting values for these factors; small median grain size, low oxygen content, high water content, and high mobility often characterize such areas. Silty, high-liquidity environments tend to exclude suspension feeders (Rhoads and Young, 1970), while low oxygen tensions may influence the depth to which deposit feeders may be found. Highly instable sediments may reduce numbers of both feeding types, as may high levels of organic matter.

Intertidal faunas, of which there are no representative samples from dredged areas in this study, should, in addition, be correlated with those factors which are liable to vary more extensively in that environment: temperature, rapid salinity changes, and tidal fluctuations.

METHODS

This research was designed to complement a study of the environmental effects of dredging in Coos Bay, being conducted by O.S.U. (1977). Primary objectives have been to determine if there are differences in vertical distribution of infauna between dredged and undredged areas, if so, whether they are ones of abundance, faunal composition, or homogeneity of vertical distribution, and whether they may be attributed to differing grain size, organic content of the sediment, or sediment mobility.

The study area consisted of stations selected at most areas of the Coos Bay, Oregon, estuary (see Figure 1). Percy et al. (1973) and the U.S.D.I. (1971) have given detailed descriptions of hydrologic conditions in the bay. The mean tidal range is 1.6 m (Johnson, 1972); the average tidal current velocity is 1.0 m/sec at the mouth (Bourke et al., 1971). During periods of low runoff the estuary is classed as well mixed; the bay becomes partially mixed when runoff is high (McAlister and Blanton, 1963). Tidal flushing is usually of greater importance to the character of the estuary than stream runoff (Rudy, 1970).

The most serious difficulty facing the student of vertical distribution is one of sampling. Grab samplers generally fail to take a sample adequately undisturbed to permit sectioning. Geologic core samplers would be ideal in this regard, but the cross sectional area is far too small for quantitative study of any but the microfauna. Gleason and Ohlmacher (1965) have developed such a coring device to

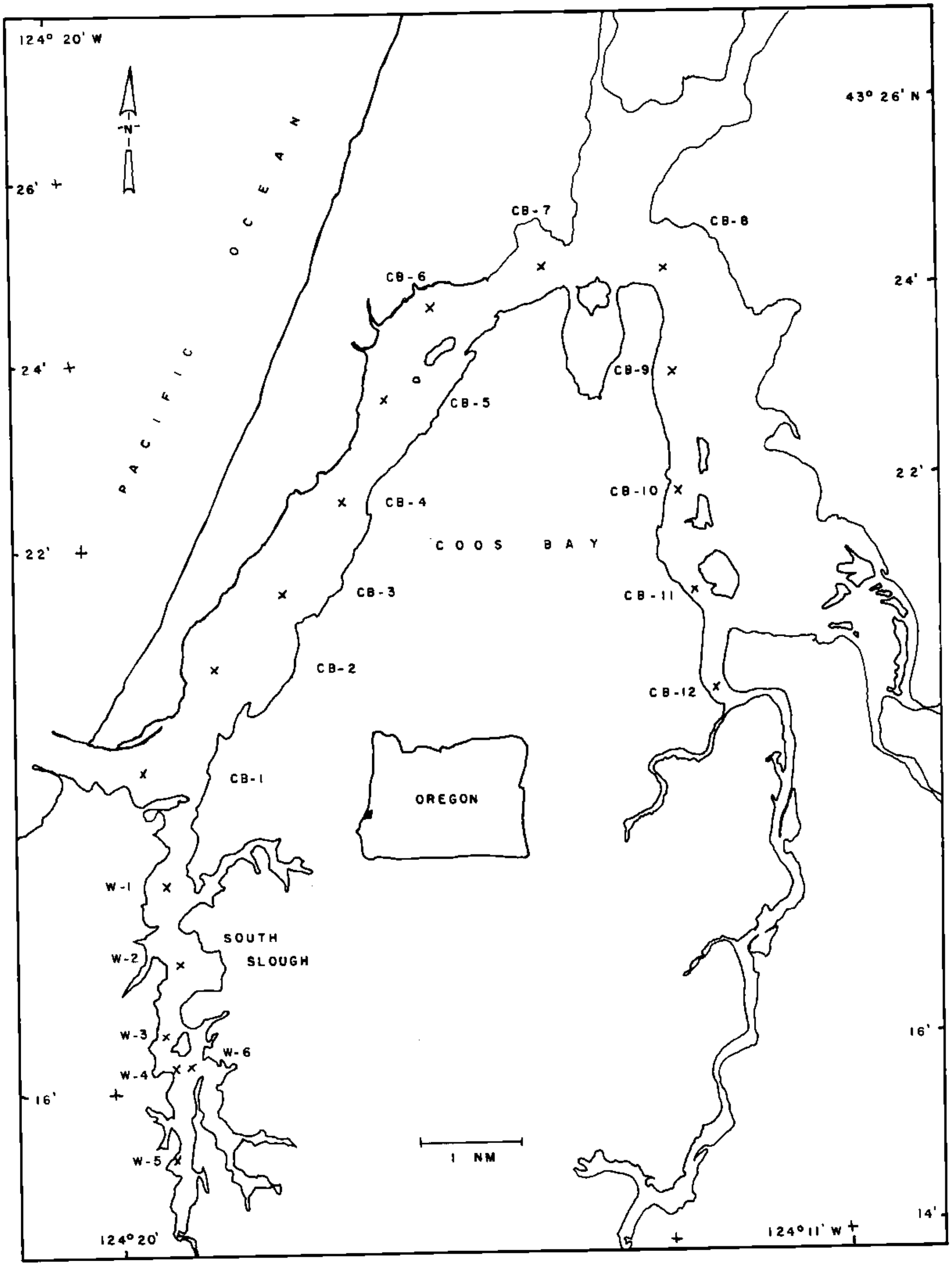


Figure 1. Map of Coos Bay, Oregon, showing station locations.

study the microvertical stratification of microfauna. The instrument described by Prych and Hubbell (1966), though large and cumbersome, is apparently highly effective, but again the diameter of 4.75 cm makes it less than useful for macrofauna. Gulliksen and Derås (1975) devised a pumping system for sampling bottom fauna, but stratification is lost in sampling. Brett (1964) stated that stratified samples were obtainable with his diver-operated suction dredge, but the device is limited to areas where a diver can work in safety. High current velocities and traffic volume make this less than feasible in the dredged channel of Coos Bay. The Knudsen sampler (1927) takes good quantitative samples, with stratification intact, but it requires the winch capabilities of a very large support vessel. The Bouma box corer (Bouma, 1969) proved satisfactory for the deeper portion of the sampling program. The Bouma sampler, as well as the related Reineck box sampler (Reineck, 1961) for intertidal work, are gravity driven corers with a mechanism ensuring closure of the bottom of the box. The Bouma sampler is a large and sometimes unwieldy instrument requiring considerable winch capabilities. This box corer takes a sample 21 by 30 cm in cross section, with a maximum sample depth of 45 cm (see Figure 2). The 83-ft R/V CAYUSE was used for an operating platform with this instrument. The box corer took satisfactory samples on all substrates encountered, with the exception of large (10 to 15 cm) shell.

The shallow depth of South Slough prevents operation of a vessel large enough to permit use of the box corer. A lightweight instrument was required which could be employed in either intertidal areas, or

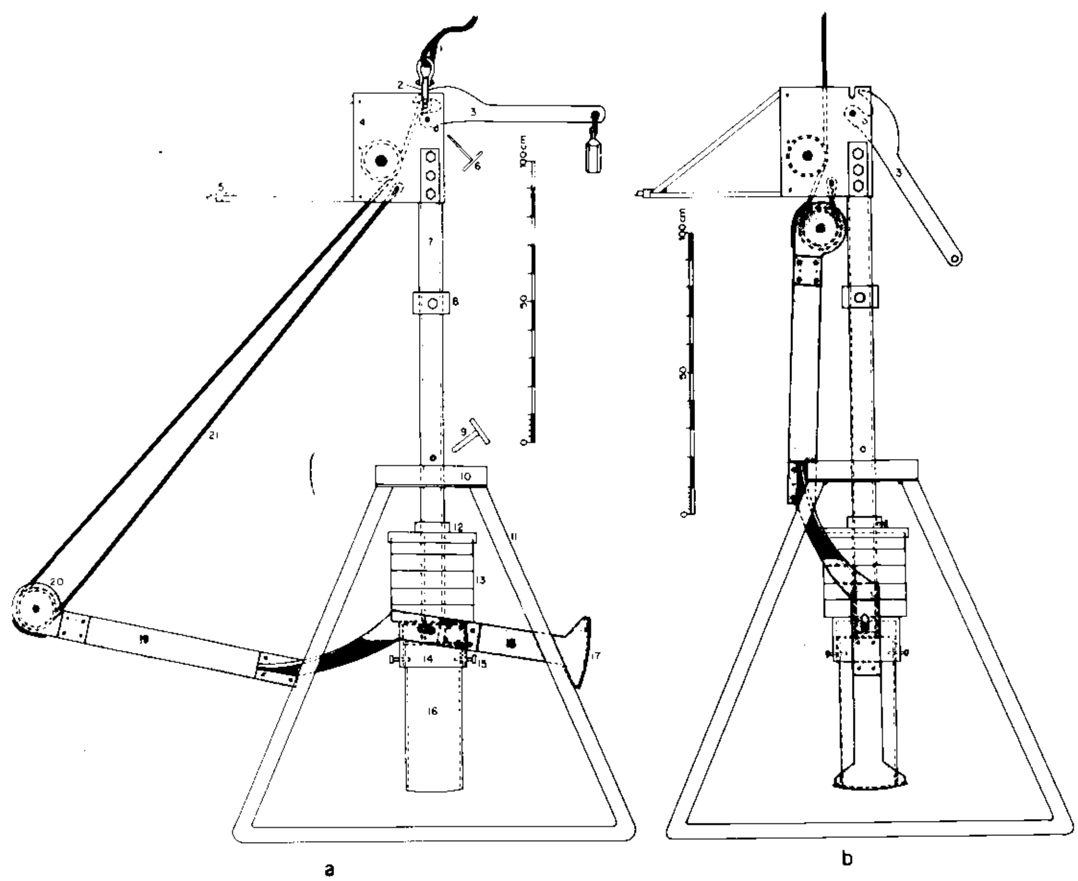


Figure 2. The Bouma box corer. A, open position for lowering. B, closed position with sample collected. [from Bouma, 1969].

subtidally by a diver. Kaplan et al. (1974) have devised a suction sampler with a reversing bucket, which is usable from a small boat. Their model samples only to 30 cm, however, and is limited to water shallower than the handle. Walker (1967) described a coring system consisting of an anchor chamber which the diver pushes into the sediment, and a pressure driven piston which forces the coring tube into the sediment. His device is again primarily a geological tool, designed for cores of 2.4 to 4.3 m in length.

Barnett and Hardy (1967) have implemented an airlift pump to drive a sampling cylinder into the deposit, with subsequent removal of the lid, and excavation of the interior with a suction pump. The instrument which Mr. Danil Hancock and I devised utilizes an airlift pump to drive a core barrel into the sediment, removal of the core being aided by a winch.

The airlift principle has been employed by several workers, primarily for excavation of sediment (Flemming, 1962; Mackereth, 1958; Simpson and Heydorn, 1965).

Appendix A gives specifications and operating procedures for the airlift corer used in this study.

Cores were taken with the Bouma box corer at twelve stations in the dredged shipping channel of Coos Bay. Six cores were taken with the airlift corer in South Slough. Figure 1 shows the station locations; Table 1 provides date of collection, depth of water in which the cores were taken, depth of penetration, and sediment type. All cores were sectioned at five centimetre intervals, fixed in 10% forma-

Table 1. Station data. Water depth, depth of core penetration, general sediment type, and distance from the mouth of Coos Bay. CB indicates dredged channel; W refers to South Slough.

Station	Water Depth (m)	Depth of Core (cm)	Distance from Mouth (nm)	Sediment Type
CB-1	12.8	23.5	1.0	sand
CB-2	8.5	10.0	2.0	sand
CB-3	8.4	25.0	3.0	sand
CB-4	9.3	12.0	4.0	shell
CB-5	8.4	22.0	5.0	sand
CB-6	9.5	27.5	6.0	sand
CB-7	9.6	21.5	7.0	sand, wood
CB-8	10.3	15.0	8.0	sand, shell
CB-9	10.6	15.0	9.0	sand, wood, shell
CB-10	10.3	45.0	10.0	clayey mud
CB-11	11.5	22.0	11.0	sand, wood
CB-12	11.6	45.0	12.0	clayey mud
W-1	1.2	50.0	2.3	sandy mud
W-2	3.0	80.0	3.1	sand, shell, mud
W-3	1.0	55.0	3.7	sandy mud
W-4	1.2	50.0	4.0	mud
W-5	1.0	52.5	5.0	mud
W-6	0.6	57.5	4.1	sand

lin-seawater solution, and stored in plastic bags for transport to the laboratory. Approximately forty grams of sediment were removed from each box core section and frozen for granulometric and volatile solids determinations.

The sections were washed in the laboratory, using a 0.5 mm screen, one to two weeks after collection. Material remaining on the sieve was stained with Rose Bengal (a bacteriological protein stain) and preserved in 70% isopropanol. Animals were removed by hand picking under a dissecting microscope, and identified to the lowest possible taxon. Nematodes and oligochaetes presented insurmountable taxonomic difficulties, and were not identified to species.

Grain size analysis was performed by the hydrometer method (Emery, 1938; Krumbein and Pettijohn, 1938; Bouyoucos, 1936). Volatile solids were determined as weight loss on ignition to 550° C. Dr. C. Sollitt (Department of Ocean Engineering, Oregon State University, Corvallis) provided sediment samples (sectioned at 10 cm intervals) for the South Slough stations.

STATISTICS

Diversity

Most recent community ecologists, in attempting to compare different biocoenoses, have used the concept of species diversity as an index measuring both the absolute number of species (richness), and the distribution of individuals among those species (evenness or equitability). The efficacy or pertinence of various of these indices has been much debated in recent literature. Most community ecologists would agree that some measure of diversity, as defined above, has utility in comparative studies. Many, however, fall into the trap suggested by Pielou: "The belief (or superstition) of some ecologists that a diversity index provides a basis (or talisman) for reaching a full understanding of community structure is wholly unfounded" (Pielou, 1975, p. 19). One must beware the all too common pitfall of employing a single statistic in attempting to describe a community. When used in conjunction with a measure of evenness, and a precise definition of taxocoenotic, temporal, and spatial limits, a diversity index may have considerable heuristic utility.

With this caveat in mind, I have utilized Shannon's index of diversity (Shannon and Weaver, 1949). This is probably the most widely used diversity statistic in community ecology. It was originally proposed as a measure of the information content of a code. The index, H", is

$$H'' = -\sum_{1}^{s} p_i \log p_i$$

where p_i represents the proportion of individuals belonging to the ith species. Any base may be used for the logarithm; base 2 and base e are the most common - I have used the latter. The index varies from zero (one species present) to the theoretical maximum of the logarithm of the number of species.

Evenness

The evenness measure which I employed is simply the ratio of observed Shannon diversity to the theoretical maximum:

$$H''/H''_{max|S}$$

where $H''_{max|S} = \log S$.

A related redundancy index, R_I, is derived from H" and its theoretical maximum and minimum for a given number of species:

$$R_I = \frac{H''_{max|S} - H''}{H''_{max|S} - H''_{min|S}}$$

where H" is the observed Shannon diversity, $H''_{max|S} = \log S$, and $H''_{min|S}$ is

$$H''_{min|S} = -[(S-1)(\frac{1}{N} \log \frac{1}{N}) + \frac{N-S+1}{N} \log \frac{N-S+1}{N}]$$

where S is the number of species and N is the total number of individuals in the collection. This redundancy index varies from zero, in a condition of maximum evenness, to unity, when maximum dominance (or redundancy) is encountered.

Heip (1974) has shown that $H''/H''_{max|S}$ remains constant when the number of individuals is incremented by a common multiple, and Sheldon (1969) has demonstrated that this evenness index is essentially independent of the number of species. Figure 3 demonstrates the superiority of $H''/H''_{max|S}$ over $1-R_I$. Case I illustrates the change in the two evenness measures when S and N increase, but the n_i's remain constant and equal for all species. The measure, $1-R_I$, exhibits a similar, but even greater, dependence on S when N remains constant at one thousand individuals, and all species have an equal proportion of the individuals. The two lower curves (Case II) ilustrate the behaviour of these indices when all but one species have unit representation in a collec-

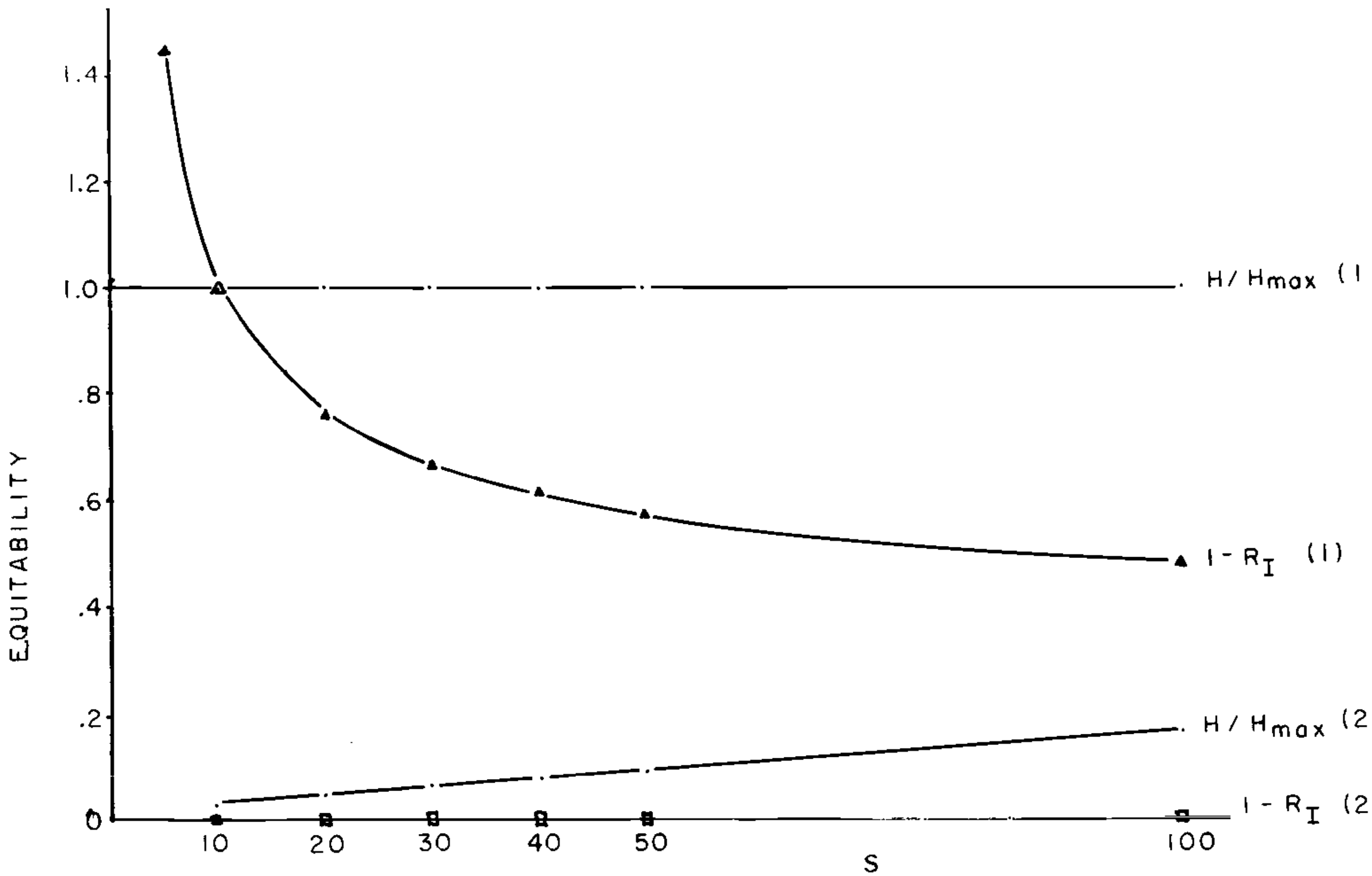


Figure 3. Equitability as a function of the number of species, S, for the evenness measures, $1-R_I$ and H''/H''_{max}. Case (1): all species equally abundant, N equals ten times S. Case (2): all species but one with representation by a single individual, N=1000.

tion of one thousand individuals. In this instance, $1-R_I$ is everywhere equal to zero.

The Equivalent Number of Equally Common Species

Given an observed value of H" less than the theoretical maximum, one may calculate the number of species, which, if equally abundant, would generate the observed value of H". This quantity, E, is equal to the antilogarithm of H", and is known as the equivalent number of equally common species. This expression probably has some utility in comparing samples from different biocoenoses. The index is related to both diversity and evenness, and may be thought of as a measure of niche diversity and level of occupation. A community with a low value of E has a high degree of dominance by one or more species. The other species are relatively underrepresented, giving rise to low diversity, low evenness, and a consequently low equivalent number of equally common species.

Niche Breadth

Niche breadth is a statistic measuring the proportion of sites at which a taxon occurs. I have utilized the following measure of niche breadth, based on relative rather than absolute abundances, and attributable to Levins (1968):

$$B = \exp \left[- \sum_{1}^{k} \frac{p_{ij}}{R_j} \log_e \frac{p_{ij}}{R_j} \right]$$

where k is the number of sites, p_{ij} is the proportion of individuals of species j occurring at site i, and R_j is the sum of the p_{ij}'s for species j over all sites. The measure ranges from unity to k, the number of sites at which the taxon occurs.

Mean niche breadth is an assessment of the average niche breadth of species at one station, or how 'cosmopolitan' in character a station is. The unweighted mean niche breadth, $\overline{B}_i$, is

$$\overline{B}_i = \frac{1}{s_i} \sum_{1}^{s_i} B_j$$

and the weighted average, $\overline{B}_{wi}$, is

$$\overline{B}_{wi} = \sum_{1}^{s_i} p_{ij} \, B_j$$

where B_j is the niche breadth of species j and p_{ij} is the proportion of individuals of species j at site i.

ESIMI

Correlations between pairs of species were calculated as ESIMI:

$$\text{ESIMI} = \frac{\sum_{1}^{k} p_{Ai} \, p_{Bi}}{\left[\sum_{1}^{k} p_{Ai}^{2} \sum_{1}^{k} p_{Bi}^{2} \right]^{1/2}}$$

where p_{Ai} is the proportion of individuals in species A at station i, and p_{Bi} is the proportion of individuals in species B at station i. Summation occurs over all sites at which the taxa are present. This measure is analogous to a correlation coefficient, but varies from zero to unity rather than from -1 to +1.

SIMI

A similar statistic may be calculated for pairs of stations (see Stander, 1970):

$$\mathrm{SIMI} = \frac{\sum_{1}^{s} p_{Aj}\, p_{Bj}}{\left[\sum_{1}^{s} p_{Aj}^{2} \sum_{1}^{s} p_{Bj}^{2}\right]^{1/2}}$$

where p_{Aj} is the proportion of individuals found in species j at station A, and p_{Bj} is a similar quantity for station B. Summation occurs over all species common to the two stations. The ESIMI and SIMI statistics are closely related, both mathematically, and intuitively, to Levin's (1968) niche overlap index, which was derived from equations due to Volterra (1926) and Gause (1934).

Clustering

Two clustering algorithms were utilized: one for grouping species over stations; one for grouping stations. The former necessitated the use of McIntire's (unpublished) CLUSB program, which uses a divisive nonhierarchical method; the latter required Richardson's (unpublished) MCRLIB (due to the large size of the data set), which is an agglomerative hierarchical method. The CLUSB program maximizes the homogeneity of each group by minimizing the within-cluster sum of squares (SS):

$$SS = \sum_{h=1}^{k} \sum_{i \epsilon S_h} \sum_{j=1}^{p} (x_{ij} - \bar{x}_j)^2$$

where x_{ij} is the proportionalized abundance of species i at station j, k is the number of clusters, and $i \varepsilon S_h$ denotes the subset of observations in cluster h.

Richardson's algorithm utilizes the Bray-Curtis dissimilarity measure (Bray and Curtis, 1957) as the basis for clustering. This index has been used by many workers in community ecology (Day et al., 1971; Field, 1969, 1970, 1971; Field and Macfarlane, 1968; Stephenson and Williams, 1971; Stephenson et al., 1972). This index (BC) is as follows:

$$BC = \frac{\sum_{1}^{s} |p_{Aj} - p_{Bj}|}{\sum_{1}^{s} (p_{Aj} + p_{Bj})}$$

where s is the number of species, and p_{Aj} and p_{Bj} are the proportions of individuals of species j at sites A and B.

Diversity, evenness, the equivalent number of equally common species, niche breadth, ESIMI, and SIMI were calculated by the AIDONE (Analysis of Information and Diversity for ONE block of data) and AIDN (Analysis of Information and Diversity for N blocks of data) programs developed by Overton (1974), and run on Oregon State University's Open Shop Operating System (OS3).

Multiple regression analysis was performed in the SIPS (Statistical Interactive Programming System) subsystem of OS3. The independent variables were added according to the STEPWISE procedure.

The MCRLIB clustering algorithm was run on the CYBER operating system of the Oregon State University Computer Center.

RESULTS

Twelve Bouma box cores were obtained from the dredged channel of Coos Bay on 5 May 1975; six airlift cores were taken in South Slough on 19 and 20 April 1975. Station locations are shown in Figure 1; CB and W refer to box and airlift cores, respectively. Table 1 lists pertinent station data. A total of 23,834 individuals in 173 taxa were identified and enumerated from 107 5-cm sections.

Figure 4 demonstrates how numbers of taxa varied with station; Figure 5 gives similar information for numbers of individuals (Figures 4 through 35, and Tables 2 through 7 may be found at the end of this section, in the order discussed, beginning on page 36). It may be seen that station CB-4 had by far the greatest number of species, while the core at W-3 showed maximal numbers of individuals. Figures 6, and 7 through 9 demonstrate the general trend of decreasing species, and individual, abundances with increasing depth in the sediment. The South Slough cores were significantly deeper than the dredged channel samples, owing to the greater efficiency of the airlift corer used in that area.

The raw species abundance data are presented in Appendix B. As the box corer samples an area 3.57 times as great as the airlift corer, counts for CB stations would need to be reduced by that fraction, and occurrences of one, two, and three organisms at those stations eliminated, to produce strict statistical equality in the two portions of the data set. As all statistical calculations performed were based on proportional (relative rather than absolute) species abundances, such a modification was deemed unnecessary.

The dredged channel stations (CB) were found to contain a large number of taxa not present at the South Slough stations (see Table 2).

Figure 10 demonstrates diversity (H") values for individual stations; corresponding evenness ($H''/H''_{max|S}$) values may be found in Figure 11. It may be seen that station CB-4 shows the highest diversity for a sample, and W-5 the lowest. Station W-5 also shows the lowest evenness (highest redundancy or dominance), while CB-9 shows the highest evenness. Diversity and evenness values with depth in each core are plotted in Figures 12-14 and 15-17, respectively. It may be seen that diversity generally decreases with increasing depth in the sediment, while evenness remains fairly constant.

The equivalent number of equally common species (E) is given, for each core, in Figure 18; CB-4 exhibits the highest value, and W-5 the lowest. Figure 19 shows the ratio of E to S (number of species actually present) for the same samples.

Niche breadth values and k's (number of stations at which the taxon occurs) for all taxa with B greater than 3.0 are given in Table 3. It may be seen that the value for B is always less than k, as no taxon is completely evenly distributed over its range of occurrence.

Figure 20 demonstrates how mean niche breadth varies with station. Station W-5 exhibits the lowest weighted mean niche breadth; a further analysis of this statistic may be found in the Discussion section.

Analysis of correlations between pairs of species (ESIMI) yielded

Figure 21. In the body of the matrix itself, only the fourteen most common taxa occurring in both CB and W samples are considered. Below those figures may be found high ESIMI values for taxa which are restricted to one area or the other (one or more members of the pairs are localized taxa - see Table 2).

Values for SIMI (correlations between pairs of stations) may be found in Figure 22. Stations W-2 and W-4 have a SIMI value of 0.95, indicating an extremely high degree of similarity between the two samples.

The results of species clustering are given in Table 4. This is a method for isolating taxa which vary in abundance and distribution in a similar manner. Clustering was continued to the twelve cluster stage, the output limit of the program with a data set of this size.

Figure 23 presents the results of station clustering using the Bray-Curtis dissimilarity index. Stations CB-10 and CB-12, CB-5 and CB-6, W-1 and W-3, and CB-1 and CB-2 cluster at a dissimilarity of less than 0.50.

Sediment parameters measured for all stations include grain size, per cent volatile solids, and percentage of water. Grain size data are given in Table 5 as percentages of sand, silt, and clay. Although these values were obtained by hydrometer analysis, it was later deemed unnecessary to record percentages of ten different grain diameters for each sample. Figure 24 gives a graphical representation of percentage of sand for cores CB-1 through CB-12; values for W-1 through W-6 may be found in Figure 25. Volatile solids (a measure of organic matter) and water content are given as percentages (by weight) in Table 5. Figures 26 and 27 demonstrate how volatile solids vary with depth in each CB and W core, respectively; percentage water as a function of depth in the sediment may be seen in Figures 28 and 29.

Multiple regression analysis of Shannon diversity as a function of depth in core, organic content, percentage water, and grain size for the CB cores yielded the functions in Table 6. It may be seen that percentage of water alone accounts for about 60% of the variance seen in diversity values. Depth in core and percentage of sand are also significant above the $\alpha=0.99$ level. Addition of organic matter concentration to the model is not significant, when the other sediment parameters are already present. The first three variables account for 82% of the variation seen in diversity. The addition of values for the South Slough stations reduces the regression coefficients significantly (see Table 7). The sediment parameters retain their relative importance, but the amount of variation explainable by each is markedly reduced. The regression of diversity on percentage water, depth in core, and percentage sand is significant above the $\alpha=0.99$ level, but the addition of volatile solid concentration to the model is not significant. The first three variables account for 63% of the variation seen in diversity.

Figures 30, 31, and 32 demonstrate the relationship between diversity and percentage water, depth in core, and percentage sand, respectively, for the dredged channel samples. The regression of diversity on volatile solids has a regression coefficeint of -0.56 and is not plotted. The relationship between diversity and percentage water, depth in core, and percentage sand, for the pooled data (dredged channel and South Slough) are plotted in Figures 33, 34, and 35, respectively. The regression of diversity on water content has the highest regression coefficient, -0.63; none of the individual regressions explains more of the variance in diversity than this.

The multiple regression coefficient of evenness with volatile solids, percentage sand, percentage water, and depth in core is only 0.51. None of the regressions of these variables with evenness has a regression coefficient greater than 0.42, and none is plotted.

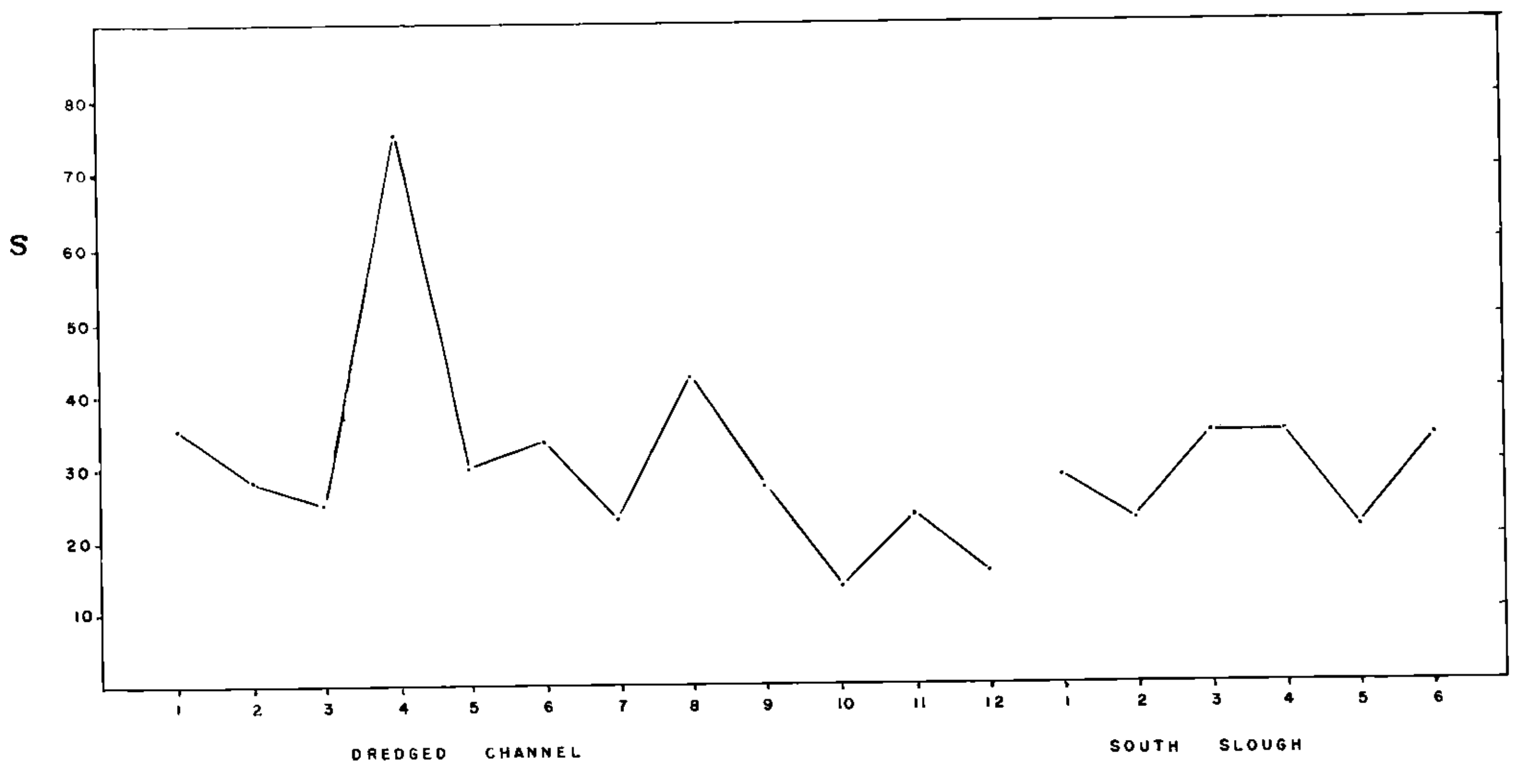


Figure 4. Number of taxa (S) as a function of distance from the mouth of Coos Bay (dredged channel stations are at one nautical mile intervals) for the dredged channel, and as a function of station number for South Slough.

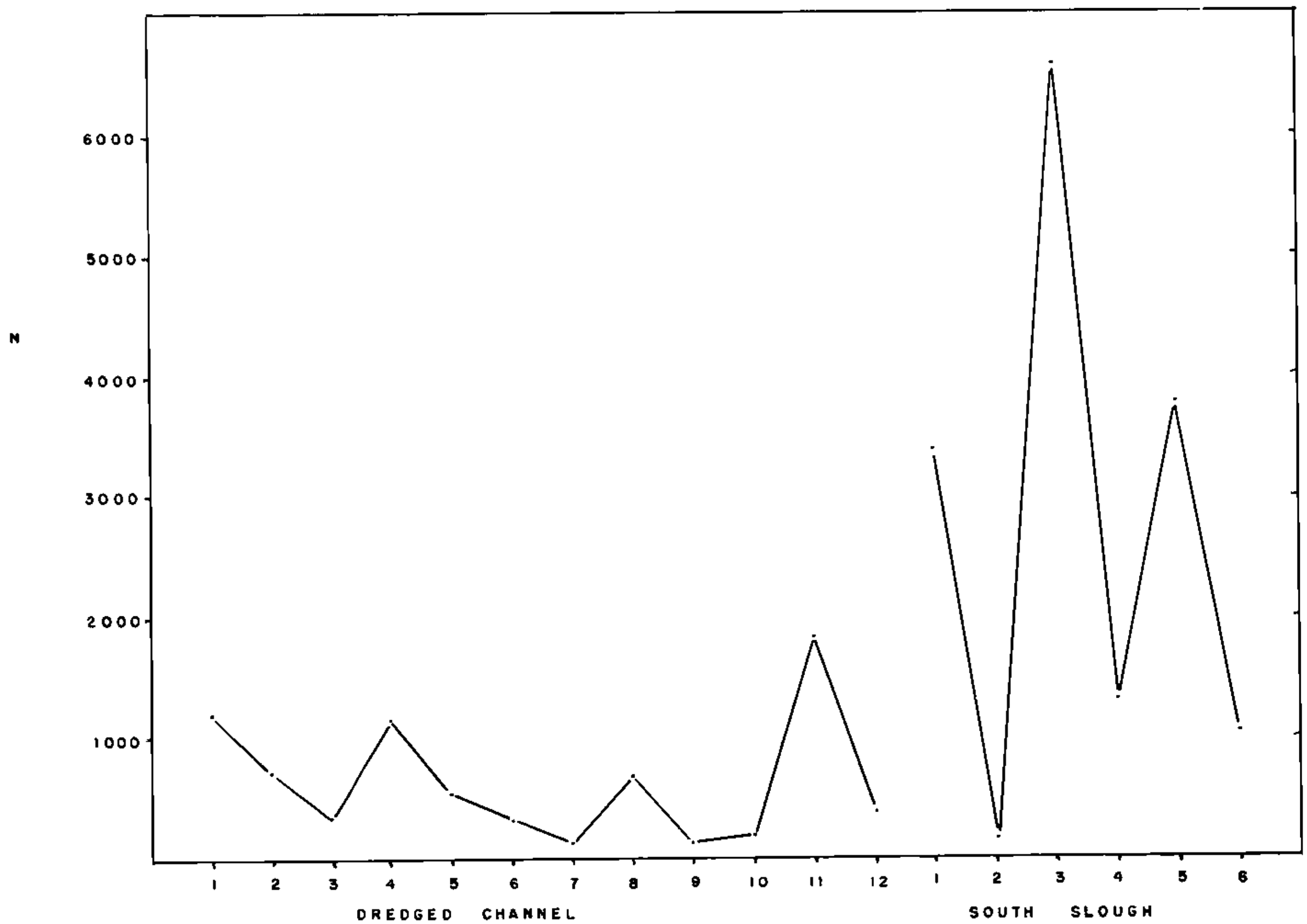


Figure 5. Number of individuals (N) as a function of distance from the mouth of Coos Bay for the dredged channel stations, and as a function of station number for South Slough.

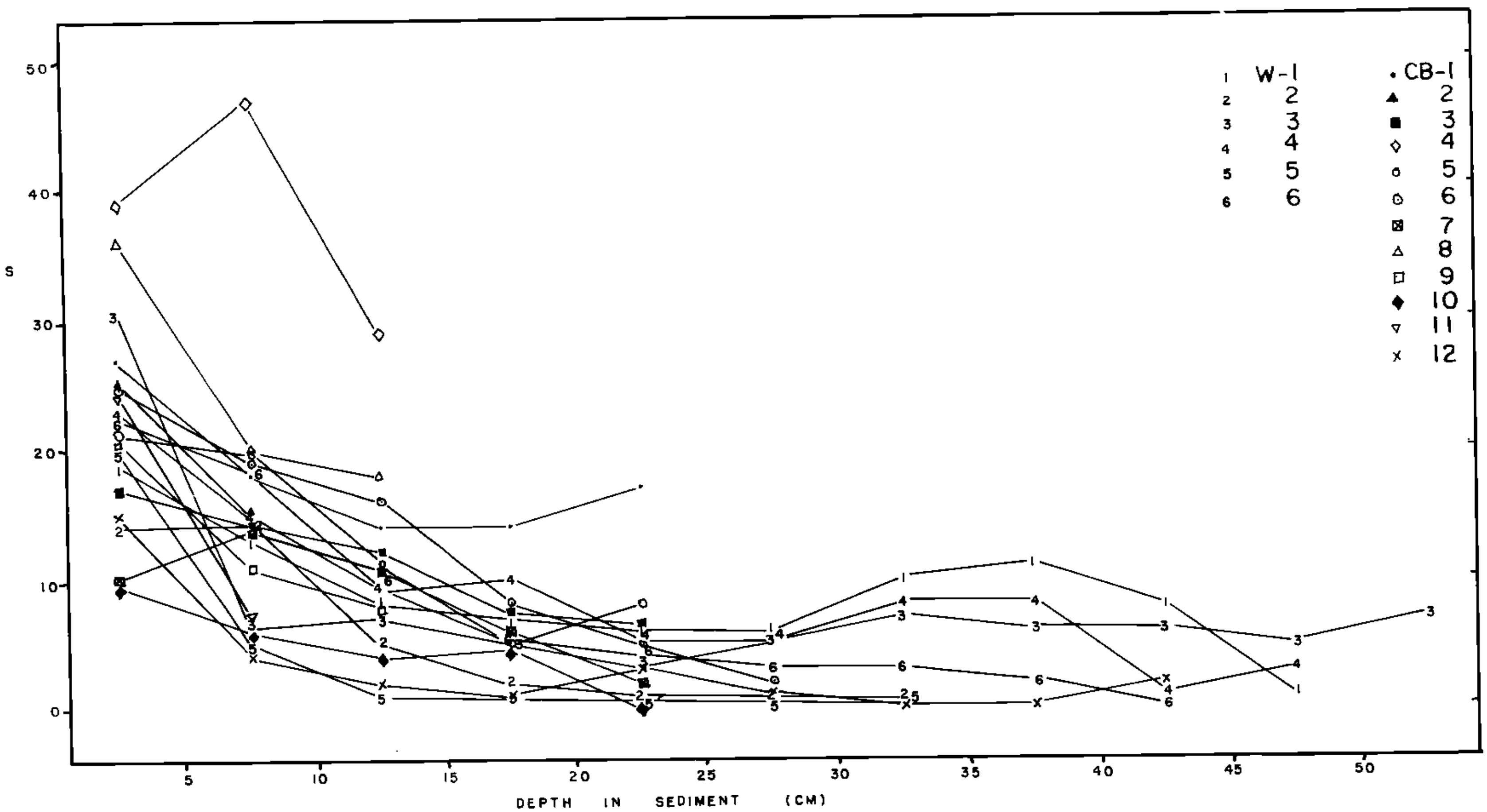


Figure 6. Number of taxa (S) as a function of depth in the sediment for all stations.

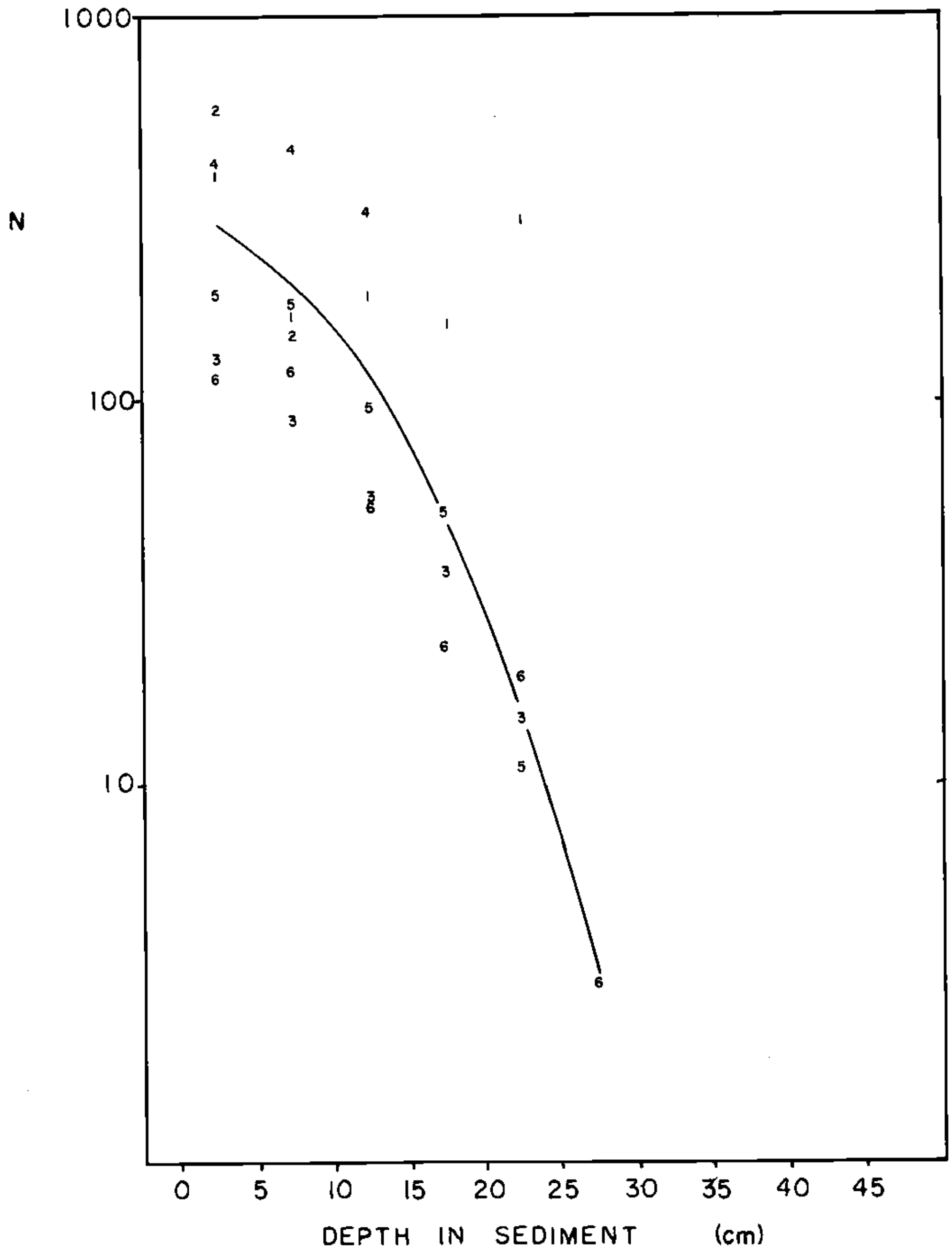


Figure 7. Number of individuals (N) as a function of depth in the sediment for stations CB-1 through CB-6 (dredged channel). Logarithmic scale; curve hand-fitted.

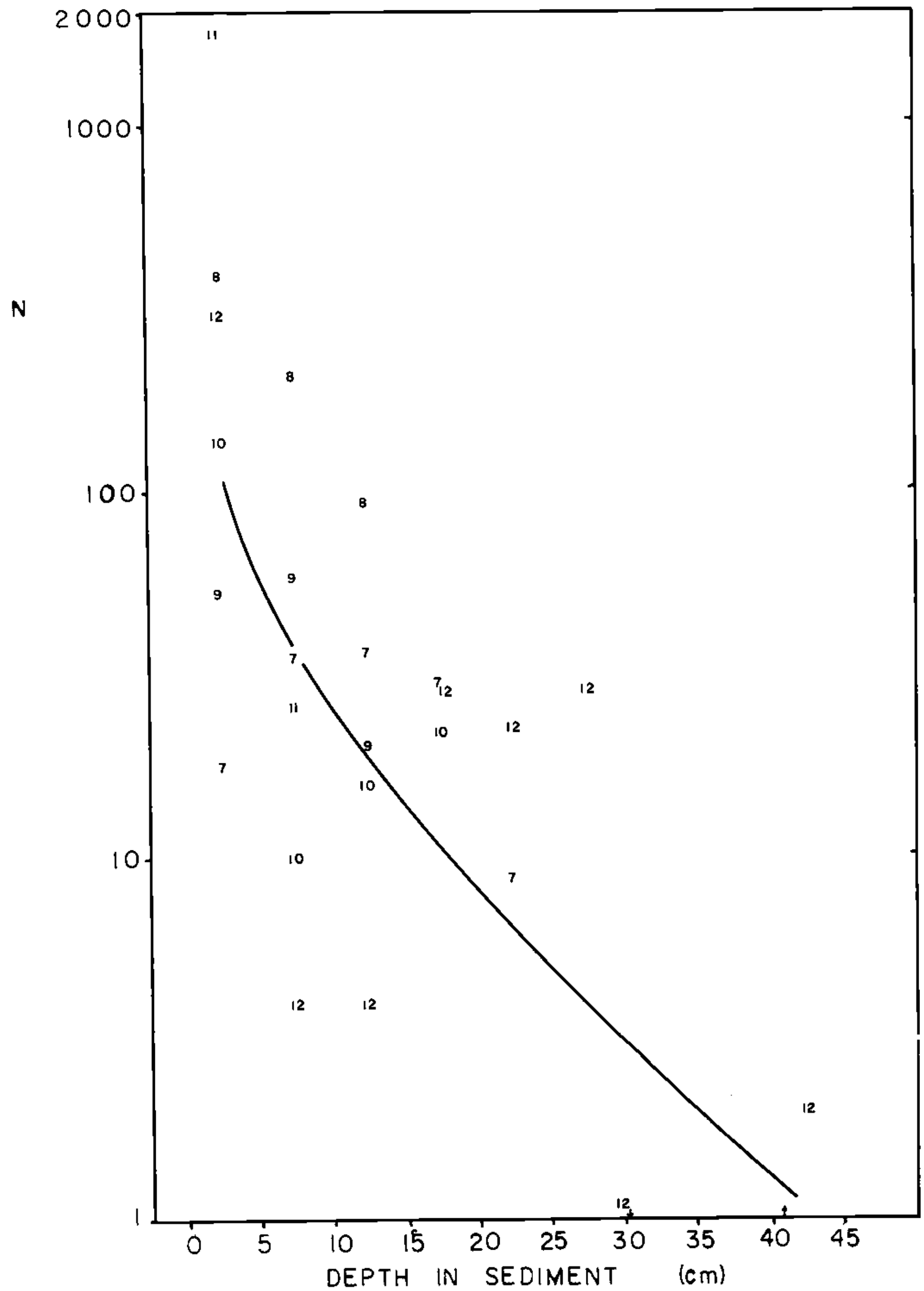


Figure 8. Number of individuals (N) as a function of depth in the sediment for stations CB-7 through CB-12 (dredged channel). Logarithmic scale; curve hand-fitted.

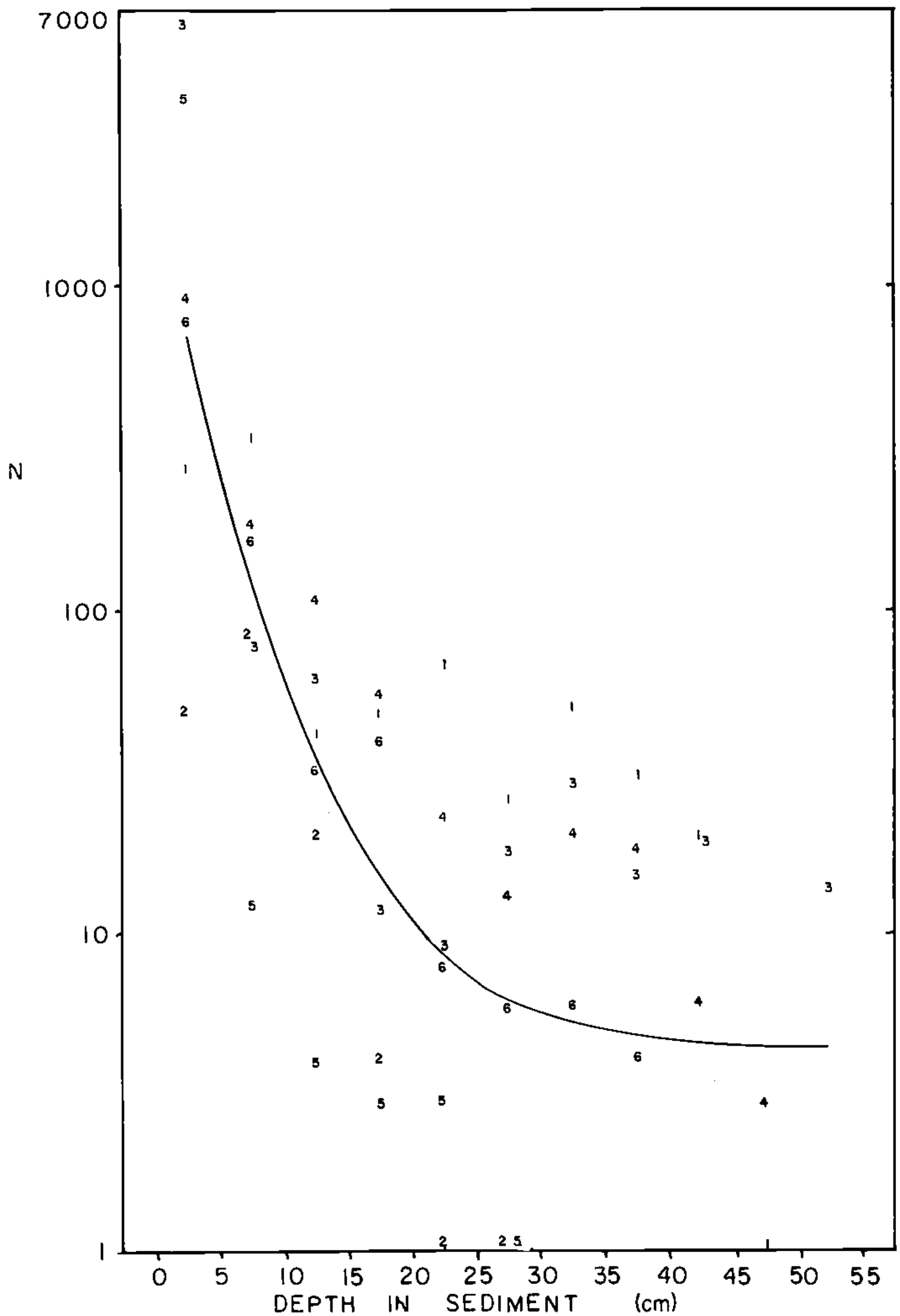


Figure 9. Number of individuals (N) as a function of depth in the sediment for stations W-1 through W-6 (South Slough). Logarithmic scale; curve hand-fitted.

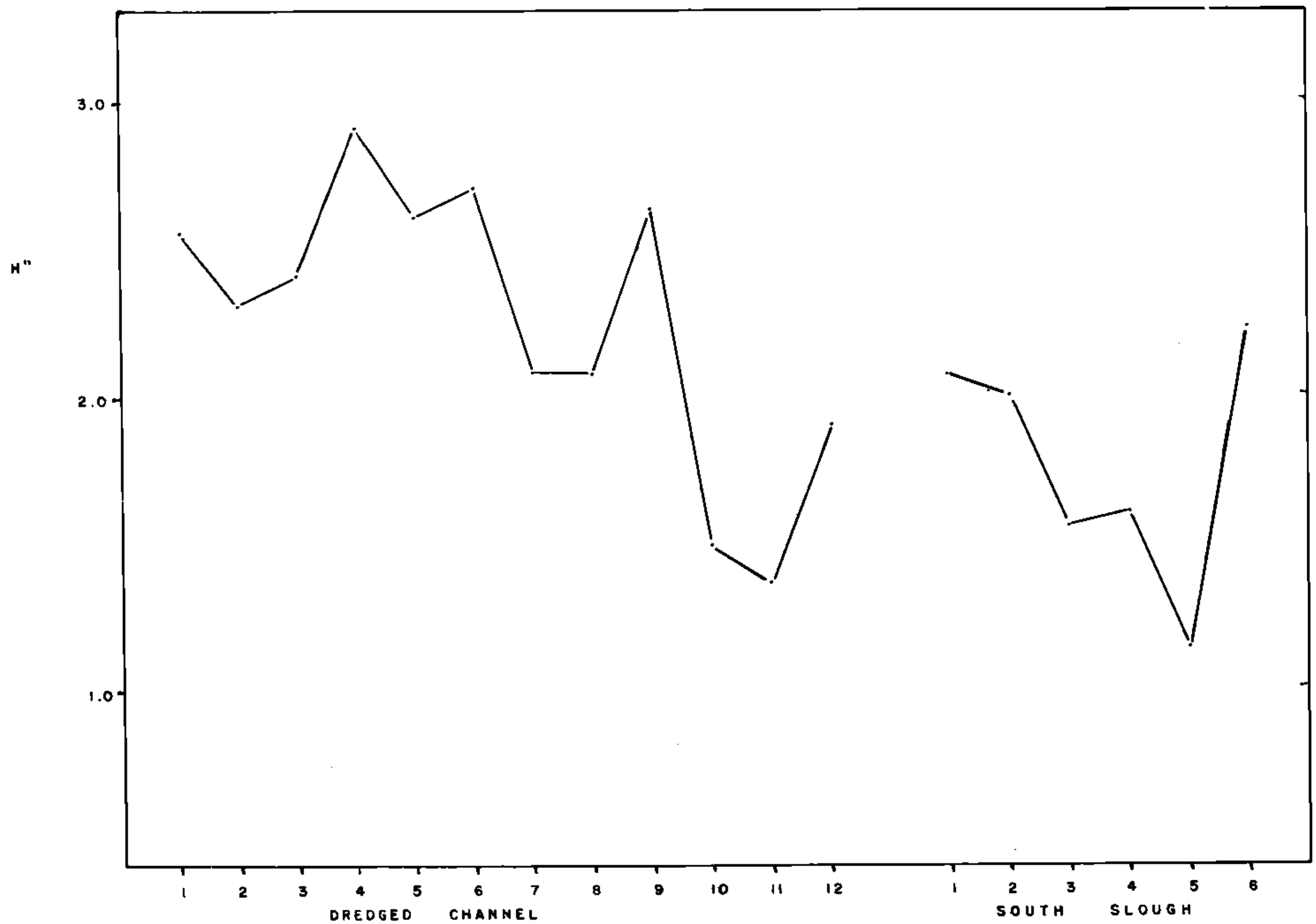


Figure 10. Diversity (H") as a function of distance from the mouth of Coos Bay (dredged channel stations), and as function of station number for South Slough.

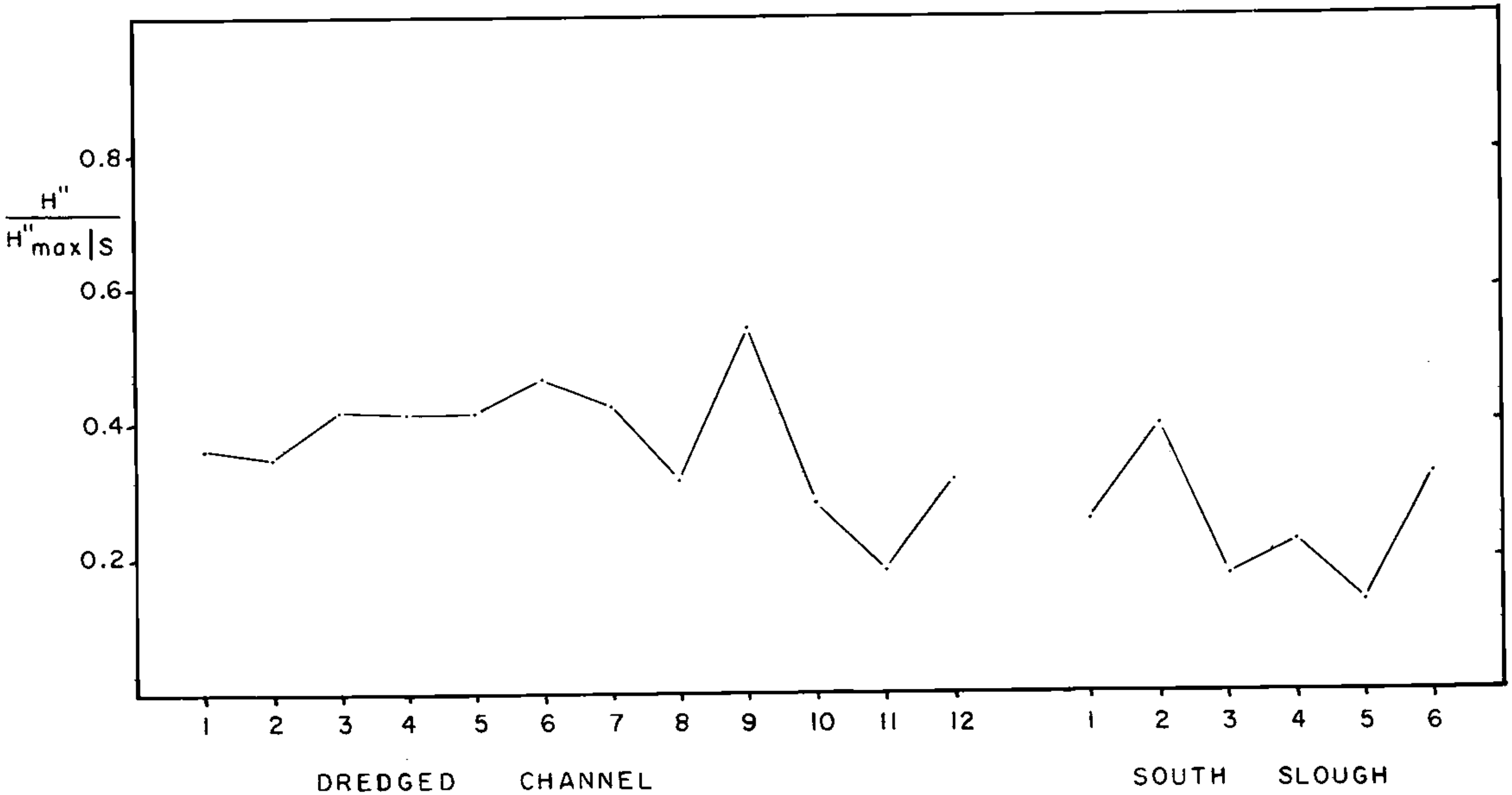


Figure 11. Evenness ($H''/H''_{max|S}$) as a function of distance from the mouth of Coos Bay (dredged channel stations), and as a function of station number in South Slough.

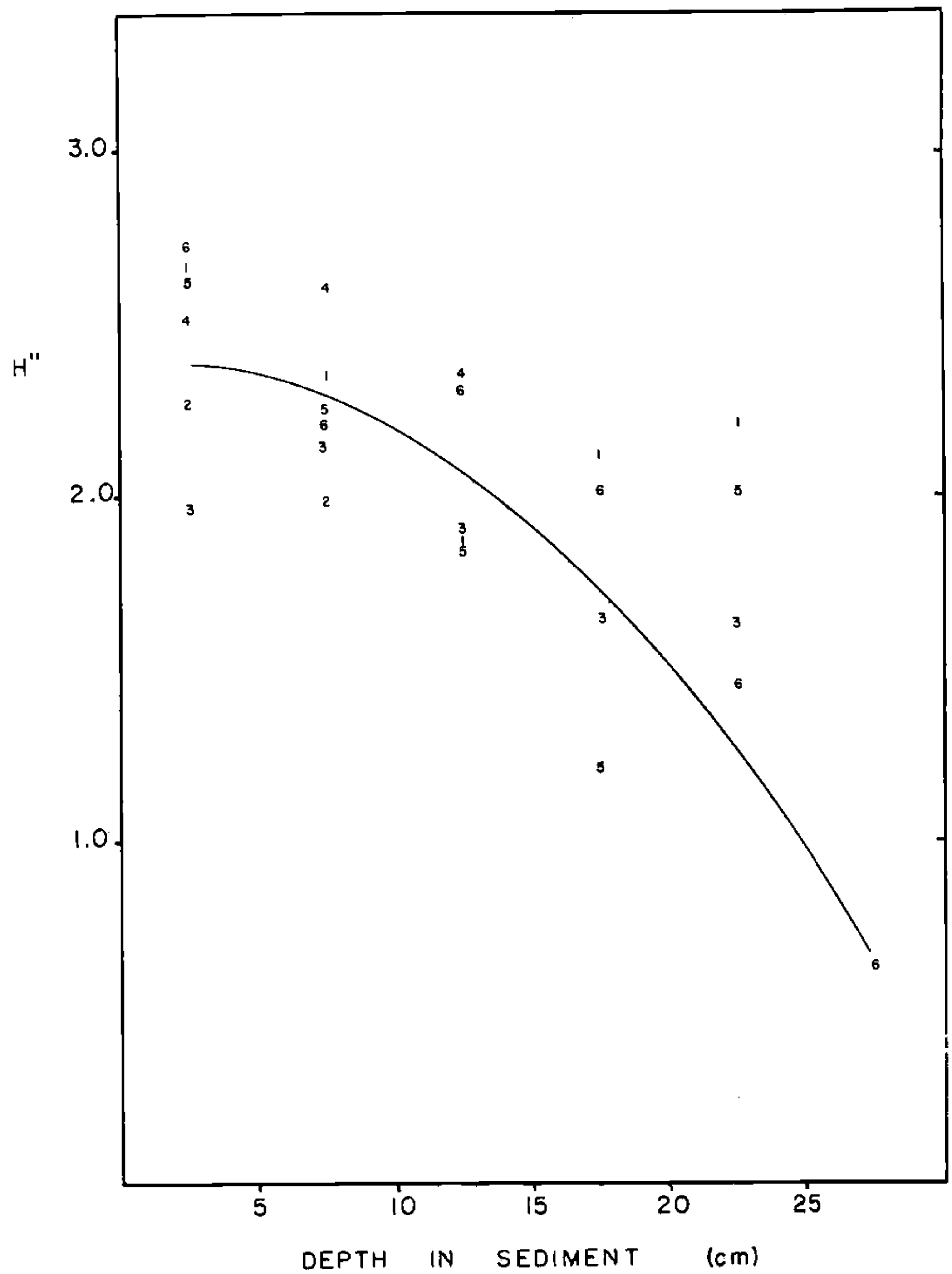


Figure 12. Diversity (H") as a function of depth in the sediment for stations CB-1 through CB-6 (dredged channel). Curve hand-fitted.

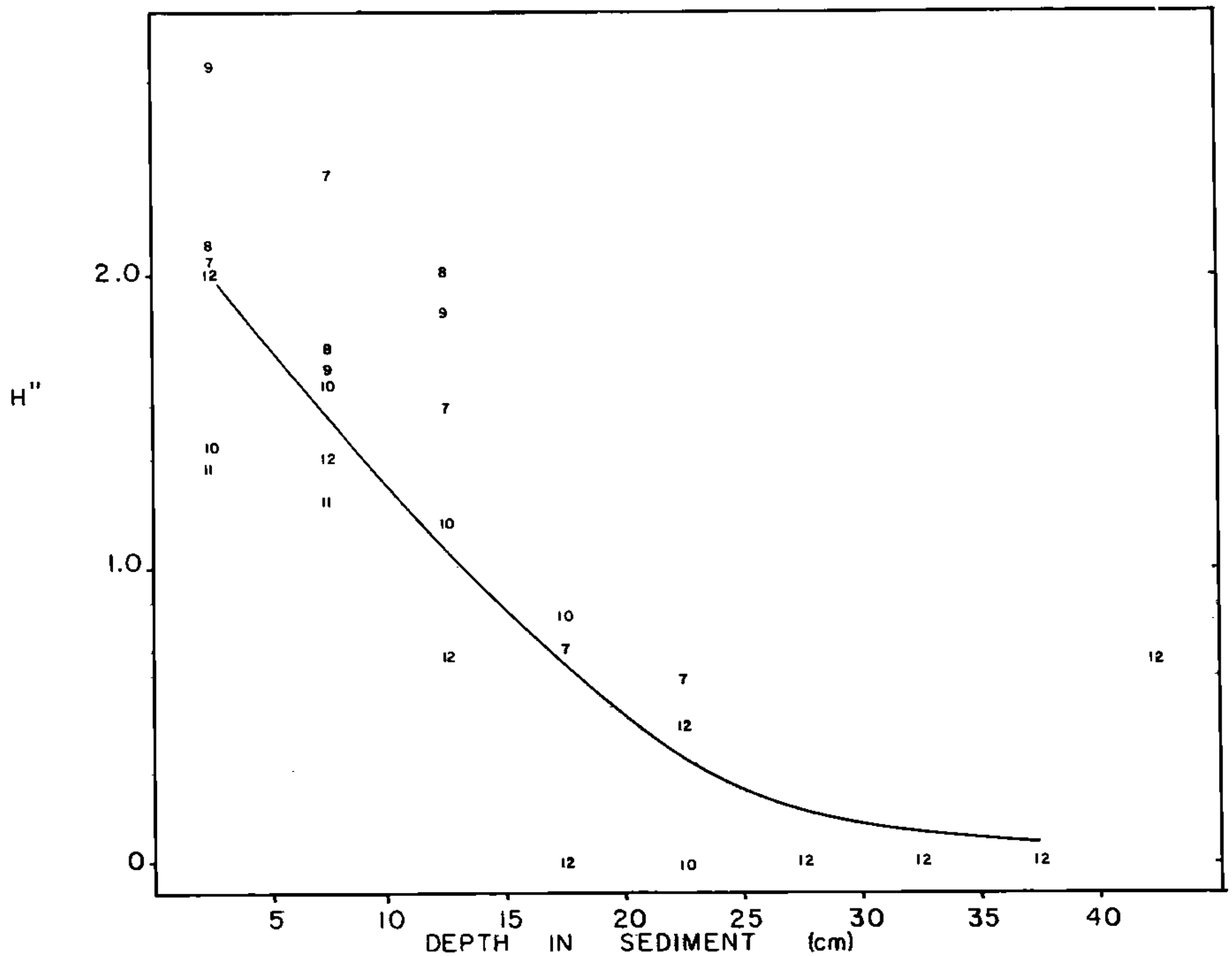


Figure 13. Diversity (H") as a function of depth in the sediment for stations CB-7 through CB-12 (dredged channel). Curve hand-fitted.

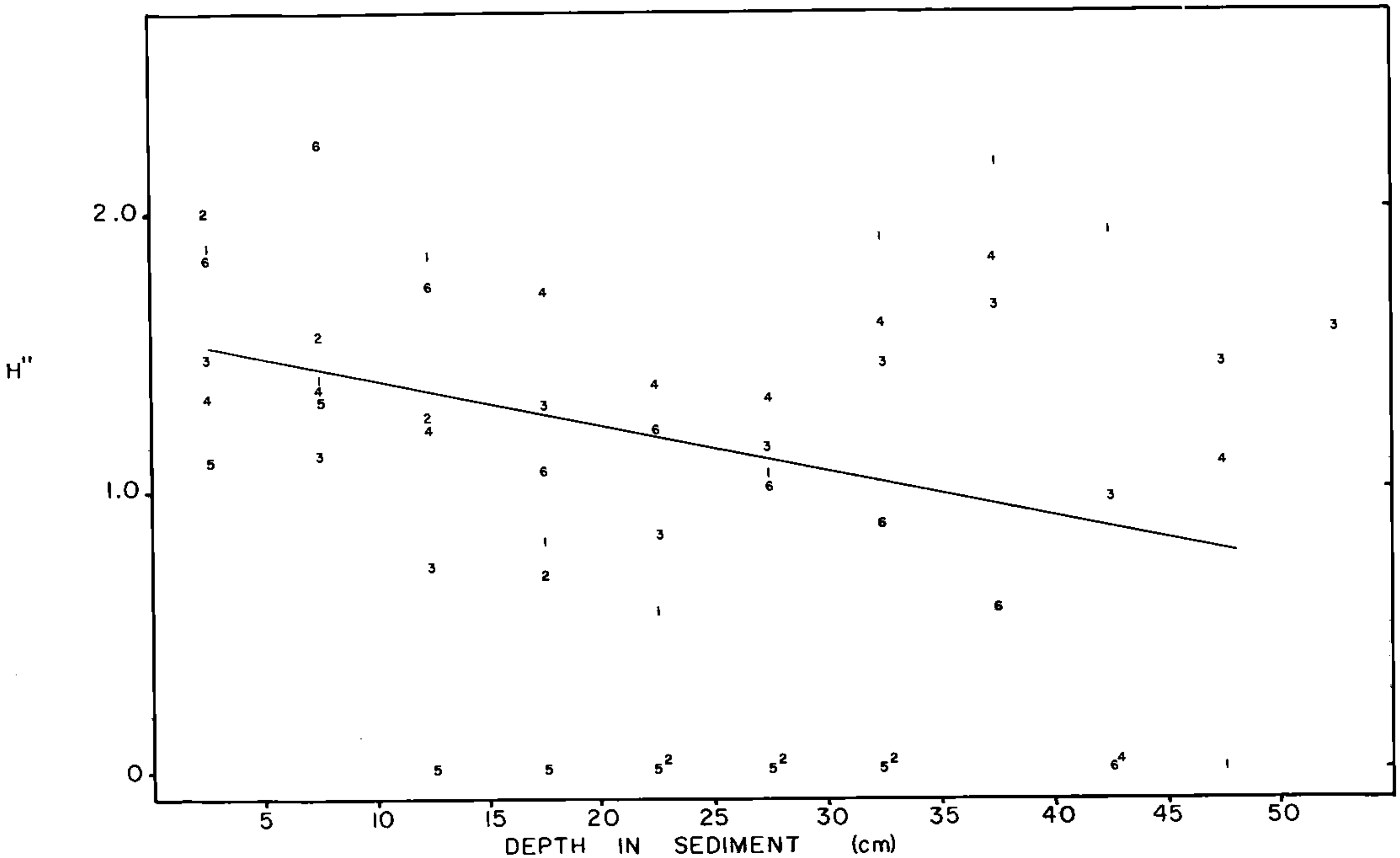


Figure 14. Diversity (H") as a function of depth in the sediment for stations W-1 through W-6 (South Slough). Curve hand-fitted.

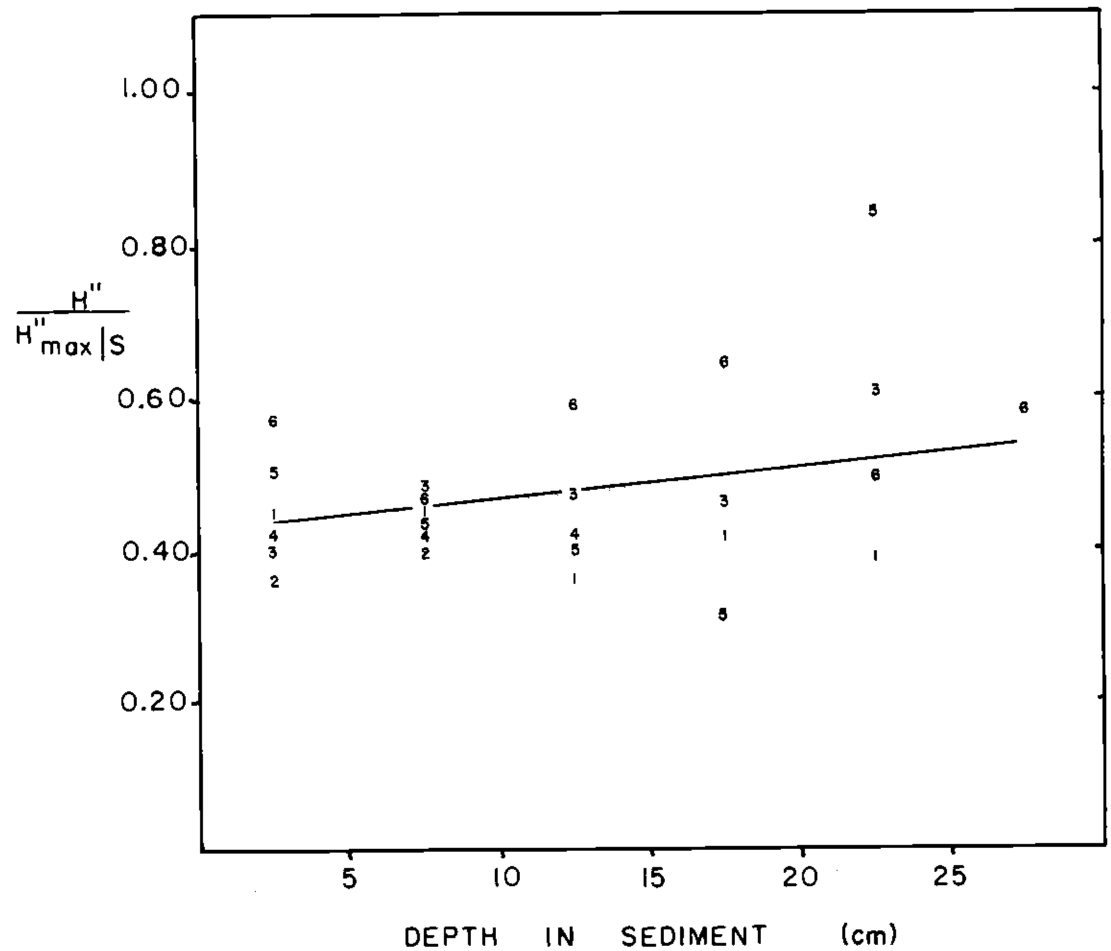


Figure 15. Evenness ($H''/H''_{max|S}$) as a function of depth in the sediment for stations CB-1 through CB-6 (dredged channel). Curve hand fitted.

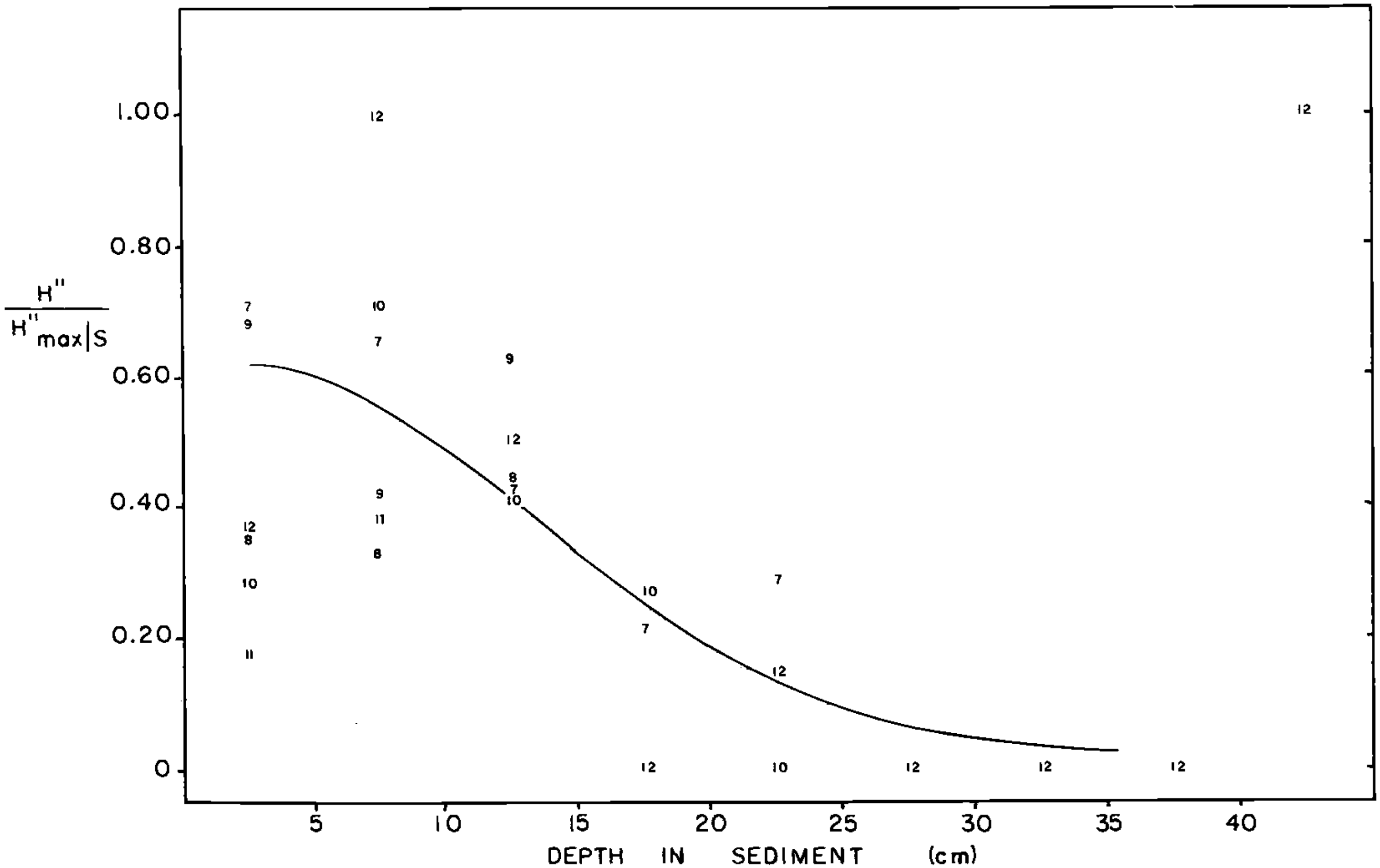


Figure 16. Evenness ($H''/H''_{max|S}$) as a function of depth in the sediment for stations CB-7 through CB-12 (dredged channel). Curve hand fitted.

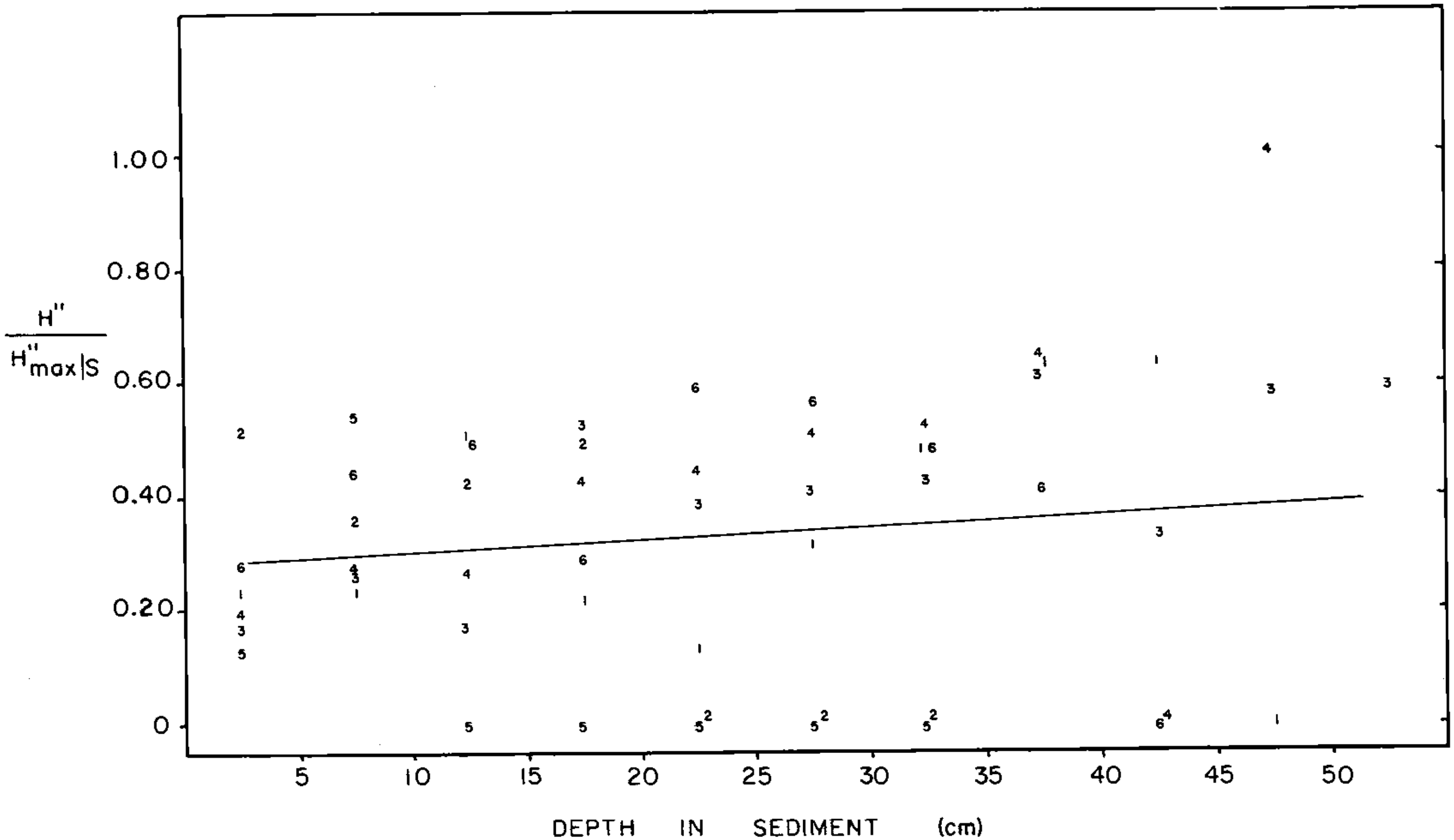


Figure 17. Evenness ($H''/H''_{max|S}$) as a function of depth in the sediment for stations W-1 through W-6 (South Slough). Curve hand fitted.

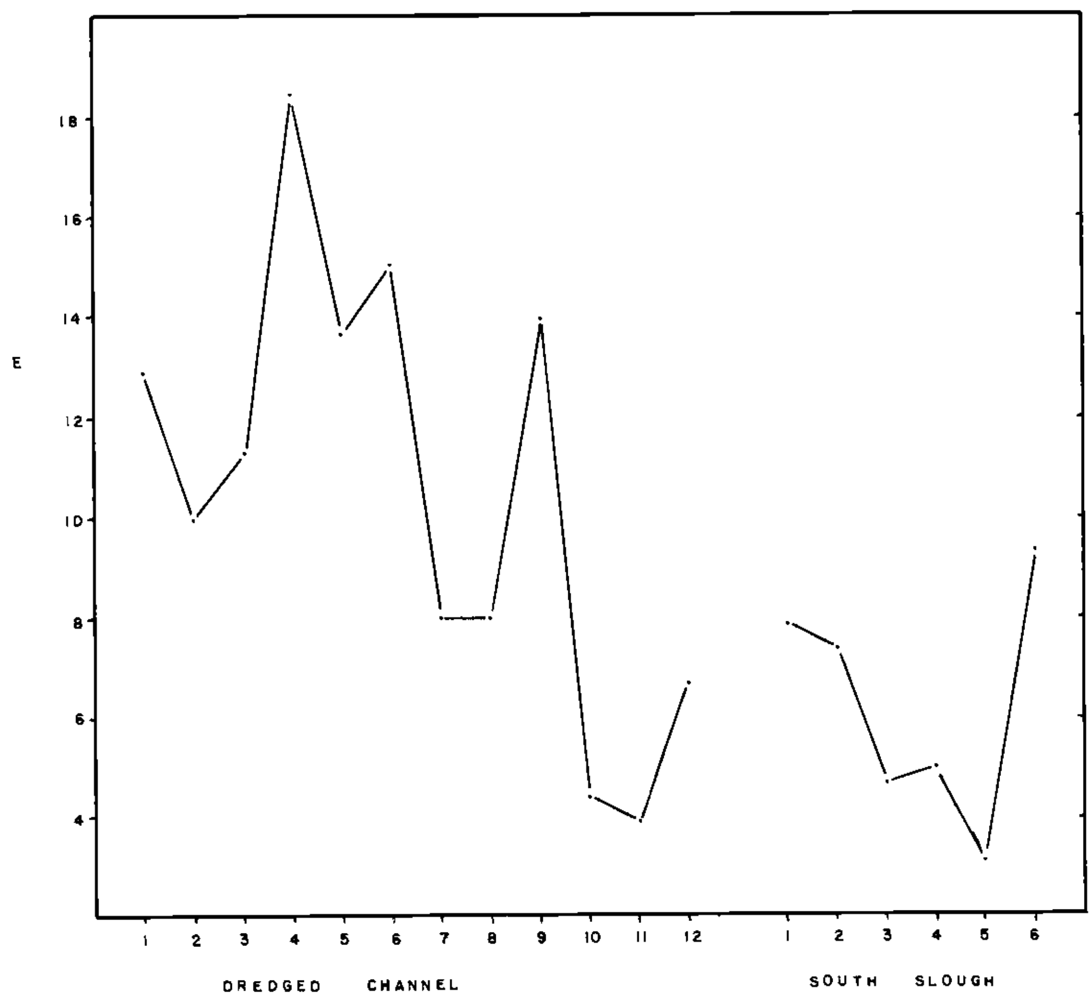


Figure 18. The equivalent number of equally common species (E) as a function of distance from the mouth of Coos Bay for the dredged channel stations, and as a function of station number for South Slough.

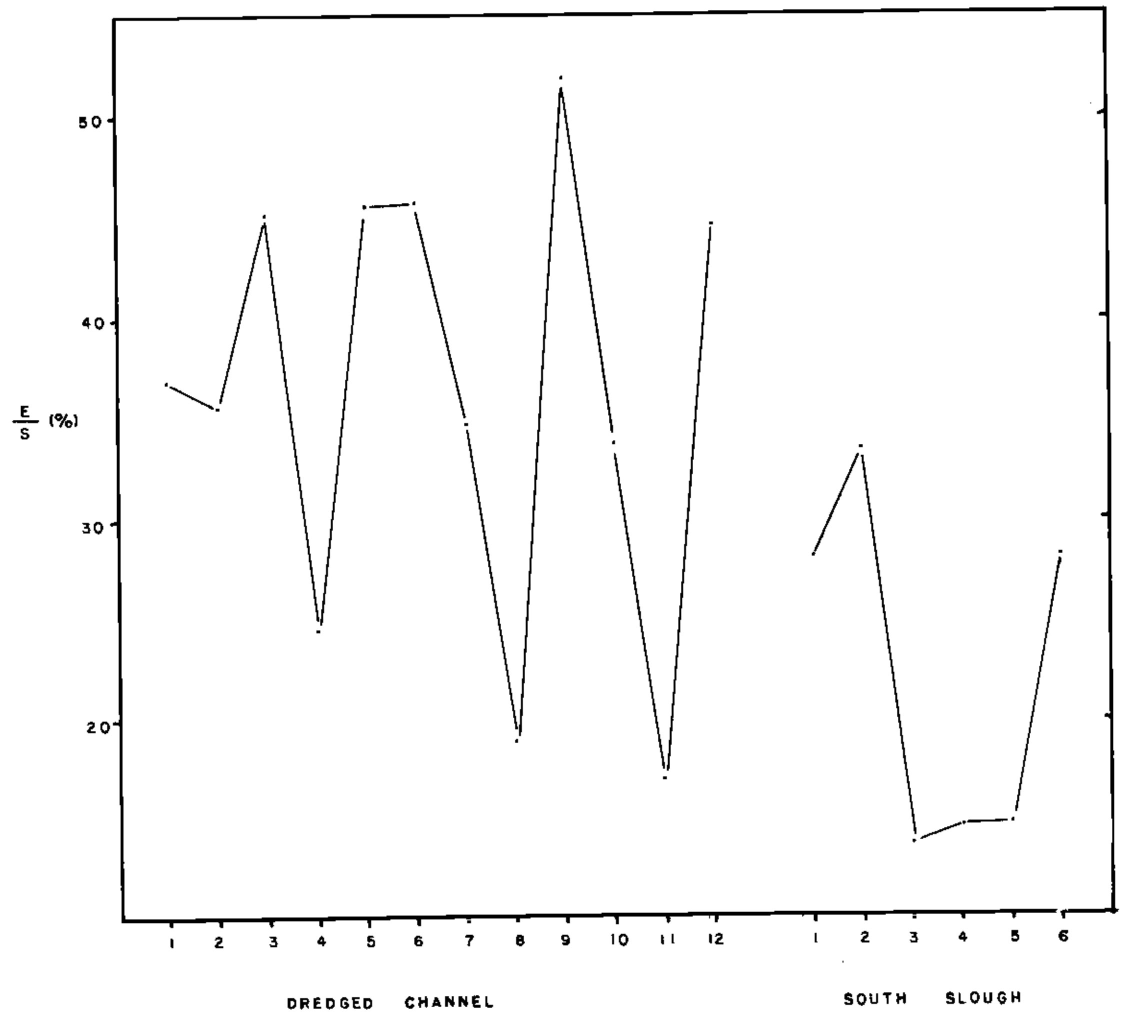


Figure 19. The ratio of the equivalent number of equally common species (E) to the observed number of taxa (S), expressed as per cent, as a function of distance from the mouth of Coos Bay for the dredged channel stations, and as a function of station number for South Slough.

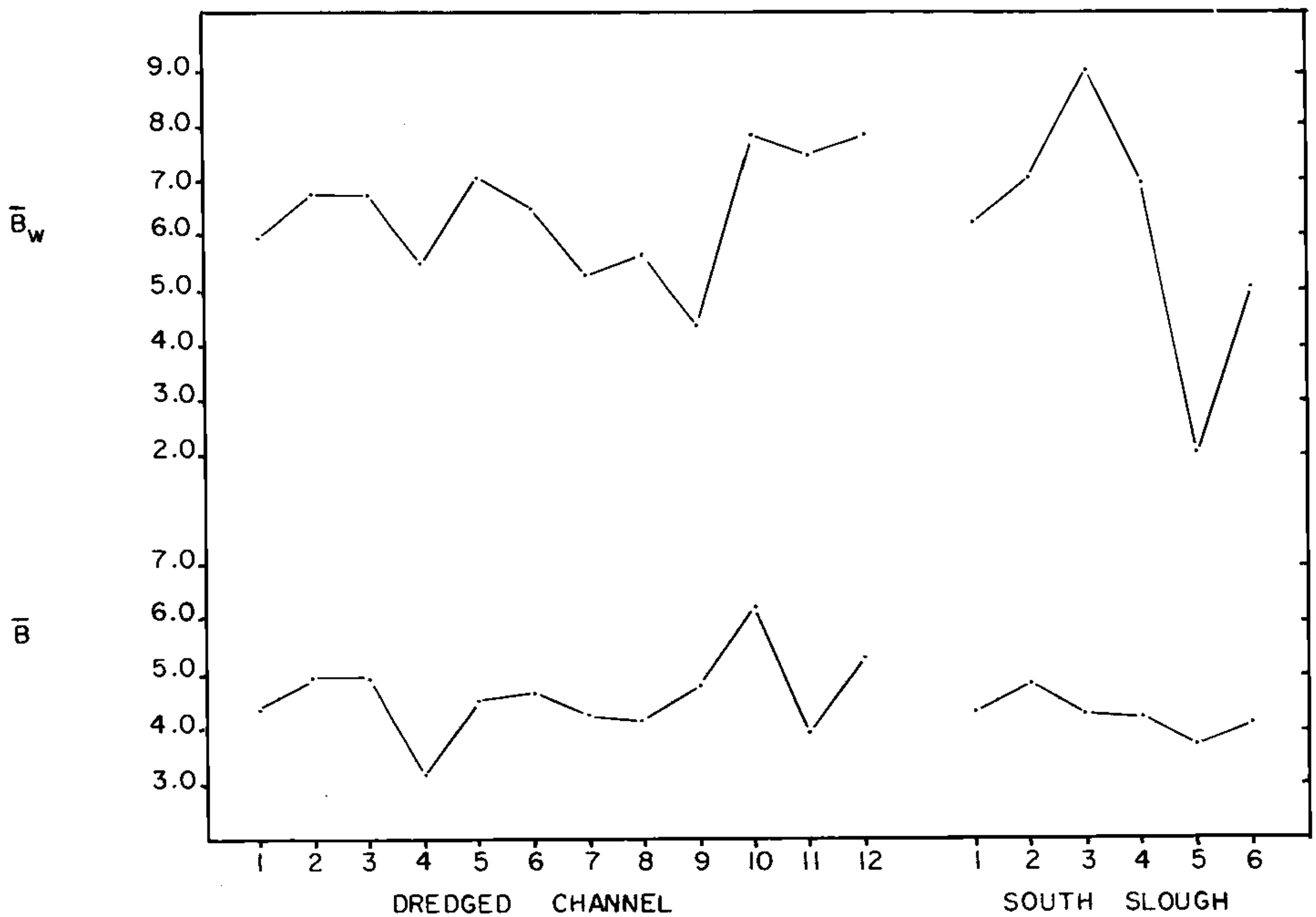


Figure 20. Unweighted mean niche breadth ($\bar{B}$) and weighted mean niche breadth ($\bar{B}_w$) as a function of distance from the mouth of Coos Bay for the dredged channel stations, and as a function of station number for South Slough.

	TAXON	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Nematoda spp.	1.00													
2	Oligochaeta spp.	.368	1.00												
3	Heteromastus filiformis	.224	.633	1.00											
4	Mediomastus acutus	.036	.035	.019	1.00										
5	Mediomastus californiensis	.142	.602	.153	.004	1.00									
6	Streblospio benedicti	.473	.047	.019	.002	.009	1.00								
7	Macoma inquinata	.203	.145	.056	.004	.147	.025	1.00							
8	Modiolus modiolus	.373	.227	.020	.009	.079	.110	.878	1.00						
9	Transennella tantilla	.286	.123	.000	.001	.039	.000	.123	.195	1.00					
10	Harpacticoida spp.	.504	.100	.031	.004	.026	.868	.057	.108	.067	1.00				
11	Ostracoda spp.	.640	.138	.003	.006	.038	.061	.130	.158	.614	.080	1.00			
12	Cumella vulgaris	.314	.232	.035	.044	.238	.086	.067	.084	.341	.130	.309	1.00		
13	Paraphoxus spinosus	.501	.341	.039	.032	.060	.042	.113	.167	.310	.086	.540	.821	1.00	
14	Eggs	.487	.079	.049	.011	.032	.360	.116	.377	.085	.314	.114	.099	.057	1.00

†Fabricia sabella oregonica, Mediomastus acutus: 0.999
*Tellina modesta, Macoma inquinata: 0.976
*Actiniaria, *Ophelia limacina: 0.942
*Tellina modesta, Modiolus modiolus: 0.840
†Leptochelia dubia, Paraphoxus spinosus: 0.821
†Leptochelia dubia, Cumella vulgaris: 0.777

†Leptochelia dubia, Ostracoda: 0.766
†Pygospio elegans, Mediomastus acutus: 0.714
†Pygospio elegans, †Fabricia sabella oregonica: 0.689
†Pygospio elegans, Paraphoxus spinosus: 0.678
†Pygospio elegans, Cumella vulgaris: 0.647
†Pygospio elegans, †Leptochelia dubia: 0.641

* occurs only in dredged channel
† occurs only in South Slough

Figure 21. Matrix of species similarity (ESIMI) for the 14 most common non-localized taxa, with additional values for 12 pairs of localized taxa.

STATION	CB-1	CB-2	CB-3	CB-4	CB-5	CB-6	CB-7	CB-8	CB-9	CB-10	CB-11	CB-12	W-1	W-2	W-3	W-4	W-5	W-6
CB-1	1.00																	
CB-2	.59	1.00																
CB-3	.55	.84	1.00															
CB-4	.37	.31	.25	1.00														
CB-5	.70	.60	.57	.34	1.00													
CB-6	.50	.59	.38	.30	.80	1.00												
CB-7	.73	.18	.40	.10	.58	.21	1.00											
CB-8	.07	.07	.08	.13	.08	.09	.03	1.00										
CB-9	.11	.11	.13	.10	.17	.18	.07	.64	1.00									
CB-10	.33	.50	.20	.19	.66	.84	.05	.07	.10	1.00								
CB-11	.13	.25	.37	.13	.27	.22	.10	.08	.08	.33	1.00							
CB-12	.38	.57	.36	.27	.71	.80	.10	.10	.14	.92	.49	1.00						
W-1	.15	.24	.31	.14	.28	.21	.08	.28	.20	.20	.29	.30	1.00					
W-2	.17	.16	.20	.22	.21	.16	.10	.80	.46	.16	.19	.22	.40	1.00				
W-3	.25	.44	.56	.22	.50	.34	.15	.16	.16	.29	.40	.47	.85	.32	1.00			
W-4	.10	.15	.20	.14	.17	.13	.05	.83	.48	.14	.17	.20	.38	.95	.32	1.00		
W-5	.01	.01	.01	.01	.05	.02	.00	.03	.02	.01	.01	.01	.04	.03	.04	.05	1.00	
W-6	.07	.12	.17	.08	.15	.10	.04	.17	.14	.09	.17	.15	.92	.26	.71	.22	.12	1.00

Figure 22. Matrix of station similarity (SIMI) for all stations.

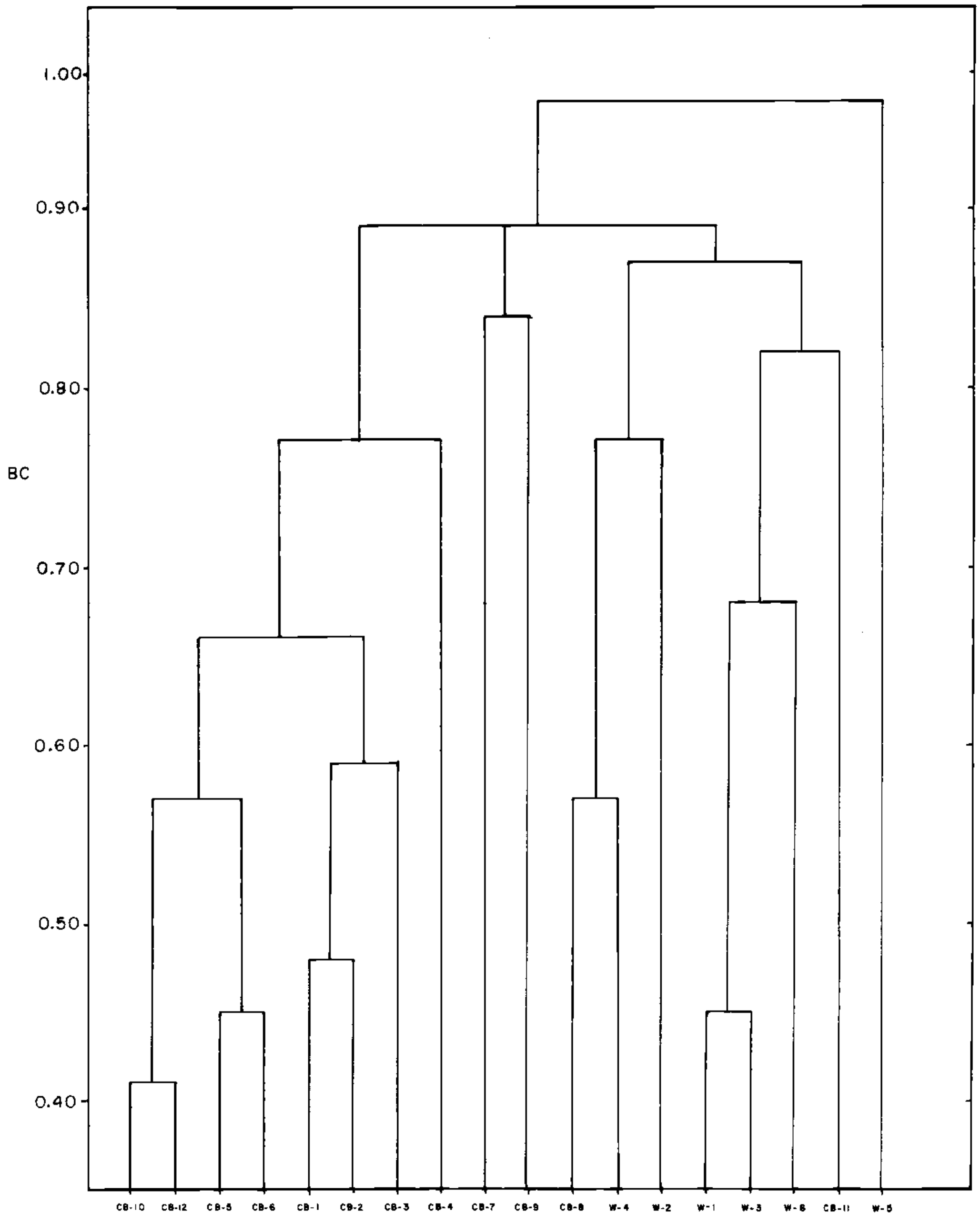


Figure 23. Dendrogram resulting from station clustering using the Bray-Curtis dissimilarity index.

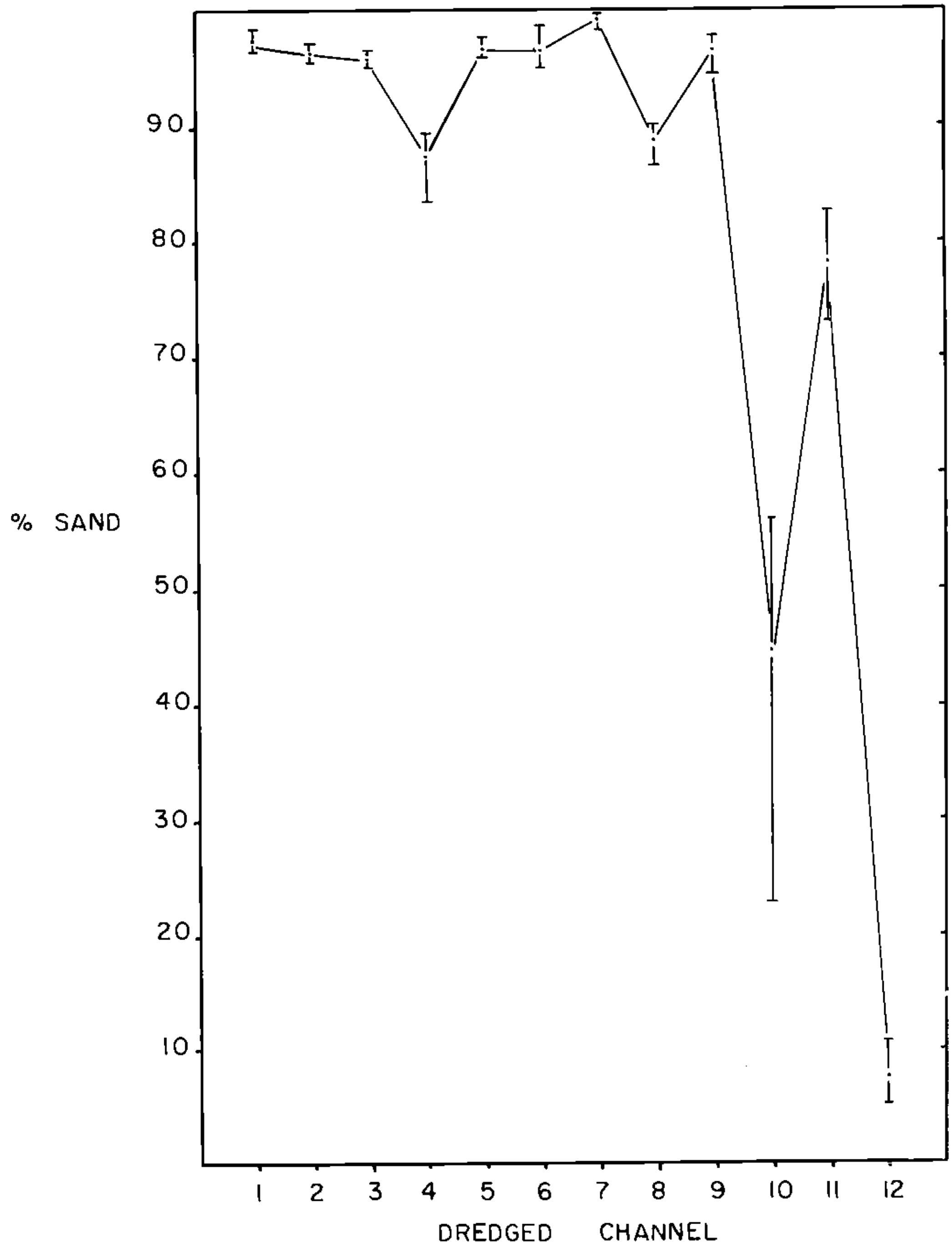


Figure 24. Mean and range for percentage of sand as a function of distance from the mouth of Coos Bay, for the dredged channel stations.

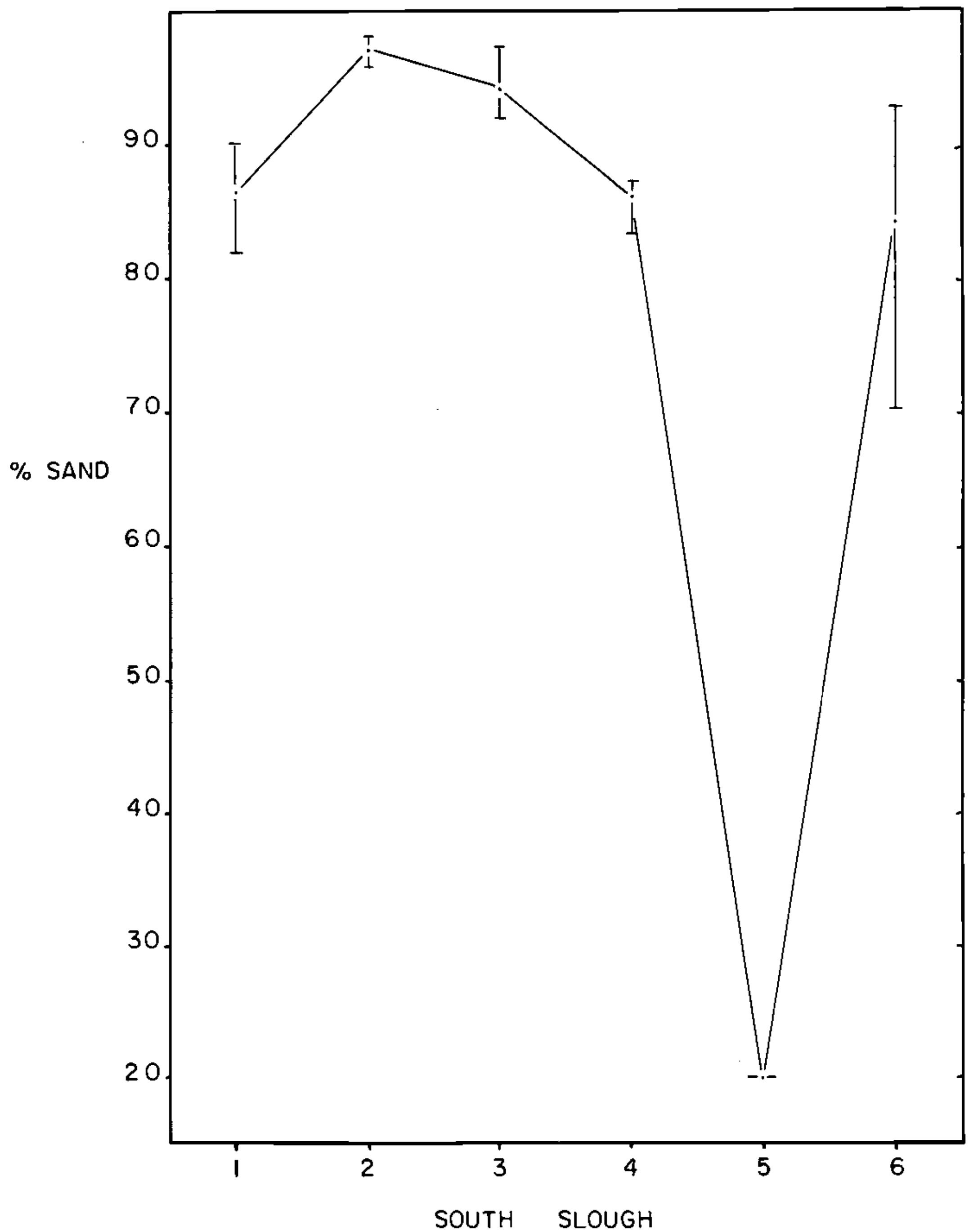


Figure 25. Mean and range of percentage of sand as a function of station number for South Slough.

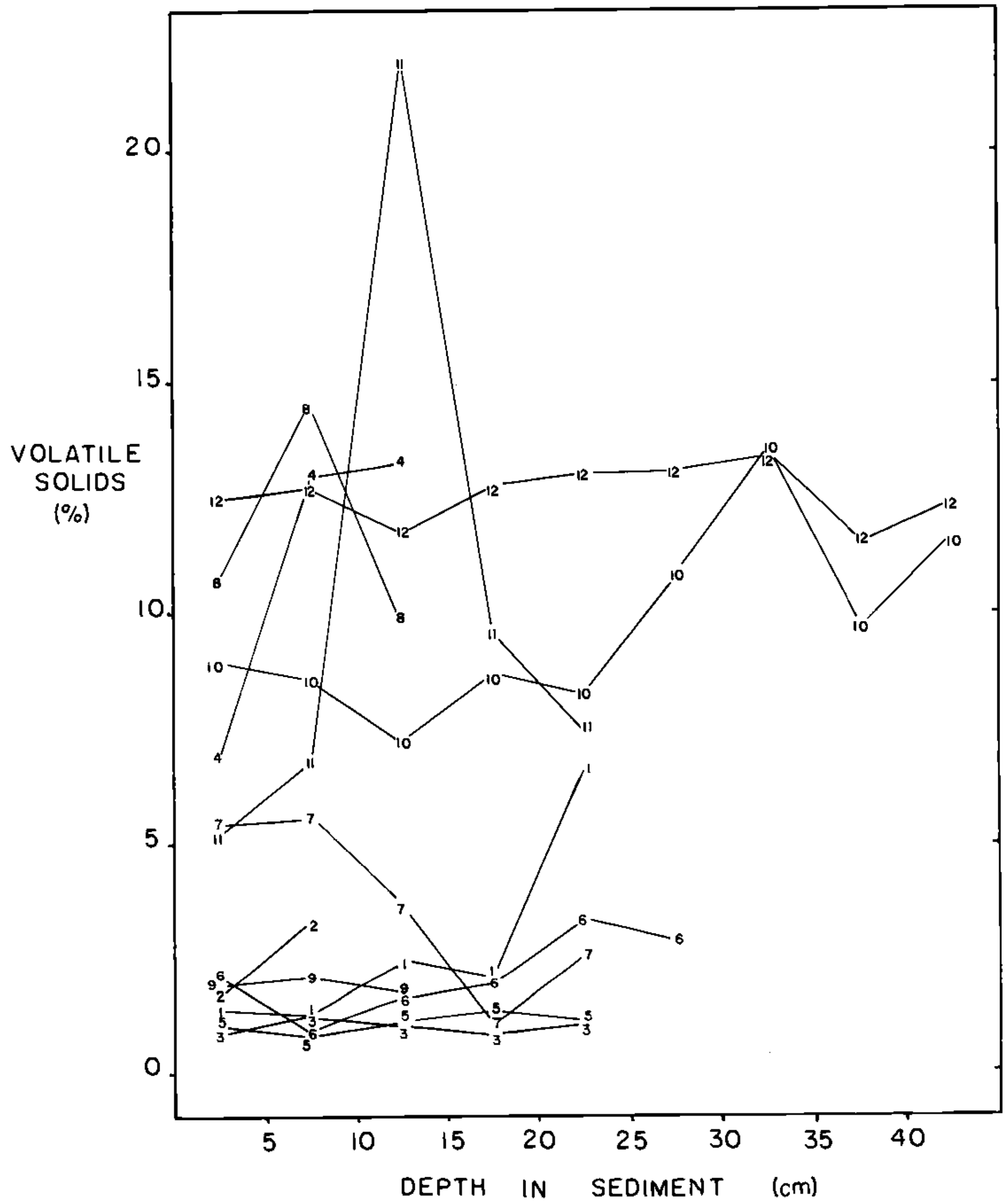


Figure 26. Percentage of volatile solids as a function of depth in the sediment for stations CB-1 through CB-12 (dredged channel).

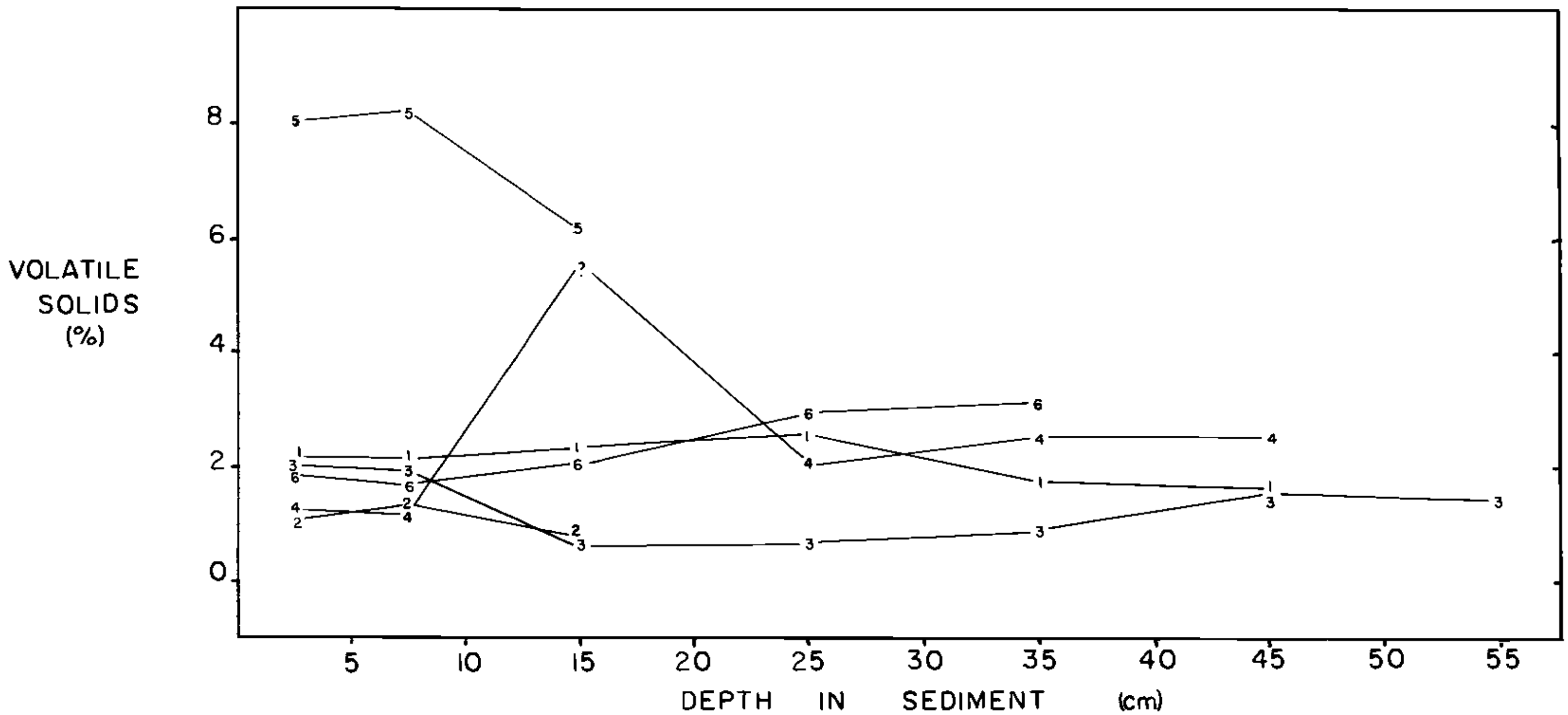


Figure 27. Percentage of volatile solids as a function of depth in the sediment for stations W-1 through W-6 (South Slough). Value at 10-20 cm for W-4 most likely due to experimental error.

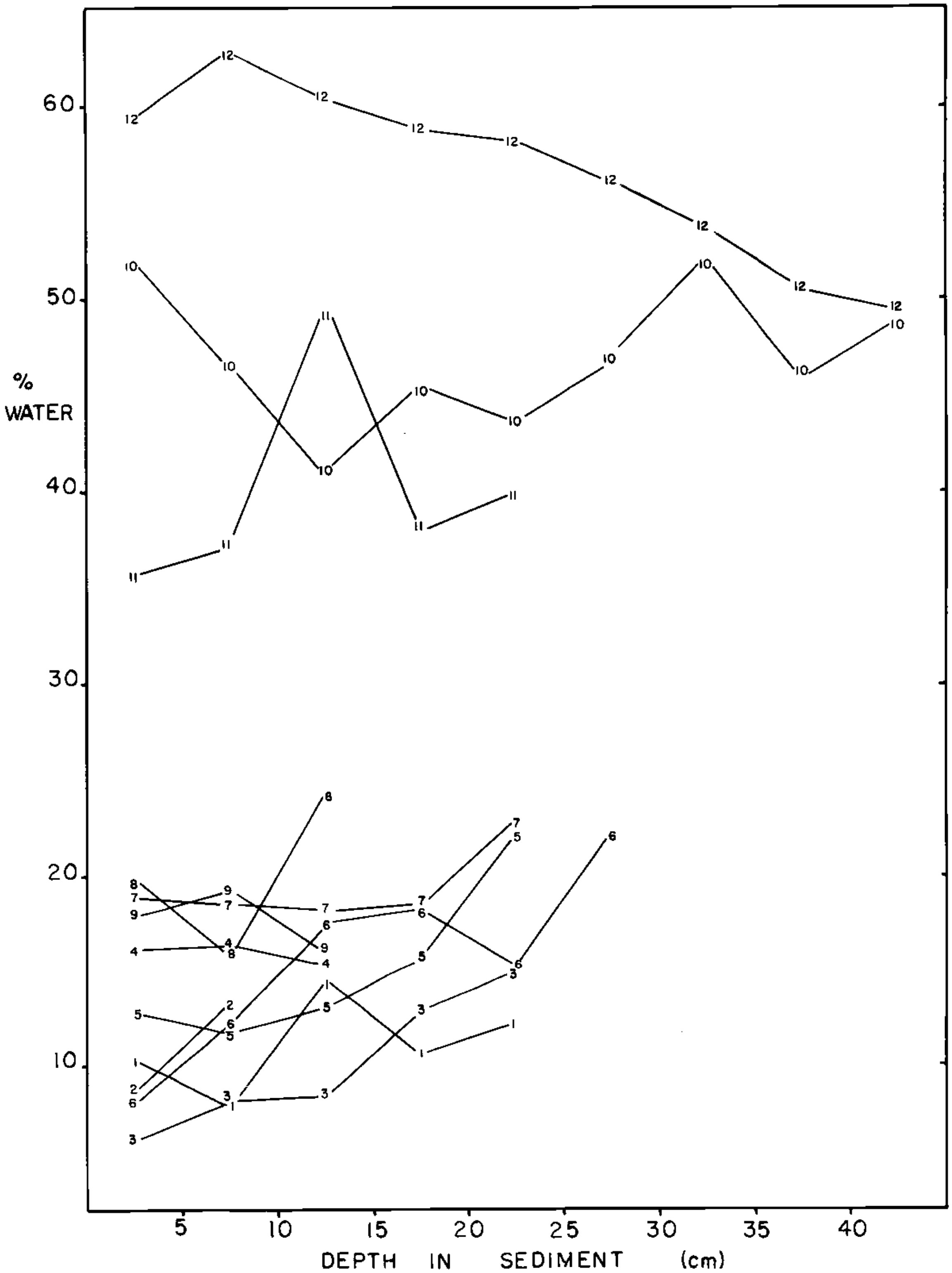


Figure 28. Percentage of water as a function of depth in the sediment for stations CB-1 through CB-12 (dredged channel).

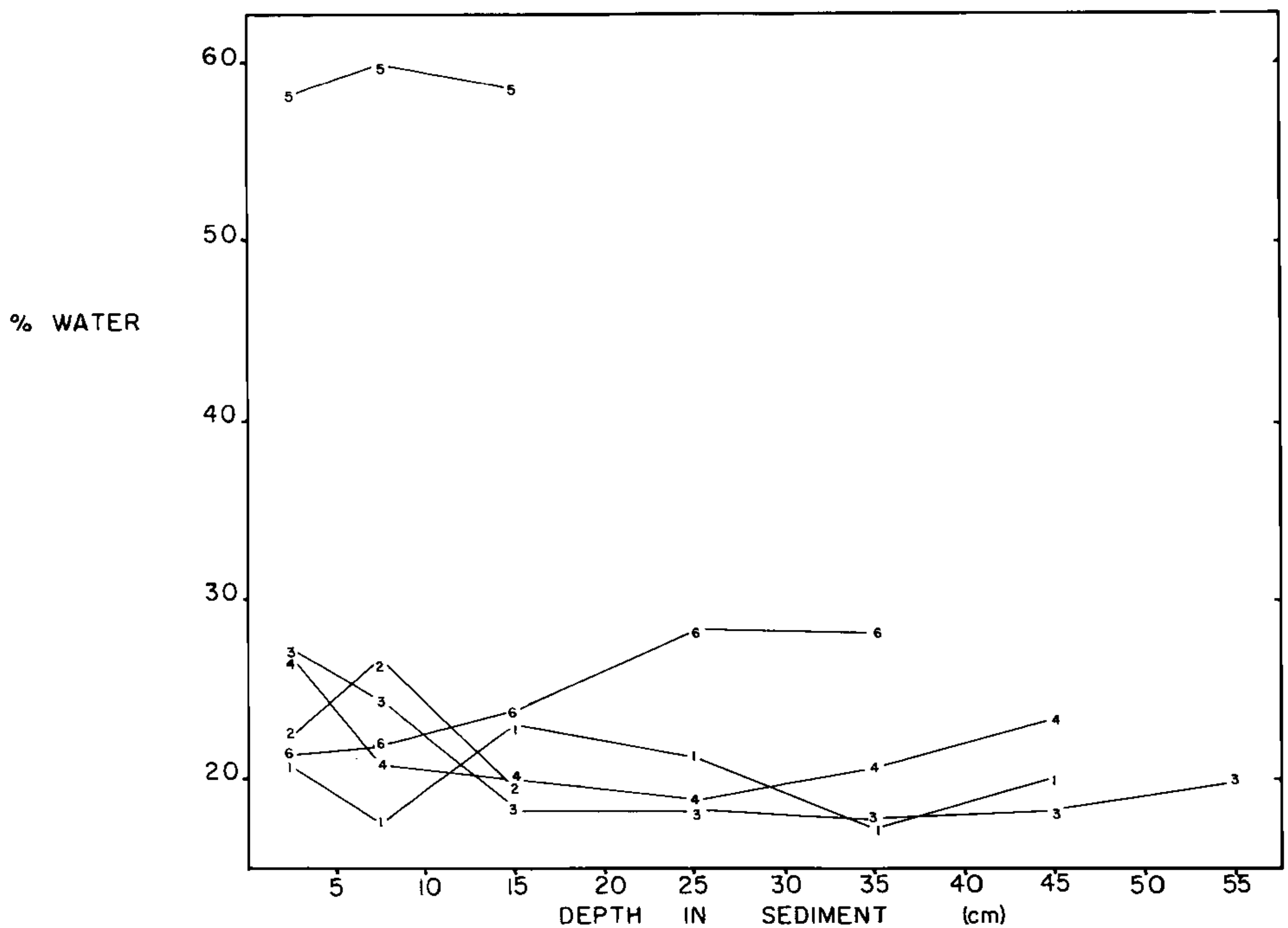


Figure 29. Percentage of water as a function of depth in the sediment for stations W-1 through W-6 (South Slough).

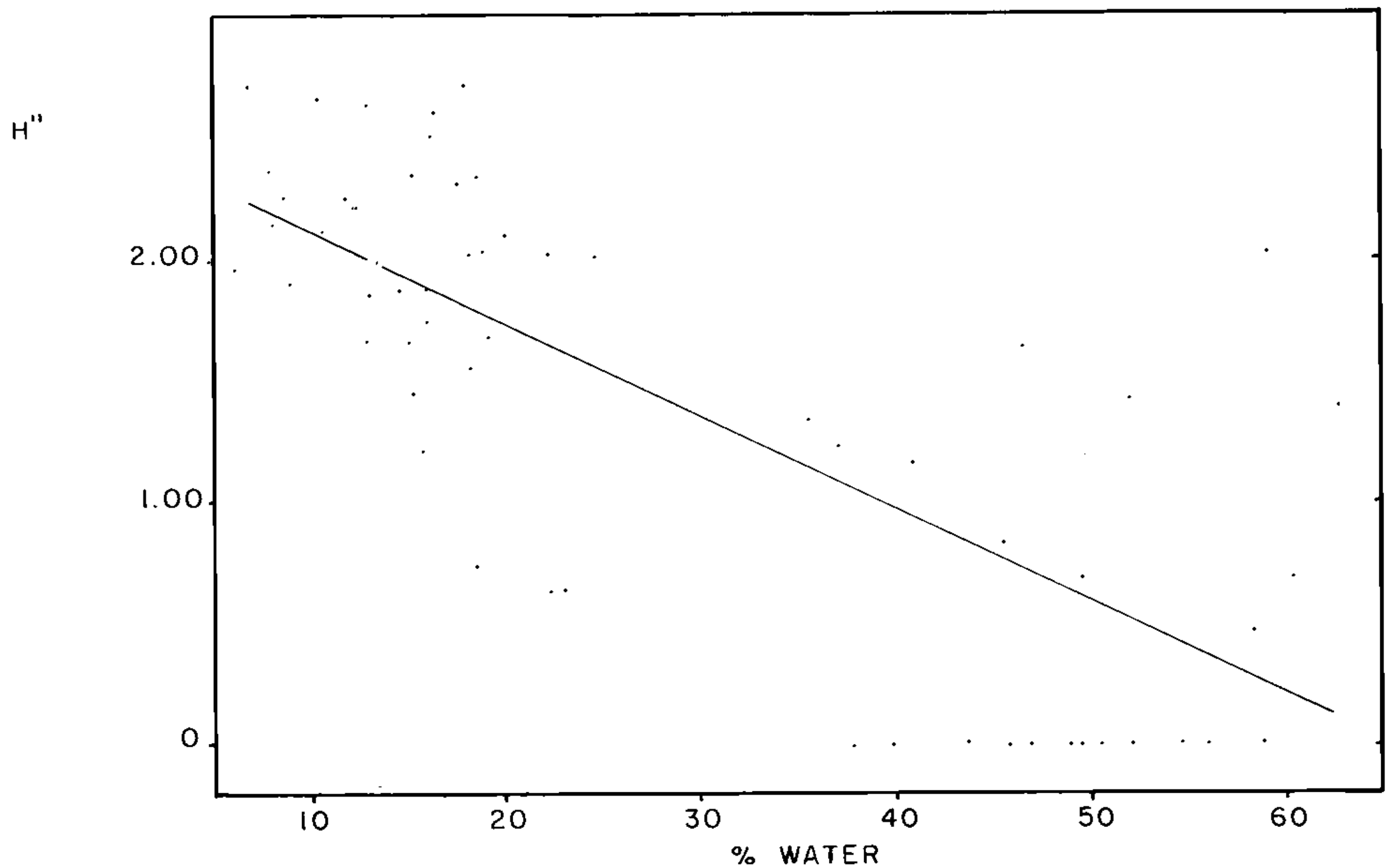


Figure 30. Diversity (H") vs. percentage of water for the dredged channel samples. R = -0.75 for the regression line shown.

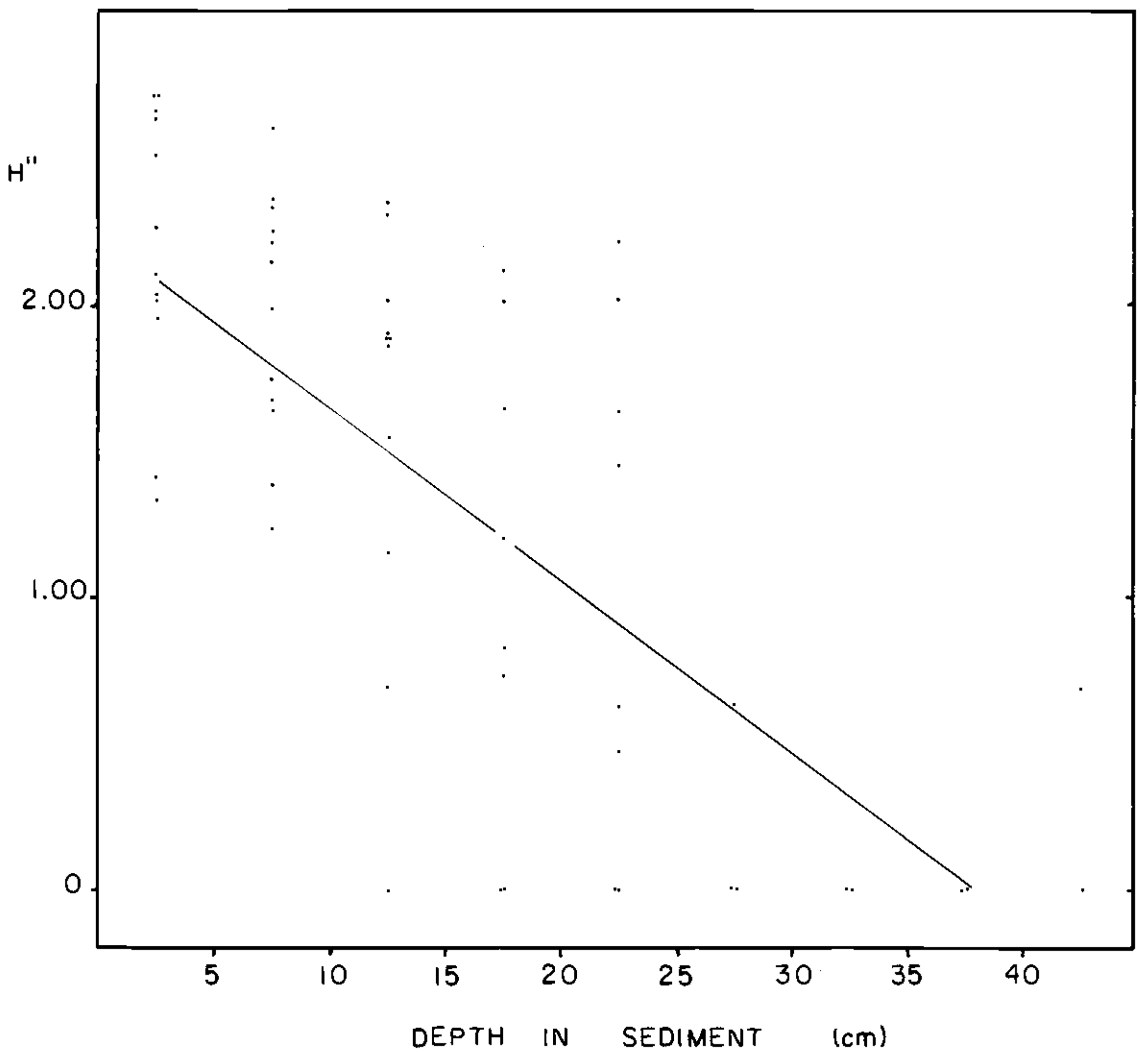


Figure 31. Diversity (H") vs. depth in the sediment for the dredged channel samples. R = -0.73 for the regression line shown.

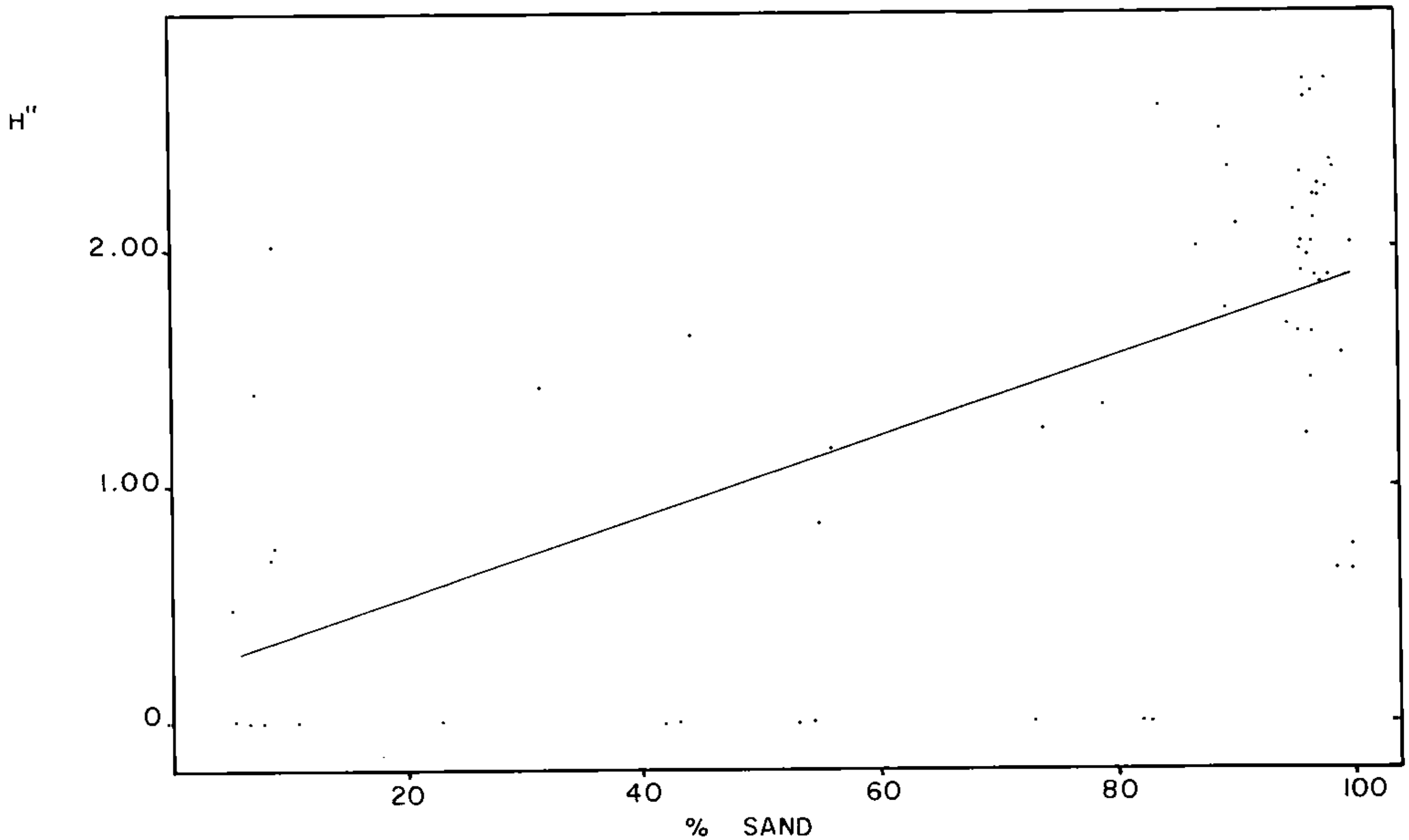


Figure 32. Diversity (H") vs. percentage of sand for the dredged channel samples. R = 0.63 for the regression line shown.

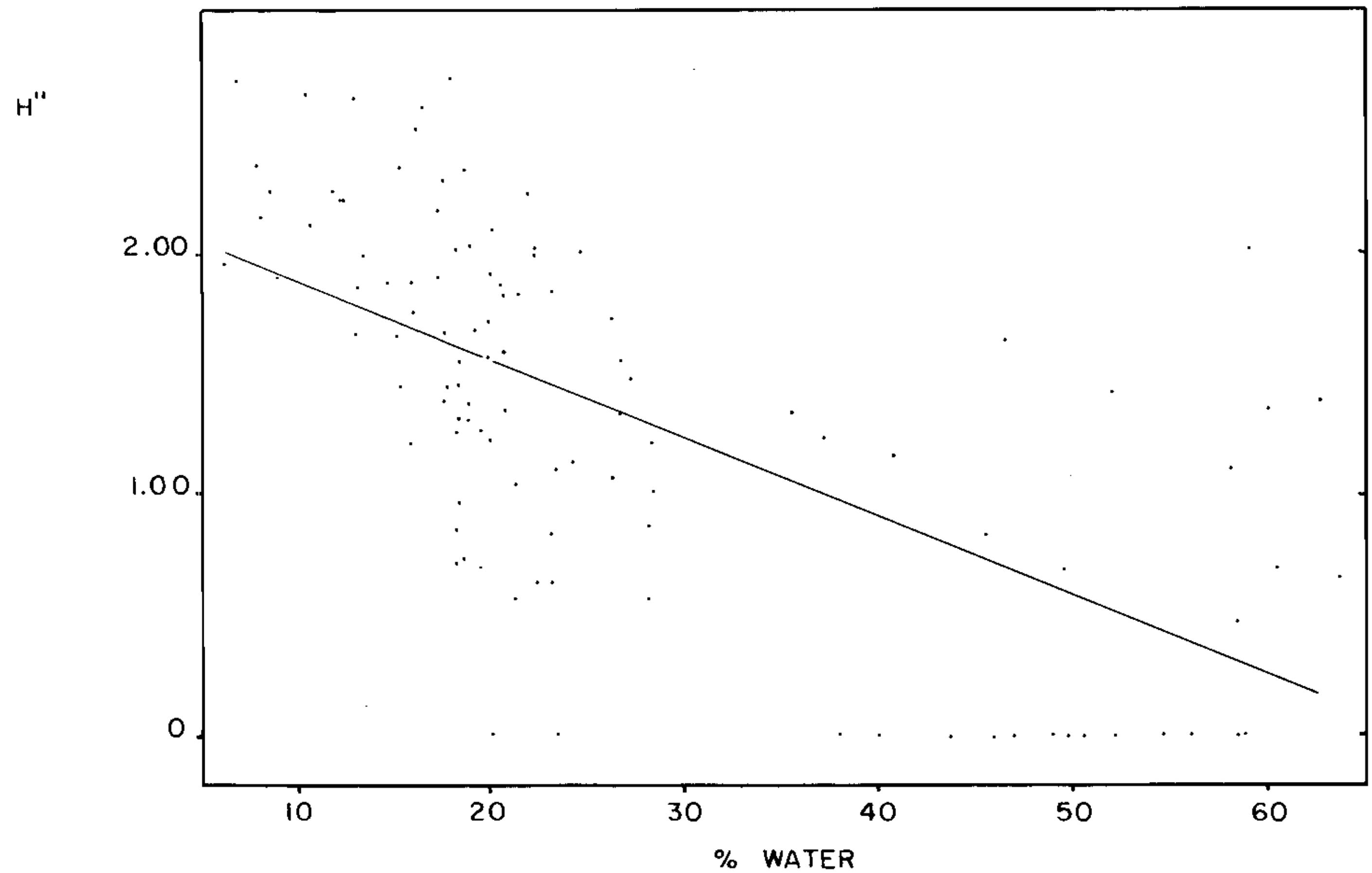


Figure 33. Diversity (H") vs. percentage of water for all stations. R = −0.63 for the regression line shown.

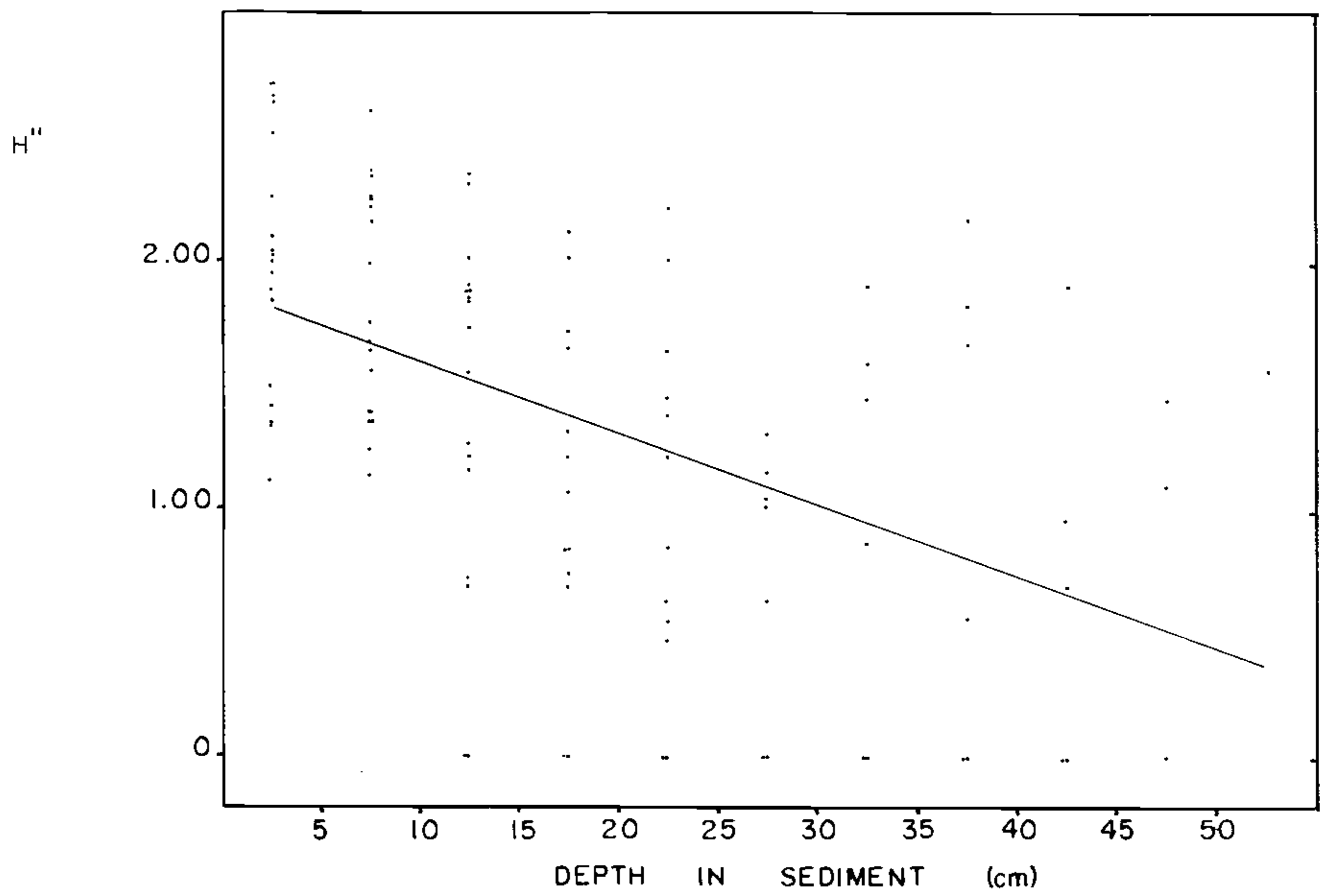


Figure 34. Diversity (H") vs. depth in the sediment for all stations. R = -0.49 for the regression line shown.

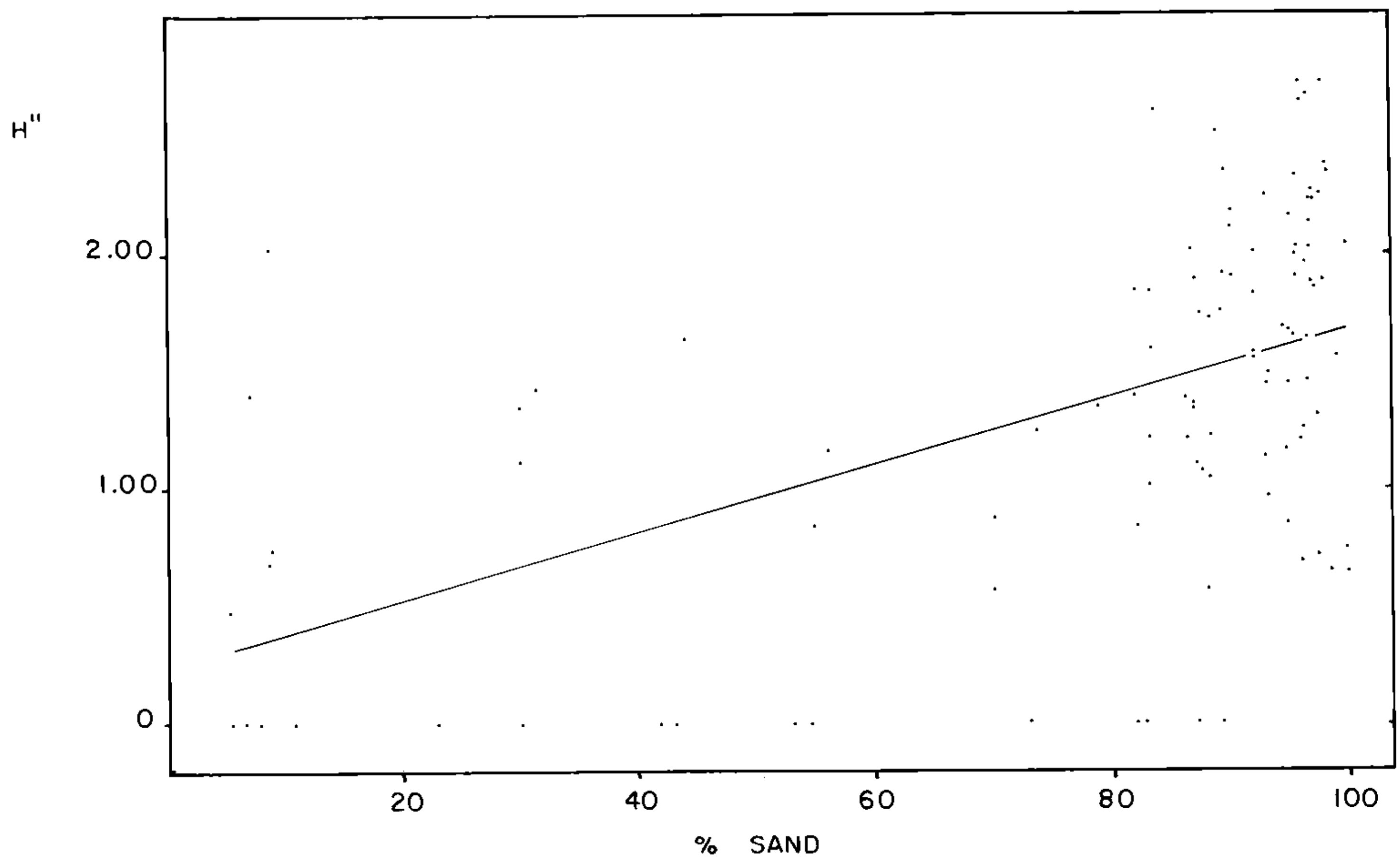


Figure 35. Diversity (H") vs. percentage of sand for all stations. R = 0.52 for the regression line shown.

Table 2. Localized taxa. A list of taxa occurring only in the dredged channel, those occurring only in South Slough, and those common to both areas.

Taxa occurring only in the dredged channel	Taxa common to both areas
	Foraminifera spp.
	Nematoda spp.
	Nemertea spp.
	Turbellaria spp.
Actiniaria spp.	Phoronida
Hydrozoa spp.	*Phoronopsis harmeri*
Acoela spp.	Oligochaeta spp.
Polychaeta	Polychaeta
Arenicola cristata	*Abarenicola* sp.
Amaeana occidentalis	*Capitella capitata*
Armandia bioculata	*Eteone californica*
Armandia brevis	*Eunoe depressa*
Autolytus prismaticus	*Glycera tenuis*
Boccardia proboscidea	*Glycinde armigera*
Brania brevipharyngea	*Heteromastus filiformis*
Capitella capitata oculata	*Langerhansia heterochaeta*
Cirratulus cirratus	*Lumbrineris zonata*
Eteone dilatae	*Magelona pitelkai*
Eteone longa	*Mediomastus acutus*
Eteone pacifica	*Mediomastus californiensis*
Eteone (Mysta) tchangsii	*Paraonides platybranchia*
Eumida bifoliata	*Polydora socialis*
Eusyllis assimilis	*Rhynchospio arenincola*
Eusyllis blomstrandi	*Streblospio benedicti*
Eusyllis magnifica	
Exogene lourei	
Glycera robusta	
Lumbrineris latreilli	
Naineris quadricuspida	
Naineris uncinata	
Nephtys parva	
Nerinides maculata	
Nerinides tridentata	
Ophelia limacina	
Ophelia sp.	
Ophryotrocha puerilis	
Paleanotus bellis	
Pionosyllis magnifica	
Protodorvillea gracilis	
Pseudopolydora kempi	
Pygospio californica	

Table 2. (Continued).

Taxa occurring only in the dredged channel	Taxa common to both areas
Sabellaria cementarium	
Scoloplos acmeceps	
Spiophanes bombyx	
Syllides longocirrata	
Syllis elongata	
Syllis gracilis	
Typosyllis aciculata	
Typosyllis alternata	
Typosyllis fasciata	
Typosyllis hyalina	
Typosyllis pulchra	
Capitellidae spp.	
Phyllodocidae juvenile spp.	
Polynoidae juvenile spp.	
Syllidae spp.	
Polychaeta juvenile sp. A	
Polychaeta juvenile sp. B	
Polychaeta juvenile spp.	
Pelecypoda	Pelecypoda
Macoma acolasta	*Clinocardium nuttallii*
Protothaca staminea	*Macoma inquinata*
Protothaca tenerrima	*Macoma secta*
Saxidomus giganteus	*Modiolus modiolus*
Tellina bodegensis	*Mya arenaria*
Tellina carpenteri	*Transennella tantilla*
Tellina modesta	Tellinidae spp.
Tellina nuculoides	
Tresus nuttallii	
Zirfaea pilsbryi	
Pelecypoda sp. B	
Pelecypoda juvenile spp.	
Gastropoda	Gastropoda
Barleeia haliotiphila	*Aglaja diomedea*
Odostomia (Evalea) phanea	
Olivella biplicata	
	Ostracoda spp.
Cirripedia spp.	Cirripedia
Balanus sp.	*Balanus improvisus*
Chthamalus dalli	
Copepoda	Copepoda
Acartia tonsa	*Clausidium vancouverense*
	Eurytemora sp.
	Harpacticoida spp.

Table 2. (Continued).

Mysidacea	
Archaeomysis grebnitzkii	
Isopoda	
Caecianiropsis psammophila	
Cumacea	Cumacea
Diastylis alaskensis	*Cumella vulgaris*
Lamprops quadriplicata	*Leucon subnasica*
Pycnogonida	
Achelia chelata	
Achelia simplissima	
Brachyura larva spp.	
Anomura	Anomura
Upogebia pugettensis	*Callianassa californiensis*
Paguridae spp.	
Amphipoda	Amphipoda
Anisogammarus confervicolus	*Corophium brevis*
Eohaustorius washingtonianus	*Paraphoxus spinosus*
Grandidierella japonica	
Mandibulophoxus gilesi	
Paraphoxus milleri	
Parapleustes pugettensis	
Photis californica	
Amphipoda juvenile spp.	
Insecta	Insecta
Diptera adult spp.	Chironomida larva sp. B
Hemiptera adult spp.	Collembola adult sp. A
Insecta larva spp.	Diptera larva sp. B
Arachnida	Arachnida
Arachnida adult spp.	Halacaridae
Chelonethida spp.	
Hydrachnida sp. A	
Hydrachnida sp. B	
Echinodermata	
Dendraster excentricus	
Pisaster ochraceus	
Pisces	
Ammodytes hexapterus	
Pisces larva spp.	
	Eggs spp.

Table 2. (Continued).

Taxa occurring only in South Slough
Polychaeta
Amphisamytha bioculata
Barantolla americana
Chone ecaudata
Fabricia sabella oregonica
Glycinde polygnatha
Haploscoloplos panamensis
Neomediomastus glabrus
Notomastus (Clistomastus) tenuis
Polydora ligni
Pygospio elegans
Pelecypoda
Macoma nasuta
Macoma sp.
Veneridae spp.
Gastropoda
Tenellia adspersa
Copepoda
Hemicyclops thysanotus
Tanaidacea
Leptochelia dubia
Pancolus californiensis
Carides
Crangon franciscorum
Amphipoda
Allorchestes angusta
Amphithoe valida
Corophium acherusicum
Corophium salmonis
Paraphoxus epistomus
Amphipoda spp.
Insecta
Diptera larva sp. A
Diptera larva sp. C
Paraclunio alaskensis

Table 3. Niche breadth (B) and k (number of stations at which the taxon occurs) for all taxa with B greater than 3.0.

TAXON	B	CB 1	CB 2	CB 3	CB 4	CB 5	CB 6	CB 7	CB 8	CB 9	CB 10	CB 11	CB 12	W 1	W 2	W 3	W 4	W 5	W 6	k
Foraminifera spp.	4.6765	x	x	x	x	x	x	x	x	x					x	x				11
Actiniaria spp.	3.4766	x	x	x			x	x												5
Hydrozoa spp.	4.1342	x	x	x	x					x			x							6
Nematoda spp.	14.6378	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	18
Nemertea spp.	9.7219	x	x	x	x	x	x	x	x	x				x		x	x	x	x	14
Turbellaria spp.	7.1114	x	x	x		x	x		x	x		x		x	x	x	x		x	13
Oligochaeta spp.	6.6893	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	17
Polychaeta																				
Amaeana occidentalis	3.0474			x	x	x			x											4
Eteone californica	5.6649				x	x	x					x					x	x	x	7
Mediomastus californiensis	3.7709				x		x		x	x			x	x	x	x	x		x	10
Nerinides tridentata	3.0482					x			x	x			x							4
Ophelia limacina	3.2865	x	x	x		x	x	x												6
Paraonides platybranchia	4.1580	x		x			x					x			x				x	6
Pygospio elegans	3.7831													x	x	x	x	x	x	6
Rhynchospio arenincola	3.0588				x											x	x		x	4
Scoloplos acmeceps	3.0391					x	x	x		x										4
Pelecypoda																				
Clinocardium nuttallii	3.2212					x	x		x								x			4
Macoma inquinata	4.3004	x	x	x	x				x		x	x			x	x	x		x	11
Modiolus modiolus	8.6536	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x		x	16
Protothaca staminea	3.7080	x			x		x		x	x										5
Tellina nuculoides	6.0427		x	x	x	x	x	x	x											7
Ostracoda spp.	4.1795				x			x					x	x		x			x	6

Table 3. (Continued).

TAXON	B	CB 1	2	3	4	5	6	7	8	9	10	11	12	W 1	2	3	4	5	6	k
Copepoda																				
Acartia tonsa	6.3657	x	x	x	x	x	x		x	x										8
Harpacticoida spp.	5.2281	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	17
Cirripedia																				
Balanus improvisus	3.1520	x			x			x	x						x					5
Mysidacea																				
Archaeomysis grebnitzkii	3.4459	x		x			x	x		x										5
Cumacea																				
Cumella vulgaris	5.3953				x	x	x		x	x	x	x		x	x	x	x	x	x	13
Leucon subnasica	6.1131		x		x	x		x	x	x	x	x	x	x		x			x	12
Tanaidacea																				
Leptochelia dubia	3.2353													x	x	x	x	x	x	6
Amphipoda																				
Eohaustorius washingtonianus	4.2387	x	x	x		x	x	x		x										7
Paraphoxus spinosus	4.4393		x		x									x	x	x	x		x	7
Halacaridae spp.	6.4897	x	x	x	x		x							x	x	x	x			9
Pisces larva spp.	4.6354	x			x	x	x		x											5
Eggs spp.	7.1034	x	x	x	x	x	x		x	x	x		x	x	x	x	x		x	15

Table 4. Results of species clustering using the CLUSB algorithm.

Number of Clusters	Cluster Membership
2	Oligochaeta, Leptochelia dubia, Eggs, Nematoda / remainder
3	Eggs, Nematoda / Oligochaeta / remainder
4	Eggs, Nematoda / Oligochaeta / Leptochelia dubia / remainder
5	Eggs, Nematoda / Oligochaeta / Leptochelia dubia / Foraminifera / remainder
6	Eggs / Nematoda / Oligochaeta / Leptochelia dubia / Foraminifera / remainder
7	Eggs / Nematoda / Oligochaeta / Leptochelia dubia / Foraminifera / Harpacticoida / remainder
8	Eggs / Nematoda / Oligochaeta / Leptochelia dubia / Foraminifera / Harpacticoida / Mediomastus acutus / remainder
9	Eggs / Nematoda / Oligochaeta / Leptochelia dubia / Foraminifera / Harpacticoida / Mediomastus acutus / Ophelia limacina, Modiolus modiolus, Macoma inquinata, Nemertea, Actiniaria, Hydrozoa / remainder
10	Eggs / Nematoda / Oligochaeta / Leptochelia dubia / Foraminifera / Harpacticoida / Mediomastus acutus / Ophelia limacina, Modiolus modiolus, Macoma inquinata, Nemertea, Actiniaria, Hydrozoa / Mediomastus californiensis, Clausidium vancouverense / remainder
11	Eggs / Nematoda / Oligochaeta / Leptochelia dubia / Foraminifera / Harpacticoida / Mediomastus acutus / Ophelia limacina, Actiniaria / Mediomastus californiensis, Clausidium vancouverense / Modiolus modiclus, Macoma inquinata, Tellina modesta, Nemertea, Hydrozoa / remainder
12	Eggs / Nematoda / Oligochaeta / Leptochelia dubia / Foraminifera / Harpacticoida / Mediomastus acutus / Ophelia limacina, Actiniaria / Mediomastus californiensis, Clausidium vancouverense / Modiolus modiolus, Macoma inquinata, Tellina modesta, Hydrozoa / Syllis gracilis, Eohaustorius washingtonianus, Turbellaria, Nemertea / remainder

Table 5. Sediment data. Grain size given as percentages of sand, silt, and clay. Volatile solids and water content also expressed as percentages. Sample numbers give area first, then station number, finally section number. All sections are at five centimetre intervals. (eg., CB-5-3 is the third section (10-15 cm) at station five in the dredged channel).

SAMPLE	% SAND	% SILT	% CLAY	% VOL. SOL.	% WATER
CB-1-1	96.6	-	3.4	1.35	10.35
2	98.1	-	2.9	1.26	7.78
3	96.7	0.3	3.0	2.42	14.61
4	96.6	0.5	2.9	2.07	10.61
5	96.7	0.2	3.1	6.62	12.23
2-1	96.9	0.5	2.6	1.65	8.52
2	95.5	1.7	2.8	3.34	13.40
3-1	96.1	1.7	2.2	0.89	6.07
2	95.0	2.9	2.1	1.22	7.97
3	95.6	1.1	3.3	1.03	8.46
4	95.3	1.9	2.8	0.86	12.95
5	96.4	0.8	2.8	1.07	15.04
4-1	88.8	5.0	6.2	6.88	16.24
2	83.7	9.1	7.2	12.94	16.42
3	89.4	5.4	5.2	13.24	15.23
5-1	95.9	1.6	2.5	0.96	12.88
2	97.7	-	2.3	0.83	11.77
3	97.3	0.5	2.2	1.07	13.03
4	95.9	1.3	2.8	1.38	15.84
5	96.5	1.1	2.4	1.08	22.29
6-1	95.9	0.4	3.7	2.05	8.10
2	97.0	0.5	2.4	0.89	12.27
3	95.5	1.1	3.4	1.63	17.56
4	95.6	1.9	2.5	1.95	18.26
5	96.4	1.4	2.2	3.35	15.29
6	98.6	1.3	0.1	2.88	22.41
7-1	99.8	-	0.2	5.41	18.95
2	98.2	1.6	0.2	5.58	18.68
3	98.9	0.9	0.2	3.62	18.33
4	99.8	0.2	-	1.05	18.53
5	99.8	0.2	-	2.61	23.12
8-1	90.0	5.2	4.8	10.64	20.09
2	89.2	5.9	4.9	14.52	16.00
3	86.7	8.3	5.0	9.85	24.71
9-1	97.5	2.1	0.4	1.98	17.99
2	94.4	4.2	1.4	2.03	19.24
3	97.8	1.0	1.2	1.67	15.95

Table 5. (Continued).

SAMPLE	% SAND	% SILT	% CLAY	% VOL. SOL.	% WATER
CB-10-1	31.3	33.9	34.8	8.93	52.04
2	44.0	36.7	19.3	8.55	46.58
3	56.0	26.0	18.0	7.20	40.86
4	54.9	27.1	18.0	8.70	45.55
5	54.4	27.8	17.8	8.35	43.62
6	53.1	29.3	17.6	10.82	46.84
7	43.0	32.5	24.5	13.52	52.06
8	41.9	38.5	19.6	9.63	45.89
9	22.9	47.0	30.1	11.64	48.93
11-1	78.8	14.1	7.1	5.11	35.58
2	73.8	17.3	8.9	6.75	37.19
3	82.1	8.9	9.0	22.01	49.68
4	82.7	9.3	8.0	9.56	37.95
5	73.0	16.5	10.5	7.44	39.99
12-1	8.5	51.1	40.4	12.47	59.10
2	7.0	52.7	40.3	12.70	62.75
3	8.6	57.1	34.3	11.77	60.35
4	7.6	56.0	36.4	12.72	58.78
5	5.1	48.5	46.4	13.02	58.27
6	5.4	49.0	45.6	13.06	56.11
7	6.5	50.2	43.3	13.40	54.68
8	10.6	49.4	40.0	11.50	50.51
9	8.4	50.7	40.9	12.36	49.58
W-1-1	87.0	12.0	1.0	2.14	20.56
2	82.0	12.0	7.0	2.14	17.57
3,4	82.06	10.69	7.25	2.32	23.14
5,6	88.06	5.16	6.78	2.59	21.26
7,8	90.09	5.44	4.47	1.72	17.28
9,10	89.19	5.56	5.25	1.65	20.02
2-1	96.0	4.0	-	1.11	22.26
2	96.0	4.0	-	1.28	26.78
3,4	98.08	1.92	-	0.72	19.53
3-1	93.0	6.0	1.0	2.05	27.26
2	93.0	6.0	1.0	1.97	24.30
3,4	97.31	1.89	0.80	0.69	18.29
5,6	94.66	2.59	2.75	0.68	18.28
7,8	94.96	2.52	2.52	0.84	17.74
9,10	93.04	3.65	3.31	1.53	18.36
11	92.11	4.45	3.44	1.42	19.84
4-1	87.0	12.0	1.0	1.19	26.76
2	87.0	12.0	1.0	1.19	20.72
3,4	88.30	7.14	4.56	5.55	19.97
5,6	86.27	8.58	5.15	2.05	18.88

Table 5. (Continued).

SAMPLE	% SAND	% SILT	% CLAY	% VOL. SOL.	% WATER
W-4-7,8	83.30	10.59	6.11	2.56	20.60
9,10	87.15	7.67	5.18	2.53	23.38
5-1	20	64	16.0	8.04	58.19
2	20	70	10.0	8.23	59.95
3	20	63	17.0	6.20	58.50
6-1	92.0	7.0	1.0	1.82	21.38
2	93.0	6.0	1.0	1.67	21.90
3,4	87.50	6.05	6.45	2.06	23.82
5,6	83.72	7.94	8.34	2.99	28.29
7,8	70.13	19.37	10.50	3.11	28.15

Table 6. Results of stepwise regression analysis of Shannon diversity (H") on percentage water (Pct H_2O), depth of sample in the sediment (Depth), percentage sand size material (Sand), and concentration of organic matter (Voltl). Multiple regression coefficient (R) and multiple R^2 given. Regression is for dredged channel (CB) samples only.

---

1. H" = 2.512 - 0.0384 (Pct H_2O)

   entering $F_{1,58}$: 76.7 $p > .99$

   R = -0.75 R^2 = 0.57

2. H" = 2.923 - 0.2099 (Depth) - 0.0272 (Pct H_2O)

   entering $F_{1,57}$: 48.0 $p > .99$

   R = 0.88 R^2 = 0.77

3. H" = 5.017 - 0.2253 (Depth) - 0.0557 (Pct H_2O) - 0.0169 (Sand)

   entering $F_{1,56}$: 18.33 $p > .99$

   R = 0.91 R^2 = 0.82

4. H" = 5.017 - 0.2250 (Depth) - 0.0568 (Pct H_2O) - 0.0169 (Sand) + 0.00476 (Voltl)

   entering $F_{1,55}$: 0.0939 not significant

   R = 0.91 R^2 = 0.82

Table 7. Results of stepwise regression analysis of Shannon diversity (H") on percentage water (Pct H_2O), depth of the sample in the sediment (Depth), percentage sand size material (Sand), and concentration of organic matter (Voltl). Multiple regression coefficient (R) and multiple R^2 given. Regression is for all samples (dredged channel and South Slough).

1. H" = 2.216 - 0.0324 (Pct H_2O)

   entering $F_{1,104}$: 69.68 $p > .99$

   R = -0.63 $R^2 = 0.40$

2. H" = 2.678 - 0.1263 (Depth) - 0.0303 (Pct H_2O)

   entering $F_{1,103}$: 45.87 $p > .99$

   R = 0.77 $R^2 = 0.59$

3. H" = 4.577 - 0.1341 (Depth) - 0.0561 (Pct H_2O) - 0.0151 (Sand)

   entering $F_{1,102}$: 12.21 $p > .99$

   R = 0.79 $R^2 = 0.63$

4. H" = 4.545 - 0.1332 (Depth) - 0.0569 (Pct H_2O) - 0.0149 (Sand) + 0.0059 (Voltl)

   entering $F_{1,101}$: 0.1427 not significant

   R = 0.79 $R^2 = 0.63$

DISCUSSION

In this section I shall first consider the information given by community composition parameters (diversity, evenness, the equivalent number of equally common species, niche breadth, and mean niche breadth); secondly, the insights available from community similarity measures (ESIMI, SIMI, species and station clustering); and finally, the relationships derivable from regression analysis.

Species and Individual Abundances and Vertical Distribution

The plots of species and individual abundances (Figures 6 through 9) produce the generalization of decreasing abundances with increasing depth in the sediment, a not unexpected result. There are, however, some notable exceptions: stations W-1, W-3, and W-4 show distinct secondary species maxima at depths in the sediment between 30 and 55 cm. Several cores also show subsurface maxima in abundance of individuals: CB-1, 7, 10, 12, W-1, 3, and 4 show distinct secondary peaks at depths of 25, 5-20, 10-20, 15-30, 10-45, 25-55, and 30-40 cm, respectively. The only individual abundance maximum which correlates well with a measured sediment parameter is that for CB-1; there is a pronounced maximum in volatile solid concentration in section five (20-25 cm). Volatile solids show slight increases at the depths of secondary individual maxima for W-1 and W-3.

This may be indicative of conditions obtaining in the cores showing subsurface maxima in species or individual abundance. It is possible that these deeper maxima are representative of higher food concentrations, higher oxygen tensions, or simply a better physiographic environment than obtains at the surface.

The deeper maxima (W-1, 3, and 4) are most likely related to the fact that these very sandy sediments will be well oxygenated to some depth; predation will be much lower in deeper levels of the deposit, and environmental perturbations much reduced, especially in intertidal areas. Organisms which can survive at deeper levels, given adequate oxygen and food resources, will be much less affected by predators and environmental fluctuations. Thes three South Slough stations are located above MLLW, and have sediments overwhelmingly of sand-sized particles. Stations CB-1 and CB-7 show shallower subsurface maxima; they are subtidal stations (13 and 10 m, respectively); the environmental variability should be much less, thereby obviating the necessity of deep burrowing to avoid the rigours of an intertidal environment.

Subsurface maxima in numbers of individuals for CB-10 and CB-12 are probably related to the frequency of disturbance. The maxima are shallow compared to the South Slough cores, and of lesser magnitude. Organisms occurring at these two stations can be assumed to be already adapted to low oxygen tensions, high organic concentrations, and small grain size. These parameters do not change significantly at levels deeper than 1 cm or so; individuals may assumedly avoid removal and mortality by remaining in slightly deeper levels of the deposit.

The only taxon consistently occurring in higher numbers at lower levels is *Phoronopsis harmeri*. This tubicolous lophophorate was shown to have maximal populations at 8 cm depth in an intertidal flat in Tomales Bay, California (Johnson, 1967). At station CB-8, it occurred from the surface to 15 cm depth (the maximum sampled), and exhibited the largest numbers in the second section (5-10 cm). The worm also occurred at W-1 and W-4; at the former, it extended from 5 to 40 cm, with a maximum at the 20-25 cm level; at W-4, Phoronopsis was found from 5 to 20 and 25 to 40 cm, with the largest numbers occurring in the third and fourth sections (10-20 cm).

Phoronopsis harmeri is essentially an intertidal species. Johnson (1967) found it at only one of 300 subtidal stations. This organism secretes a stiff sandy tube 3.5 to 18.0 cm in length. Johnson found the top of this tube at depths of up to 20 cm below the sediment surface. He also noted that many individuals are shorter than their tubes, and remain in the lower portions. I have found entire animals at depths of 35-40 cm in the sediment. This species has been shown to be capable of surviving six weeks in an anaerobic environment (Hamby, cited in Johnson, 1967).

The relationship between diversity, evenness, and various sediment parameters will be considered below, in the section o regressions.

Community Composition Parameters

When one considers the numerical dominance of "localized" over widespread taxa (see Table 2), the relatively low niche breadth values are not particularly surprising. Nematodes are the most ubiquitous of taxa considered: they occur at all eighteen stations, and show a niche breadth of 14.6, indicating a relatively even distribution. As specific identification of this and a few other taxa (Nemertea, Turbellaria, Oligochaeta, Foraminifera, and Coelenterata) was found to be inordinately difficult, it is highly possible (even probable) that individual species in these groups would be found to be much less widely distributed. The species showing the highest niche breadth, Modiolus modiolus, was found to occur widely in the bay (at sixteen stations), and frequently to considerable depth in the sediment (to the 40-45 cm level). Note the niche breadth for Oligochaeta: 6.7; while this group occurred at 17 of 18 stations, individuals were present in very low numbers in all of the CB cores (except CB-8), and in relatively high numbers in the W cores.

The figures for mean niche breadth are quite interesting. Both weighted and unweighted mean niche breadth values have been presented in Figure 20, as something different may be learned from each. Unweighted mean niche breadth is simply the geometric mean of the niche breadth values for all taxa occurring at the site. Weighted mean niche breadth produces a density-dependent statistic; each species' niche breadth is multiplied by the proportion of individuals in the sample belonging to that species. Note the values for station W-5. The value for unweighted mean niche breadth is low, about 3.7; when species abundances are considered, the value drops to 2.0. Examination of the data in Appendix B provides the answer to this marked reduction. Station W-5 is characterized by large numbers of three polychaete taxa: Pygospio elegans, Mediomastus acutus, and Fabricia sabella oregonica. The first of these has an abundance 40% greater at W-5 than at any other station; the number of M. acutus is two orders of magnitude greater than at any other station. Fabricia occurs only at W-5, and numbers are high. The station is also characterized by a large number of insect taxa, many of which were found only there.

Station W-5 is anomalous among the other South Slough stations. The sediment is characterized by a water content higher than any other locality sampled in the bay, except CB-12. Volatile solids are high, and median grain size is very small. Station W-5 is very similar to CB-10 and CB-12 in terms of measured sediment parameters, but the faunas are quite different. Station W-5 is located very far up South Slough in a backwater (not in the central channel of the Slough), and must be assumed to be very seldom disturbed. Sampling operations at this site are most likely the most catastrophic events to which the fauna is exposed. However, the physiographic environment is similar to CB-10 and CB-12 in frequently disturbed or even polluted areas; the fauna may be expected to reflect this. Mediomastus ambiseta has been noted as an opportunistic species characteristic of polluted or disturbed environments, as have Polydora ligni and Streblospio benedicti (Grassle and Grassle, 1974). The latter two spionid taxa are probably fairly closely related to Pygospio, and all would seem to be characteristic of low oxygen, small grain size environments. This physiographic regime is probably produced at W-5 solely as a function of current velocity, while conditions obtaining at CB-10 and CB-12 are the result of dredging, industrial activity, and frequent disturbance.

Station W-3 is represented by a group of species very similar to those found in other South Slough stations (except W-5), especially W-1 and W-6. The difference is one of abundance; individuals are relatively evenly distributed over most species, the exceptions being cosmopolitan species. This overabundance of species with high niche breadth values contributes to the high weighted mean niche breadth value seen for the station.

The case for stations CB-10, 11, and 12 may be similarly argued. These stations have high proportions of cosmopolitan taxa, and consequently, high values for weighted mean niche breadth. Grassle and Grassle (1974) have shown that species characteristic of disturbed environments are generally cosmopolitan. For example, _Streblospio benedicti_, the dominant species at CB-11 and CB-12, is widespread on the western and eastern coasts of North America and in Europe. The capitellids, _Mediomastus acutus_, _M. californiensis_, _M. ambiseta_, and _Heteromastus filiformis_ are closely related, and widely occurring. Parr (1974) found _Streblospio benedicti_ to be the dominant organism at stations in the dredged channel near CB-11 and CB-12.

Station CB-4 had a remarkably high number of species, as well as high diversity, and shows a low value for mean niche breadth. Of 75 species encountered at the station, 28 were found only at CB-4. This may be similarly related to the thesis of Grassle and Grassle: endemic species are characteristic of stable environments. Station CB-4 exhibited a sediment composed mostly of shell, but with relatively high organic content. This can probably be extrapolated to indicate a well-oxygenated, but reasonably food-rich environment. Many species are present in low abundances, indicating an extensive subdivision of available resources into relatively equal microhabitats of niches - the classical high-diversity, stable community.

Consideration of the values for the equivalent number of equally common species (E) at each station may have some utility. For example, CB-9 has an E value of fourteen species. Twenty seven species were actually present, yielding an E to S ratio of 51.9%. This may be construed to mean that 51.9% of the species present could account for 100% of the diversity observed, had they been equally represented. Ergo, the observed distribution of individuals among species was relatively uneven. According to Levins (1968), a community in which niches are equally broad can hold fewer species than one with non-uniform niche breadths. He has stated that as a community matures it is capable of supporting more species: "Thus a waif fauna of diverse origins should reach a demographic equilibrium with fewer species than old faunae hold." (Levins, 1968, p. 55). An uncertain environment forces niche expansion. The number of species present in a community is roughly, inversely proportional to the degree of environmental uncertainty. The number of species should be higher in stable environments, smaller in groups with good homeostasis, and smaller in newly-derived faunas.

Community Similarity Measures

Similarity values for pairs of species (ESIMI) were calculated in an attempt to describe taxa which vary concurrently. For example, the value for Macoma inquinata and Modiolus modiolus (0.878) indicates a fairly high level of co-occurrence at relatively constant levels of abundance. The high values for the Harpacticoida - Streblospio benedicti and Cumella vulgaris - Paraphoxus spinosus pairs may be interpreted in a similar fashion. The Actiniaria - Ophelia limacina pair shows a high value primarily because both occur at stations CB-1, 2, 3, 6, and 7; Actiniaria occur nowhere else; a few Ophelia limacina are additionally found at CB-5, but at no other stations. The extremely high value for Mediomastus acutus and Fabricia sabella oregonica is due to the fact that the latter occurs only at W-5; M. acutus has the highest abundance of any taxon at that station; and this station is also where the species shows its greatest abundance. The values for the Leptochelia dubia pairs presented are high because of the fact that L. dubia shows great numerical dominance at stations where it occurs; any taxa which occur at those stations in fairly high numbers will correlate well with L. dubia.

Similarity values for pairs of stations (SIMI) are fairly self-explanatory (see Figure 22). Stations with high SIMI values have similar relative abundances, for those taxa which occur at both stations. It should be noted that this index does not reflect taxa which occur at one station, but are absent from the other; it is merely a measure of the similarity of relative abundances of species which occur at both sites. For example, stations W-2 and W-4 have a SIMI value of 0.95, indicating a high similarity in relative abundance of common taxa. Yet, of 34 taxa occurring at W-4, only 13 are common to W-2.

Species clustering using the CLUSB algorithm was carried to the twelve cluster stage (see Table 4). At that point, seven of the clusters had unit representation, indicating little relation to other taxa. However, the multiple member clusters are quite interesting. Note that *Modiolus modiolus*, *Macoma inquinata*, *Tellina modesta*, and Hydrozoa have been placed in a single cluster. The Hydrozoa occur only in higher salinity environments; *Macoma inquinata* is found in low numbers throughout the estuary, with minor exceptions; *Modiolus modiolus* is found through most of the bay as well, but is much less abundant in the upper (lower salinity) portions of both South Slough and the dredged channel (see Table 8). *Tellina modesta* occurs at only one station, CB-4, but in large numbers. *Modiolus modiolus* and *Macoma inquinata* also have maximal populations at CB-4. Recall the high ESIMI values (all greater than 0.80) seen for the relationships among these three pelecypod taxa.

The cluster containing *Syllis gracilis*, *Eohaustorius washingtonianus*, Turbellaria, and Nemertea may also be interpreted as a high salinity assemblage. *Syllis gracilis* and *E. washingtonianus* occur only in the dredged channel, with maximal populations at CB-5 and CB-6. Turbellaria and Nemertea show maximum abundances in the lower reaches of the dredged channel and South Slough; they are found in the lower salinity portions of both areas, but in much reduced numbers. Specific identification for these two groups might show more distinct

Table 8. Salinity data for those stations corresponding to stations implemented by the NSF-RANN (O.S.U., 1977) research team. Measurements were taken in July, 1974, and the data supplied by Dr. K. Williamson, School of Engineering, Oregon State University, Corvallis.

STATION	SALINITY (°/₀₀)
CB-3	36.0
CB-12	24.0-27.0
W-1	29.5-30.5
W-2	31.0-31.5
W-3	31.0-31.5
W-4	30.0-32.0
W-5	29.0
W-6	31.0-32.0

zonation patterns.

The Ophelia limacina - Actiniaria cluster is another high salinity assemblage. Ophelia limacina does not occur above CB-7 or in South Slough, and exhibits a maximum at CB-2. Actiniaria are similarly limited to station CB-7 and below, also with maximum abundance at CB-2.

The Mediomastus californiensis - Clausidium vancouverense group exhibits maximum populations at CB-8, CB-9, and W-1. These stations have lower salinities than those considered heretofore, and slightly higher water content (15-20%).

Use of the Bray-Curtis dissimilarity index in station clustering overcomes the problem encountered with SIMI: namely, the fact that SIMI does not account for species which occur at only one of the two stations. The Bray-Curtis measure considers all taxa which occur, and derives relationships between stations based on faunal composition and relative abundance.

Clusters derived at a dissimilarity of less than 0.50 are: CB-10 and CB-12; CB-5 and CB-6; W-1 and W-3; and CB-1 and CB-2 (see Figure 23). Examination of the similarity index values (Figure 22) confirms the fact that the members of these groups are closely related. For example, CB-10 and 12 cluster at a BC value of 0.41; their SIMI value is 0.92. Stations CB-10 and 12 have seven common species (see Appendix B) which all show similar relative abundances; station CB-12 has eight taxa which do not occur at CB-10; of these, four are represented by single individuals. Three of five taxa occurring at CB-10 but not at CB-12 are single individuals.

It is interesting to note that station W-5 does not cluster with any other until the 0.96 level of dissimilarity is reached. Station W-5 exhibits relatively few species, numerous individuals, and the lowest diversity and evenness of any station sampled.

Note also that CB-8 and W-4 cluster at BC=0.57. Although these stations are far distant geographically, values for measured sediment parameters are in close agreement for the two stations, and their faunas are quite similar. Co-dominant taxa include Oligochaeta, *Phoronopsis harmeri*, *Mediomastus californiensis*, *Glycinde armigera*, *Macoma inquinata*, *Mya arenaria*, and *Modiolus modiolus*.

Sediment Parameters

Concentration of organic matter has been noted (Purdy, 1964) as a possible controlling factor in faunal distributions. Volatile solids at CB-10 and CB-12 vary in a similar fashion; stations CB-2, 3, 5, 6, and 9 also show like values. Station CB-11, which demonstrated the lowest diversity in the dredged channel, also is shown to have the highest organic content (greater than 22% volatile solids). When the samples were taken, it was noted that the sediment at station eleven contained large quantities of wood chips, a byproduct of industrial activity in the area. All of the South Slough cores, except W-5, show similar values for volatile solids. Station W-5 exhibits concentrations of organic matter of 6-8% by weight, over the depths sampled. These values are in the same range as those for CB-10. Station W-5, with the highest levels of organics in South Slough, also shows the lowest diversity.

Rhoads and Young (1970) have noted that a high water content, especially in surficial layers, prevents the occurrence of suspension-feeding organisms, and may reduce abundances of deposit feeders as well (see Introduction, pp. 13-15). Stations CB-10, 11, and 12, all with greater than 35% water content, show the lowest diversities in the dredged channel. South Slough station W-5 has a water content above 55%, placing it in the same range as CB-12, and also shows the lowest diversity in South Slough.

Regression Analysis

Results of the regression analysis of diversity on percentage water, depth of the sample in the sediment, and percentage sand have been shown to be highly significant (see Table 6). The fact that 57% of the variation seen in diversity can be accounted for by water content in the sediment (in the CB cores) is notable. When depth of the sample is added to the model, another 20% of the variation can be explained; the further addition of a measure of grain size (percentage sand) increases the explainable variation to eighty two per cent. At that point the multiple correlation coefficient between Shannon diversity and the model containing three sediment parameters is 0.91, an impressively high value.

The fact that addition of the South Slough cores to the regression model causes pejoration of the fit, is most likely due to the difference in environment. The South Slough fauna seems to be more deeply distributed (with the exception of W-5, which is much more similar to CB-10 and CB-12 than to any other South Slough station), the sediments in South Slough are mostly intertidal, and are less frequently disturbed. The percentage of water is high enough at only one station in South Slough (W-5) to cause a marked change in faunal composition. The lack of frequent mechanical disturbance at the South Slough stations would imply a greater diversity, compared to the dredged channel stations, were that the only factor operating. However, the intertidal location of all the South Slough stations (with the exception of W-2, which is only 3 m deep) implies a tidal variation in various chemical parameters of the sediment: salinity, temperature, and interstitial oxygen. These variables are not operating, at least on such a short time span, in the dredged channel stations. Intertidal stations are also notoriously less diverse than their subtidal counterparts (Boucot, 1977).

Sediment reworking, such as that seen in dredging, or that caused by infaunal deposit feeders, has been shown to produce sediments with a high water content, especially in upper layers (Rhoads and Young, 1970). A high water content implies a mobile sediment, affording little chance of attachment, or even the manufacture of burrows. Few organisms have adapted to life in extreme habitats of this type. The exceptions are generally small organisms, capable of withstanding low oxygen and high organic matter concentrations.

The most important chronic effects of dredging in Coos Bay on the vertical distribution of infauna are liable to be the increased water content of the surface layers of the sediment, and the reduction in grain size seen in these indesinently disturbed deposits. The fauna in the upper portion of the dredged channel (stations CB-10, 11, and 12, especially the latter) is apparently adapted to frequent disturbance (Parr, 1974); dredging does not represent a "catastrophe" to this suite of organisms. Dredging has occurred on a recurrent basis in this area of Coos Bay since the mid 1800's. The infaunal community has evolved to one able to withstand frequent disturbance of the surface, and high concentrations of water and organic matter in the deposit. A concomitant result seems to be a low oxygen tenor. The most notable result seen in the vertical distribution pattern is that organisms appear to be more limited to the upper layers of the deposit at these stations (CB-10, 11, and 12) than at undredged sites, and at dredged stations lower in the bay.

It would seem that dredging has a relatively minor influence on faunas in the lower reaches of the estuary. In the upper reaches, the higher water and organic content, and the much reduced grain size appear to have a deleterious effect on the faunal diversity, and depth of distribution. Stations CB-10 and CB-12 show low numbers of species and individuals, mostly restricted to the upper layers. Those species which do occur are generally cosmopolitan, opportunistic ones. Station W-5, far up South Slough, also has high water and volatile solids concentrations, as well as a small grain size, most likely due only to current velocity and circulation patterns; this station exhibits the lowest diversity of any sampled.

In the upper reaches of the dredged channel, it is, however, difficult to distinguish between the effects of dredging, per se, shipping traffic (which can contribute to the instability of the bottom through propwash and anchor dragging), and industrial activity. The large amounts of organic matter (especially wood chips) continually being added to the sediments in the area of CB-10, 11, and 12 appear to be at least partially responsible for the reduction in evenness and diversity.

Samples taken in the course of this survey have shown organisms to be living at depths of up to 55 cm in a sedimentary deposit. This is in general agreement with recent research (Fenchel, 1971; Fenchel and Jansson, 1966; Fenchel et al., 1967; Jansson, 1966, 1968; Renaud-Debyser, 1963; Renaud-Debyser and Salvat, 1963; and Ganapati and Rao, 1962), but older studies (prior to about 1960) put forth the belief that organisms were restricted to about the surface 15 cm (eg., Thorson, 1957). It is unfortunate that this older view is still propounded to undergraduates and beginning students of benthic ecology.

Organisms have been shown to occur deeper in the sediment in relatively undisturbed areas (South Slough), although this may reflect the intertidal location of all but one of these stations, or may simply be a sampling artifact. It would be highly proficuous to examine the vertical distribution of particular species in areas such as these, with an eye toward defining how a particular organism deals with frequency of disturbance. Smaller sections (eg., 1 cm), and many more samples, would be required in order to test an hypothesis of differing reactions to differing frequencies of disturbance. It would also be useful to take deeper cores, in order to determine maximum depth limitations in various physiographic environments. I have found organisms in the last (bottom) section in 14 of 18 cores, indicating the possibility of individual occurrences at even greater depths, especially in coarser sediments.

This study is one of many which has refuted Pennak (1951), who stated that grain size has "no constant relationship to either number or distribution of individuals." I have shown that grain size and water content, rather than frequency of disturbance, are limiting factors in regard to both vertical distribution and faunal diversity. Station W-5 (in an undisturbed area) is remarkably similar to both CB-10 and CB-12 as concerns grain size, volatile solid concentration, and water content. Although the respective faunal assemblages are quite distinct, both areas are characterized by high numerical dominance by one or a few opportunistic species. At W-5, these organisms are Fabricia sabella oregonica, Pygospio elegans, and Mediomastus acutus, while at CB-10 and CB-12, the dominant species is Streblospio benedicti. Although Fabricia was undetected at any of the other stations in my study, the work of O.S.U. (1977) has shown it to be a dominant organism in a diked spoil area upstream from CB-12. All these species are opportunistic ones, well adapted to life in stressful environments. Reproductive cycles are short, on the order of a few months (see Parr, 1974), and they all seem to be highly capable of outcompeting other organisms in low oxygen, small grain size, high liquidity environments. Fabricia appears to be restricted to surface layers (both O.S.U., 1977 and I have found this organism only in surface layers), and thus it is not well adapted for existence in an environment of frequent mechanical disturbance.

The faunal assemblages in the lower reaches of the dredged channel appear to reflect firstly, the coarser sediment type, and secondly, the role of mechanical disturbance. These assemblages are far more diverse, and more 'normal', than those further up the bay (CB-10 through CB-12). The taxa encountered in the lower reaches of the dredged channel are less liable to be 'cosmopolitan' ones, than in the upper reaches of the dredged channel. In South Slough, with the exception of W-5, the faunal assemblages exhibit a similar trend; evenness is higher, and mean niche breadth lower, than in the stressed environment of W-5. The fauna is distributed to deeper levels in the sediment in South Slough, reflecting the lower frequency of disturbance compared to the dredged channel.

The depth to which organisms are found in the sediments of South Slough may be a response to increased environmental variation in the intertidal, as well as a lower frequency of disturbance. The sediments are coarse grained, and should be well oxygenated to some depth, thereby allowing organisms to avoid the increased predation and environmental variation obtaining in surface layers, by occupying deeper levels in the sediment. The faunal assemblages in the lower reaches of the dredged channel do not have to contend with environmental variation on such a large scale, due to their subtidal location; increased pressure from mechanical disturbance may further limit them to surface layers. Periodic disturbance may not only remove sediment, but may also redeposit it at another location; the concentration of dissolved oxygen frequently decreases during dredging operations (Parr, 1974), and the water column may experience an increase in fine-grained suspended matter. All of these factors may possibly be considered to be stressful to organisms deep within the sediment. The disadvantage of possible removal by remaining in surface layers is apparently outweighed by advantages accruing to an organism through a near-surface position in the deposit, at least in frequently disturbed areas.

The respective faunal assemblages of the dredged channel and South Slough are postulated to reflect the fact that the former is periodically disturbed. Conceivably, the two communities were quite similar before dredging and marine commerce became important in the ecology of Coos Bay. The first major dredging operation presumably eradicated a goodly number of taxa in the bay, possibly with subsequent repopulation. When the frequency of disturbance became too high to permit repopulation by taxa present in the undisturbed environment, a situation was created wherein opportunistic species possessed a competitive advantage. Wass (1967) has described these opportunistic species in a most succinct manner as "weeds which proliferate over broad areas of man's disclimaxes." Reproductive strategies are probably the most important feature these organisms possess, in allowing them to outcompete nearly all other taxa. These "weed" species require frequent disturbance to maintain their competitive advantage. Were shipping and dredging in Coos Bay suddenly to cease, one would expect the faunal composition to return to some approximation of a pre-dredging community, given some aoristic interval.

CONCLUSIONS

1. A study of the vertical distribution of meio and macroinfauna at twelve dredged and six undredged sites in Coos Bay, Oregon, has shown the respective faunas to be quite distinct.
2. A total of 173 taxa were identified in the samples; 101 were restricted to the dredged channel, and 27 taxa were found only in the undredged South Slough environment. The difference is postulated to be related to tidal level differences in station location (dredged channel stations were in 10 m of water and deeper, while all but one South Slough station (W-2, 3 m water depth) were intertidal), and to frequency of disturbance.
3. All but one taxon exhibited maximum abundance in surface layers, with declining numbers of individuals in deeper layers.
4. Phoronopsis harmeri consistently showed a subsurface abundance maximum, due either to an ability to maintain a connection with the sediment surface, or, in the absence of such a connection, to withstand prolonged periods (up to six weeks) of anaerobiosis.
5. South Slough faunas were consistently distributed to deeper levels in the sediment than dredged channel associations, due most probably to differences in frequency of disturbance, and the intertidal location of all but one station.
6. Regression analysis of Shannon diversity on water content, depth in the sediment, and grain size produced a multiple correlation coefficient of 0.91 for the dredged channel samples. The addition

of organic matter concentration to the regression model did not produce a significant increase in the correlation coefficient.

7. Consideration of all samples in the regression model yielded a multiple correlation coefficient of 0.79; volatile solid concentration was again not significant. The pejorative effect of addition of the South Slough samples is postulated to be due to a difference in frequency of disturbance.

8. Dredging, shipping traffic, and industrial activity in the upper reaches of the dredged channel appear to have a marked effect on the faunal diversity and depth of distribution, due most probably to increased water and organic matter concentrations, decreased grain size, and physical disturbance and periodic removal of surface layers of the deposit. Those species which do occur are generally cosmopolitan, opportunistic ones, restricted to the upper ten centimetres of the sedimentary column.

9. Stations in the lower reaches of the dredged channel, and all but one of the undredged stations (W-5, which was more closely allied to the up-bay dredged channel stations, due to an aberrant sedimentation and current velocity pattern) showed far more speciose faunas distributed to deeper levels in the deposit.

LITERATURE CITED

Barnard, J.L. and O. Hartman. 1959. The sea bottom off Santa Barbara, California: biomass and community structure. Pacif. Nat. 1(6): 1-16.

Barnett, P.R.O. 1968. Distribution and ecology of harpacticoid copepods of an intertidal mud flat. Int. Revue ges. Hydrobiol. 53: 177-209.

Barnett, P.R.O. and B.L.S. Hardy. 1967. A diver-operated bottom sampler for sand macrofaunas. Helgoländ. wiss. Meeresunters. 15: 390-398.

Boaden, P.J.S. 1962. Colonization of graded sand by an interstitial fauna. Cah. Biol. Mar. 3:245-248.

________. 1968. Water movement - a dominant factor in interstitial ecology. Sarsia 34:125-236.

Bougis, P. 1946. Analyse quantitative de la micro-faune d'une vase marine à Banyuls. C.R. Acad. Sci., Paris 222:1122-1124.

Bouma, A.H. 1969. Methods for the study of sedimentary structures. John Wiley & Sons, New York. 458 pp.

Bouma, A.H. and N.F. Marshall. 1964. A method for obtaining and analysing undisturbed oceanic sediment samples. Mar. Geol. 2:81-99.

Bourke, R.H., B. Glenne, and B.W. Adams. 1971. The nearshore physical oceanographic environment of the Pacific Northwest Coast. School of Oceanography Ref. 71-45. Oregon State University, Corvallis 127 pp.

Boucot, A.J. 1977. Professor, Dept. of Geology, Oregon State University, Corvallis. personal communication.

Bouyoucos, G.J. 1936. Directions for making mechanical analyses of soil by the hydrometer method. Soil Sci. 42:225-228.

Bray, J.R. and J.T. Curtis. 1957. An ordination of the upland forest communities of southern Wisconsin. Ecol. Monogr. 27:325-349.

Brett, C.E. 1964. A portable diver-operated dredge-sieve for sampling subtidal macrofauna. J. Mar. Res. 22:205-209.

Bush, L.F. 1966. Distribution of sand fauna in beaches at Miami, Florida. Bull. Mar. Sci. Gulf Caribb. 16:58-75.

Chapman, G. 1949. The thixotropy and dilatancy of marine soil. J. Mar. Biol. Ass. U.K. 28:123-140.

Day, J.H., J.G. Field, and M.P. Montgomery. 1971. The use of numerical methods to determine the distribution of the benthic fauna across the continental shelf off North Carolina. J. Anim. Ecol. 40:93-123.

Delamare-Deboutteville, C. 1960. Biologie des eaux souterraines littorales et continentales. Hermann, Paris. 740 pp.

Driscoll, E.G. 1967. Attached epifauna-substrate relations. Limnol. Oceanogr. 12:633-641.

Ekman, S. 1947. Ueber die Festigkeit der marinen Sedimente als Faktor der Tierverbreitung. Zool. Bidr. Uppsala 25:1-20.

Emery, K.O. 1938. Rapid method of mechanical analysis of sands. J. Sedim. Petrol. 8:105-11.

Fager, E.W. 1964. Marine sediments: effects of a tube-dwelling polychaete. Science 143:356-359.

Fenchel, T. 1967. The ecology of marine microbenthos. I. The quantitative importance of ciliates as compared with metazoans in various types of sediments. Ophelia 4:121-137.

________. 1971. The reduction-oxidation properties of marine sediments and the vertical distribution of the microfauna. Vie Milieu Suppl. 22:509-521.

Fenchel, T. and B.-O. Jansson. 1966. On the vertical distribution of the microfauna in the sediments of a brackish-water beach. Ophelia 3:161-177.

Fenchel, T., B.-O. Jansson, and W. von Thun. 1967. Vertical and horizontal distribution of the metazoan microfauna and of some physical factors in a sandy beach in the northern part of the Øresund. Ophelia 4:227-243.

Field, J.G. 1969. The use of the information statistic in the numerical classification of heterogeneous systems. J. Ecol. 57:565-569.

________. 1970. The use of numerical methods to determine benthic distribution patterns from dredges in False Bay. Trans. Roy. Soc. S. Afr. 39:183-200.

________. 1971. A numerical analysis of changes in the soft-bottom fauna along a transect across False Bay, South Africa. J. Exp. Mar. Biol. Ecol. 7:215-253.

Field, J.G. and G. Macfarlane. 1968. Numerical methods in marine ecology. I. A quantitative "similarity" analysis of rocky shore samples in False Bay, South Africa. Zool. Afr. 3:119-137.

Flemming, N.C. 1962. Sunken cities and forgotten wrecks. pp. 123-171 in G.R. Deacon, ed., Oceans. Hamlyn, London.

Ganapati, P.N. and G.C. Rao. 1962. Ecology of the interstitial fauna inhabiting the sandy beaches of Waltair coast. J. Mar. Biol. Ass. India 4:44-57.

Gause, G.F. 1934. The struggle for existence. Williams & Wilkins, Baltimore. 163 pp.

Ginsburg, R.N. and H.A. Lowenstam. 1958. The influence of marine bottom communities on the depositional environment of sediments. J. Geol. 66:310-318.

Gleason, G.R., Jr. and F.J. Ohlmacher. 1965. A core sampler for in situ freezing of benthic sediments. Oc. Sci. Oc. Eng. 2:737-741.

Grassle, J.F. and J.P. Grassle. 1974. Opportunistic life histories and genetic systems in marine benthic polychaetes. J. Mar. Res. 32:253-284.

Gray, J.S. 1965. The behaviour of Protodrilus symbioticus Giard in temperature gradients. J. Anim. Ecol. 34:455-461.

________. 1966. The response of Protodrilus symbioticus Giard (Archiannelida) to light. J. Anim. Ecol. 35:246-249.

Gulliksen, B. and K.M. Derås. 1975. A diver-operated suction sampler for fauna on rocky bottoms. Oikos 26:246-249.

Hallam, A. 1965. Environmental causes of stunting in living and fossil marine invertebrates. Paleontology 8:132-155.

Hardy, A.C. 1965. The Open Sea: Its Natural History. Houghton Mifflin & Co., Boston. 322 pp.

Heip, C. 1974. A new index measuring evenness. J. Mar. Biol. Ass. U.K. 54:555-557.

Holme, N.A. 1953. The biomass of the bottom fauna in the English Channel off Plymouth. J. Mar. Biol. Ass. U.K. 32:1-49.

________. 1964. Methods of sampling the benthos. Adv. Mar. Biol. 2:171-260.

Hopper, B.E. and S.P. Meyers. 1967. Population studies on benthic nematodes within a subtropical sea-grass community. Mar. Biol. 1:85-96.

Jansson, B.-O. 1966. Microdistribution of factors and fauna in marine sandy beaches. Veröff. Inst. Meeresforsch. Bremerh. (Sonderbd.) 2:77-86.

________. 1967a. The importance of tolerance and preference experiments for the interpretation of mesopsammon field distributions. Helgoländ. wiss. Meeresunters. 15:41-58.

________. 1967b. The availability of oxygen for the interstitial fauna of sandy beaches. J. Exp. Mar. Biol. Ecol. 1:122-143.

________. 1967c. The significance of grain size and pore water content for the interstitial fauna of sandy beaches. Oikos 18:311-3221

________. 1967d. Diurnal and annual variations of temperature and salinity of interstitial water in sandy beaches. Ophelia 4:173-201.

________. 1968. Quantitative and experimental studies of the interstitial fauna in four Swedish sandy beaches. Ophelia 5:1-71.

Johansen, A.C. 1927. Preliminary experiments with Knudsen's bottom sampler for hard bottom. Medd. Komm. Havundersøg., København, Ser. Fisk. 8(4):1-6.

Johnson, J.W. 1972. Tidal inlets on the California, Oregon and Washington coasts. Hydraulic Engineering Laboratory. HEL 24-12. Univ. California, Berkeley. 145 pp.

Johnson, R.G. 1967. The vertical distribution of the infauna of a sand flat. Ecology 48:571-578.

Jones, N.S. 1950. Marine bottom communities. Biol. Rev. 25:283-313.

Kaplan, E.H., J.R. Welker, and M.G. Krause. 1974. A shallow-water system for sampling macrobenthic infauna. Limnol. Oceanogr. 19: 346-350.

King, A. 1977. Acute effects of sedimentation on Cumella vulgaris Hart 1930 (Cumacea). M.S. Thesis, Oregon State University, Corvallis. (in press).

Kinne, O. 1964. The effects of temperature and salinity on marine and brackish water animals. II. Salinity and temperature salinity combinations. Oceanogr. Mar. Biol. Ann. Rev. 2:281-339.

Kinner, P., D. Maurer, and W. Leathem. 1974. Benthic invertebrates in Delaware Bay: animal-sediment associations of the dominant species. Int. Revue ges. Hydrobiol. 59:685-701.

Kischke, U. 1956. Die Nematoden aus der Torf-Zone der Hochmoore des Oberharzes nebst Bemerkungen Uber gewisse Gruppen der terricolen Begleitfauna (Rotatoria, Acarina, Collembola). Hydrobiologia 52: 210-277.

Knudsen, M. 1927. A bottom sampler for hard bottom. Medd. Komm. Havundersøg., København, Ser. Fisk. 8(3):1-4.

Krogerus, R. 1932. Über die Ökologie und Verbreitung der Arthropoden der Triebsandgebiet an den Küsten Finnlands. Acta Zool. Fennica, Helsingfors 12:1-308.

Krumbein, W.C. and F.J. Pettijohn. 1938. Manual of Sedimentary Petrography. Appleton-Century Crofts, New York. 549 pp.

Levins, R. 1968. Evolution in changing environments. Princeton Univ. Press, Princeton. 120 pp.

MacCoy, C.V. 1966. Zonation of benthic meiofauna in tidal creeks of an estuary. Verh. Int. Verein. Theor. Angew. Limnol. 16:1471-1475.

MacGinitie, G.E. 1935. Ecological aspects of a California marine estuary. Amer. Nidl. Nat. 16:629-765.

________. 1939. Littoral marine communities. Amer. Midl. Nat. 21: 28-55.

Mackereth, F.J.H. 1958. A portable core sampler for lake deposits. Limnol. Oceanogr. 3:181-191.

Mare, M.F. 1942. A study of a marine benthic community with special reference to the microorganisms. J. Mar. Biol. Ass. U.K. 25:517-554.

McAlister, W.B. and J.O. Blanton. 1963. Temperature, salinity, and current measurements for Coos Bay, Oregon. Department of Oceanography, Oregon State University, Corvallis. Data Rep. 10. 33 pp.

McIntire, C.D. N.D. Instructions for the use of CLUSB. A computer program to cluster observations of multivariate data. Professor, Department of Botany, Oregon State University, Corvallis. Unpublished.

McIntyre, A.D. 1961. Quantitative differences in the fauna of boreal mud associations. J. Mar. Biol. Ass. U.K. 41:599-616.

McIntyre, A.D. 1964. Meiobenthos of sublittoral muds. J. Mar. Biol. Ass. U.K. 44:665-674.

________. 1968. The meiofauna and macrofauna of some tropical beaches. J. Zool. Lond. 156:377-392.

________. 1969. Ecology of marine meiobenthos. Biol. Rev. 44:245-290.

________. 1971. Deficiency of gravity corers for sampling meiobenthos and sediments. Nature 231:260.

________. 1973. Meiobenthos. Proc. Challenger Soc. 4(3):1-9.

McNulty, J.K., R.C. Work, and H.B. Moore. 1962. Some relationships between the infauna of the level bottom and the sediments in South Florida. Bull. Mar. Sci. Gulf Caribb. 12:322-332.

Molander, A.R. 1928. Investigations into the vertical distribution of the fauna of the bottom deposits in the Gullmar fjord. Svenska Hydrog.-Biol. Komm. Skrifter, Ser. Hydrografi 6(6):1-5.

Moore, H.B. 1931. The muds of the Clyde sea area. III. Chemical and physical conditions; rate and nature of sedimentation; and fauna. J. Mar. Biol. Ass. U.K. 17:325-358.

Muus, B.J. 1967. The fauna of Danish estuaries and lagoons. Meddr. Danm. Fisk.-og. Havunders. 5:1-316.

Muus, K. 1966. A quantitative 3-year study on the meiofauna of known macrofauna communities in the Öresund. Veröff. Inst. Meeresforsch. 11:289-292.

Ohlmacher, F.J. and H.E. Schlichting, Jr. 1967. Vertical stratification and viability of algae, bacteria, and protozoa in frozen core samples. Texas J. Sci. 19:77-86.

Oregon State University. 1977. Final Report, NSF-RANN Grant Number 80N-7101908. Dredge Spoil Distribution and Estuarine Effects. [In preparation].

Overton, W.S. 1974. AID programs (Analysis of Information and Diversity). Professor, Department of Statistics, Oregon State University, Corvallis. Unpublished.

Parr, R.A. 1974. Harbor dredging and benthic infauna: a case study. M.S. Thesis, Oregon State University, Corvallis. 114 pp.

Pennak, R.W. 1942. Ecology of some copepods inhabiting intertidal beaches near Woods Hole, Massachusetts. Ecology 23:446-456.

Pennak, R.W. 1951. Comparative ecology of the interstitial fauna of freshwater and marine beaches. Année Biol. 27(6):449-480.

Percy, K.L., D.A. Bella, and P.C. Klingeman. 1973. Descriptions and information for Oregon estuaries. Water Resources Institute, Oregon State University, Corvallis. 190 pp.

Perkins, E.J. 1958. Microbenthos of the shore at Whitstable, Kent. Nature 181:791.

Pielou, E.C. 1975. Ecological Diversity. John Wiley & Sons, New York. 165 pp.

Prenant, M. 1960. Études écologiques sur les sables intercôtideaux. I. Questions de methode granulometrique. Application à trois anses de la baie de Quiberon. Cah. Biol. Mar. 1:295-340.

________. 1961. Faunes des plages marines et granulométrie des sédiments. Bull. Soc. Zool. France 86:412-424.

Prych, E.A. and D.W. Hubbell. 1966. A sampler for coring sediments in rivers and estuaries. Geol. Soc. Amer. Bull. 77:549-556.

Purasjoki, K.J. 1947. Quantitative Untersuchungen über die Mikrofauna des Meeresbodens in der Umgebung der Zoologischen Station Tvärminne an der Südküste Finnlands. Commentat. Biol. 9:1-24.

Purdy, E.G. 1964. Sediments as substrates. pp. 238-271 in Imbrie, J. and N. Newell, eds., Approaches to Paleoecology. John Wiley & Sons, New York.

Rees, C.B. 1940. A preliminary study of the ecology of a mud-flat. J. Mar. Biol. Ass. U.K. 24:185-199.

Reineck, H.E. 1961. Die Herstellung von Meeresboden-Präparaten im Senckenberg-Institut Wilhelmshaven. Museumskunde 30:87-89.

Reish, D.J. 1959. A discussion of the importance of the screen size in washing quantitative marine bottom samples. Ecology 40:307-309.

________. 1962. A study of succession in recently constructed marine harbors in southern California. Proc. Natn. Conf. Cstl. Shallow Wat. Res. (Baltimore) 1:570-573.

Remane, A. and E. Schulz. 1934. Das Küstengrundwasser als Lebensraum. Schr. Naturw. Ver. Schlesw.-Holst. 20:399-408.

Renaud-Debyser, J. 1963. Recherches écologiques sur la faune interstitielle des sables (Bassin d'Arcachon, Ile de Bimini, Bahamas).

Vie Milieu Suppl. 15:1-157.

Renaud-Debyser, J. and B. Salvat. 1963. Élements de prospérité des biotopes des sédiments meubles intercôtideaux et écologie de leurs populations en microfaune et macrofaune. Vie Milieu 3:463-550.

Rhoads, D.C. and D.K. Young. 1970. The influence of deposit-feeding organisms on sediment stability and community trophic structure. J. Mar. Res. 28:150-178.

Richardson, M.C. N.D. "Instructions for the use of MCRLIB." Research Associate, School of Oceanography, Oregon State University, Corvallis. Unpublished. [Title added].

Ricketts, E.F., J. Calvin, and J.W. Hedgpeth. 1968. Between Pacific Tides. Stanford Univ. Press, Stanford. 614 pp.

Rieger, R. and J. Ott. 1971. Gerzeitenbedingte Wanderungen von Turbellarien und Nematoden eines nordadriatischen Sandstrandes. Vie Milieu Suppl. 22:425-447.

Rudy, P. 1970. Some problems of the coastal zone. pp. 120-122, in Bur. Sport Fish. and Wildlife, Proc. of Northwest Estuarine and Coastal Zone Symposium. Portland, Oregon, 28-30 Oct., 1970.

Rullier, F. 1959. Étude bionomique de l'Aber de Roscoff. Trav. Stat. Biol. Roscoff (N.S.) 10:350 pp.

Salvat, B. 1964. Les conditions hydrodynamiques interstitielles des sédiments meubles intertideaux et la répartition verticale de la faune endogée. C.R. Acad. Sci., Paris 259:1576-1579.

________. 1967. La macrofaune carcinologique endogée des sédiments meubles intertideaux (Tanaidacées, Isopodes, et Amphipodes), éthologie, bionomie, et cycle biologique. Mém. Mus. Natn. Hist Nat., Paris, N.S., Zool. 45:1-275.

Sanders, H.L. 1958. Benthic studies in Buzzard's Bay. I. Animal - sediment relationships. Limnol. Oceanogr. 3:245-258.

Schmidt, P. and W. Westheide. 1971. Études sur la répartition de la microfaune et de la microflore dans une plage de l'île de Sylt (Mer du Nord). Vie Milieu Suppl. 22:449-464.

Shannon, C.E. and W. Weaver. 1949. The mathematical theory of communication. University of Illinois Press, Urbana. 117 pp.

Sheldon, A.L. 1969. Equitability indices: dependence on the species count. Ecology 50:466-467.

Simpson, E.W.S. and A.E.F. Heydorn. 1965. Vema seamount. Nature, Lond. 207:249-251.

Smidt, E.L.B. 1951. Animal production in the Danish Waddensea. Meddr. Danm. Fisk-og. Havunders. 11:1-151.

Stander, J.M. 1970. Diversity and similarity of benthic fauna off Oregon. M.S. Thesis, Oregon State University, Corvallis. 72 pp.

Stephenson, W. and W.T. Williams. 1971. A study of the benthos of soft bottoms, Sek Harbour, New Guinea, using numerical analysis. Aust. J. Mar. Freshwater Res. 22:11-34.

Stephenson, W., W.T. Williams, and S. Cook. 1972. Computer analyses of Petersen's original data on bottom communities. Ecol. Monogr. 42:387-415.

Swedmark, B. 1964. The interstitial fauna of marine sand. Biol. Rev. 39:1-42.

Taylor, J.L. and C.H. Saloman. 1968. Some effects of hydraulic dredging and coastal development in Boca Ciega Bay, Florida. U.S. Fish Wildl. Serv. Fishery Bull. 67:213-241.

Teal, J.M. and W. Wieser. 1966. The distribution and ecology of nematodes in a Georgia salt marsh. Limnol. Oceanogr. 11:217-222.

Thiel, von H. 1966. Quantitative Untersuchungen über die Meiofauna des Tiefseebodens. Veröff. Inst. Meeresforsch. Bremerh. (Sonderbd.) 2:131-148.

Thorson, G. 1957. Sampling the benthos. Mem. Geol. Soc. Amer. 67 (1):61-73.

U.S. Dept. of Interior. 1971. Natural resources, ecological aspects, uses and guidelines for the management of Coos Bay, Oregon. A Special Report. 128 pp.

VanStraaten, L.M.J.U. and P.H. Kuenen. 1958. Tidal action as a cause of clay accumulation. J. Sedim. Petrol. 28:406-413.

Volterra, V. 1926. Variazione e Fluttuazione del Numero d'Individui in Specie Animali Conviventi. Mem. Accad. Naz. Lincei 2:31-113.

Walker, B. 1967. A diver-operated pneumatic core sampler. Limnol. Oceanogr. 12:144-146.

Wass, M.L. 1967. Biological and physiological basis of indicator organisms and communities. pp. 271-283 in Olson, T.A. and F.J. Burgess, Pollution and Marine Ecology. Interscience, New York.

Wieser, W. 1959. The effect of grain size on the distribution of small invertebrates inhabiting the beaches of Puget Sound. Limnol. Oceanogr. 4:181-194.

________. 1960a. Benthic studies in Buzzard's Bay. II. The meiofauna. Limnol. Oceanogr. 5:121-137.

________. 1960b. Populationsdichte und Vertikalverteilung der Meiofauna mariner Böden. Int. Revue ges. Hydrobiol. Hydrogr. 45:487-492.

Wieser, W. and J. Kanwisher. 1961. Ecological and physiological studies on marine nematodes from a small salt marsh near Woods Hole, Massachusetts. Limnol. Oceanogr. 6:262-270.

Wigley, R.L. and A.D. McIntyre. 1964. Some quantitative comparisons of offshore meiobenthos and macrobenthos south of Martha's Vineyard. Limnol. Oceanogr. 9:485-493.

APPENDICES

APPENDIX A

A DIVER-OPERATED AIR-LIFT CORE SAMPLER[1]

K. Jefferts and D.R. Hancock

ABSTRACT

A diver-operated air-lift corer for use in sampling shallow water sediments is described. Advantages of the sampling device are portability, ease of operation, and large sample size. Undeveloped, but apparently feasible, modifications for use in deeper water or for sediment chemistry investigations are discussed. Additionally, an extruder capable of extruding large (15 cm) diameter cores of length up to 1.5 m is detailed. The device has been used to study infaunal distribution with depth in the sediments of South Slough, Coos Bay, Oregon.

INTRODUCTION

A research program designed to investigate infaunal stratification in estuarine sediments necessitated the development of a sampling device which could penetrate one metre into unconsolidated sediments, yet be operable in an intertidal or shallow subtidal area. The Bouma box sampler (Bouma and Marshall, 1964), satisfactory in the deeper areas of the estuary, required the winch capabilities of a large support vessel. Operation depth of the box corer became limited by the draught of the ship, the type of substrate, and the depth of

1. This manuscript was prepared for the December, 1975 meeting of the Western Society of Naturalists, and the January, 1976 meeting of the Oregon Marine Biological Society; it was presented at the latter.

water necessary for effective sampling, as the only impetus to penetration is gravity: gravitational acceleration during free-fall of the instrument to the bottom, and the gravitational force imparted to the box by the lead weights above it. On some substrates (gravel and shell), a water depth of ten metres was insufficient to obtain adequate cores (see Table A1).

A sampling device was required which could take cores in one metre of water as easily as in thirty. The sampling cylinder designed by Barnett and Hardy (1967) appeared to have good possibilities, with modification. The air-lift principle has been used to anchor samplers in the bottom (Mackereth, 1958; Walker, 1967) or, as by Barnett and Hardy, to provide a sampling frame. The coring device herein described utilizes an air-lift pump to drive a core barrel into the sediment. Penetration to 80 cm requires from one to five minutes, depending on substrate type. The primary resistance of the cylinder to pepetration is proportional to circumference; driving force is proportional to the cross-sectional area. Larger cylinders should, therefore, penetrate more efficiently.

DESCRIPTION

The barrel of the corer (Figure A1) is an 80 cm length of 15.2 cm outside diameter aluminum irrigation pipe (wall thickness 0.1 cm). An aluminum flange, 2.1 cm high by 1.9 cm wide, with a 0.32 cm O-ring groove, is welded flush with one end of the barrel. Aluminum supports for clamps to secure the lid and for a bridle are welded to the barrel

Table A1. Relative efficiencies of Bouma box corer (BBC) and air-lift corer (ALC) in the dredged channel (CB) and South Slough (W) of Coos Bay, Oregon.

Station	Instrument	Sediment type	Water depth	Penetration depth
CB-1	BBC	sand	14 m	23 cm
CB-2	BBC	sand	9	10
CB-3	BBC	sand	9	25
CB-4	BBC	shell	10	12
CB-5	BBC	sand	9	22
CB-6	BBC	sand	10	28
CB-7	BBC	sand, wood	10	21
CB-8	BBC	sand, shell	11	15
CB-9	BBC	sand, wood, shell	11	15
CB-10	BBC	mud	11	45 (maximum)
CB-11	BBC	wood, sand	13	22
CB-12	BBC	mud	13	45 (maximum)
W-1	ALC	sandy mud	1	50
W-2	ALC	sand, shell	3	80 (maximum)
W-3	ALC	sandy mud	1	55
W-4	ALC	mud	1	50
W-5	ALC	mud	1	53
W-6	ALC	sand	1	58

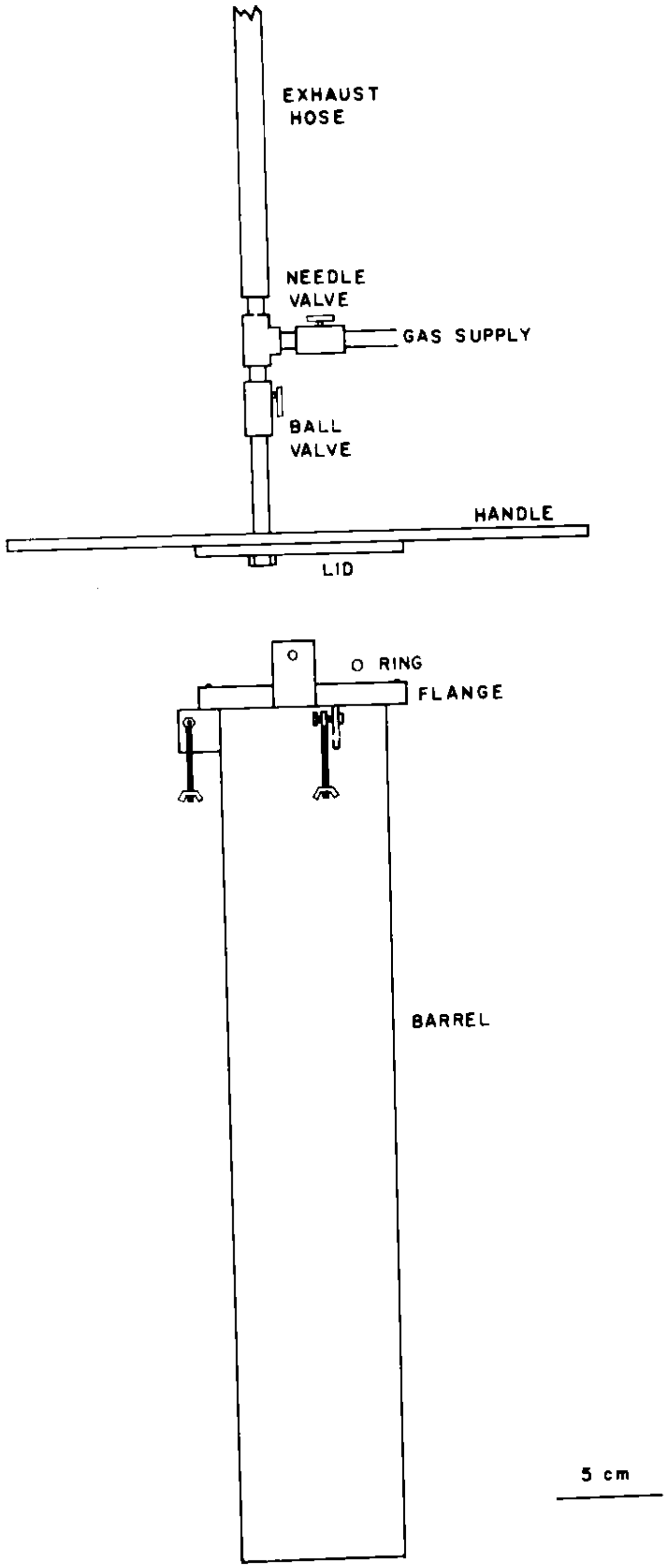


Figure A1. Air-lift corer, showing component parts.

and flange, respectively.

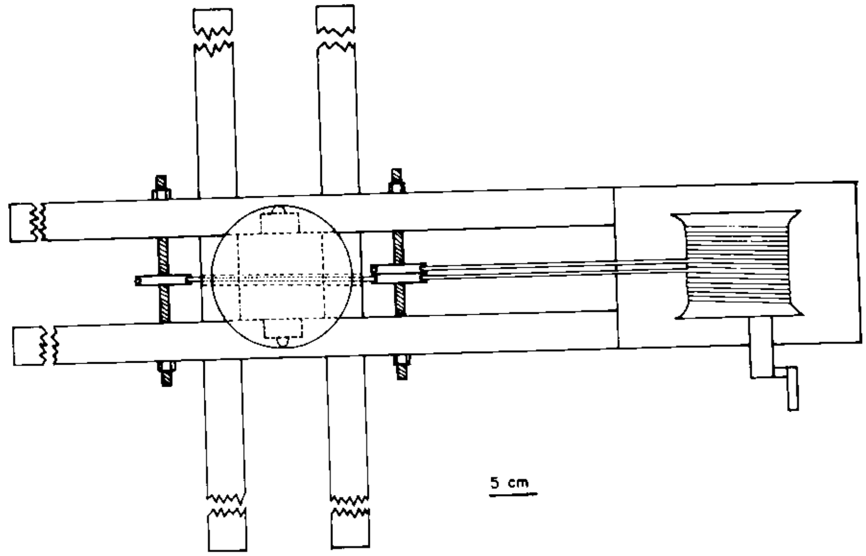
The lid, a 0.95 cm thick piece of aluminum, with slots for clamps, is fitted with a handle to aid initial positioning of the corer. A 15.2 cm section of 1.3 cm (1/2" NPT) diameter pipe is bolted through the lid. The lower end of the pipe is fitted with a screen of appropriate mesh size, in order to retain light animals at the sediment-water interface within the sample. A ball valve is attached to the upper end of the pipe. Above the ball valve is a T-connection, followed by a hose-clamp connection to a 3.0 m length of 2.5 cm clear Tygon tubing, and terminating in a float.

A compressed gas (air, oxygen, or nitrogen) flows through 23 m (length dependent upon water depth) of 1.3 cm inside bore rubberized high pressure hose, through a needle valve, where flow rate is regulated, through the T-connection, and into the water column which extends from the interior of the core barrel to the end of the Tygon tubing. Oxygen is currently being used in the system. A high pressure cylinder and regulator, of the sort used in welding, are required. Gas in the water column reduces the density of the water and causes it to rise, thus reducing the pressure inside the core barrel (providing there is a good seal between the sediment and the lower end of the barrel). The pressure differential between the head of water above the corer and the reduced pressure inside the barrel forces the corer into the sediment.

After the corer has penetrated, it is withdrawn from the sediment with a three horsepower gasoline-powered winch mounted on the support vessel. A 5 m catamaran operable in 0.2 m of water, with a central well, has been used for sampling. The central well facilitates deployment and retrieval of the corer and divers.

As the corer emerges from the sediment, a diver places a cap over the end of the barrel. The cap consists of an aluminum plate identical to that used for the lid, and three rubber tie-down straps. The rubber straps are hooked over a ring on the bottom of this plate, pass through slots in the plate, up alongside the barrel, and are hooked together atop the lid. If straps of length appropriate to the length of the barrel are selected, a very good seal is made between the barrel and the cap.

With the cap in place, the entire apparatus is transported to the surface to be extruded. To section the core at appropriate intervals, an extruder was constructed to the barrel specifications. It consists of a structure to maintain the barrel in a vertical position and a hand winch to pull the barrel down, the core itself remaining stationary. The extruder (Figure A2) is built almost entirely of clear, kiln-dried, Douglas Fir. The post consists of a central 4x4, 95 cm in length, with 80 cm lengths of 1x2 and 1" hardwood half-round centered on each face. The base is constructed of 2x4's using edge cross lap joints around the base of the central post. The hand winch is mounted at one end of the base. Pulleys are mounted on threaded rod as shown. Thr first cable passes through a hole drilled in the base, around the pulley on the side opposite to the winch, and is attached to the barrel at its upper surface. The second cable passes through a pulley



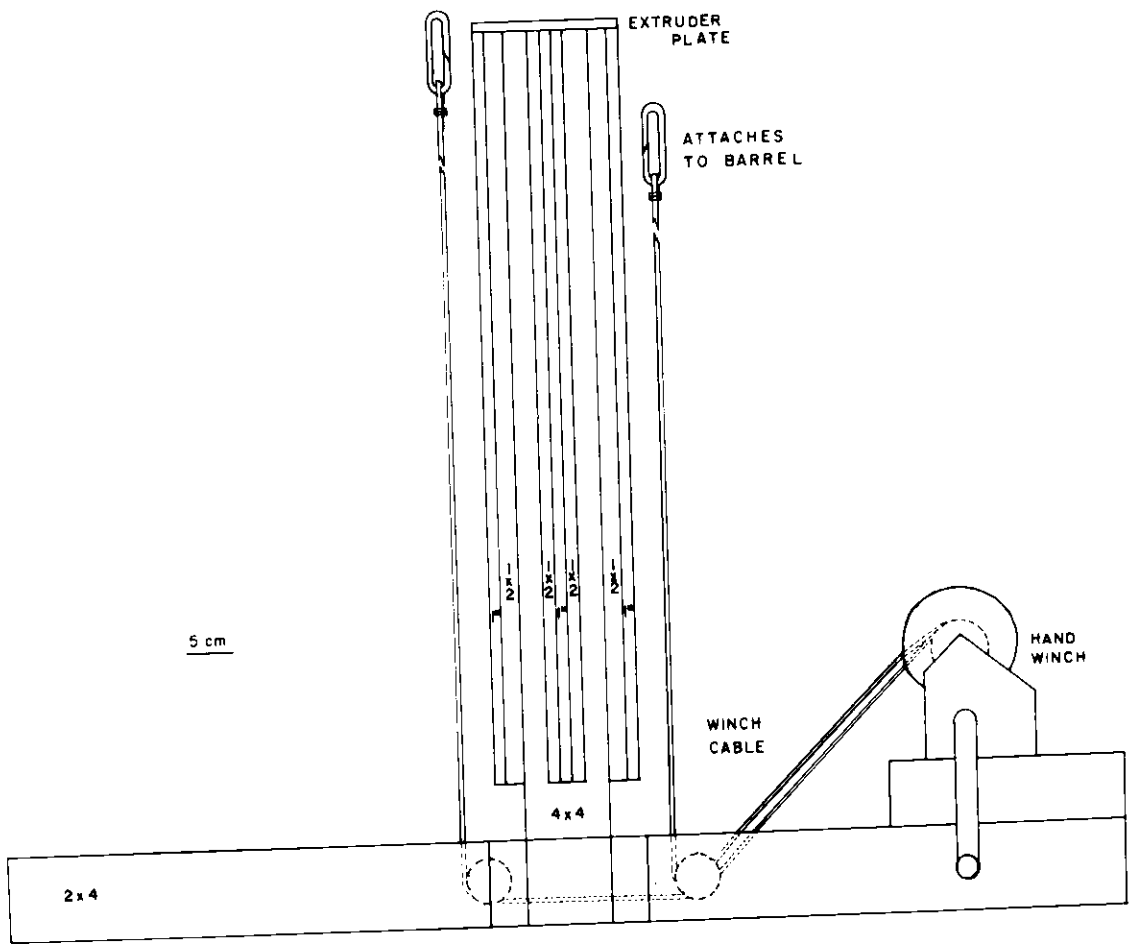


Figure A2. Extruder for air-lift corer, showing construction details.

on the same side of the post as the winch and attaches to the barrel 180° from the first. The actual extruder plate is aluminum, of the same stock as the corer lid and bottom plate, machined to fit the inside of the core barrel, and is screwed onto the top surface of the post. The post is sanded to fit the barrel fairly tightly, and all wood surfaces are coated with an oil sealer to prevent swelling when wet.

Any water remaining above the core is removed prior to extrusion. A section of the irrigation pipe cut to the desired section height is placed atop the barrel and used as a guide. When the top of the guide reaches the top of the sediment, a thin aluminum cutting plate is inserted between the guide and the barrel, the section removed to a sample container, labeled, and fixed with formalin.

OPERATION

Operation of the sampling device requires two divers and a tender on the support vessel. The lid, and bridle with attached winch cable, are secured to the corer while still on board. The divers carry the corer to the bottom with the ball valve open and the needle valve closed. The tender pays out winch cable and high pressure hose (the gas cylinder and regulator remain aboard and turned off). On the bottom, the divers place the corer in a vertical position, and start the corer into the sediment. It is necessary to ensure a good seal between the lower end of the barrel and the sediment. This may be accomplished by imparting a semi-rotary motion to the sampler during the coring operation. As soon as the corer has been started into the sediment, the needle valve is opened, and one of the divers signals the tender to turn on the gas. The device should now proceed into the sediment. It is important to prevent too rapid a flow of gas through the system, for if the exhaust hose is completely filled with gas, the airlift principle ceases to operate. When the corer has penetrated fully, the ball valve is turned off, and then the needle valve, maintaining a slightly lower pressure inside the barrel, which aids in retaining the core during removal from the sediment. The apparatus is pulled clear of the sediment with the winch, and the bottom plate rapidly attached. Once aboard, the lid and attached plumbing are removed, any water remaining above the core siphoned off, and the barrel placed on the extruder post. This maneuver is accomplished by sliding the cutting plate between the cap and the bottom of the core barrel, then placing the barrel and cutting plate on the extruder post, centering the barrel over the post, and withdrawing the cutting plate. The cables from the hand winch are attached to the barrel with the bridle shackles, the guide is positioned, and the barrel is drawn down until the top of the sediment is flush with the top of the guide. One then slides the cutting plate under the guide, and removes the first section. The process is repeated until the entire core has been sectioned. It is a time-conserving measure to use more than one core barrel, for while one core is being sectioned, another is being taken.

DISCUSSION

The air-lift corer described above has been used in Coos Bay, Oregon. A coring device was needed which would supply a large enough sample for the enumeration and identification of the zoological component. The corer, as now in use, will take a sample of up to sixteen five-centimetre sections, each 15.0 cm in diameter. Longer cores could easily be taken using a longer barrel, but extrusion of cores longer than 1.5 m would probably have to be horizontally in a V-shaped tray, unless sectioned core liners were used. The current version has taken samples in water as shallow as 1 m, while the depth maximum is limited only by the available gas pressure. Cylinder pressure must be only slightly greater than _in situ_ hydrostatic pressure for effective penetration. The depth limit, as a diver-operated tool, is probably less than 60 m, due to diver decompression time. Below that depth, it most probably could be effectively used by a submersible, the only difficulty being a source of compressed gas. We are currently using oxygen due to availability and a slight density advantage over compressed air. Nitrogen has a slightly greater density advantage, and could also be used, but care must be exercised in using fittings and a regulator designed for the particular gas. A 6500 cm^3 cylinder, filled to 600 kg/cm^2, provides enough gas for three cores in 10 m of water.

This coring device could be used for sediment chemistry investigations if inert core liners were used. Aluminum was chosen as the main component for reasons of strength, resistance to corrosion, and light weight. The corer has penetrated effectively in all unconsolidated sediments attempted, except large (greater than 10 to 15 cm) shell.

Appendix B. Species abundance data. Number of individuals of each taxon identified from each five-centimetre section.

	CB-1					CB-2		CB-3					CB-4			CB-5				
TAXON section number:	1	2	3	4	5	1	2	1	2	3	4	5	1	2	3	1	2	3	4	5
Foraminifera spp.	30	47	80	32	72	12	5	2	6	7	9	3	2	3	2	25	4	16	30	2
Actiniaria spp.	12	20	21	16	40	91	50	3	18	7	13	5								
Hydrozoa spp.	17	13	17	48	48	29	19				5		26	35	35					
Nematoda spp.	57	4	4	6	34	120	8	25	28	24	1	3	37	32	21	18	51	19	2	1
Nemertea spp.	52	5	2	5	11	33	3	9	3	2		1	20	17	3	15	13	10		1
Acoela spp.													2							
Turbellaria spp.	40	3	3	5	25	22		1	7	2						4	14			
Phoronida																				
<u>Phoronopsis harmeri</u>																				
Oligochaeta spp.	3	1		2			1		1				13	6				1		
Polychaeta																				
<u>Abarenicola</u> sp.																				
<u>Amaeana occidentalis</u>								1					1	7	5	1				
<u>Amphisamytha bioculata</u>																				
<u>Arenicola cristata</u>																				
<u>Armandia bioculata</u>													1							
<u>Armandia brevis</u>														3	4	14				
<u>Autolytus prismaticus</u>														3						
<u>Barantolla americana</u>																				
<u>Boccardia proboscidea</u>													1							
<u>Brania brevipharyngea</u>														1						
<u>Capitella capitata</u>																				
<u>Capitella capitata oculata</u>														1						
<u>Chone ecaudata</u>																				
<u>Cirratulus cirratus</u>																				
<u>Eteone californica</u>													2	6		3	1			
<u>Eteone dilatae</u>																				
<u>Eteone longa</u>														6	6					
<u>Eteone pacifica</u>														1						
<u>Eteone (Mysta) tchangsii</u>														2	2					
<u>Eumida bifoliata</u>													1							
<u>Eunoë depressa</u>																				
<u>Eusyllis assimilis</u>																				
<u>Eusyllis blomstrandi</u>													4							
<u>Eusyllis magnifica</u>														2						
<u>Exogene lourei</u>														1						
<u>Fabricia sabella oregonica</u>																				
<u>Glycera robusta</u>														2						
<u>Glycera tenuis</u>	8	4												1						
<u>Glycinde armigera</u>																				
<u>Glycinde polygnatha</u>																				
<u>Haploscoloplos panamensis</u>																				
<u>Heteromastus filiformis</u>																				
<u>Langerhansia heterochaeta</u>	45	22	4	10	3	5								5						
<u>Lumbrineris latreilli</u>						1							1							
<u>Lumbrineris zonata</u>														4						
<u>Magelona pitelkai</u>																	1	1		
<u>Mediomastus acutus</u>						1								1		2			4	2
<u>Mediomastus californiensis</u>													5	2						
<u>Naineris quadricuspida</u>													1							
<u>Naineris uncinata</u>																	1	1		
<u>Neomediomastus glabrus</u>																				
<u>Nephtys parva</u>						1														
<u>Nerinides maculata</u>														1						
<u>Nerinides tridentata</u>																2				
<u>Notomastus (Clistomastus) tenuis</u>																				
<u>Ophelia limacina</u>	15	2			1	119	13	48	9	1							9	2		
<u>Ophelia</u> sp.														1						
<u>Ophryotrocha puerilis</u>													4	4	1					
<u>Paleanotus bellis</u>															2					
<u>Paraonides platybranchia</u>	1				1				2											
<u>Pionosyllis magnifica</u>														2						
<u>Polydora ligni</u>																				
<u>Polydora socialis</u>															1					
<u>Protodorvillea gracilis</u>													1	2	11					
<u>Pseudopolydora kempi</u>													1							
<u>Pygospio elegans</u>																				
<u>Pygospio californica</u>													1							
<u>Rhynchospio arenincola</u>														1						
<u>Sabellaria cementarium</u>																				
<u>Scoloplos acmeceps</u>																8	12	3		
<u>Spiophanes bombyx</u>																	1		1	
<u>Streblospio benedicti</u>																				
<u>Syllides longocirrata</u>																	2			
<u>Syllis elongata</u>														2						
<u>Syllis gracilis</u>															10	1	1			
<u>Typosyllis aciculata</u>														1	2					
<u>Typosyllis alternata</u>														33						
<u>Typosyllis fasciata</u>							1	3	4	4	4	1								
<u>Typosyllis hyalina</u>														1						
<u>Typosyllis pulchra</u>													46	3						
Capitellidae spp.																	1			
Phyllodocidae juvenile spp.																				
Polynoidae juvenile spp.						1														
Syllidae spp.					1	1			2											
Polychaeta juvenile spp.																				
Polychaeta juvenile sp. A																				
Polychaeta juvenile sp. B																				
Pelecypoda																				
<u>Clinocardium nuttallii</u>																1				
<u>Macoma acolasta</u>																28				
<u>Macoma inquinata</u>	12					11		4					62	116						
<u>Macoma nasuta</u>																				
<u>Macoma secta</u>	1												1		4					
<u>Macoma</u> sp.																				

Appendix B. (Continued).

TAXON	CB-1					CB-2		CB-3					CB-4			CB-5				
section number:	1	2	3	4	5	1	2	1	2	3	4	5	1	2	3	1	2	3	4	5
Modiolus modiolus	9	8	20	9	26	6	21			2	2	2	109	100	42	6	4	9	9	
Mya arenaria			2		2															
Protothaca staminea	1													1						
Protothaca tenerrima																				
Saxidomus giganteus																				
Tellina bodegensis																				
Tellina carpenteri																	4			
Tellina modesta															109					
Tellina nuculoides						8	1	2					7	3	7	6	2	2		
Transennella tantilla	14	5	1		4								1		4					
Tresus nuttallii																				
Zirfaea pilsbryi													1	1	1					
Tellinidae spp.																				
Veneridae spp.																				
Pelecypoda sp. B																				
Pelecypoda juvenile spp.	2		1																	
Gastropoda																				
Barleeia haliotiphila													5	11	6					
Odostomia (Evalea) phanea						1														
Olivella biplicata																				
Aglaja diomedea														2	1					
Tenellia adspersa																				
Ostracoda spp.														2	2					
Copepoda																				
Acartia tonsa	3			1		10		2	2				2			2				
Clausidium vancouverense	1																			
Eurytemora sp.																				
Hemicyclops thysanotus																				
Harpacticoida spp.				1		5	1	1		2	2		3	2			3			1
Cirripedia spp.																				
Balanus improvisus	6	12	9	10	13									2						
Balanus sp.													1							
Chthamalus dalli	1		1																	
Mysidacea																				
Archaeomysis grebnitzkii	3							24		1										
Cumacea																				
Cumella vulgaris													2	1		8				
Diastylis alaskensis															1					
Lamprops quadriplicata						1														
Leucon subnasica						4							2			7	2			
Tanaidacea																				
Leptochelia dubia																				
Pancolus californiensis																				
Isopoda																				
Caecianiropsis psammophila													24							
Amphipoda																				
Allorchestes angusta																				
Amphithoë valida																				
Anisogammarus confervicolus																				
Corophium acherusicum																				
Corophium brevis																				
Corophium salmonis																				
Eohaustorius washingtonianus	8	2					1	3	1							20	15			1
Grandidierella japonica													1							
Mandibulophoxus gilesi								2												
Paraphoxus epistomus																				
Paraphoxus milleri								2								1				2
Paraphoxus spinosus						1							3	4	1					
Parapleustes pugettensis													2							
Photis californica					2															
Amphipoda juvenile spp.															1					
Carides																				
Crangon franciscorum																				
Anomura																				
Callianassa californiensis																				
Upogebia pugettensis																				
Paguridae spp.														1						
Brachyura																				
Brachyura larva spp.														1						
Insecta																				
Paraclunio alaskensis																				
Chironomida larva sp. B																				
Collembola adult sp. A																				
Diptera larva sp. A																				
Diptera larva sp. B																				
Diptera larva sp. C																				
Diptera adult spp.		1																		
Hemiptera adult spp.																				
Insecta larva spp.					1															
Arachnida																				
Arachnida adult spp.																				
Halacaridae spp.				1		1	1			1			1	1						
Chelonethida spp.																				
Hydrachnida sp. A																				
Hydrachnida sp. B																				
Pycnogonida																				
Achelia chelata	1																			
Achelia simplissima															1					
Echinodermata																				
Dendraster excentricus	2	5				5	1		6	2										
Pisaster ochraceus													1							
Pisces																				
Ammodytes hexapterus	1							1												
Pisces larva spp.		1													3		1			
Eggs spp.	45	12	22	12	12	80	24		2				1	16	15	14	39	32	7	

Appendix B. (Continued).

TAXON section number:	CB-6 1	CB-6 2	CB-6 3	CB-6 4	CB-6 5	CB-6 6	CB-7 1	CB-7 2	CB-7 3	CB-7 4	CB-7 5	CB-8 1	CB-8 2	CB-8 3	CB-9 1	CB-9 2	CB-9 3	CB-10 1	CB-10 2	CB-10 3
Foraminifera spp.	1		3	3	4		6	5	22	24	6		2		1					
Actiniaria spp.		3	1	2						1										
Hydrozoa spp.															+					
Nematoda spp.	14	18	4				1	7	1		3	22	6	3	3	1	2	20	3	2
Nemertea spp.	4	13	4	3	2		1	3	1			11	7	6	1	4				
Acoela spp.																				
Turbellaria spp.	6	9	3									3	1				2			
Phoronida																				
Phoronopsis harmeri												3	10	7						
Oligochaeta spp.	1	1										150	88	41	9	4	6	5		
Polychaeta																				
Abarenicola sp.												1								
Amaeana occidentalis												1	1							
Amphisamytha bioculata																				
Arenicola cristata																			1	
Armandia bioculata																				
Armandia brevis																				
Autolytus prismaticus																				
Barantolla americana																				
Boccardia proboscidea																				
Brania brevipharyngea																				
Capitella capitata																				
Capitella capitata oculata																				
Chone ecaudata																				
Cirratulus cirratus												1								
Eteone californica		1																		
Eteone dilatae									1			3								
Eteone longa																				
Eteone pacifica																				
Eteone (Mysta) tchangsii																				
Eumida bifoliata																				
Eunoë depressa												1	1							
Eusyllis assimilis									4											
Eusyllis blomstrandi																				
Eusyllis magnifica																				
Exogene lourei																				
Fabricia sabella oregonica																				
Glycera robusta																				
Glycera tenuis																				
Glycinde armigera												4	2	3						
Glycinde polygnatha																				
Haploscoloplos panamensis																				
Heteromastus filiformis																		1		
Langerhansia heterochaeta												1								
Lumbrineris latreilli																				
Lumbrineris zonata																				
Magelona pitelkai		2																		
Mediomastus acutus	1		1																	
Mediomastus californiensis			3									112	60	17	3	13	4			
Naineris quadricuspida																				
Naineris uncinata	2	1	1												5					
Neomediomastus glabrus																				
Nephtys parva																				
Nerinides maculata	1						1	1								1				
Nerinides tridentata												1			1	1				
Notomastus (Clistomastus) tenuis																				
Ophelia limacina	4	1						1												
Ophelia sp.																				
Ophryotrocha puerilis																				
Paleanotus bellis																				
Paraonides platybranchia		1																		
Pionosyllis magnifica																				
Polydora ligni																				
Polydora socialis																				
Protodorvillea gracilis																				
Pseudopolydora kempi												1								
Pygospio elegans																				
Pygospio californica																				
Rhynchospio arenincola																				
Sabellaria cementarium																1				
Scoloplos acmeceps	2								1						4					
Spiophanes bombyx	4	1	1															2	1	
Streblospio benedicti																				
Syllides longocirrata																				
Syllis elongata																				
Syllis gracilis	6	19	3	3	1															
Typosyllis aciculata																				
Typosyllis alternata																				
Typosyllis fasciata																				
Typosyllis hyalina								1				1			3					
Typosyllis pulchra																				
Capitellidae spp.																				
Phyllodocidae juvenile spp.												1								
Polynoidae juvenile spp.												2								
Syllidae spp.																				
Polychaeta juvenile spp.															2					
Polychaeta juvenile sp. A																				
Polychaeta juvenile sp. B																				
Pelecypoda																				
Clinocardium nuttallii	2											3								
Macoma acolasta																				
Macoma inquinata												10	1	4				2		
Macoma nasuta																				
Macoma secta																				
Macoma sp.																				

Appendix B. (Continued).

TAXON	CB-6						CB-7					CB-8			CB-9			CB-10		
section number:	1	2	3	4	5	6	1	2	3	4	5	1	2	3	1	2	3	1	2	3
Modiolus modiolus	2	1	3	4	6	2			2	1		5	2		1			5		
Mya arenaria												2		1		5	1			
Protothaca staminea		1	2									4			1					
Protothaca tenerrima													1							
Saxidomus giganteus													1							
Tellina bodegensis	2																			
Tellina carpenteri								2												
Tellina modesta																				
Tellina nuculoides	1							1				3		1						
Transennella tantilla																				
Tresus nuttallii														1						
Zirfaea pilsbryi																				
Tellinidae spp.												8	1	2						
Veneridae spp.																				
Pelecypoda sp. B												1								
Pelecypoda juvenile spp.																				
Gastropoda																				
Barleeia haliotiphila																				
Odostomia (Evalea) phanea																				
Olivella biplicata	1																			
Aglaja diomedea													1							
Tenellia adspersa																				
Ostracoda spp.							1													
Copepoda																				
Acartia tonsa	1											8			2					
Clausidium vancouverense												1	4	2		27	3			
Eurytemora sp.																				
Hemicyclops thysanotus																				
Harpacticoida spp.	1		3	4		1	1					4		2				16	3	6
Cirripedia spp.	1																			
Balanus improvisus								1	2			2		1						
Balanus sp.																				
Chthamalus dalli																				
Mysidacea																				
Archaeomysis grebnitzkii	10						2	3		1					1					
Cumacea																				
Cumella vulgaris	6											2	1	1	4				1	
Diastylis alaskensis																				
Lamprops quadriplicata	11		1						1	1					8		1			
Leucon subnasica							1	1				4		1	1		1	6	1	1
Tanaidacea																				
Leptochelia dubia																				
Pancolus californiensis																				
Isopoda																				
Caecianiropsis psammophila												7	15	1						
Amphipoda spp.																				
Allorchestes angusta																				
Amphithoë valida																				
Anisogammarus confervicolus								2												
Corophium acherusicum																				
Corophium brevis												2								
Corophium salmonis																				
Eohaustorius washingtonianus	9	10					1	1	1						1					
Grandidierella japonica																				
Mandibulophoxus gilesi																				
Paraphoxus epistomus																				
Paraphoxus milleri	4	2					3	7	1						1					
Paraphoxus spinosus																				
Parapleustes pugettensis																				
Photis californica																				
Amphipoda juvenile spp.																				
Carides																				
Crangon franciscorum																				
Anomura																				
Callianassa californiensis															1					
Upogebia pugettensis												1								
Paguridae spp.																				
Brachyura																				
Brachyura larva spp.																				
Insecta																				
Paraclunio alaskensis																				
Chironomida larva sp. B																				
Collembola adult sp. A										1										
Diptera larva sp. A																				
Diptera larva sp. B																				
Diptera larva sp. C																				
Diptera adult spp.												1								
Hemiptera adult spp.																				
Insecta larva spp.																				
Arachnida																				
Arachnida adult spp.																		1		
Halacaridae spp.		1	1	1																
Chelonethida spp.																				
Hydrachnida sp. A																				
Hydrachnida sp. B																				
Pycnogonida																				
Achelia chelata																				
Achelia simplissima																				
Echinodermata																				
Dendraster excentricus																				
Pisaster ochraceus																				
Pisces																				
Ammodytes hexapterus																				
Pisces larva spp.		1										2								
Eggs spp.	25	33	19	3	6								1	1	1	1		79		7

Appendix B. (Continued).

TAXON	CB-10						CB-11					CB-12								
section number:	4	5	6	7	8	9	1	2	3	4	5	1	2	3	4	5	6	7	8	9
Foraminifera spp.																				
Actiniaria spp.																				
Hydrozoa spp.												12								
Nematoda spp.	2						502	1				82		2		1				
Nemertea spp.																				
Acoela spp.																				
Turbellaria spp.							4	1												
Phoronida																				
Phoronopsis harmeri																				
Oligochaeta							32					9								
Polychaeta																				
Abarenicola sp.																				
Amaeana occidentalis																				
Amphisamytha bioculata																				
Arenicola cristata																				
Armandia bioculata																				
Armandia brevis																				
Autolytus prismaticus																				
Barantolla americana																				
Boccardia proboscidea																				
Brania brevipharyngea																				
Capitella capitata							1													
Capitella capitata oculata																				
Chone ecaudata																				
Cirratulus cirratus																				
Eteone californica							6													
Eteone dilatae																				
Eteone longa																				1
Eteone pacifica																				
Eteone (Mysta) tchangsii																				
Eumida bifoliata																				
Eunoë depressa																				
Eusyllis assimilis																				
Eusyllis blomstrandi																				
Eusyllis magnifica																				
Exogene lourei																				
Fabricia sabella oregonica																				
Glycera robusta																				
Glycera tenuis							1													
Glycinde armigera												1								
Glycinde polygnatha																				
Haploscoloplos panamensis																				
Heteromastus filiformis																				
Langerhansia heterochaeta																				
Lumbrineris latreilli																				
Lumbrineris zonata																				
Magelona pitelkai																				
Mediomastus acutus																				
Mediomastus californiensis												1								
Naineris quadricuspida																				
Naineris uncinata																				
Neomediomastus glabrus																				
Nephtys parva																				
Nerinides maculata																				
Nerinides tridentata												4								
Notomastus (Clistomastus) tenuis																				
Ophelia limacina																				
Ophelia sp.																				
Ophryotrocha puerilis																				
Paleanotus bellis																				
Paraonides platybranchia							9													
Pionosyllis magnifica																				
Polydora ligni																				
Polydora socialis																				
Protodorvillea gracilis																				
Pseudopolydora kempi																				
Pygospio elegans																				
Pygospio californica																				
Rhynchospio arenincola																				
Sabellaria cementarium																				
Scoloplos acmeceps																				
Spiophanes bombyx																				
Streblospio benedicti							232	16				43	1							
Syllides longocirrata																				
Syllis elongata																				
Syllis gracilis																				
Typosyllis aciculata																				
Typosyllis alternata																				
Typosyllis fasciata																				
Typosyllis hyalina																				
Typosyllis pulchra																				
Capitellidae spp.																				
Phyllodocidae juvenile spp.																				
Polynoidae juvenile spp.																				
Syllidae spp.																				
Polychaeta juvenile spp.							1													
Polychaeta juvenile sp. A																				
Polychaeta juvenile sp. B																				
Pelecypoda																				
Clinocardium nuttallii																				
Macoma acolasta																				
Macoma inquinata							6													
Macoma nasuta																				
Macoma secta								1				3								
Macoma sp.																				

Appendix B. (Continued).

	CB-10						CB-11					CB-12								
TAXON section number:	4	5	6	7	8	9	1	2	3	4	5	1	2	3	4	5	6	7	8	9
Modiolus modiolus	1											12	1			2				1
Mya arenaria																				
Protothaca staminea																				
Protothaca tenerrima																				
Saxidomus giganteus																				
Tellina bodegensis																				
Tellina carpenteri																				
Tellina modesta																				
Tellina nuculoides																				
Transennella tantilla																				
Tresus nuttallii																				
Zirfaea pilsbryi																				
Tellinidae spp.																				
Veneridae spp.																				
Pelecypoda sp. B																				
Gastropoda																				
Barleeia haliotiphila																				
Odostomia (Evalea) phanea																				
Olivella biplicata																				
Aglaja diomedea																				
Tenellia adspersa																				
Ostracoda spp.												1								
Copepoda																				
Acartia tonsa																				
Clausidium vancouverense																				
Eurytemora sp.							10													
Hemicyclops thysanotus																				
Harpacticoida spp.	1						917	5				40	1							
Cirripedia spp.																				
Balanus improvisus																				
Balanus sp.																				
Chthamalus dalli																				
Mysidacea																				
Archaeomysis grebnitzkii																				
Cumacea																				
Cumella vulgaris							9													
Diastylis alaskensis																				
Lamprops quadriplicata																				
Leucon subnasica							50	1				35		2						
Tanaidacea																				
Leptochelia dubia																				
Pancolus californiensis																				
Isopoda																				
Caecianiropsis psammophila																				
Amphipoda spp.																				
Allorchestes angusta																				
Amphithoë valida																				
Anisogammarus confervicolus							2													
Corophium acherusicum																				
Corophium brevis																				
Corophium salmonis																				
Eohaustorius washingtonianus																				
Grandidierella japonica																				
Mandibulophoxus gilesi																				
Paraphoxus epistomus																				
Paraphoxus milleri																				
Paraphoxus spinosus																				
Parapleustes pugettensis																				
Photis californica																				
Amphipoda juvenile spp.																				
Carides																				
Crangon franciscorum																				
Anomura																				
Callianassa californiensis																				
Upogebia pugettensis																				
Paguridae spp.							1													
Brachyura																				
Brachyura larva spp.																				
Insecta																				
Paraclunio alaskensis																				
Chironomida larva sp. B								1												
Collembola adult sp. A							1													
Diptera larva sp. A																				
Diptera larva sp. B							3													
Diptera larva sp. C																				
Diptera adult spp.																				
Hemiptera adult spp.												1								
Insecta larva spp.																				
Arachnida																				
Arachnida adult spp.	1																			
Halacaridae spp.																				
Chelonethida spp.							1													
Hydrachnida sp. A							5													
Hydrachnida sp. B							4													
Pycnogonida																				
Achelia chelata																				
Achelia simplissima																				
Echinodermata																				
Dendraster excentricus																				
Pisaster ochraceus																				
Pisces																				
Ammodytes hexapterus																				
Pisces larva spp.																				
Eggs spp.	17											55	1		29	20	29			

Appendix B. (Continued).

TAXON	W-1										W-2							W-3		
section number:	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	1	2	3
Foraminifera spp.											1			2	1			5		
Actiniaria spp.																				
Hydrozoa spp.																				
Nematoda spp.	478	162	9	4	4	1	5	6	4		11	5	4					3023	10	
Nemertea spp.	3	4	5	1	2															
Acoela spp.																				
Turbellaria spp.	2	1									1							6		
Phoronida																				
Phoronopsis harmeri		1	9	39	60	18	11	7												
Oligochaeta spp.	258	106	9	2			8	3	6		17	50	11					206	48	52
Polychaeta																				
Abarenicola sp.	5																	15		
Amaeana occidentalis																				
Amphisamytha bioculata																				
Arenicola cristata																				
Armandia bioculata																				
Armandia brevis																				
Autolytus prismaticus																				
Barantolla americana																				
Boccardia proboscidea																				
Brania brevipharyngea																				
Capitella capitata																		2		
Capitella capitata oculata																				
Chone ecaudata																		1		
Cirratulus cirratus																				
Eteone californica																				
Eteone dilatae																				
Eteone longa																				
Eteone pacifica																				
Eteone (Mysta) tchangsii																				
Eumida bifoliata																				
Eunoë depressa							1													
Eusyllis assimilis																				
Eusyllis blomstrandi																				
Eusyllis magnifica																				
Exogene lourei																				
Fabricia sabella oregonica																				
Glycera robusta																				
Glycera tenuis	1																			
Glycinde armigera		1									1									
Glycinde polygnatha																		2		
Haploscoloplos panamensis											1	1								
Heteromastus filiformis																		2	1	
Langerhansia heterochaeta											1	1	2							
Lumbrineris latreilli	4	3		1																
Lumbrineris zonata																				
Magelona pitelkai														2						
Mediomastus acutus		2																25		
Mediomastus californiensis	13	20	5			1	2	2	2			1						10		3
Naineris quadricuspida																				
Naineris uncinata																				
Neomediomastus glabrus																		1		
Nephtys parva																				
Nerinides maculata																				
Nerinides tridentata																				
Notomastus (Clistomastus) tenuis						1			1											
Ophelia limacina																				
Ophelia sp.																				
Ophryotrocha puerilis																				
Paleanotus bellis																				
Paraonides platybranchia											1	2								
Pionosyllis magnifica																				
Polydora ligni																				
Polydora socialis																				
Protodorvillea gracilis																				
Pseudopolydora kempi																				
Pygospio elegans	122						1					1						322	1	
Pygospio californica																				
Rhynchospio arenincola																		16		
Sabellaria cementarium																				
Scoloplos acmeceps																				
Spiophanes bombyx																				
Streblospio benedicti																				
Syllides longocirrata																				
Syllis elongata																				
Syllis gracilis																				
Typosyllis aciculata																				
Typosyllis alternata																				
Typosyllis fasciata																				
Typosyllis hyalina																				
Typosyllis pulchra																				
Capitellidae spp.																				
Phyllodocidae juvenile spp.																				
Polynoidae juvenile spp.																				
Syllidae spp.																				
Polychaeta juvenile spp.																				
Polychaeta juvenile sp. A																				
Polychaeta juvenile sp. B																				
Pelecypoda																				
Clinocardium nuttallii																				
Macoma acolasta																				
Macoma inquinata											1							3		
Macoma nasuta																				1
Macoma secta												2								
Macoma sp.																				

Appendix B. (Continued).

TAXON section number:	W-1 1	2	3	4	5	6	7	8	9	10	W-2 1	2	3	4	5	6	7	W-3 1	2	3
Modiolus modiolus	7	1	1					1	2		1	9	2							
Mya arenaria				1		4		3	2											
Protothaca staminea																				
Protothaca tenerrima																				
Saxidomus giganteus																				
Tellina bodegensis																				
Tellina carpenteri																				
Tellina modesta																				
Tellina nuculoides																				
Transennella tantilla	136																			
Tresus nuttallii																				
Zirfaea pilsbryi																				
Tellinidae spp.																		3		
Veneridae spp.					1		5	2												
Pelecypoda sp. B																				
Pelecypoda juvenile spp.																				
Gastropoda																				
Barleeia haliotiphila																				
Odostomia (Evalea) phanea																				
Olivella biplicata																				
Aglaja diomedea																				
Tenellia adspersa					1															
Ostracoda spp.	60		1	1														113		2
Copepoda																				
Acartia tonsa																				
Clausidium vancouverense								1												
Eurytemora sp.																		1		
Hemicyclops thysanotus																		4		
Harpacticoida spp.	125	9					1				3	2						24		
Cirripedia spp.																				
Balanus improvisus																1				
Balanus sp.																				
Chthamalus dalli																				
Mysidacea																				
Archaeomysis grebnitzkii																				
Cumacea																				
Cumella vulgaris	138							1	1		1							14		1
Diastylis alaskensis																				
Lamprops quadriplicata																				
Leucon subnasica	2																	5		
Tanaidacea																				
Leptochelia dubia	1186	26	2		1	1	14	4	3	1		3						1877	18	2
Pancolus californiensis																				
Isopoda																				
Caecianiropsis psammophila																				
Amphipoda spp.																		1		
Allorchestes angusta																		4		
Amphithoë valida																		1		
Anisogammarus confervicolus																				
Corophium acherusicum																		3		
Corophium brevis	1																	4		
Corophium salmonis																				
Eohaustorius washingtonianus																				
Grandidierella japonica																				
Mandibulophoxus gilesi																				
Paraphoxus epistomus											2	2								
Paraphoxus milleri																				
Paraphoxus spinosus	122	1					1				6							282	3	1
Parapleustes pugettensis																				
Photis californica																				
Amphipoda juvenile spp.																				
Carides																				
Crangon franciscorum																				
Anomura																				
Callianassa californiensis																				
Upogebia pugettensis																				
Paguridae spp.																				
Brachyura																				
Brachyura larva spp.																				
Insecta																				
Paraclunio alaskensis																				
Chironomida larva sp. B																				
Collembola adult sp. A																				
Diptera larva sp. A																				
Diptera larva sp. B																				
Diptera larva sp. C																				
Hemiptera adult spp.																				
Insecta larva spp.																				
Arachnida																				
Arachnida adult spp.																				
Halacaridae spp.								1				1						1		
Chelonethida spp.																				
Hydrachnida sp. A																				
Hydrachnida sp. B																				
Pycnogonida																				
Achelia chelata																				
Achelia simplissima																				
Echinodermata																				
Dendraster excentricus																				
Pisaster ochraceus																				
Pisces																				
Ammodytes hexapterus																				
Pisces larva spp.																				
Eggs spp.	87											2	1					317		

Appendix B. (Continued).

TAXON	W-3								W-4									
section number:	4	5	6	7	8	9	10	11	1	2	3	4	5	6	7	8	9	10
Foraminifera spp.																		
Actiniaria spp.																		
Hydrozoa spp.																		
Nematoda spp.	1	2	1	4	1	1	1	1	183	15	6	6	1	1	1	2		
Nemertea spp.								1	3	3	3	2	2		2	1		
Acoela spp.																		
Turbellaria spp.						1						1						
Phoronida																		
Phoronopsis harmeri										2	5	5		1	1	1		
Oligochaeta spp.	6	6	11	13	3	1	4	2	482	125	74	20	7	4	2	2		1
Polychaeta																		
Abarenicola sp.																		
Amaeana occidentalis																		
Amphisamytha bioculata																		
Arenicola cristata																		
Armandia bioculata																		
Armandia brevis																		
Autolytus prismaticus																		
Barantolla americana																		
Boccardia proboscidea																		
Brania brevipharyngea																		
Capitella capitata		1							1	5	1							
Capitella capitata oculata																		
Chone ecaudata																		
Cirratulus cirratus																		
Eteone californica										1		2						
Eteone dilatae																		
Eteone longa																		
Eteone pacifica																		
Eteone (Mysta) tchangsii																		
Eumida bifoliata																		
Eunoë depressa																		
Eusyllis assimilis																		
Eusyllis blomstrandi																		
Eusyllis magnifica																		
Exogene lourei																		
Fabricia sabella oregonica																		
Glycera robusta																		
Glycera tenuis																		
Glycinde armigera									1	1								
Glycinde polygnatha																		
Haploscoloplos panamensis																		
Heteromastus filiformis									147	16	3	1						
Langerhansia heterochaeta																		
Lumbrineris latreilli																		
Lumbrineris zonata																		
Magelona pitelkai																		
Mediomastus acutus									6	6								
Mediomastus californiensis	3									1	7	16	9	6	11	7	6	1
Naineris quadricuspida																		
Naineris uncinata																		
Neomediomastus glabrus									2			1	4					
Nephtys parva																		
Nerinides maculata																		
Nerinides tridentata																		
Notomastus (Clistomastus) tenuis																		
Ophelia limacina																		
Ophelia sp.																		
Ophryotrocha puerilis																		
Paleanotus bellis																		
Paraonides platybranchia																		
Pionosyllis magnifica																		
Polydora ligni																		
Polydora socialis																		
Protodorvillea gracilis																		
Pseudopolydora kempi																		
Pygospio elegans					2				1									
Pygospio californica																		
Rhynchospio arenincola									11									
Sabellaria cementarium																		
Scoloplos acmeceps																		
Spiophanes bombyx																		
Streblospio benedicti									3									
Syllides longocirrata																		
Syllis elongata																		
Syllis gracilis																		
Typosyllis aciculata																		
Typosyllis alternata																		
Typosyllis fasciata																		
Typosyllis hyalina																		
Typosyllis pulchra																		
Capitellidae spp.																		
Phyllodocidae juvenile spp.																		
Polynoidae juvenile spp.																		
Syllidae spp.																		
Polychaeta juvenile spp.																		
Polychaeta juvenile sp. A																		
Polychaeta juvenile sp. B																		
Pelecypoda																		
Clinocardium nuttallii									1									
Macoma acolasta																		
Macoma inquinata									11									
Macoma nasuta											2							
Macoma secta																		
Macoma sp.										1								

Appendix B. (Continued).

TAXON section number:	W-3 4	5	6	7	8	9	10	11	W-4 1	2	3	4	5	6	7	8	9	10
Modiolus modiolus				1					3	1					1			
Mya arenaria									1						2	2		
Protothaca staminea																		
Protothaca tenerrima																		
Saxidomus giganteus																		
Tellina bodegensis																		
Tellina carpenteri																		
Tellina modesta																		
Tellina nuculoides																		
Transennella tantilla																		
Tresus nuttallii																		
Zirfaea pilsbryi																		
Tellinidae spp.														1				
Veneridae spp.																		
Pelecypoda sp. B																		
Pelecypoda juvenile spp.																		
Gastropoda																		
Barleeia haliotiphila																		
Odostomia(Evalea) phanea																		
Olivella biplicata																		
Aglaja diomedea									1									
Tenellia adspersa																		
Ostracoda spp.				1														
Copepoda																		
Acartia tonsa																		
Clausidium vancouverense																		
Eurytemora sp.																1		
Hemicyclops thysanotus																2		
Harpacticoida spp.					2				9	4								
Cirripedia spp.																		
Balanus improvisus																		
Balanus sp.																		
Chthamalus dalli																		
Mysidacea																		
Archaeomysis grebnitzkii																		
Cumacea																		
Cumella vulgaris			3	1		1		1	1									
Diastylis alaskensis																		
Lamprops quadriplicata																		
Leucon subnasica																		
Tanaidacea																		
Leptochelia dubia			2	9	5	15	4	7	1									
Pancolus californiensis																		
Isopoda																		
Caecianiropsis psammophila																		
Amphipoda spp.																		
Allorchestes angusta																		
Amphithoë valida																		
Anisogammarus confervicolus																		
Corophium acherusicum																		
Corophium brevis							1	1										
Corophium salmonis																		
Eohaustorius washingtonianus																		
Grandidierella japonica																		
Mandibulophoxus gilesi																		
Paraphoxus epistomus																		
Paraphoxus milleri																		
Paraphoxus spinosus	1			1	2	1	2	1	2									
Parapleustes pugettensis																		
Photis californica																		
Amphipoda juvenile spp.																		
Carides																		
Crangon franciscorum									1									
Anomura																		
Callianassa californiensis																		
Upogebia pugettensis																		
Paguridae spp.																		
Brachyura																		
Brachyura larva spp.																		
Insecta																		
Paraclunio alaskensis																		1
Chironomida larva sp. B																		
Collembola adult sp. A									1									
Diptera larva sp. A																		
Diptera larva sp. B																		
Diptera larva sp. C																		
Diptera adult spp.																		
Hemiptera adult spp.																		
Insecta larva spp.																		
Arachnida																		
Arachnida adult spp.																		
Halacaridae spp.										1								
Chelonethida spp.																		
Hydrachnida sp. A																		
Hydrachnida sp. B																		
Pycnogonida																		
Achelia chelata																		
Achelia simplissima																		
Echinodermata																		
Dendraster excentricus																		
Pisaster ochraceus																		
Pisces																		
Ammodytes hexapterus																		
Pisces larva spp.																		
Eggs spp.	1		1						3	5	6	1			1			

Appendix B. (Continued).

TAXON	W-5							W-6								
section number:	1	2	3	4	5	6	7	1	2	3	4	5	6	7	8	9
Foraminifera spp.																
Actiniaria spp.																
Hydrozoa spp.																
Nematoda spp.	47	1						28	32	14	22	4	3	1		
Nemertea spp.	2	1							1	1						
Acoela spp.																
Turbellaria spp.											1					
Phoronida																
Phoronopsis harmeri																
Oligochaeta	61		4	3	3			10	41	6		2	2	4	3	
Polychaeta																
Abarenicola sp.	2							13	1							
Amaeana occidentalis																
Amphisamytha bioculata								1								
Arenicola cristata																
Armandia bioculata																
Armandia brevis																
Autolytus prismaticus																
Barantolla americana								1							1	
Boccardia proboscidea																
Brania brevipharyngea																
Capitella capitata									4							
Capitella capitata oculata																
Chone ecaudata																
Cirratulus cirratus																
Eteone californica	1							6								
Eteone dilatae																
Eteone longa																
Eteone pacifica																
Eteone (Mysta) tchangsii																
Eumida bifoliata																
Eunoë depressa																
Eusyllis assimilis																
Eusyllis blomstrandi																
Eusyllis magnifica																
Exogene lourei																
Fabricia sabella oregonica	861															
Glycera robusta																
Glycera tenuis																
Glycinde armigera																
Glycinde polygnatha																
Haploscoloplos panamensis																
Heteromastus filiformis						1			4							
Langerhansia heterochaeta																
Lumbrineris latreilli																
Lumbrineris zonata																
Magelona pitelkai																
Mediomastus acutus	2251							4	18		1					
Mediomastus californiensis									6	2	3	1	1	1		
Naineris quadricuspida																
Naineris uncinata																
Neomediomastus glabrus								2								
Nephtys parva																
Nerinides maculata																
Nerinides tridentata																
Notomastus (Clistomastus) tenuis																
Ophelia limacina																
Ophelia sp.																
Ophryotrocha puerilis																
Paleanotus bellis																
Paraonides platybranchia								10	14	1						
Pionosyllis magnifica																
Polydora ligni	1															
Polydora socialis									1							
Protodorvillea gracilis																
Pseudopolydora kempi																
Pygospio elegans	502	5						127	4							
Pygospio californica																
Rhynchospio arenincola								9								
Sabellaria cementarium																
Scoloplos acmeceps																
Spiophanes bombyx																
Streblospio benedicti								9	1							
Syllides longocirrata																
Syllis elongata																
Syllis gracilis																
Typosyllis aciculata																
Typosyllis alternata																
Typosyllis fasciata																
Typosyllis hyalina																
Typosyllis pulchra																
Capitellidae spp.																
Phyllodocidae juvenile spp.																
Polynoidae juvenile spp.																
Syllidae spp.																
Polychaeta juvenile spp.																
Polychaeta juvenile sp. A																
Polychaeta juvenile sp. B																
Pelecypoda																
Clinocardium nuttallii																
Macoma acolasta																
Macoma inquinata								7								
Macoma nasuta									1							
Macoma secta																
Macoma sp.																

Appendix B. (Continued).

	W-5							W-6								
TAXON section number:	1	2	3	4	5	6	7	1	2	3	4	5	6	7	8	9
Modiolus modiolus												1				
Mya arenaria	4															
Protothaca staminea																
Protothaca tenerrima																
Saxidomus giganteus																
Tellina bodegensis																
Tellina carpenteri																
Tellina modesta																
Tellina nuculoides																
Transennella tantilla																
Tresus nuttallii																
Zirfaea pilsbryi																
Tellinidae spp.								9								
Veneridae spp.																
Pelecypoda sp. B																
Pelecypoda juvenile spp.																
Gastropoda																
Barleeia haliotiphila																
Odostomia (Evalea) phanea																
Olivella biplicata																
Aglaja diomedea																
Tenellia adspersa	1															
Ostracoda spp.								1								
Copepoda																
Acartia tonsa																
Clausidium vancouverense																
Eurytemora sp.																
Hemicyclops thysanotus																
Harpacticoida spp.	2							4	6	3	13					
Cirripedia spp.																
Balanus improvisus																
Balanus sp.																
Chthamalus dalli																
Mysidacea																
Archaeomysis grebnitzkii																
Cumacea																
Cumella vulgaris	3							93	4							
Diastylis alaskensis																
Lamprops quadriplicata																
Leucon subnasica								3								
Tanaidacea																
Leptochelia dubia	2							354	20	1						
Pancolus californiensis	1							1								
Isopoda																
Caecianiropsis psammophila																
Amphipoda spp																
Allorchestes angusta								1								
Amphithoë valida																
Anisogammarus confervicolus																
Corophium acherusicum																
Corophium brevis																
Corophium salmonis								1								
Eohaustorius washingtonianus																
Grandidierella japonica																
Mandibulophoxus gilesi																
Paraphoxus epistomus																
Paraphoxus milleri																
Paraphoxus spinosus								84	1							
Parapleustes pugettensis																
Photis californica																
Amphipoda juvenile spp.																
Carides																
Crangon franciscorum																
Anomura																
Callianassa californiensis										1						
Upogebia pugettensis																
Paguridae spp.																
Brachyura																
Brachyura larva spp.																
Insecta																
Paraclunio alaskensis	7															
Chironomida larva sp. B	5	1														
Collembola adult sp. A																
Diptera larva sp. A	8															
Diptera larva sp. B	2															
Diptera larva sp. C	1	4														
Diptera adult spp.																
Hemiptera adult spp.																
Insecta larva spp.																
Arachnida																
Arachnida adult spp.																
Halacaridae spp.																
Chelonethida spp.																
Hydrachnida sp. A																
Hydrachnida sp. B																
Pycnogonida																
Achelia chelata																
Achelia simplissima																
Echinodermata																
Dendraster excentricus																
Pisaster ochraceus																
Pisces																
Ammodytes hexapterus																
Pisces larva spp.																
Eggs spp.								2	3							

Jordan Cove LNG	Hydrodynamic Studies – Hydrodynamic Analysis		moffatt & nichol
	Document Number: J1-000-MAR-TNT-DEA-00008-00		
	Rev.: B	Rev. Date: September 19, 2018	

TECHNICAL MEMORANDUM

DATE:	September 19, 2018
ATTENTION:	Drew Jackson, P.E.
COMPANY:	Jordan Cove LNG, LLC (JCLNG)
ADDRESS:	5615 Kirby Drive, Suite 500, Houston, TX 77005
FROM:	Cheng-Feng Tsai, P.E., William Gerken, P.E. – Moffatt & Nichol
SUBJECT:	Hydrodynamic Analysis
DEA PROJECT NAME:	Ad Hoc Permitting Support
DEA PROJECT NO:	JLNG0000-0003
M&N PROJECT NO:	9929-03, Task Order MN-1130-002
DOCUMENT #	J1-000-MAR-TNT-DEA-00008-00
COPIES TO:	DEA (Sean Sullivan, Loren Stucker)

1. INTRODUCTION

Jordan Cove Energy Project, LP ("JCEP") is seeking authorization from the Federal Energy Regulatory Commission ("FERC") under Section 3 of the Natural Gas Act ("NGA") to site, construct, and operate a natural gas liquefaction and liquefied natural gas ("LNG") export facility ("LNG Terminal"), located on the bay side of the North Spit of Coos Bay, Oregon. The LNG Terminal, related facilities, temporary construction sites, and other sites/actions associated with LNG Terminal construction are collectively referred to as the "JCEP Project Area" as shown on Figure 1-1.

The JCEP Project Area is made up of the following selected components, among others not listed here because they are not relevant to the scope of this memorandum:

- Slip – a permanent facility between Ingram Yard and the Access Channel. LNG carriers will enter the Slip via the Access Channel, get loaded with LNG, and leave for export. The Slip will include an LNG carrier loading berth and LNG loading facilities, a tug berth, and an emergency lay berth to safely moor a temporarily disabled LNG carrier.
- Access Channel – the Access Channel will be dredged north of the Federal Navigation Channel ("FNC") to provide LNG carriers with access from the FNC to the Slip.
- Material Offloading Facility ("MOF") – a permanent facility east of the Slip where fill will be placed to construct a barge berth. Dredging will occur to access the MOF.
- Navigation Reliability Improvements ("NRI") – four permanent dredge areas adjacent to the FNC that will allow for navigation efficiency and reliability for vessel transit under a broader weather window.

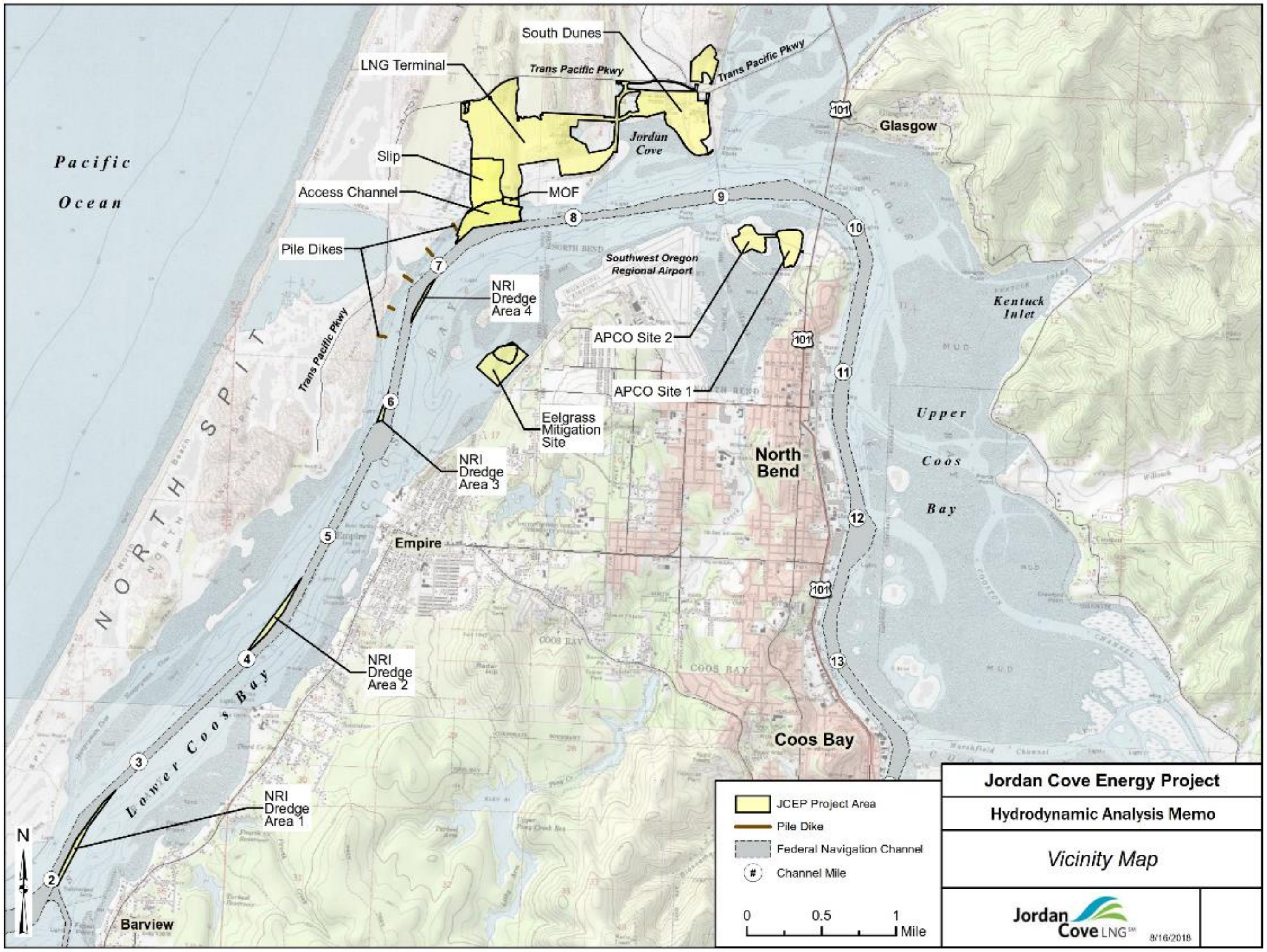


Figure 1-1. JCEP Project Area

In support of the permitting efforts for the JCEP, Moffatt & Nichol ("M&N") has prepared this technical memorandum summarizing hydrodynamic analysis work performed. The purpose of this study is to assess changes to existing tidal current patterns and tidal prism as a result of the JCEP (NRI areas, Slip and Access Channel, MOF, and Eelgrass Mitigation site). The objective is to provide a basis for evaluating potential effects on navigation, the FNC, pile dikes, and aquatic resources.

Table 1-1 summarizes the two modeling scenarios, "Without-Project" and "With-Project", and the corresponding design features. The Without-Project scenario is based on the existing FNC with a channel depth of 38' MLLW (37' navigation depth + 1' advance maintenance). In areas which have historically maintained a depth below -38' MLLW, the existing bathymetry used in the Oregon International Port of Coos Bay's ("OIPCB") Section 204(f) Channel Modification Project modeling efforts (OIPCB 2017b) was used. The With-Project scenario adopts the same FNC depths used in the Without-Project scenario, and adds the four NRI areas, the Slip and Access Channel, the MOF, and the Eelgrass Mitigation site. This approach allows the changes due to the JCEP to be evaluated. All vertical elevations in this document are referenced to mean lower low water (MLLW) tidal datum, unless otherwise noted.

Table 1-1. Summary of Modeling Scenarios

Location	Without-Project	With-Project
Federal Navigation Channel Maintained Depth (ft, MLLW)	≤ 38.0	≤ 38.0*
NRI Dredged Depth (ft, MLLW)	Existing	39.0
Access Channel Dredged Depth (ft, MLLW)	Existing	46.7
Slip Dredged Depth (ft, MLLW)	N/A	45.5
Side Slope for Sand Bottom	Existing	3H:1V (NRI 1-3) 4H:1V (NRI 4) 3H:1V (Slip & Access Channel)
Side Slope for Rock Bottom	Existing	1H:1V

* In this study, the water depth of 38 ft is a minimum depth in the FNC. The actual bathymetry used at the entrance and elsewhere is naturally deeper.

Construction side slopes for the NRI areas and access channel are employed in the With-Project modeling scenario. These construction side slopes are stable against mass failure (sloughing) during and after construction. Stable construction side slopes are based on the analysis completed for the OIPCB Project (OIPCB 2017b). Estimations of long-term equilibrated side slopes in non-rock (sand) material will vary. The majority of material to be removed for construction of the Access Channel, NRI 3 and NRI 4 is sand, portions of NRI 1 and NRI 2 are also composed of sandy material overlying rock. In these areas sand side slopes will equilibrate over time to a slope flatter than the initial construction slope. Estimations of long-term equilibrated side slopes in non-rock material can vary significantly. Based on the analysis methodology followed on the OIPCB Project (OIPCB 2017b) the conservative long term equilibrated slopes may vary between approximately 5H:1V and 20H:1V

Estimated long-term equilibrated side slopes were not used in the With-Project scenario modeling. After the completion of initial construction dredging, the side slopes will continue to evolve over a period of time (estimated 5 to 10 years depending on depth of dredge cut, slope material properties, hydraulic forces acting on slope, and other factors) until they reach a stable slope angle, after which sedimentation patterns may reach a quasi-equilibrium state. There is an inherent level of uncertainty in estimating the long-term equilibrium side slope configuration and the amount of time until long term equilibrium is reached. Construction side slopes were used as the starting point in the sediment transport analysis to better show the potential changes in sedimentation patterns associated with the JCEP.

The material to be removed for construction of NRI 1 and NRI 2 is primarily rock; rock side slopes will not change from the 1H:1V initial construction slope, and no long-term adjustments for the equilibration process are warranted in these locations.

This revised technical memorandum includes results and analyses based on additional supplemental modeling completed to address issues and questions resulting from the U.S. Army Corps of Engineers (USACE), Northwest Division, Portland District (NWP) review of the 408 60% Design Package (Rev. A; JCLNG Document No J1-000-MAR-TNT-DEA-00008-00). Modifications to the numerical model included matching the With-Project model generated bathymetric grid to the Without-Project model gridded bathymetry outside of the project areas. For clarity, results are now presented as the difference of 99th percentile currents and the difference of mean currents between With-Project and Without-Project scenarios, not the difference at specific timestep(s) as previously provided. Modifications resulted in a more representative/accurate comparison of results and assessment of potential hydrodynamic changes due to the JCEP, particularly in the north jetty root/log spiral bay and south of pile dike 7.3 areas.

2. HYDRODYNAMIC MODELING

2.1 MODEL OVERVIEW

The hydrodynamic modeling was performed using the MIKE-21 suite, developed by the Danish Hydraulic Institute ("DHI"). The two-dimensional ("2D") Hydrodynamic model ("HD"), solves the depth-averaged shallow water equations and simulates water level variations and flows in response to a variety of forcing functions (DHI 2014). The 2D HD model uses unstructured triangular elements with varying resolutions throughout the modeling domain. The advantage of unstructured elements is that their use allows for computationally efficient representation of the project area without imposing unnecessary resolution in areas where it is not required.

In the horizontal domain, the model grid consists of approximately 90,500 unstructured elements. Figure 2-1 shows the modeling domain and Figure 2-2 illustrates the unstructured elements at and near the NRI 4, the Slip and Access Channel, and the Eelgrass Mitigation Site. The finest resolution is a 10 ft. element length in the Slip and Access Channel area.

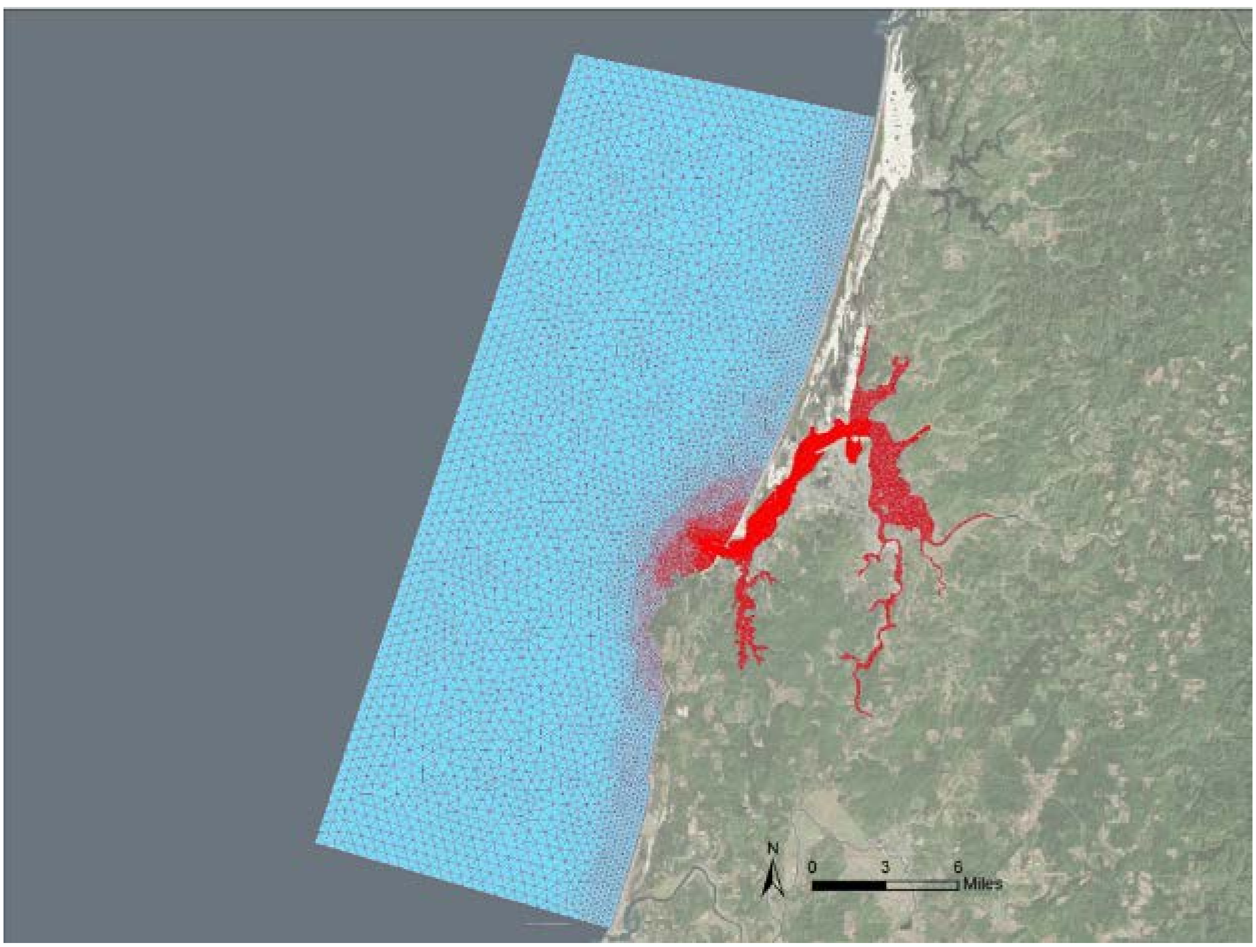


Figure 2-1. Modeling Domain and Elements with Varying Resolutions

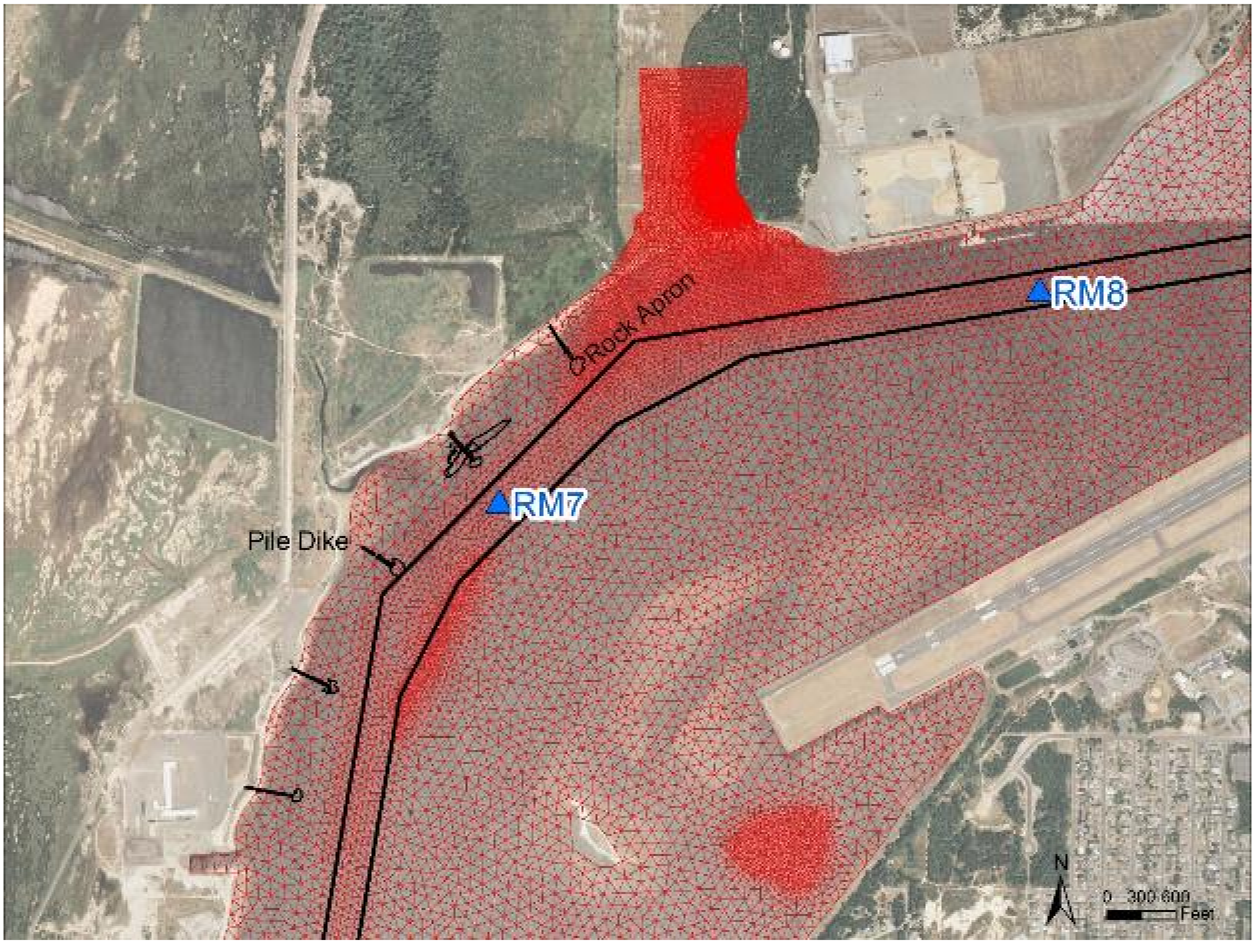


Figure 2-2. Numerical Modeling Elements at and near the NRI 4, Slip and Access Channel, and Eelgrass Mitigation Site

2.2 MODEL SETUP/INPUT

2.2.1 MODELING BATHYMETRY

The following three bathymetric data sources were incorporated into the model bathymetry:

- Near the Slip and Access Channel, Solmar Hydro, Inc. conducted a multibeam bathymetric survey on September 29, 2016 (Solmar 2016). The bathymetric data was referenced to the North American Vertical Datum of 1988 (“NAVD88”). Figure 2-3 shows the data coverage.
- David Evans and Associates, Inc. (“DEA”) compiled a composite of multiple existing data sets collected between 2007 and 2016 in the vicinity of the FNC (OIPCB 2017a). The final data set was referenced to the MLLW vertical datum. Figure 2-4 illustrates the data sources compiled.
- The 2014 LiDAR survey by USACE was used at South Slough and most of the mudflats inside the estuary (USACE 2014). The LiDAR was referenced to NAVD88 vertical datum. Figure 2-5 shows the data coverage.

For consistency, the DEA compiled bathymetric data was converted to NAVD88 vertical datum using the industry-standard tool, NOAA vertical datum conversion model VDatum v3.7 (NOAA 2017). For modeling purpose, the NAVD88 datum was used. Figure 2-6 shows the bathymetry for the entire domain. Figure 2-7 through Figure 2-10 show the bathymetric changes between the Without-Project and With-Project scenarios.

To meet the objectives of the evaluation, stated in Section 1, a more detailed representation of pile dikes was included in the model. The remaining visible piles within the pile dike structures were modeled as individual piles to capture the increasing flow resistance in the water column imposed by the pile dikes as the flow increases/changes. The remaining identifiable enrockments and rock aprons were designated as nonerodable surfaces in the model.

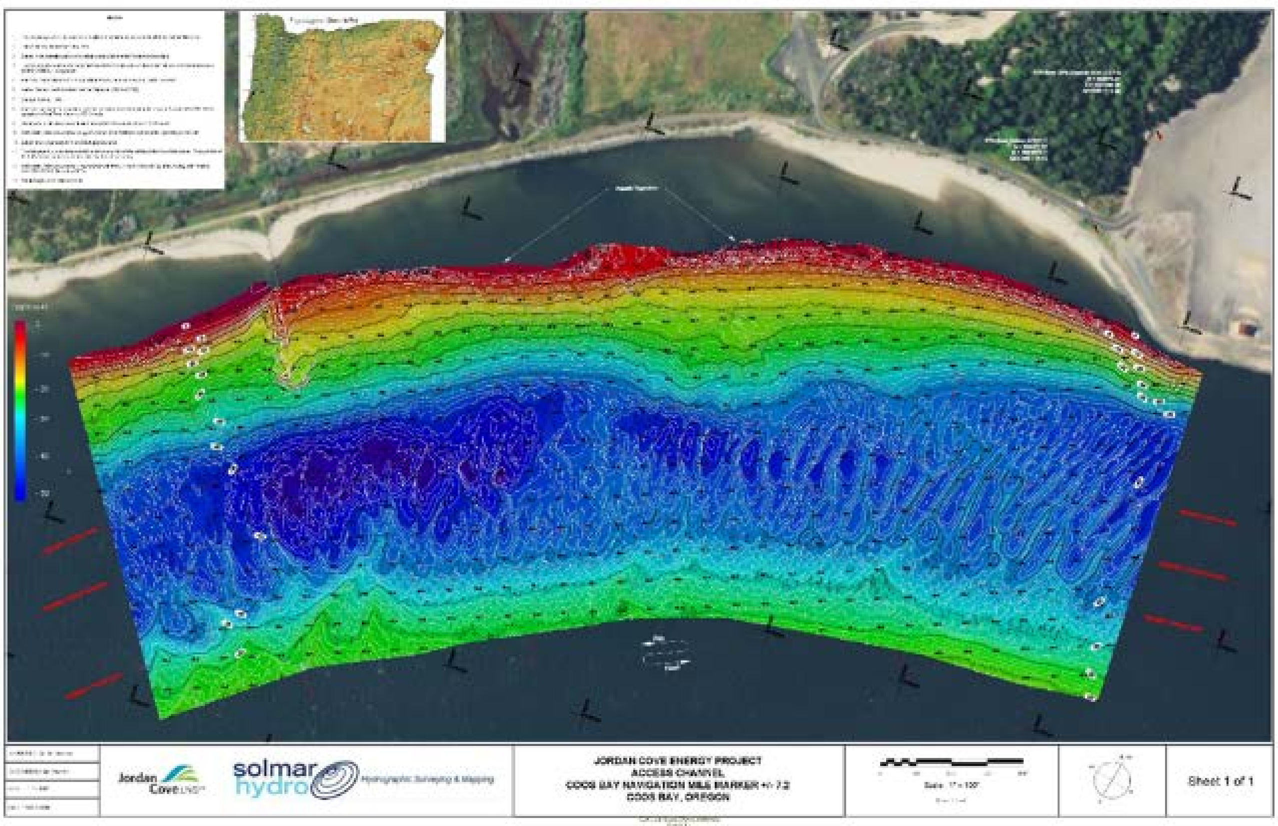


Figure 2-3. Multibeam Survey near the Slip and Access Channel (Excerpted from Solmar 2016)

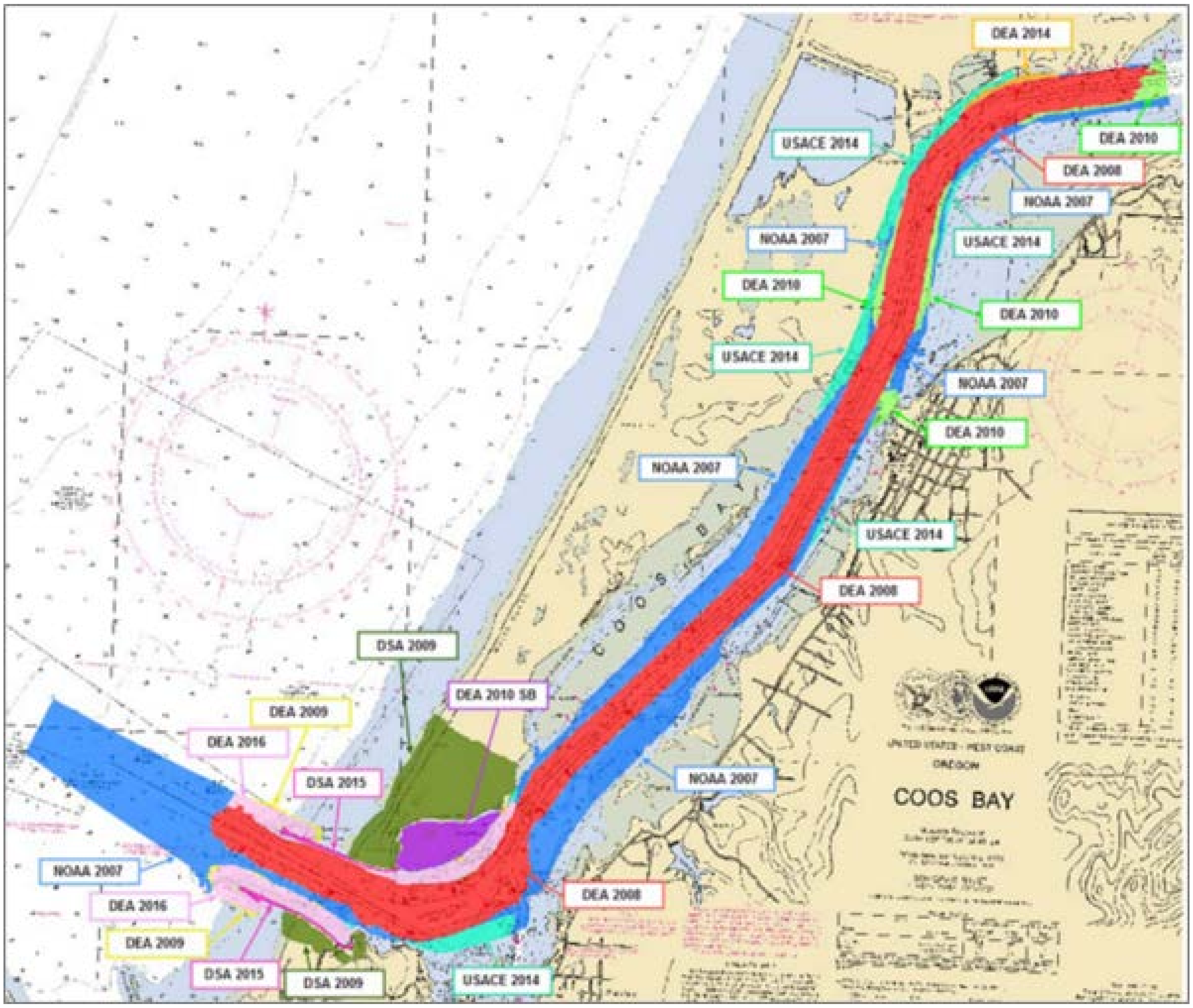


Figure 2-4. Bathymetric Data Sources Compiled by DEA (Excerpted from OIPCB 2017a)

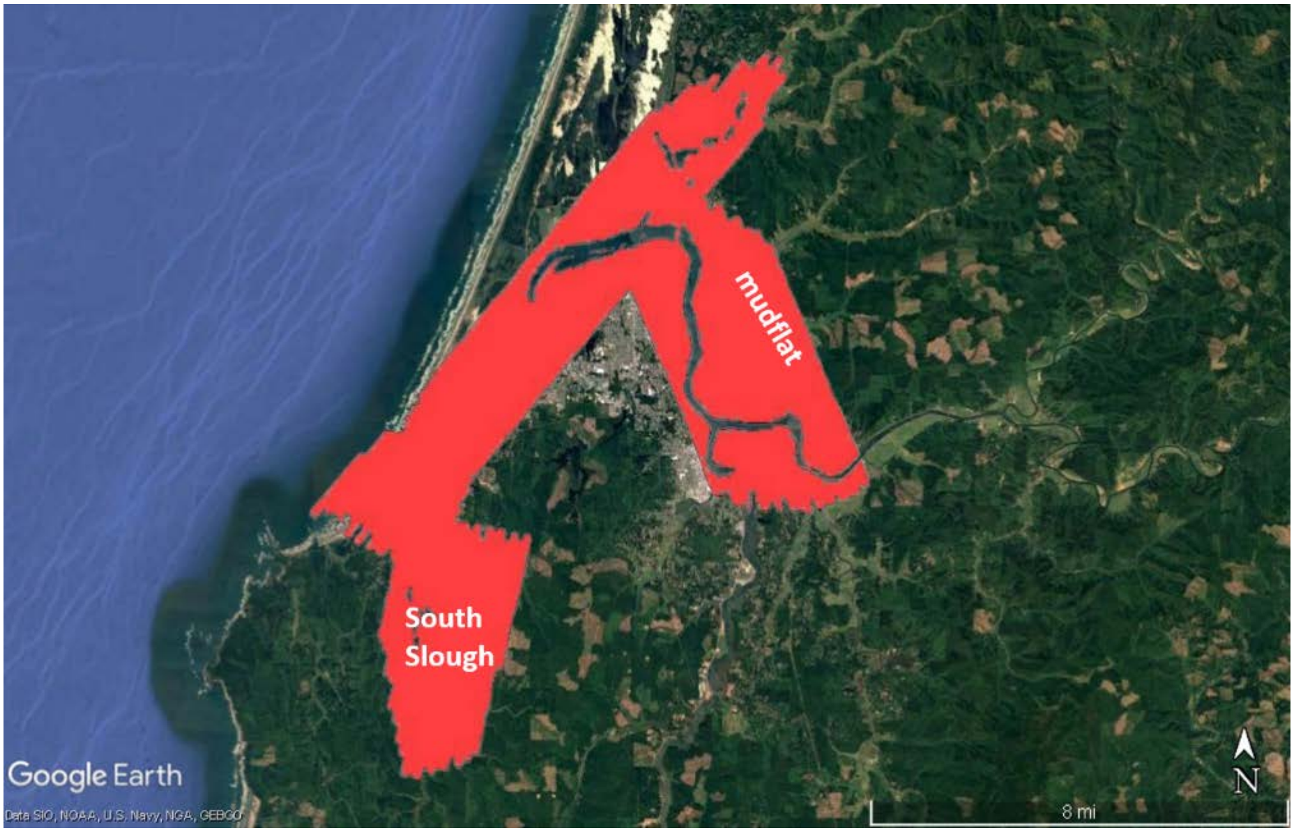


Figure 2-5. Data Coverage of USACE 2014 LiDAR Survey

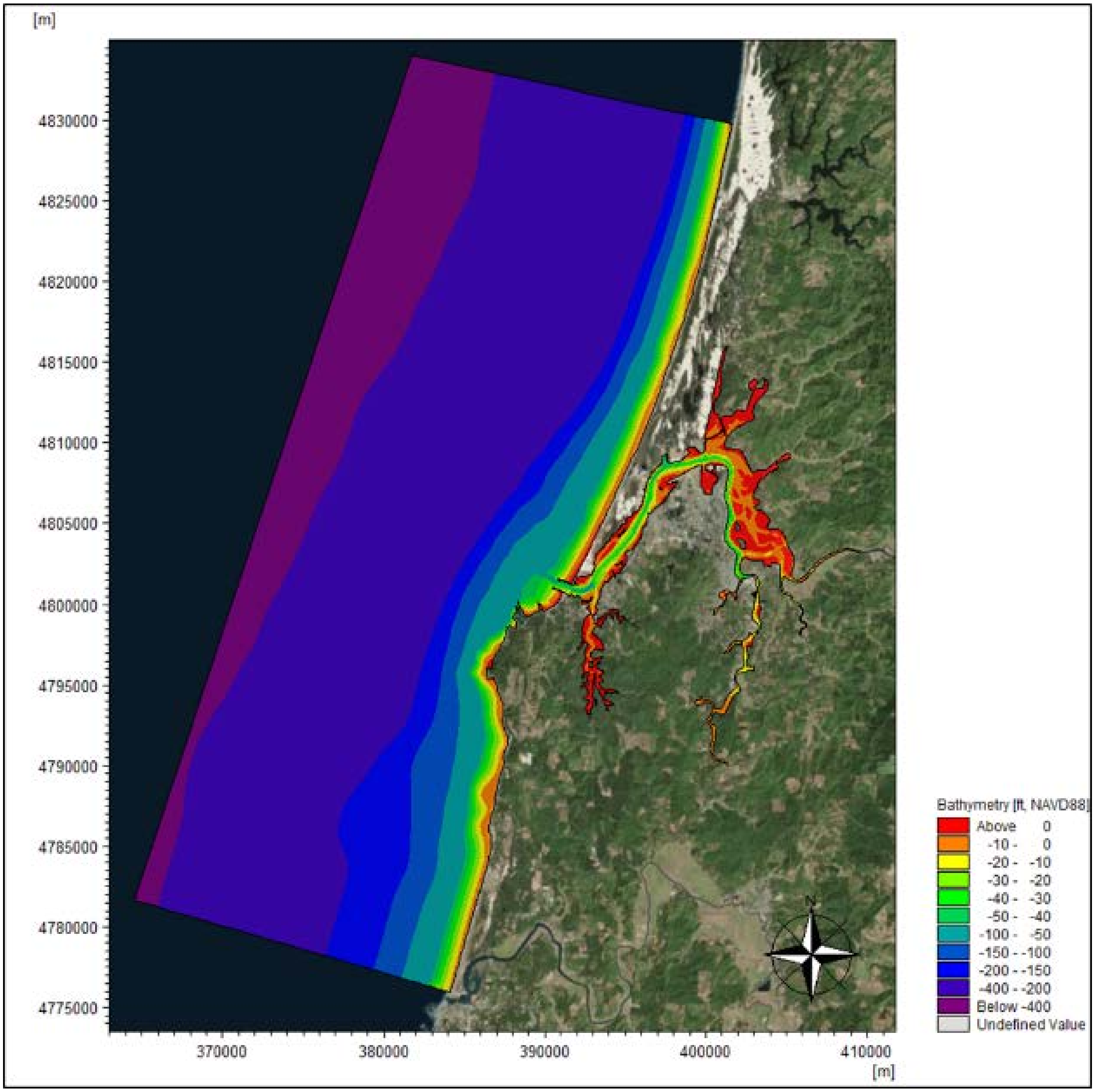


Figure 2-6. Modeling Bathymetry

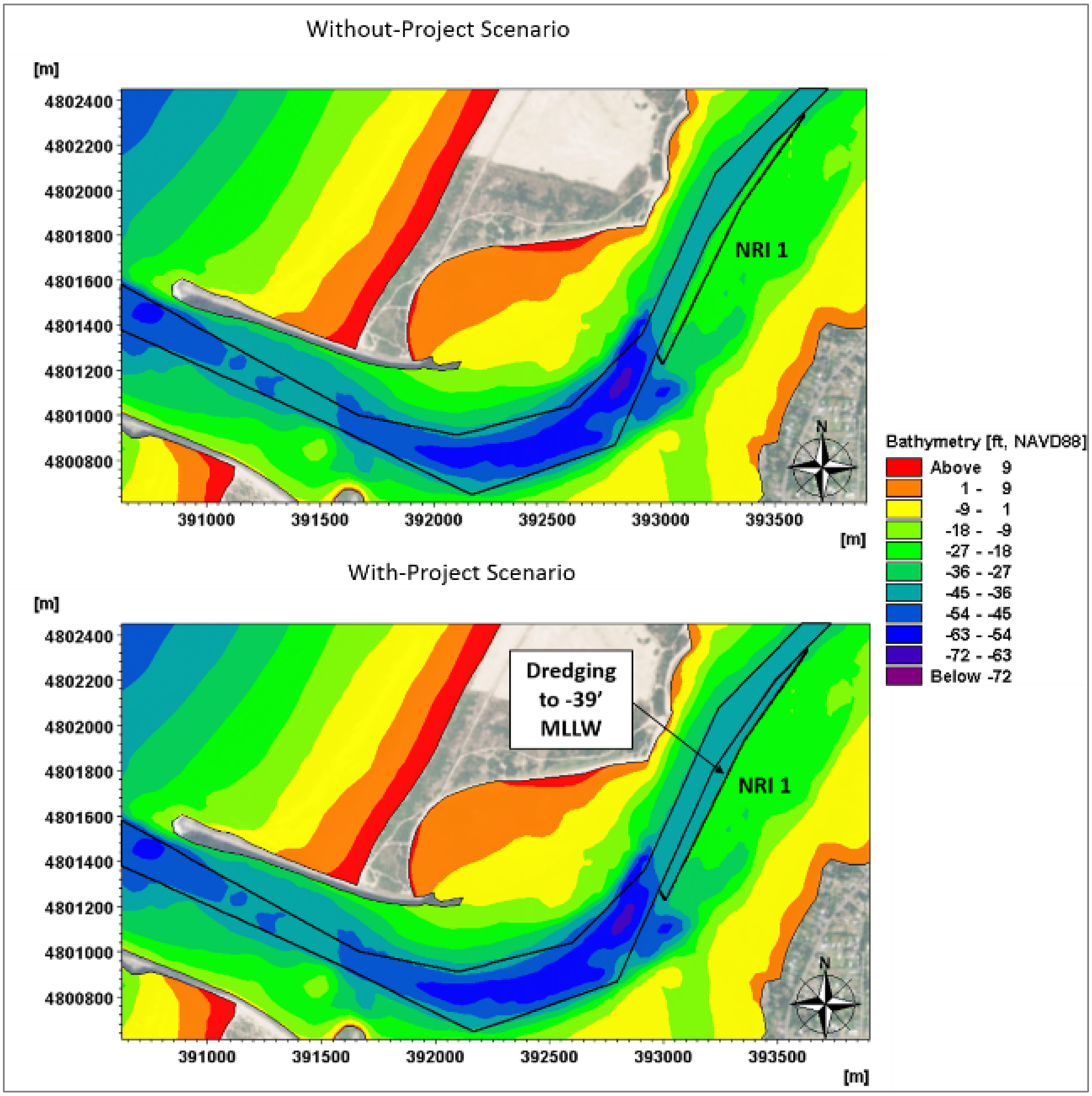


Figure 2-7. Bathymetric Changes at and near the NRI 1

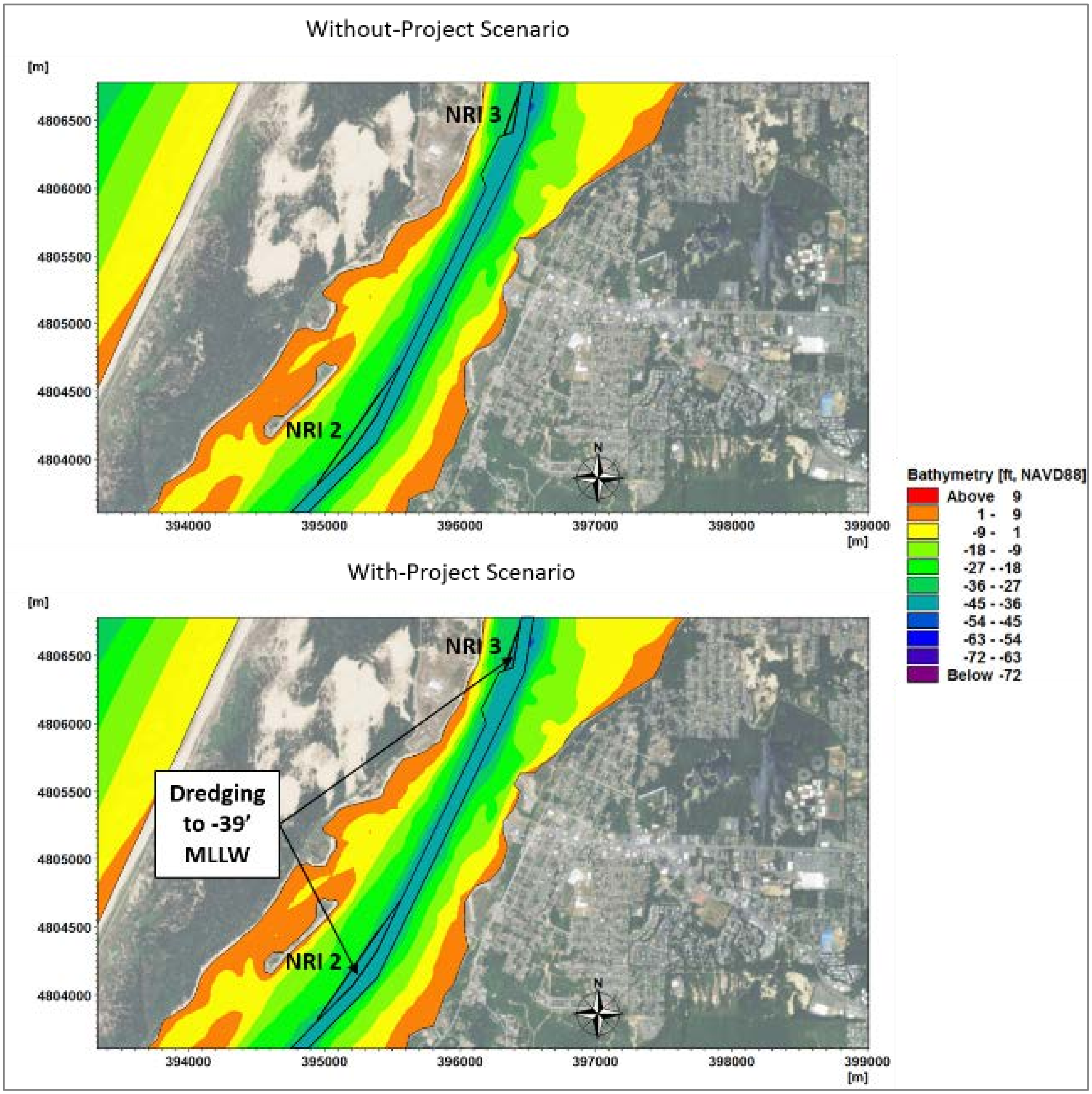


Figure 2-8. Bathymetric Changes at and near the NRI 2 and NRI 3

Jordan Cove LNG℠	Hydrodynamic Studies – Hydrodynamic Analysis		moffatt & nichol
	Document Number: J1-000-MAR-TNT-DEA-00008-00		
	Rev.: B	Rev. Date: September 19, 2018	

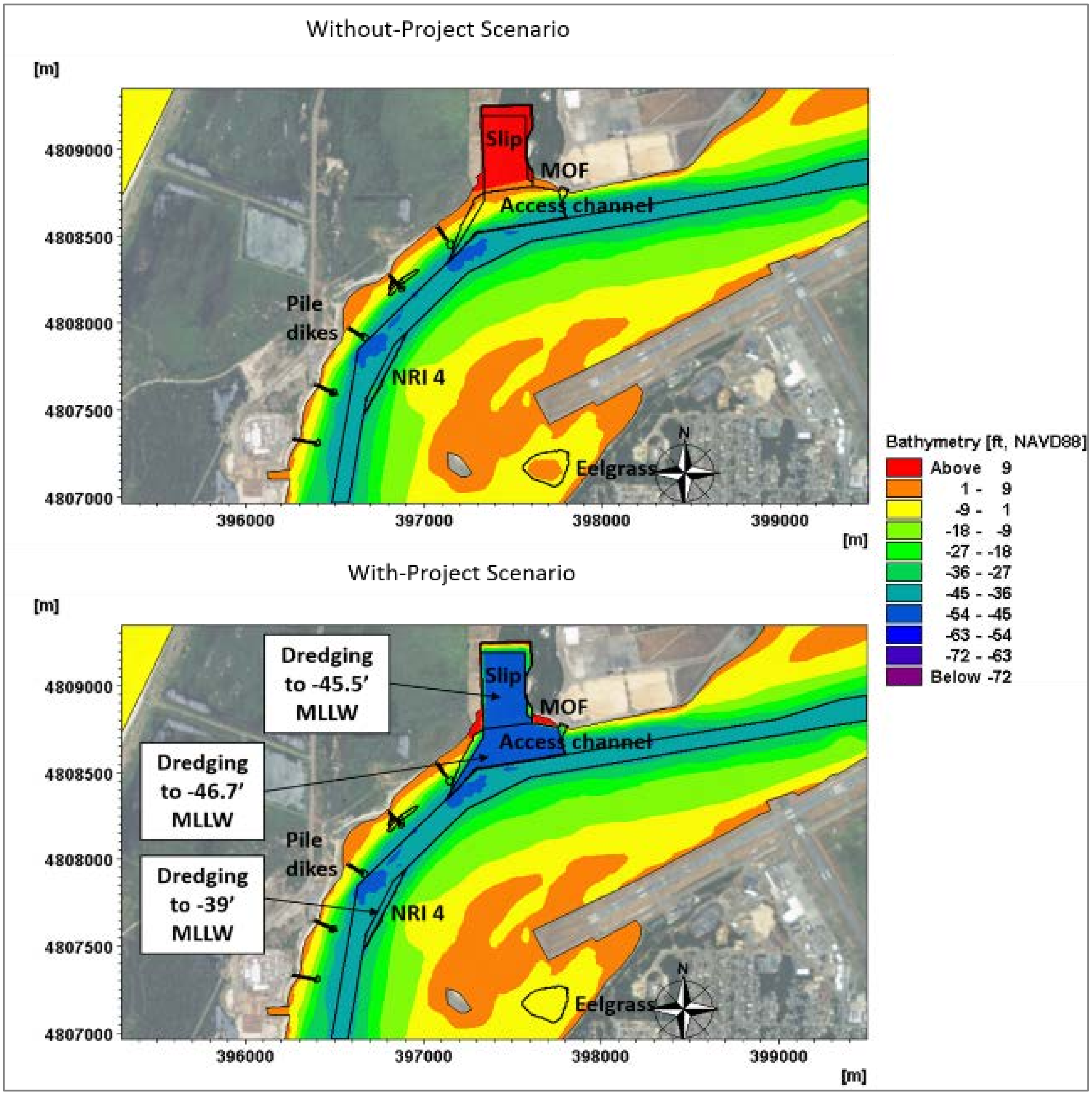


Figure 2-9. Bathymetric Changes at and near the NRI 4, Slip, and Access Channel

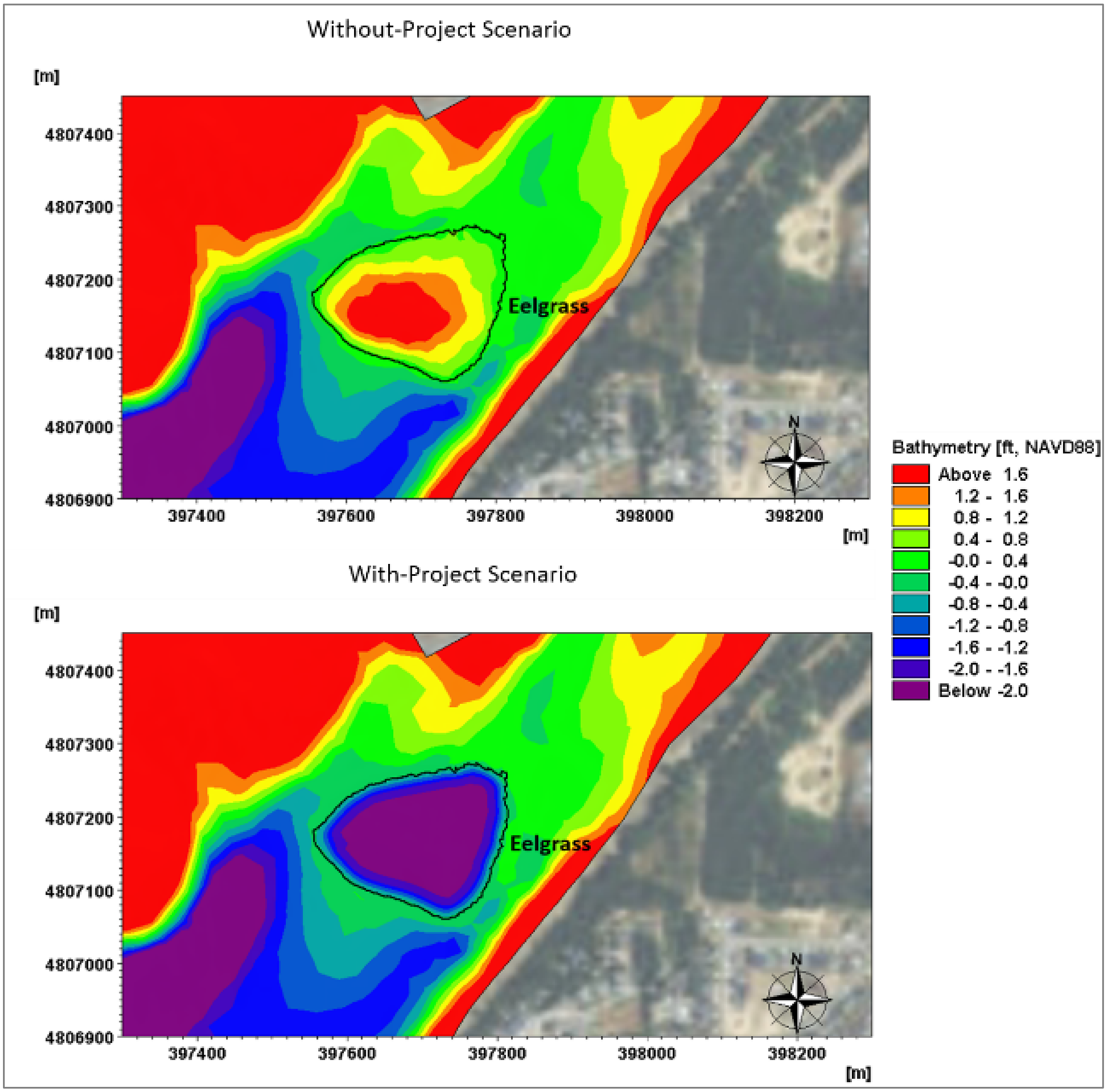


Figure 2-10. Bathymetric Changes at the Eelgrass Mitigation Site

2.2.2 BOUNDARY CONDITIONS

A boundary condition is a condition that is required to be satisfied at all or part of the boundary of a region in which a set of differential equations is to be solved. For the HD model, boundary conditions are required to drive the hydrodynamics. There are three open offshore boundaries and five freshwater runoff boundaries in the modeling domain. A summary of boundary conditions is presented in Table 2-1.

The offshore boundary conditions, both tidal levels and currents, were extracted from the Oregon State University ("OSU") tidal database (Egbert & Erofeeva 2002). The upstream fresh water boundary conditions include the Coos River, the North Slough, the Kentuck and Willanch Sloughs, the Isthmus Slough, and the South Slough. The upstream fresh water boundaries are labeled in Figure 2-11.

Table 2-1. Hydrodynamic Boundary Conditions

Input	Source	Comment
Tides and currents (Offshore boundary conditions)	Oregon State University tidal database	Varying tidal levels and flow velocities along three offshore boundaries.
Fresh water runoff (Upstream boundary conditions)	Fresh water discharge of Coos River: Based on discharge measured by the Coos Watershed Association Other (much smaller) inputs: Seasonal values based on rainfall-runoff analysis (OIPCB 2017b)	Fresh water inflow varies seasonally but is normally small compared to tidal influence.

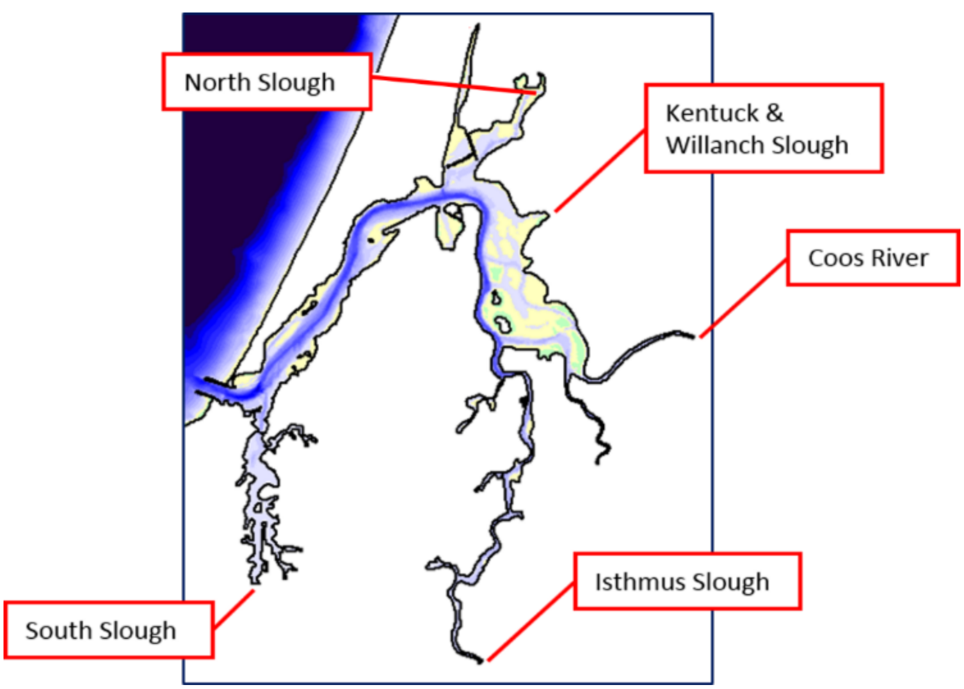


Figure 2-11. Upstream Fresh Water Open Boundaries

2.2.3 MEASURED TIDES AND CURRENTS

Available tides and currents measurements were compiled for the OIPCB Project (OIPCB 2017b). Figure 2-12 shows the location of measuring stations and transects. Following is available data considered:

- NOAA Long-term Tidal Station – NOAA has been recording tidal elevations at Charleston, Oregon since 1970. This is the only active long-term tide gauge in the Coos Bay estuary.
- DEA Stationary ADCP – DEA used Teledyne RD Instruments, 600 kHz Workhorse bottom-mounted Acoustic Doppler Current Profilers ("ADCP") and measured tidal elevations and currents at three locations from March 28 to April 23, 2010 (OIPCB 2010). Two of these locations are inside the estuary, while the third is offshore. Each recorded horizontal current (easting and northing components).
- DEA ADCP Transects – DEA also used vessel-mounted ADCP and measured velocity from bank-to-bank along three transects during flood and ebb tides (OIPCB 2010).
- NOAA Short-Term Tide and Current Gauges – NOAA measured one-month duration tidal elevations at Sitka Dock, North Bend, and Isthmus Slough in September 1982. Presently, these tide gauges are not operating. NOAA also measured currents during the same 1982 period throughout the estuary, labeled as NOAA 01 through NOAA 15 in Figure 2-12. However, because the channel has undergone deepening since the 1982 measurements, these earlier measurements were not used in the calibration.

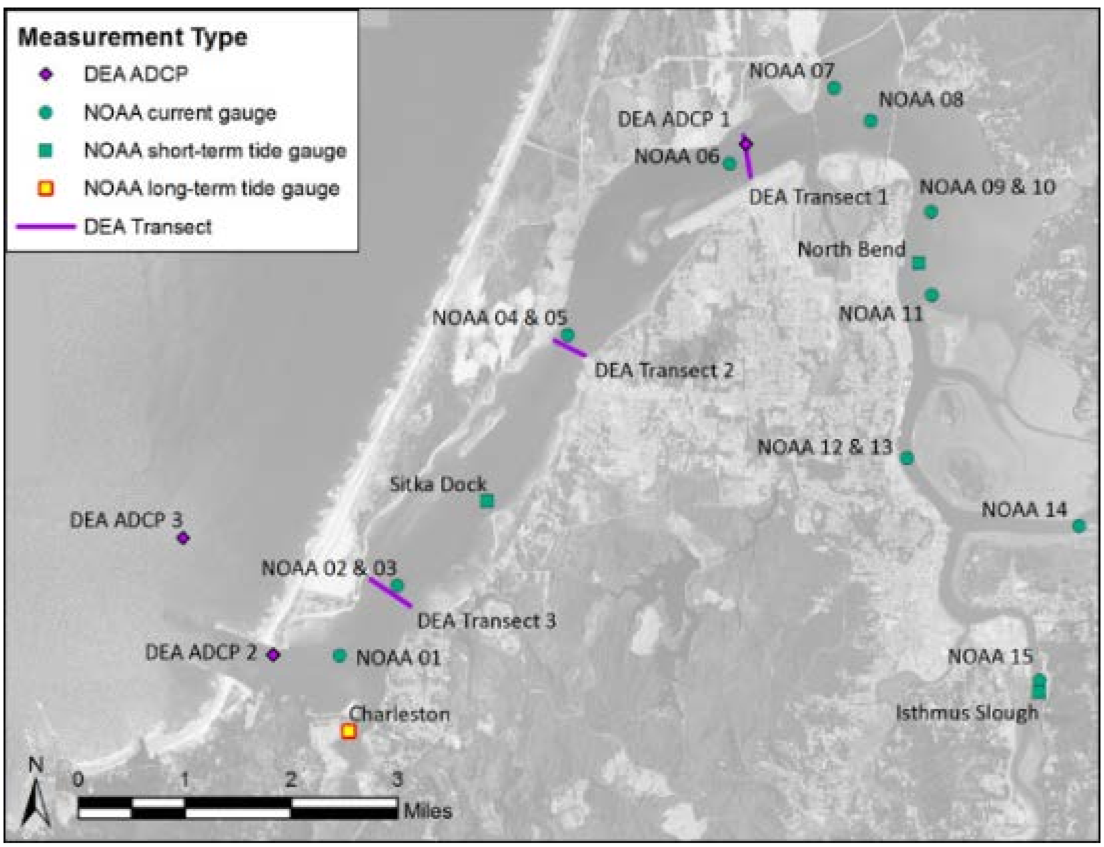


Figure 2-12. Location of Measuring Stations and Transects

2.2.4 MODEL PARAMETERS

Table 2-2 lists the bed roughness and viscosity parameters used in the HD model. Both parameters were determined through calibration, as opposed to direct measurement. These model parameters were adjusted within their typical ranges for model calibration. Manning's-n bed roughness was found to have greater impact on the tidal hydraulics than the horizontal eddy viscosity. Therefore, Manning's-n bed roughness was selected as the primary calibration parameter.

Table 2-2. Model Parameters for Hydrodynamic Model

Parameter	Value	Comment
Bed Roughness (Manning's n)	A constant of 0.016	This parameter was determined through calibration as the primary calibration parameter.
Horizontal Eddy Viscosity (Smagorinsky coefficient)	A constant of 0.24	Default value is 0.28. This parameter was determined through calibration as the secondary calibration parameter.

Manning's n quantifies bed roughness and accounts for energy loss due to friction. Bed roughness varies spatially within the estuary as a function of water depth, bedform, and substrate. However, it is commonly accepted practice for estuarine hydrodynamic modeling applications to use a constant bed roughness as the calibration parameter. For example, hydrodynamic and water quality modeling for Savannah Harbor Expansion Project used a constant bed roughness value of 0.02 (Tetra Tech 2006). In addition, a sensitivity analysis showed slight changes in model results with bed roughness values of 0.015, 0.02, and 0.025 (Tetra Tech 2006).

For Manning's n bed roughness, the DHI MIKE-21 User Manual provides a typical range between 0.025 and 0.050, with a suggested value of 0.03125 as the first approximation. Bed roughness values within the range of 0.015 and 0.050 were tested and a value of 0.016 was found to provide the best fit calibration. Model calibration included conducting a sensitivity analysis, see Section 2.3 for further details on model calibration. The conclusions of this sensitivity testing, along with the experience in Savannah supported the decision to adopt a constant bed roughness value.

Eddy viscosity quantifies the turbulent transfer of momentum by eddies giving rise to an internal fluid friction, in a manner analogous to the action of molecular viscosity in laminar flow, but taking place on a much larger scale. For the horizontal eddy viscosity, the DHI MIKE-21 User Manual suggests a typical range between 0.25 and 1, with a default value of 0.28. In this study, a value of 0.24 was found to provide the best fit calibration.

2.3 MODEL CALIBRATION

The following statistical parameters were used to evaluate the goodness of fit between model predictions and measurements.

- Root-Mean-Squared ("RMS") Error: $\varepsilon_{RMS} = \sqrt{\overline{(x-y)^2}}$
- Mean Absolute Error ("MAE"): $MAE = \overline{|x-y|}$
- Index of Agreement (d): $d = 1 - \frac{\overline{(x-y)^2}}{\overline{\left(|x-\bar{x}| + |y-\bar{x}|\right)^2}}$, $0 \le d \le 1$

Where $\bar{x}$ and $\bar{y}$ represent the mean value of the modeled and the measured data, respectively. The ability of the model to accurately simulate the outcome can be estimated using the index of agreement between the modeled (calculated) and the measured data sets.

Relative to model calibration, the calibration case achieves the lowest RMS error and MAE and the greatest index of agreement within the typical ranges of the modeling parameters.

The discharge data from the HD model along three transects during flooding and ebbing tide was compared with the observed discharge data for validation of the model results after calibrating the modeling parameters to observed water levels and current magnitude. The modeled total discharges agree with the measurements.

2.3.1 COMPARISON OF WATER LEVELS

Figure 2-13 shows water level comparison between the 2D HD model outputs, the hourly measurements at the NOAA Charleston tide gauge, and the DEA ADCP1 location (measured). The period of record is between March 28 and April 18, 2010. The RMS errors for water levels at the Charleston tide gauge and DEA ADCP1 was 0.35 ft and 0.42 ft, respectively. The index of agreement at both locations was calculated to be equal to 0.99. A regression analysis shows that the phase difference is 12-minutes (modeled values are ahead) and 6-minutes (modeled values are ahead), respectively.

There are no standard thresholds regarding the error metrics since they are highly dependent on the application. A review of recent and similar studies approved by USACE, e.g. ERDC/CHL (Grays Harbor, WA and Matagorda Bay, TX) and DHI (Coastal Hazard Study for San Francisco Bay) among others, showed the present study was consistent with these studies in terms of goodness of fit.

2.3.2 COMPARISON OF CURRENTS AT DEA ADCP1 LOCATION

DEA deployed bottom-mounted ADCPs and measured tidal currents from March 28 to April 23, 2010 (OIPCB 2010). Figure 2-14 shows the depth-averaged longitudinal (along the channel) velocity comparison between the 2D HD model outputs and the DEA ADCP1 location (measured). The results show that the model slightly under predicts currents (< 0.2 knots) along the channel at the location of DEA ADCP1. This difference is likely due to difference in model bathymetry with actual bathymetry at the time of measurement and will not affect comparison of With- and Without-Project scenarios. The index of agreement was calculated to be equal to 0.99.

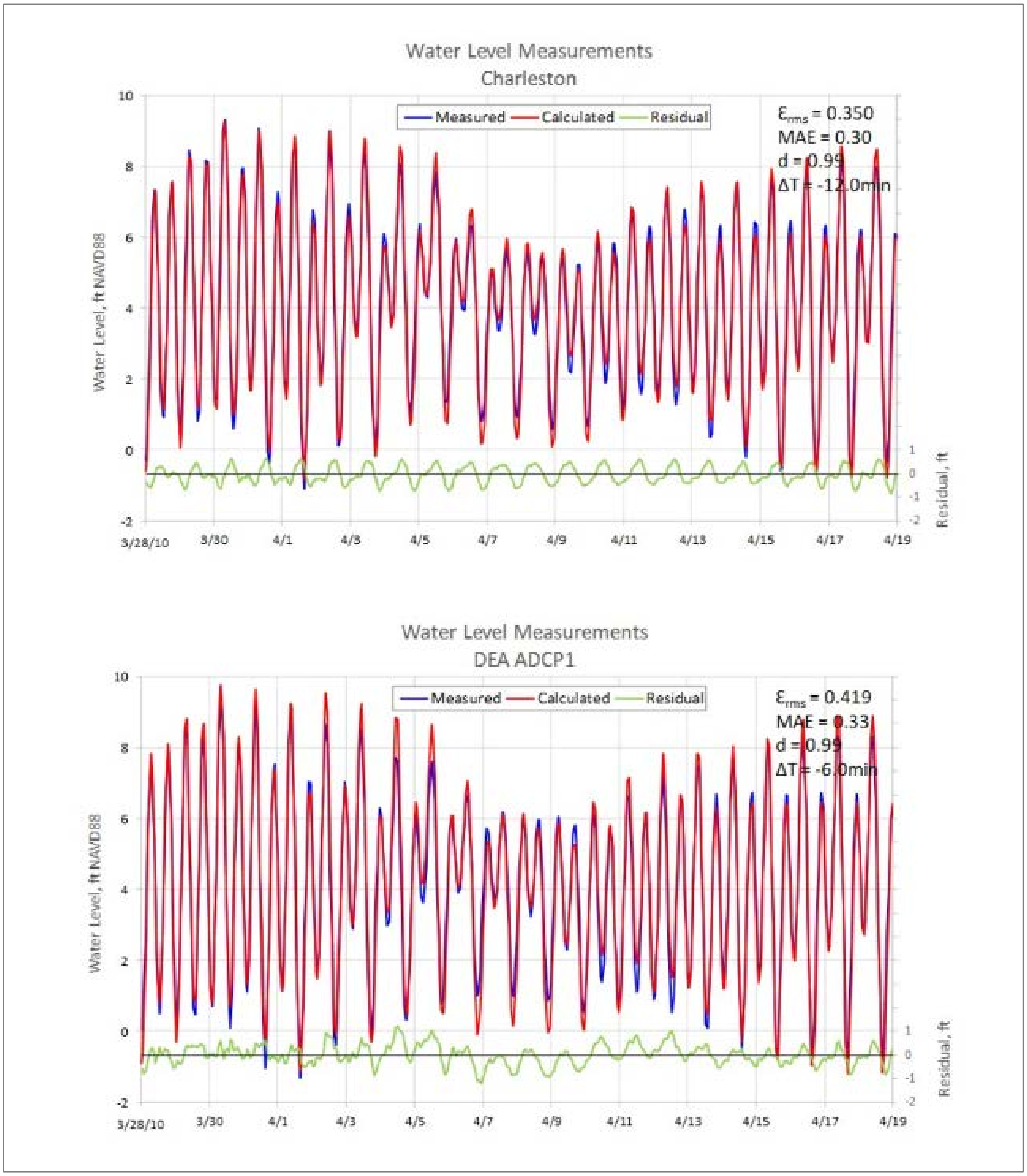


Figure 2-13. Comparison of Water Levels at Charleston and DEA ADCP1 Location

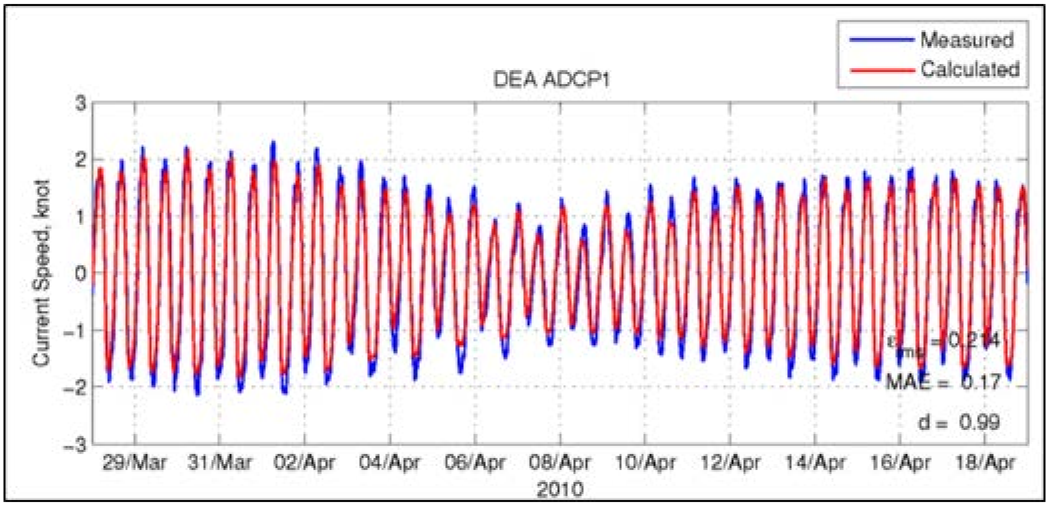


Figure 2-14. Comparison of Longitudinal Component of Velocity at DEA ADCP1 Location

2.3.3 COMPARISON OF DISCHARGE ALONG DEA ADCP TRANSECTS

DEA used vessel-mounted ADCPs to measure bank-to-bank discharges along three transects, shown in Figure 2-12, during flood and ebb tides (OIPCB 2010). Table 2-3 provides the log of ADCP survey work performed between March 18 and March 19, 2010. Figure 2-15 through Figure 2-17 show the discharge comparison along each transect. For the modeled values, the DHI MIKE-21 HD model computes the discharge data by integrating the depth-averaged velocities over the channel cross-section area. The ADCP program uses a similar algorithm based on integrating the measured velocity profile within the water column to determine the depth-averaged velocity. Therefore, the two methods are compatible.

A comparison of model results against measurements showed that modeled discharges at two locations along Transects 1 and 2 were equal to measured discharges. Along Transect 3, modeled discharges were within 10% of those measured.

Table 2-3. Log of DEA ADCP Transect Survey Periods

DEA Transect	Tide	Start Date/Time (LDT)	End Date/Time (LDT)
1	Flood	3/18/2010 11:41	3/18/2010 12:05
	Ebb	3/18/2010 16:49	3/18/2010 17:05
2	Flood	3/18/2010 12:21	3/18/2010 12:36
	Ebb	3/18/2010 17:35	3/18/2010 18:05
3	Flood	3/19/2010 12:14	3/19/2010 12:48
	Ebb	3/19/2010 18:32	3/19/2010 18:55

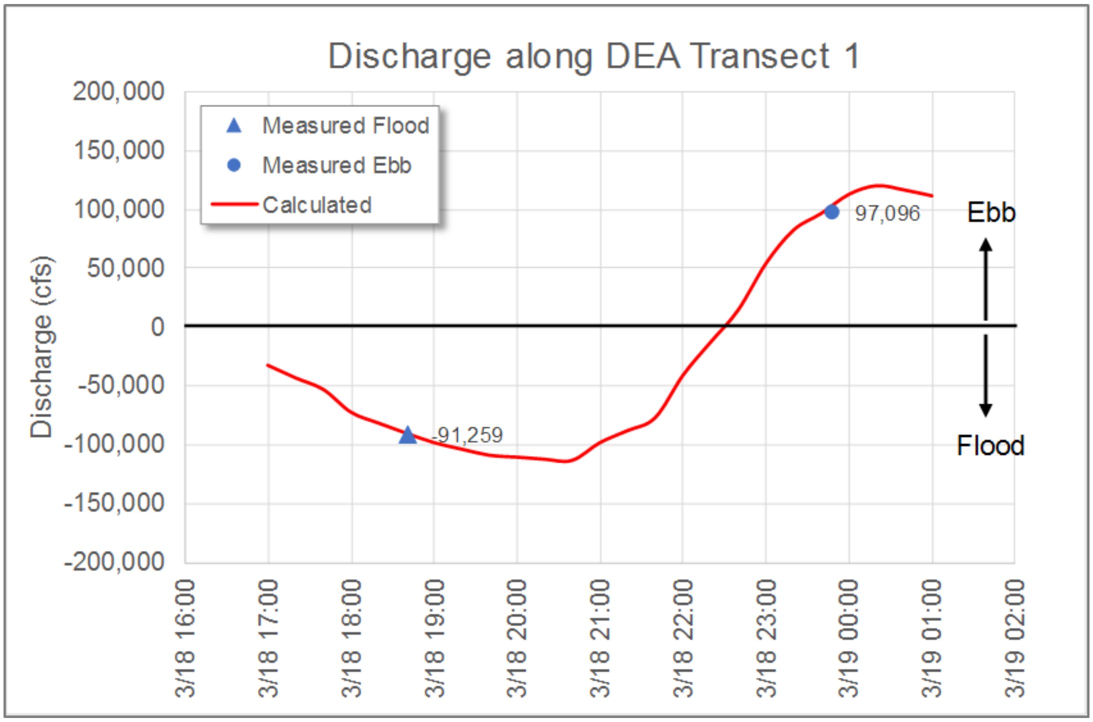


Figure 2-15. Comparison of Measured Discharge along DEA Transect 1 with Modeled (Calculated) Results

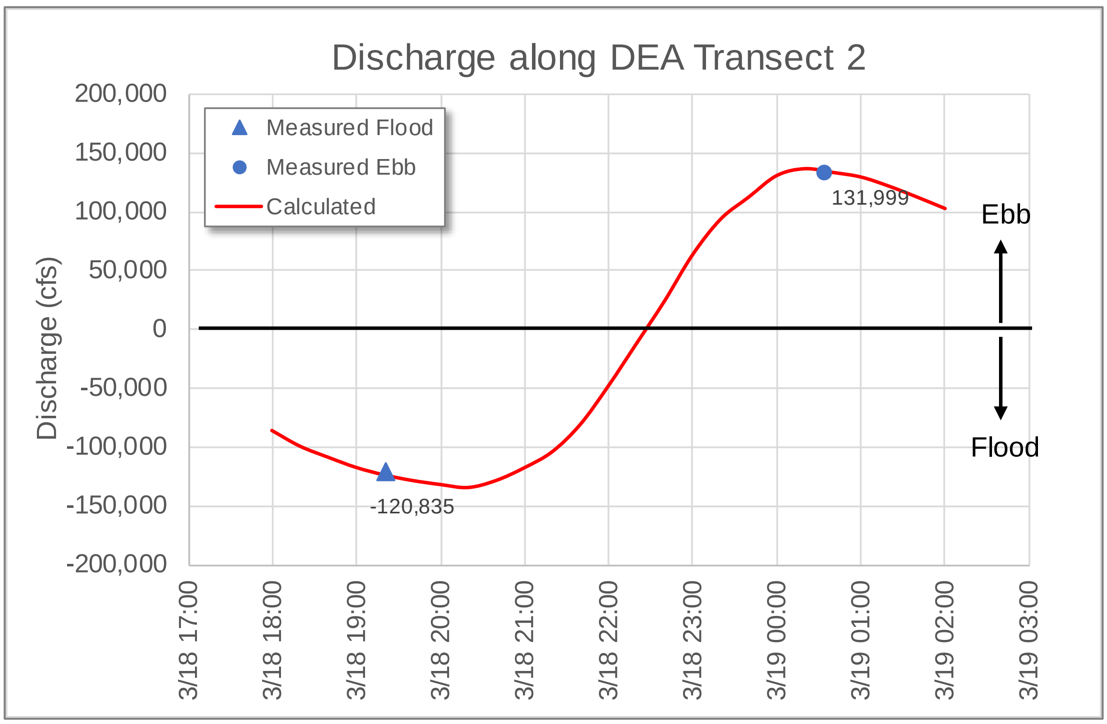


Figure 2-16. Comparison of Measured Discharge along DEA Transect 2 with Modeled (Calculated) Results

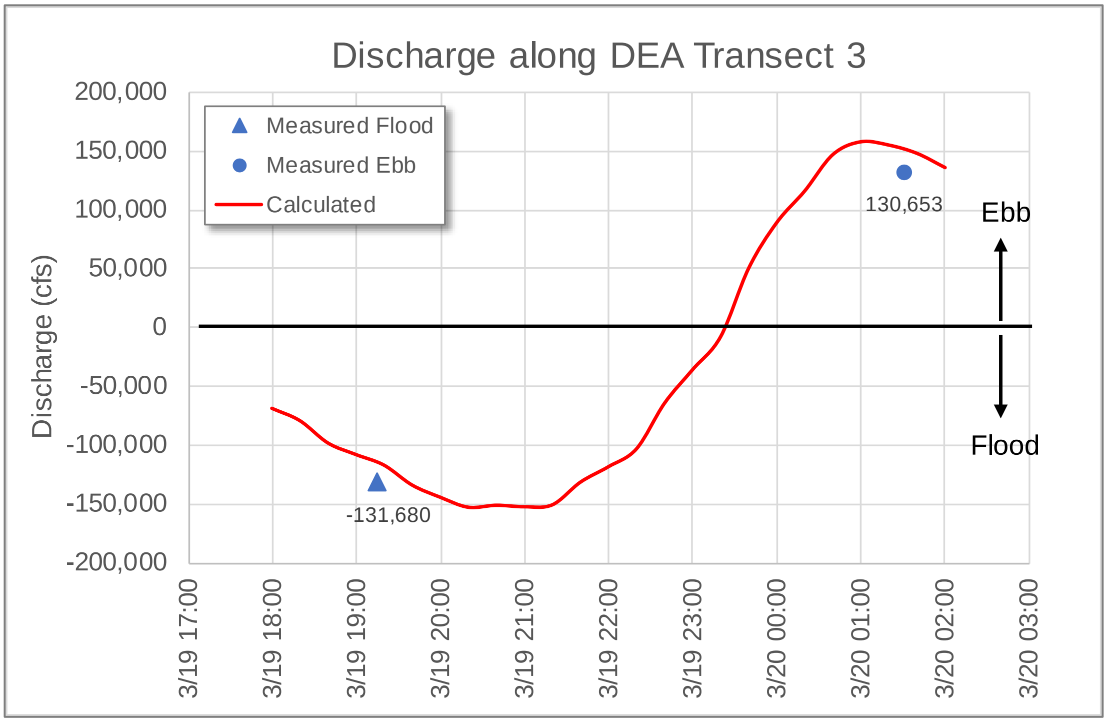


Figure 2-17. Comparison of Measured Discharge along DEA Transect 3 with Modeled (Calculated) Results

2.4 MODEL RESULTS

MIKE-21 hydrodynamic simulations were conducted for two scenarios: “Without-Project” and “With-Project”. A comparison of the two scenarios provides an indication of changes to tidal hydraulics and tidal prism related to modifications at the proposed JCEP project areas. The HD model was used to simulate a 30-day period from December 21, 2011 to January 19, 2012. The simulation replicates large winter tides and high runoffs.

2.4.1 MODEL OUTPUT LOCATIONS

Figure 2-18 shows the HD model output locations. The output locations were selected to represent the areas of interest to evaluate the changes in hydrodynamics (tidal datums and currents) as a result of modifications by the JCEP (NRI areas, Slip and Access Channel, MOF, and Eelgrass Mitigation site). The results extracted for individual output locations are listed in Table 2-4. The results for all locations in the model are graphically shown in Figure 2-19 through Figure 2-30. There are slight differences between the values listed in Table 2-4 and the figures because the model generates results at every node, which cannot be tabulated.

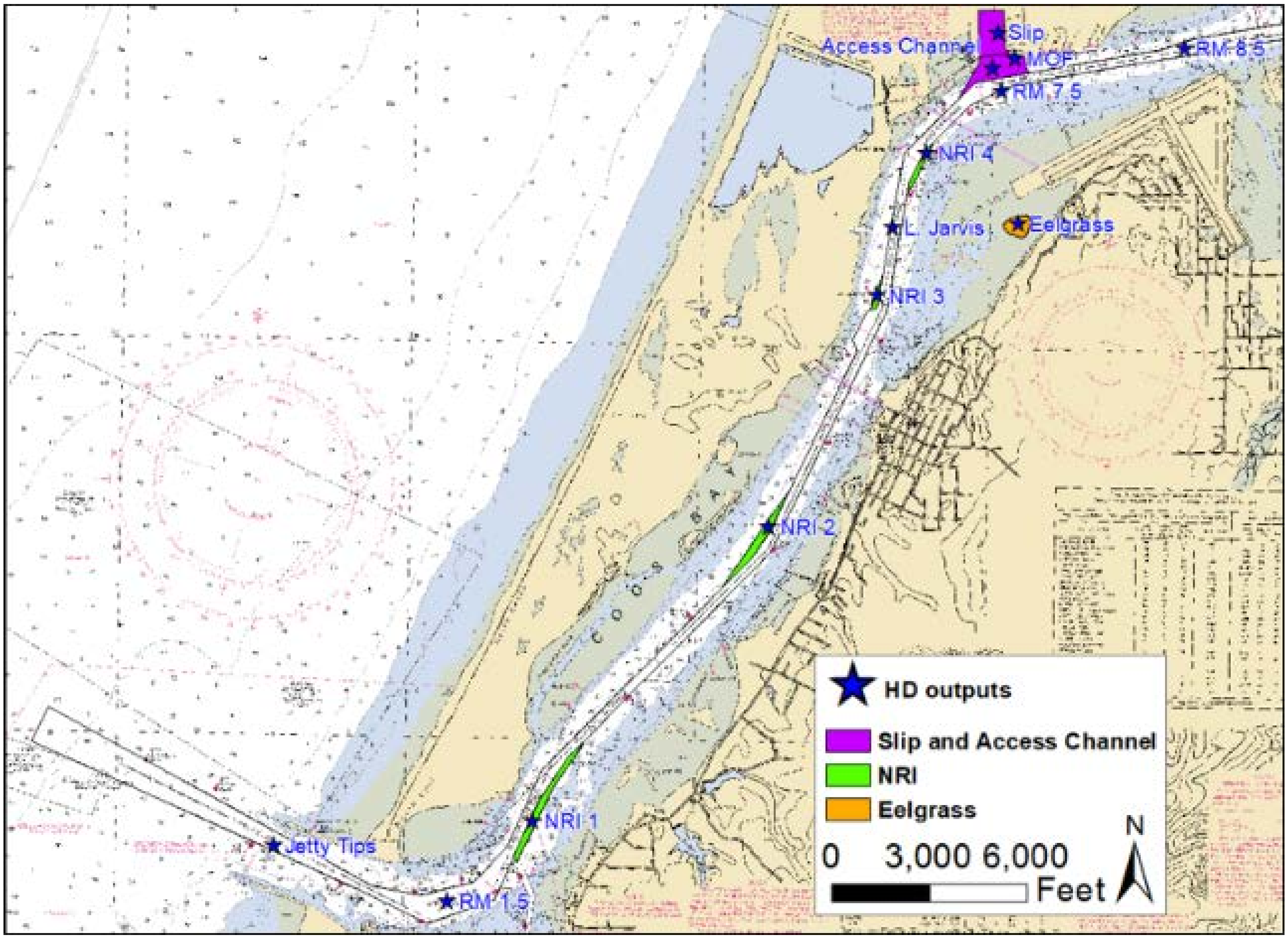


Figure 2-18. Base Map Showing the HD Model Output Locations

2.4.2 TIDAL PRISM

A tidal prism is the volume of water in an estuary between mean high tide and mean low tide, and it can be calculated by multiplying the mean tidal range by the surface area of the estuary. Table 2-4 shows that the mean tidal range is unchanged between the two scenarios. In addition, the surface area is nearly the same because all the deepening occurs below the mean low tide. Therefore, the analysis concludes the tidal prism is unchanged as a result of the JCEP.

2.4.3 TIDAL HYDRAULICS

Table 2-4 also compares the current speeds for the mean and 99th percentile (only 1% of the values exceeding the 99th percentile value) values. By calculating the 99th percentile values, the numerical oscillation due to the HD model wetting and drying can be filtered out systematically. The mean current speed was analyzed separately for flood and ebb tides, and the 99th percentile was analyzed for the entire time series. Only the results of the With-Project scenario at the MOF and Slip are listed in the table.

Model results listed in Table 2-4 indicate that most tidal hydraulics are unchanged. The most notable changes to the tidal hydraulics are seen in the Access Channel, with a 50% reduction in mean current speed during flood tides, a 25% reduction in mean current speed during ebb tides, and an 11% reduction in 99th percentile current speeds. This is an expected result because dredging the access channel, slip and MOF increases the water column depth across these locations, and that should lead to a reduction in current speeds. Variation is not predicted in the results for the FNC at RM 7.5, or upstream and downstream at RM 8.5 and NRI 4, indicating that the variance is local to the Terminal area.

At the pile dike area, an increased current speed is predicted between the western slope of the Access Channel and Pile Dike CB 7.3. Additional discussion of this change in current velocities is provided in a separate memorandum focusing on the pile dikes (M&N 2017).

At the eelgrass mitigation site, a 50% reduction in mean current speed during flood tides and a 25% reduction in 99th percentile is predicted. This is also due to the deepening of the site.

Figures 2-19 through Figure 2-30 comprise a series of three-figure sequences depicting current speeds. Each three-figure sequence shows the “Without-Project” scenario, the “With-Project” scenario, and the difference between the two scenarios as further described in the text that follows.

Figure 2-19 through Figure 2-21 show the 99th percentile flood currents. Within the estuary, changes to tidal currents are less than 0.3 knots for the 99th percentile flood currents except at the western slope of the Access Channel where the model predicts higher currents due to the JCEP Project (e.g. an increase of approximately 0.7 knots).

Figure 2-22 through Figure 2-24 show the 99th percentile ebb currents. Similarly, changes to tidal currents are less than 0.3 knots for the 99th percentile ebb currents except in an area near the offshore end of the CB 7.3 pile dike enrockment (e.g. an increase of up to 0.5 knots).

Figure 2-25 through Figure 2-27 show the mean flood currents and Figure 2-28 through Figure 2-30 show the mean ebb currents. In most areas, the difference of mean currents (flood or ebb) between the two scenarios is less than 0.1 knots, which is shown as no color. Only a few localized areas have changed (less than 0.3 knots) in current magnitude.

Detailed plots of the 99th percentile currents and the mean currents are provided in Appendix A.

Figure 2-31 and Figure 2-32 present the current vector snapshots during a strong flood tide (12/26/2011 8:00 AM). Figure 2-33 and Figure 2-34 present the current vector snapshots during a strong ebb tide (12/24/2011 10:00 PM). These figures show limited change in flow direction/patterns within the FNC between the With-Project and Without-Project conditions.

Detailed plots of the strong flood and ebb currents are provided in Appendix B.

Table 2-4. Changes to Tides and Currents

Location	Jetty Tips	RM 1.5	NRI 1	NRI 2	NRI 3	Lower Jarvis	Eelgrass	NRI 4	RM 7.5	Access Channel	MOF	Slip	RM 8.5
	Mean Tidal Range (feet)												
Without-Project	5.5	5.5	5.6	5.8	5.9	5.9	5.9	6.0	6.0	6.0	-	-	6.2
With-Project	5.5	5.5	5.6	5.8	5.9	5.9	5.9	6.0	6.0	6.0	6.0	6.0	6.2
% Change	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%			0%
	Mean Higher High Water (feet, MLLW)												
Without-Project	7.9	8.0	8.0	8.2	8.3	8.4	8.4	8.4	8.5	8.5	-	-	8.6
With-Project	7.9	8.0	8.0	8.2	8.3	8.4	8.4	8.4	8.5	8.5	8.5	8.5	8.6
% Change	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%			0%
	Mean Sea Level (feet, MLLW)												
Without-Project	4.1	4.2	4.2	4.3	4.3	4.3	4.3	4.3	4.4	4.4	-	-	4.4
With-Project	4.1	4.2	4.2	4.3	4.3	4.3	4.3	4.3	4.4	4.4	4.4	4.4	4.4
% Change	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%			0%
	Mean Current Speed during Flood Tides (knots)												
Without-Project	1.0	1.0	1.0	0.9	0.9	0.9	0.2	1.0	0.9	0.6	-	-	0.9
With-Project	1.0	1.0	1.0	0.9	0.9	0.9	0.1	1.0	0.9	0.3	0.3	0.1	0.9
% Change	0%	0%	0%	0%	0%	0%	-50%	0%	0%	-50%			0%
	Mean Current Speed during Ebb Tides (knots)												
Without-Project	1.3	1.2	1.3	1.2	1.3	1.2	0.1	1.2	1.1	0.4	-	-	1.1
With-Project	1.3	1.2	1.3	1.2	1.3	1.2	0.1	1.2	1.1	0.3	0.1	0.2	1.1
% Change	0%	0%	0%	0%	0%	0%	0%	0%	0%	-25%			0%
	99th Percentile Current Speed (knots)												
Without-Project	2.7	2.4	2.5	2.6	2.5	2.5	0.4	2.3	2.1	0.9	-	-	2.2
With-Project	2.6	2.4	2.6	2.5	2.5	2.5	0.3	2.3	2.1	0.8	0.7	0.4	2.2
% Change	-4%	0%	+4%	-4%	0%	0%	-25%	0%	0%	-11%			0%

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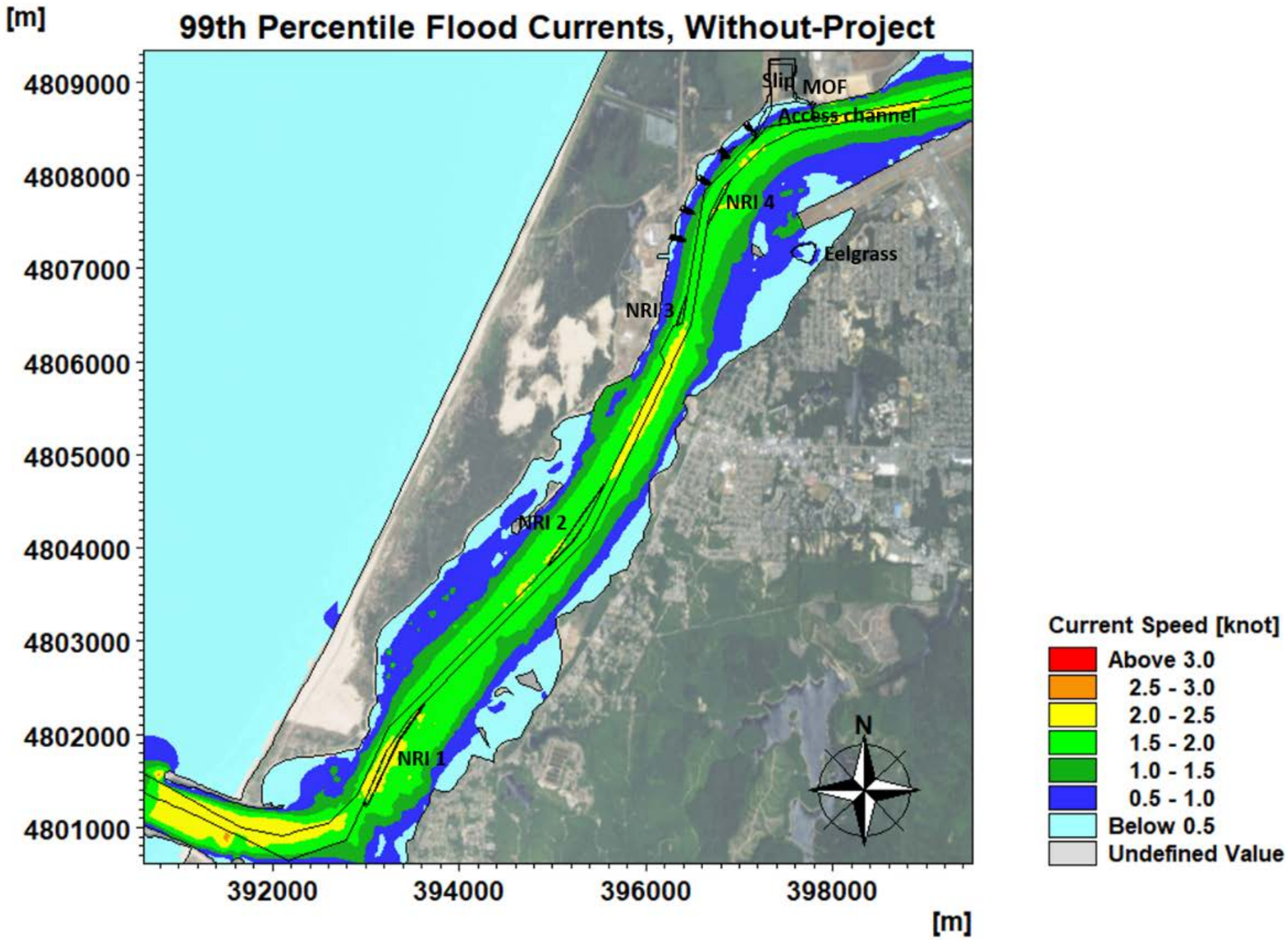

Figure 2-19. The 99th Percentile Flood Currents, Without-Project

Jordan Cove LNG	Hydrodynamic Studies – Hydrodynamic Analysis		moffatt & nichol
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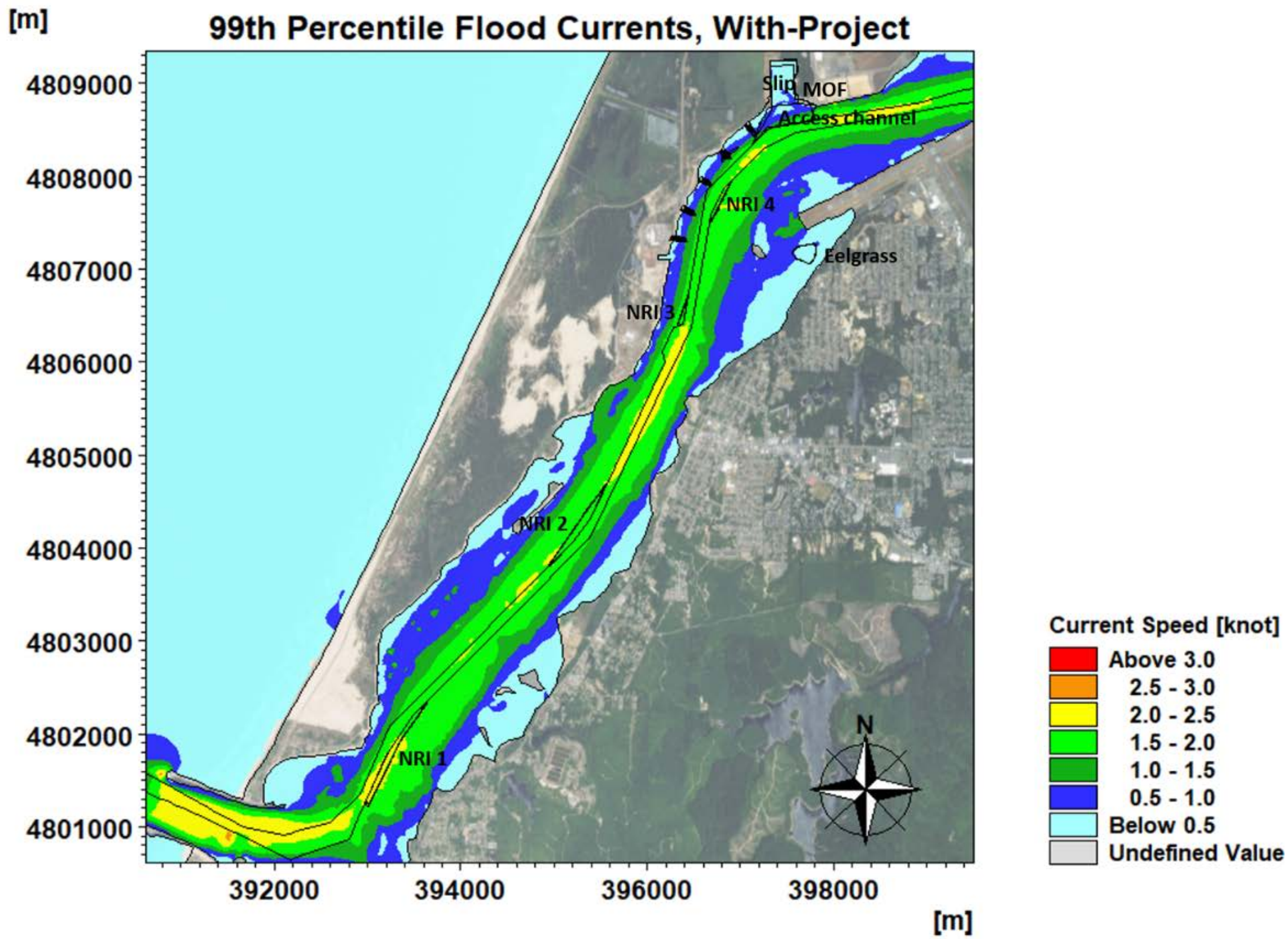

Figure 2-20. The 99th Percentile Flood Currents, With-Project

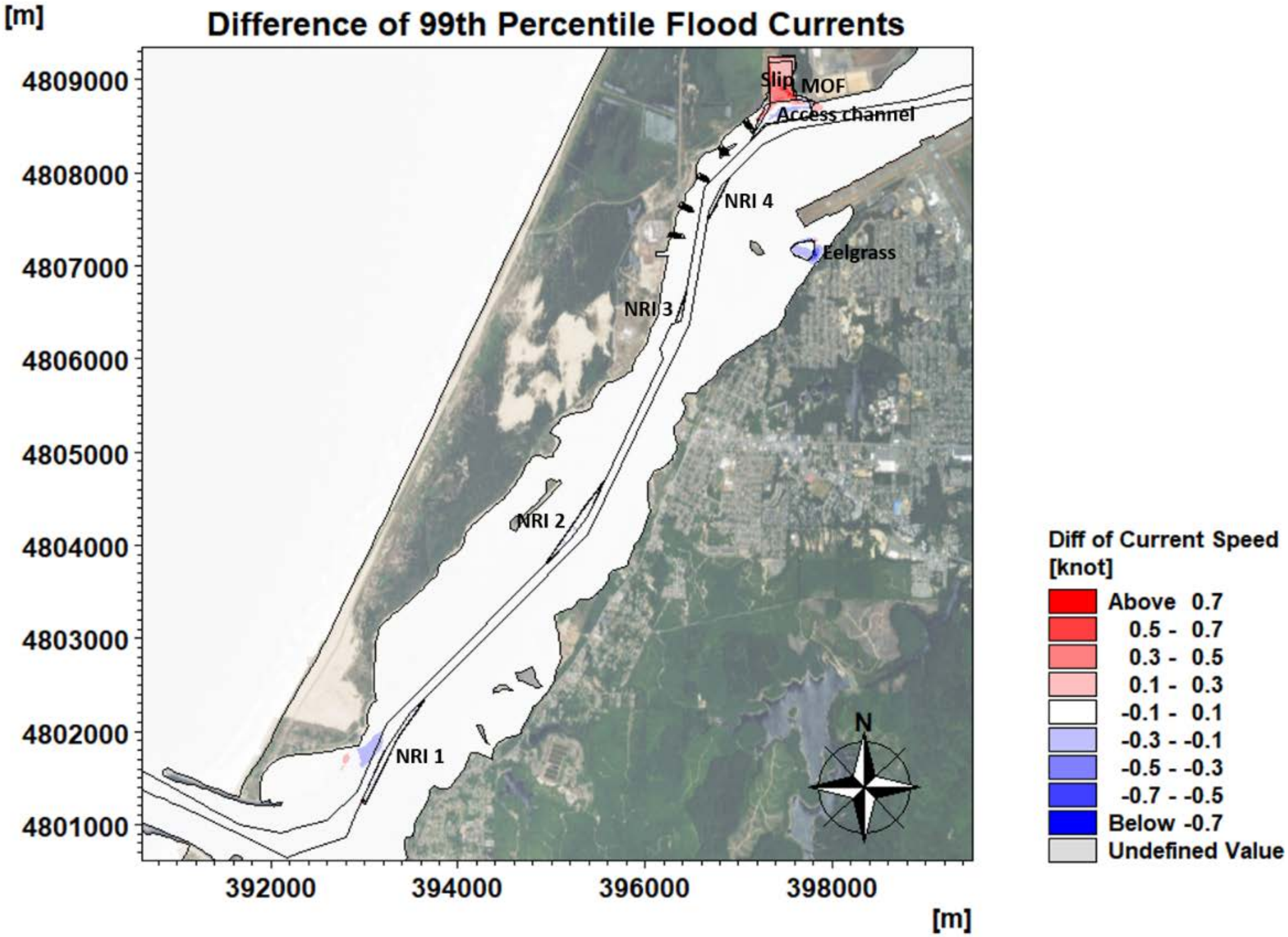

Figure 2-21. ***Difference of the 99th Percentile Flood Currents, Without-Project vs. With-Project***

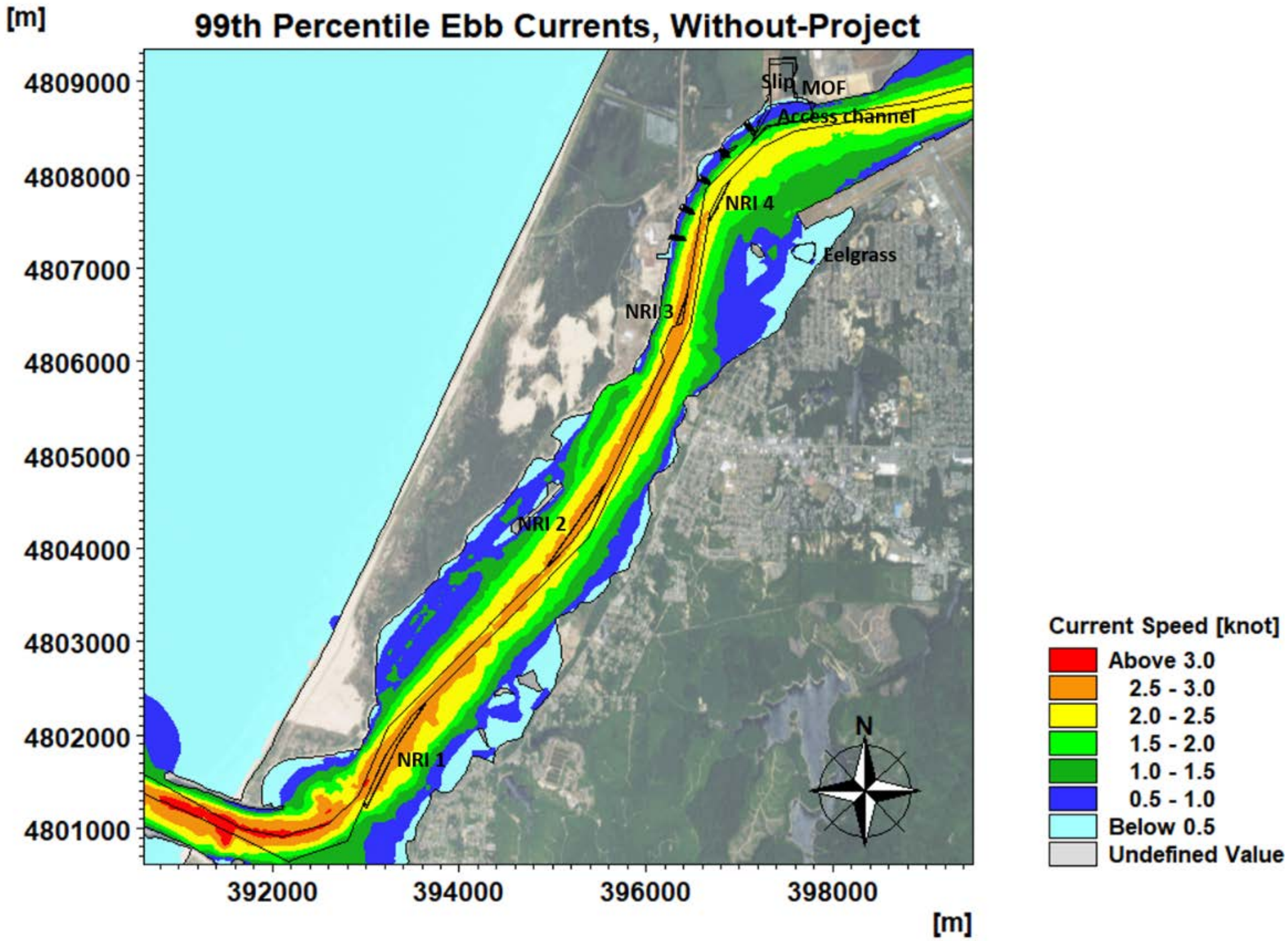

Figure 2-22. ***The 99th Percentile Ebb Currents, Without-Project***

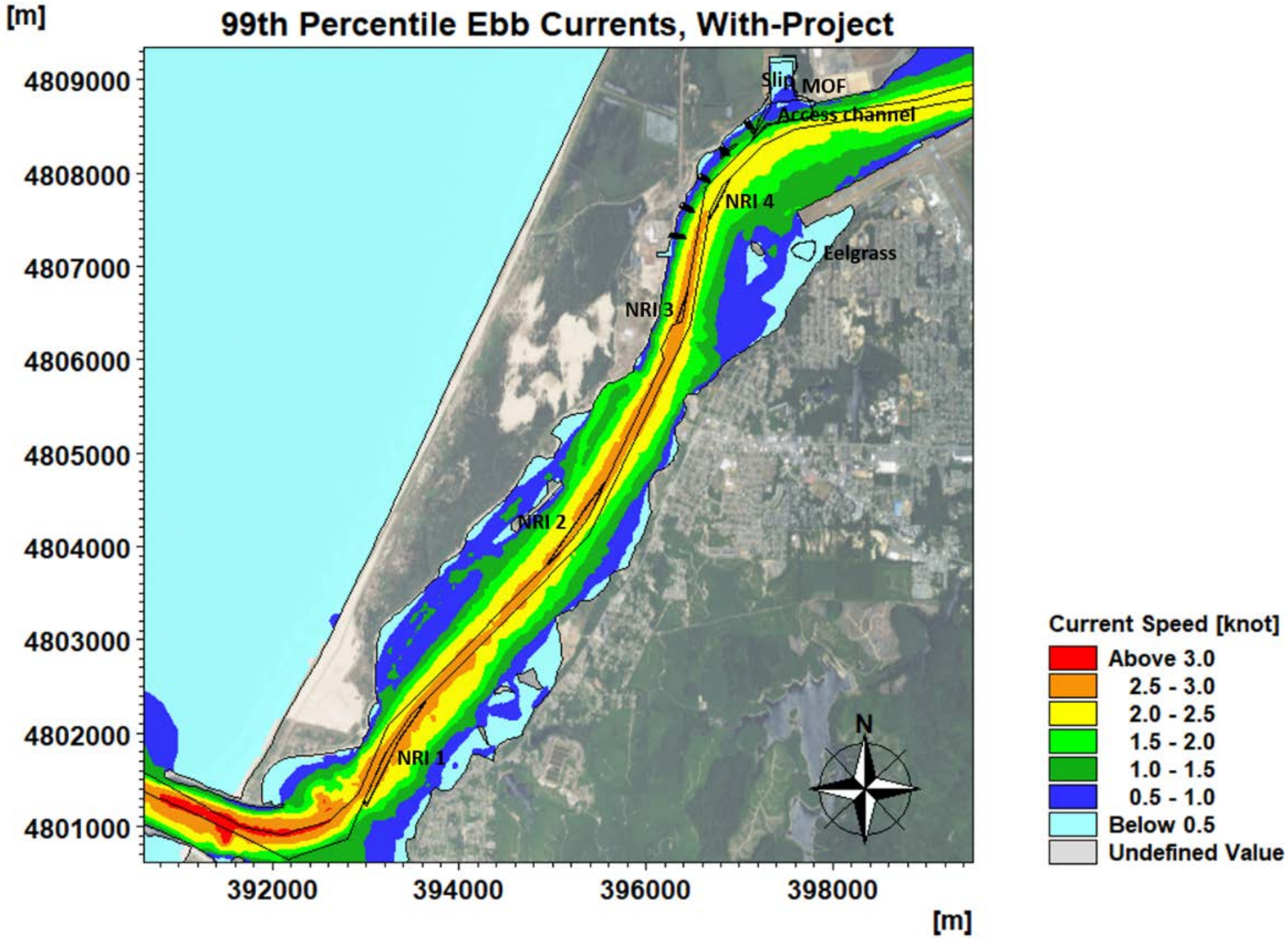

Figure 2-23. ***The 99th Percentile Ebb Currents, With-Project***

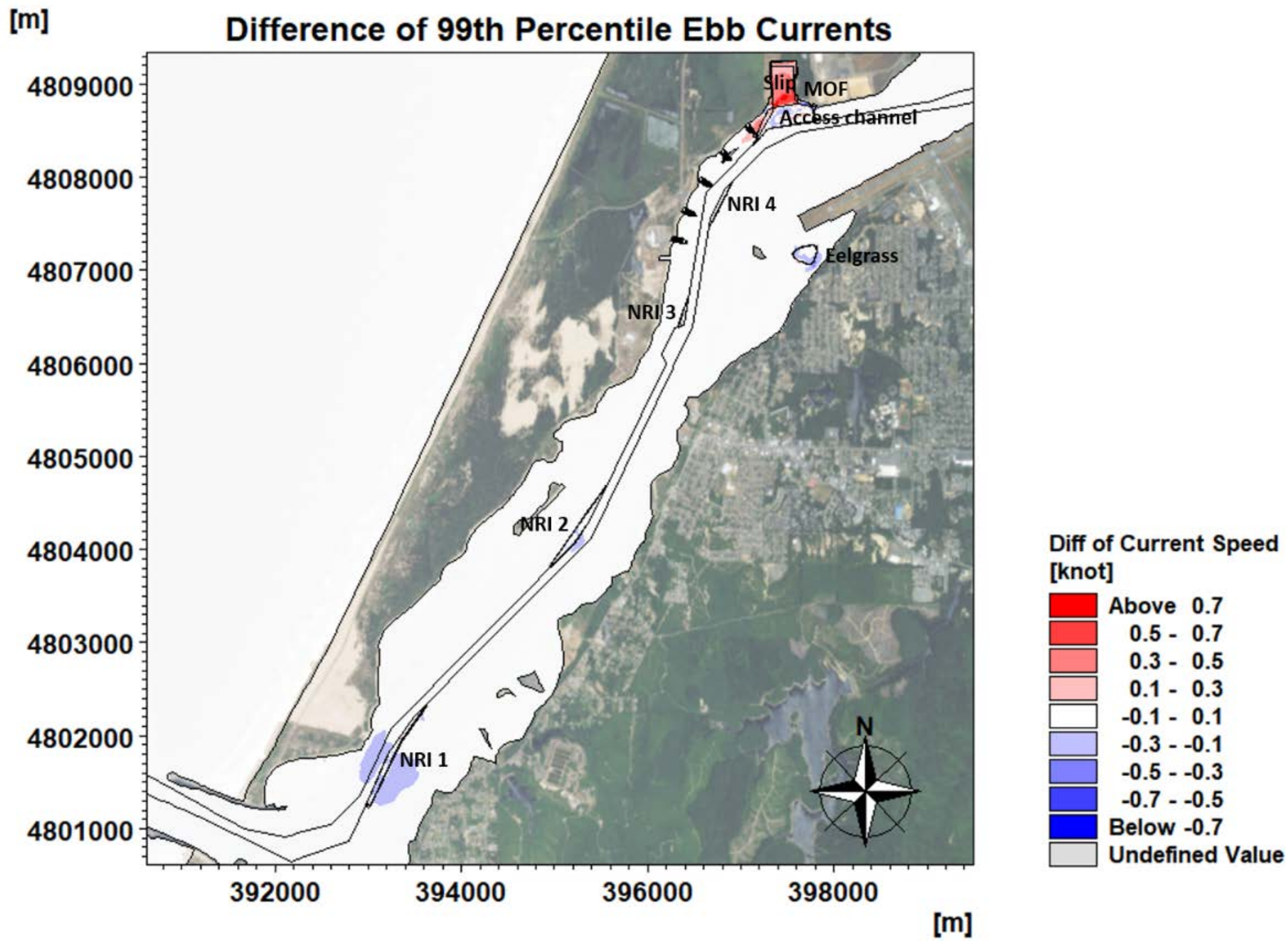

Figure 2-24. ***Difference of the 99th Percentile Ebb Currents, Without-Project vs. With-Project***

Jordan Cove LNG	Hydrodynamic Studies – Hydrodynamic Analysis		moffatt & nichol
	Document Number: J1-000-MAR-TNT-DEA-00008-00		
	Rev.: B	Rev. Date: September 19, 2018	

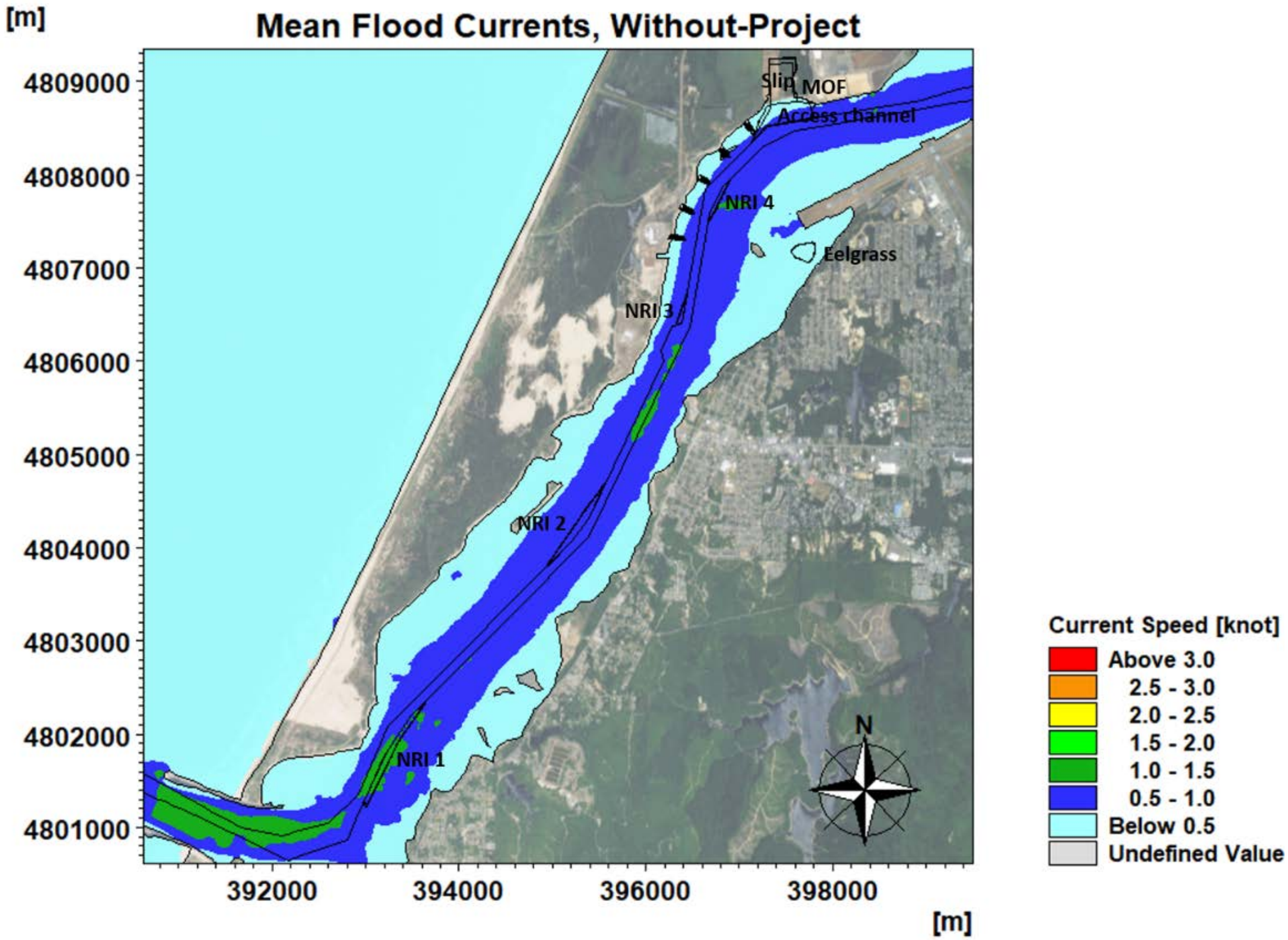

Figure 2-25. ***Mean Flood Currents, Without-Project***

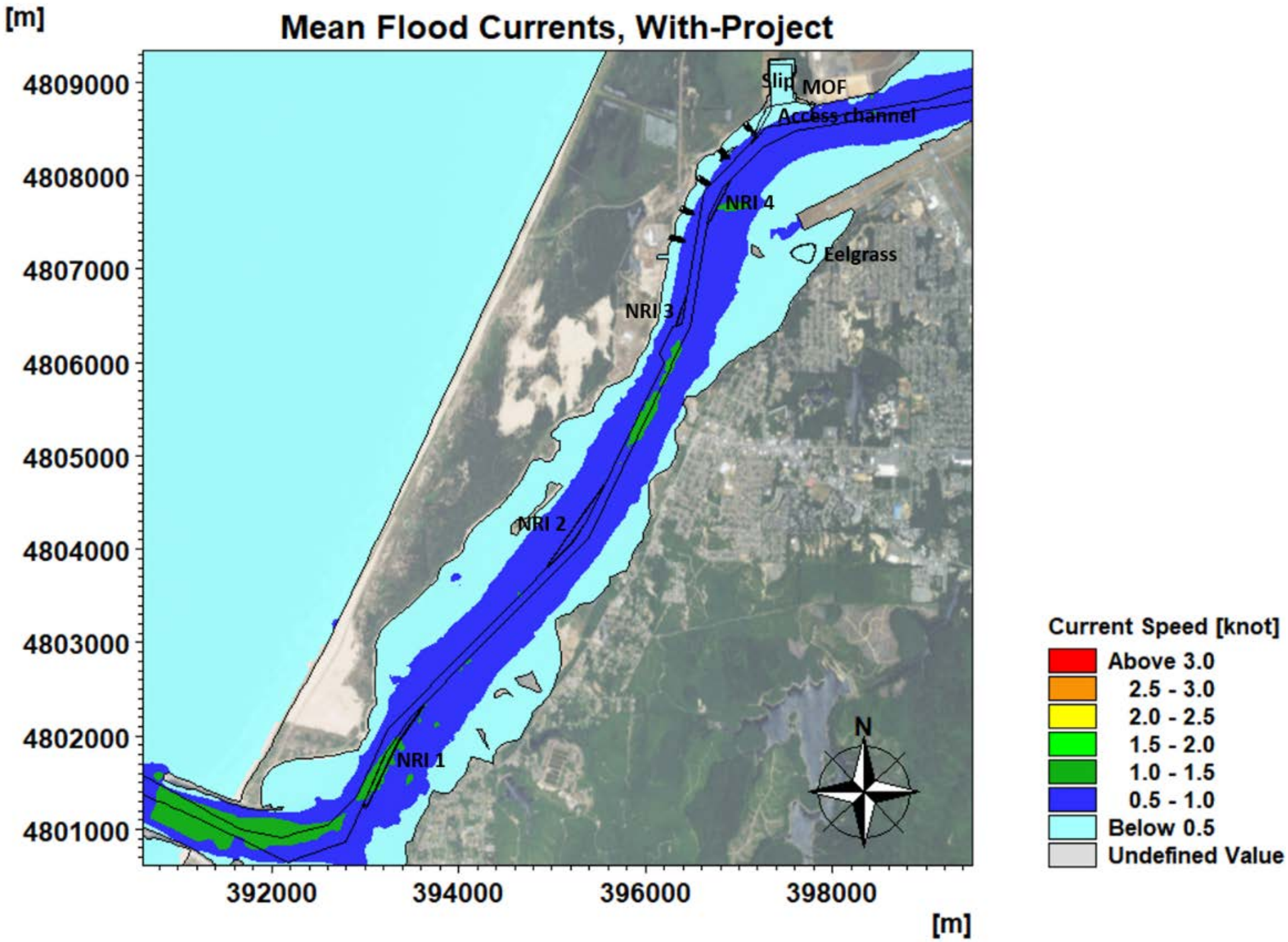

Figure 2-26. ***Mean Flood Currents, With-Project***

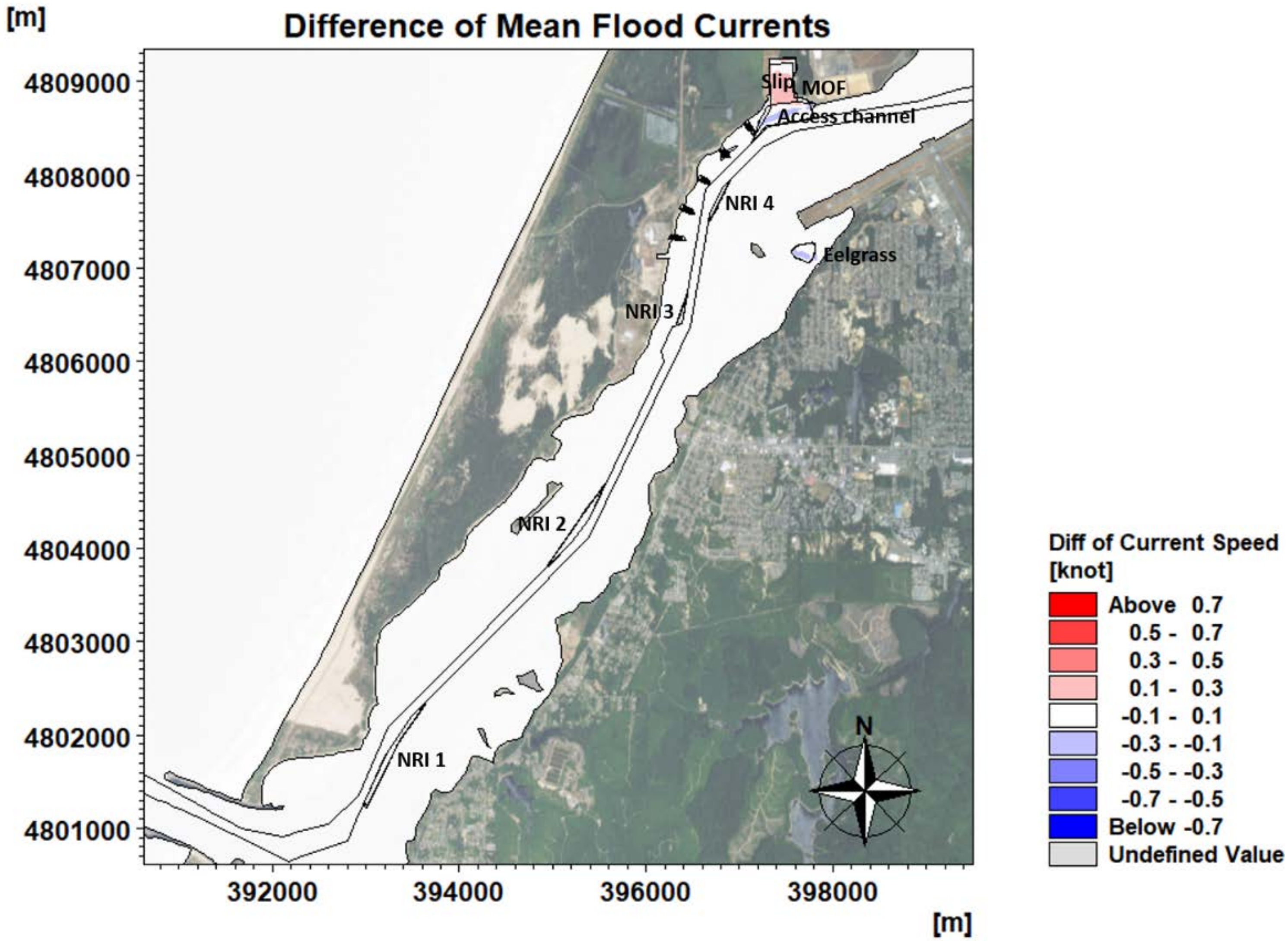

***Figure 2-27.** Difference of Mean Flood Currents, Without-Project vs. With-Project*

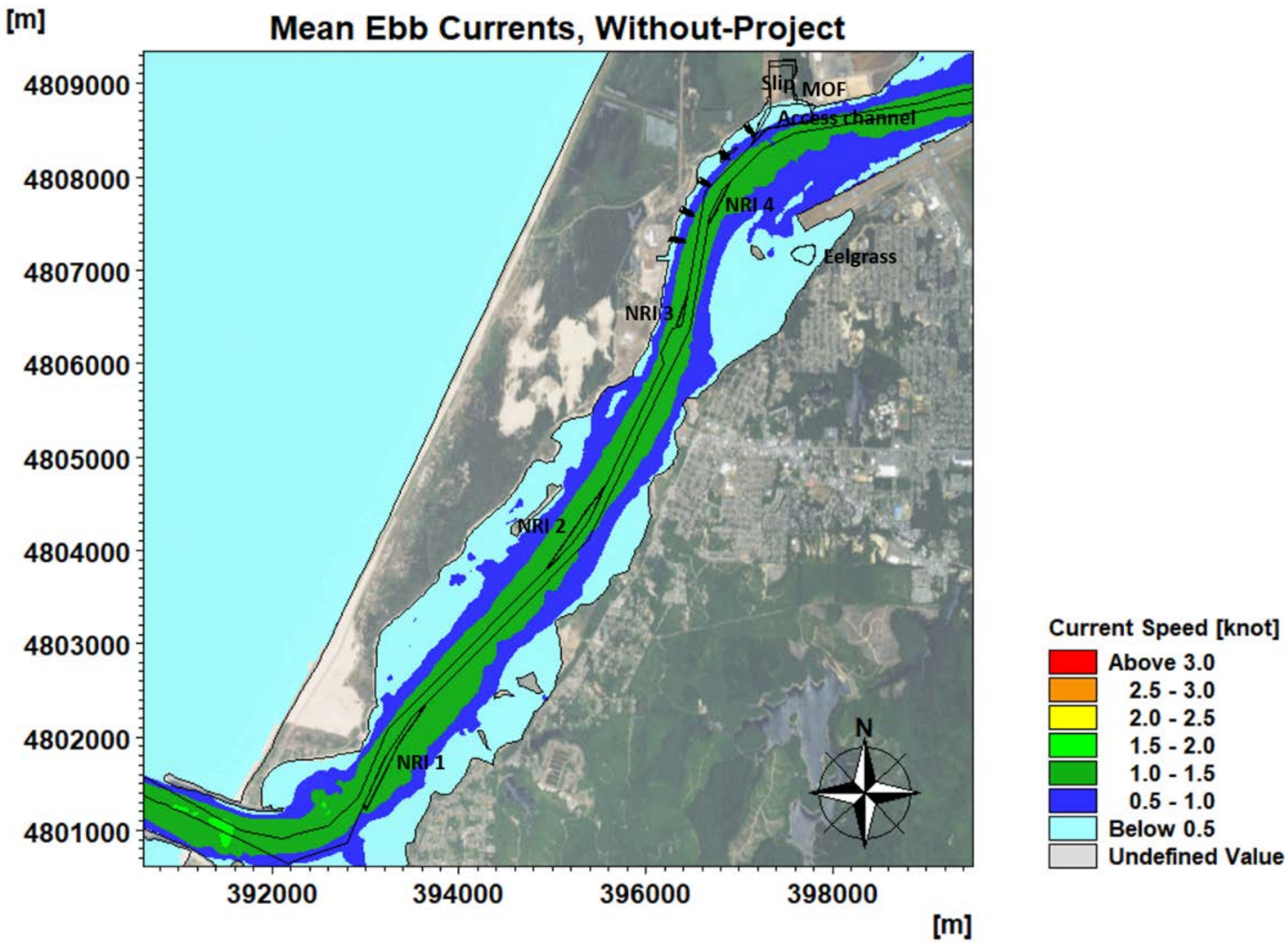

Figure 2-28. ***Mean Ebb Currents, Without-Project***

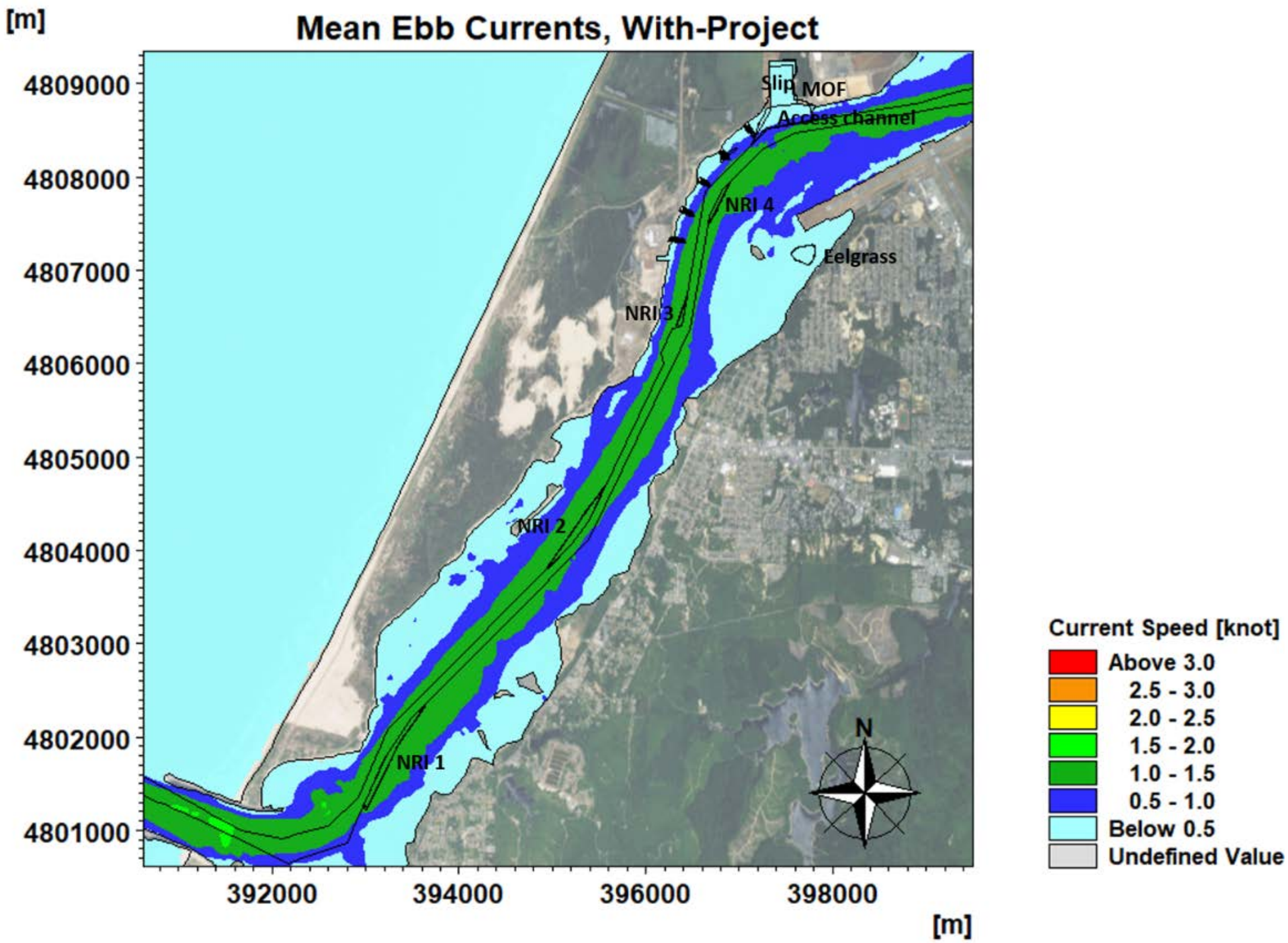

Figure 2-29. ***Mean Ebb Currents, With-Project***

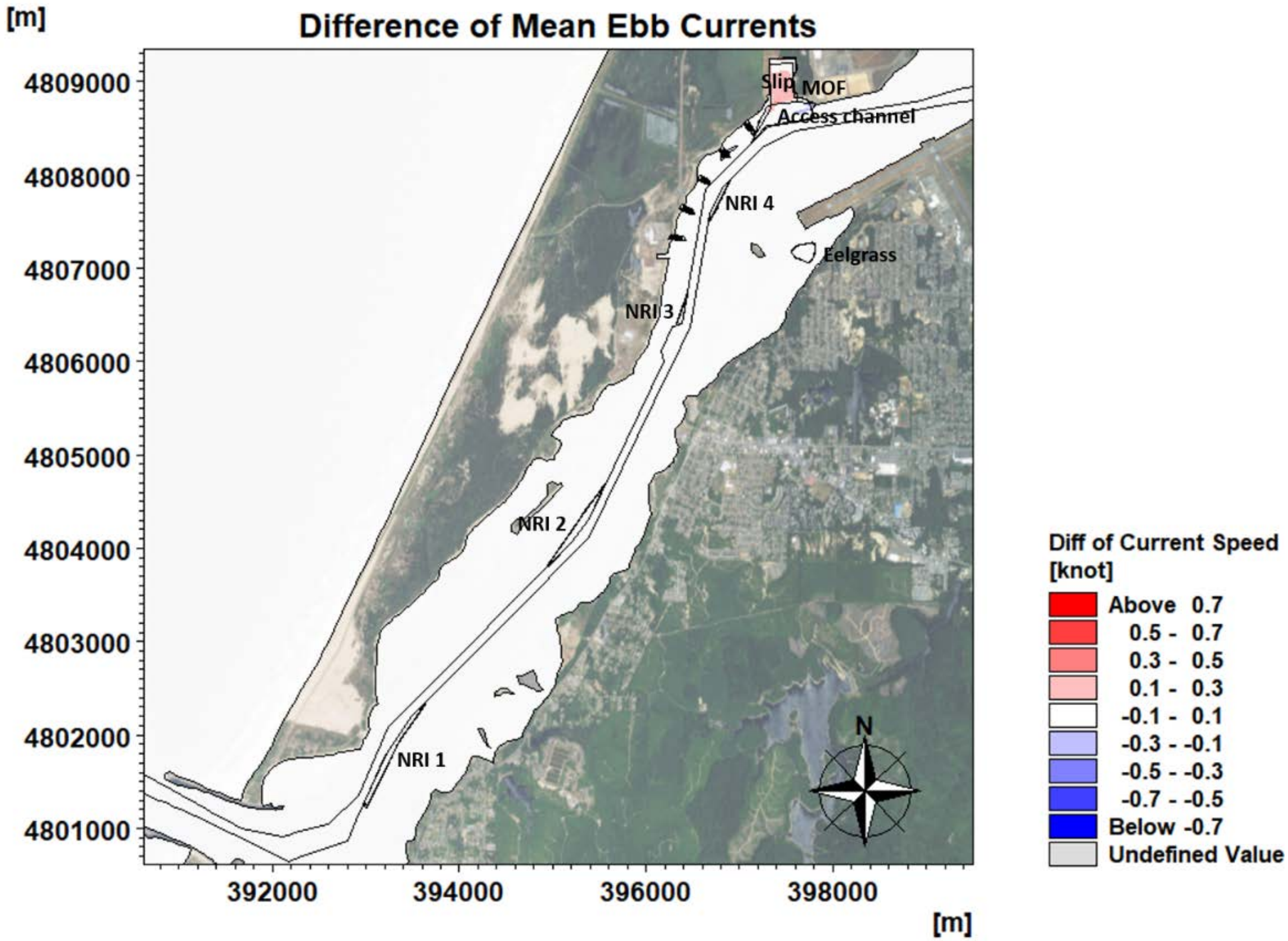

Figure 2-30. Difference of Mean Ebb Currents, Without-Project vs. With-Project

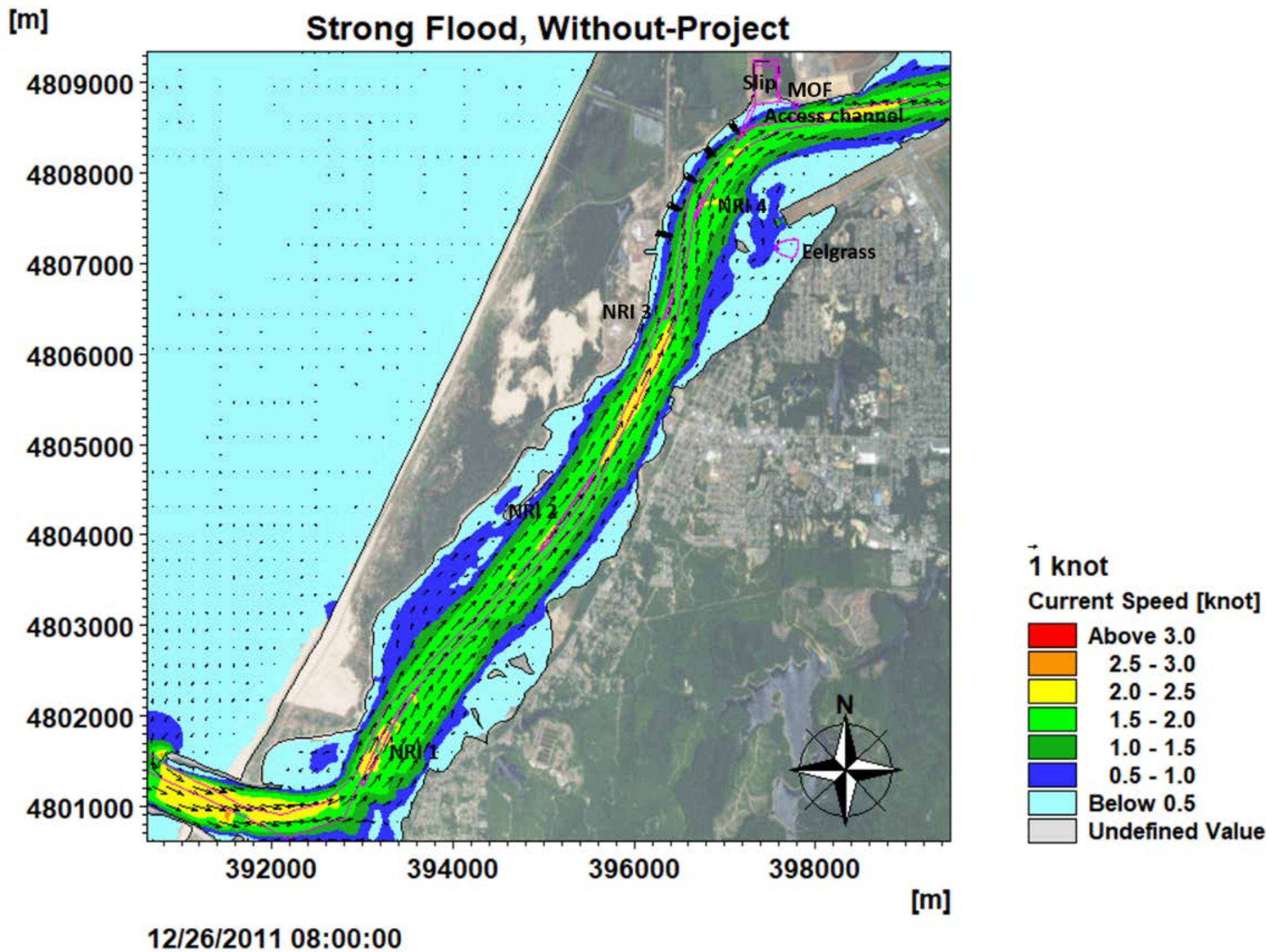

Figure 2-31. ***Strong Flood Currents, Without-Project***

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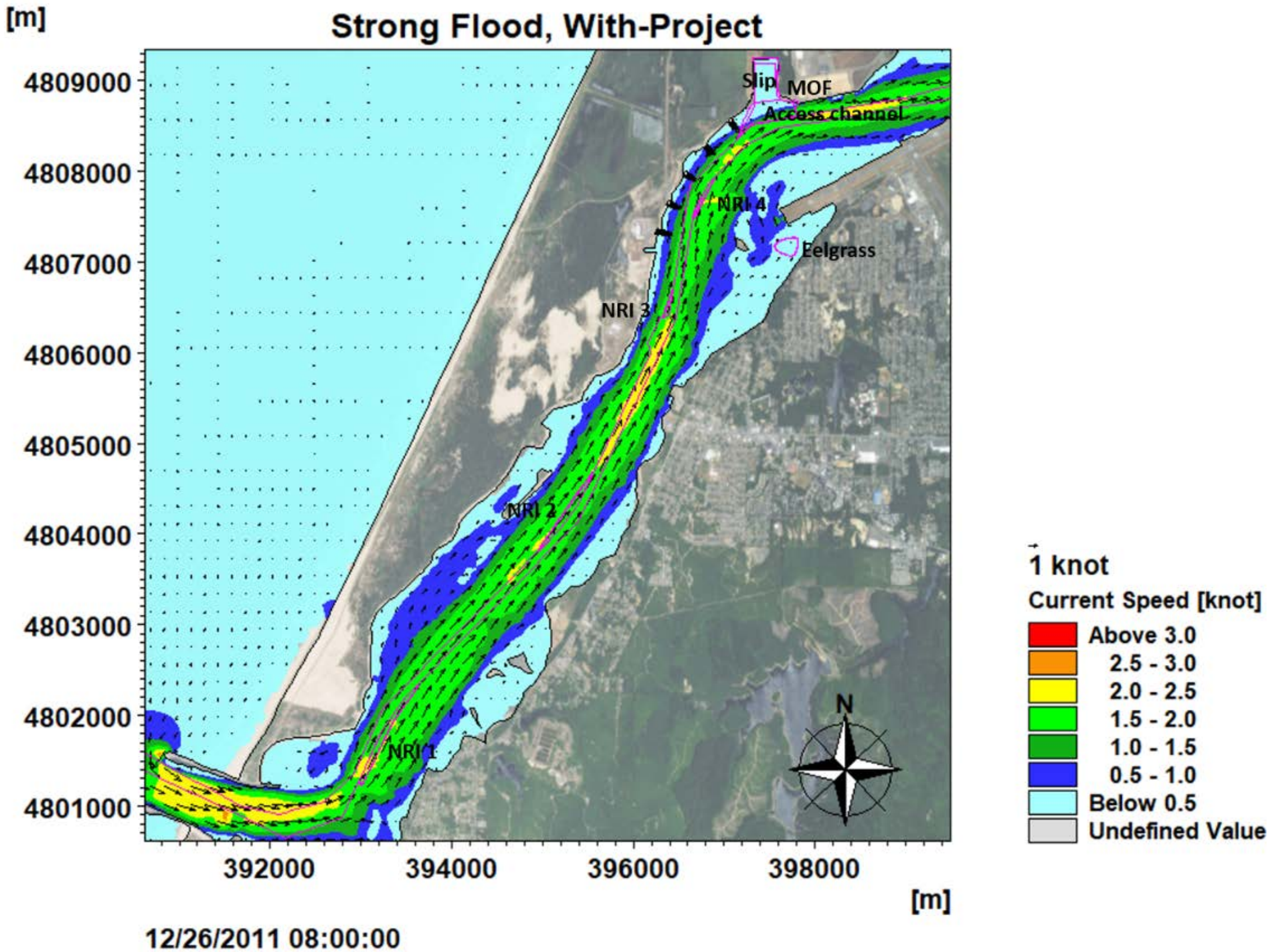

Figure 2-32. ***Strong Flood Currents, With-Project***

Jordan Cove LNG℠	Hydrodynamic Studies – Hydrodynamic Analysis		moffatt & nichol
	Document Number: J1-000-MAR-TNT-DEA-00008-00		
	Rev.: B	Rev. Date: September 19, 2018	

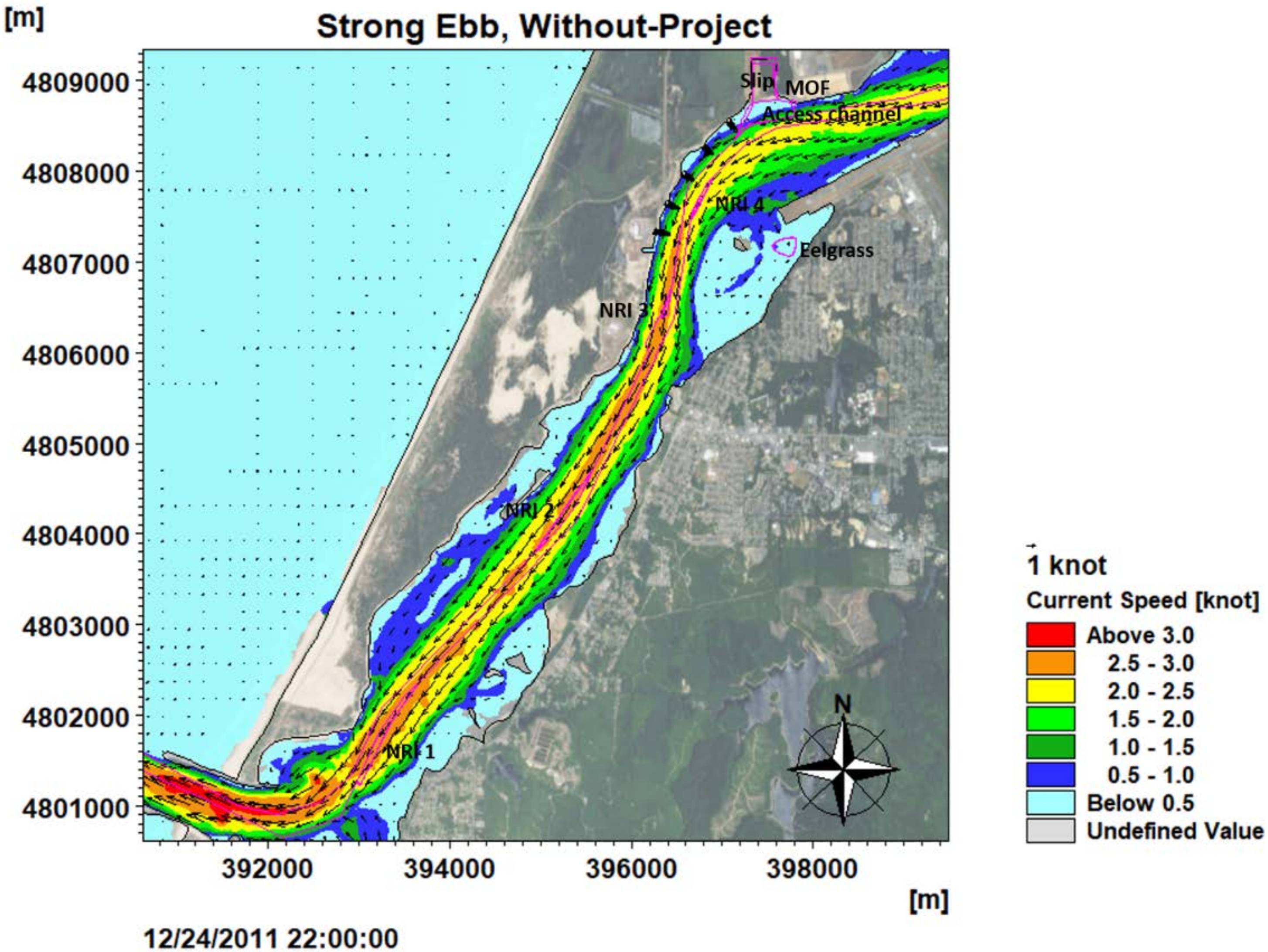

Figure 2-33. ***Strong Ebb Currents, Without-Project***

Jordan Cove LNG℠	Hydrodynamic Studies – Hydrodynamic Analysis		moffatt & nichol
	Document Number: J1-000-MAR-TNT-DEA-00008-00		
	Rev.: B	Rev. Date: September 19, 2018	

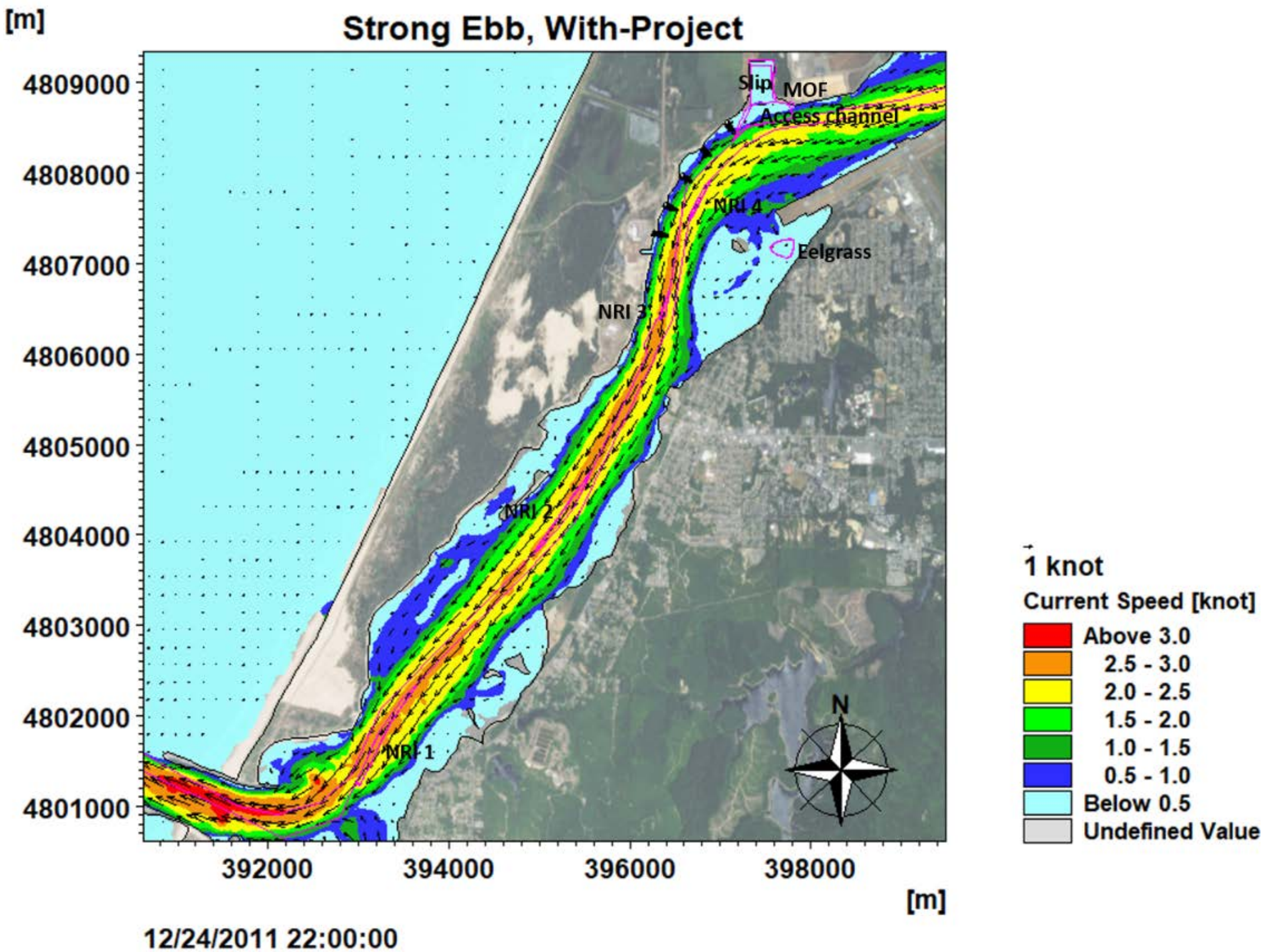

Figure 2-34. ***Strong Ebb Currents, With-Project***

3. SUMMARY

Jordan Cove Energy Project, LP ("JCEP") is seeking authorization from the Federal Energy Regulatory Commission ("FERC") under Section 3 of the Natural Gas Act ("NGA") to site, construct, and operate a natural gas liquefaction and liquefied natural gas ("LNG") export facility ("LNG Terminal"), located on the bay side of the North Spit of Coos Bay, Oregon.

M&N conducted a numerical modeling study at the request of JCEP to evaluate changes in hydrodynamics of the Coos Bay estuary as a result of the proposed JCEP Project (including NRI areas, Slip and Access Channel, MOF, and Eelgrass Mitigation site). The model domain in this study included the entire Coos Bay estuary. A two-dimensional hydrodynamic modeling was performed using the MIKE 21 FM model (DHI 2014). The model was calibrated against observations of water levels at NOAA Charleston tide station as well as measurements of water levels, currents, and discharge[1] collected by DEA (2010) along three transects. The model was then used to simulate two scenarios: "Without-Project" and "With-Project".

Differences in tides and currents between these two scenarios were assessed to evaluate possible changes in as a result of the proposed JCEP Project. The RMS errors for water levels was with the level of accuracy achieved in comparable USACE studies.

The hydrodynamic model results showed that the mean tidal range (MHHW – MLLW) remained unchanged. Model results also showed that tidal currents remain unchanged for most areas except for a small increase (< 0.3 knots) near Access Channel and < 0.7 knots increase in the localized areas around pile dike CB-7.3 and at the eastern and western slopes of the Access Channel.

1 Discharge was calculated based on measurements of currents along three transects and was not directly measured, see DEA (2010).

4. REFERENCES

Danish Hydraulic Institute (DHI), 2014. MIKE 21 Flow Model FM – Hydrodynamic Module User Guide. JCLNG Document No. J1-000-MAR-PCD-DHI-00002-00.

DHI Water and Environment, Inc. (DHI). 2011. Regional Coastal Hazard Modeling Study for North and Central San Francisco Bay. Rev: 02. Dated 10/21/2011. JCLNG Document No. (currently not available

Egbert, G.D. and Erofeeva, S.Y. 2002. Efficient Inverse Modeling of Barotropic Ocean Tides. Journal of Atmospheric and Oceanic Technology, Volume 19. JCLNG Document No. (currently not available).

Moffatt & Nichol (M&N), 2017 "Hydrodynamic Studies – Pile Dikes Analysis". Prepared for JCLNG, November 2017. JCLNG Doc No. J1-000-MAR-TNT-DEA-00004-00.

National Oceanic and Atmospheric Administration (NOAA), 2017. Vertical Datum Transformation. VDatum v3.7. https://vdatum.noaa.gov/. JCLNG Document No. (currently not available)

OIPCB, 2010. Coos Bay Channel Modifications Project Current and Wave Monitoring Survey Results, March-April 2010. Prepared by David Evans and Associates, Inc. May 2010. JCLNG Document No. (currently not available).

OIPCB, 2017a. Coos Bay Channel Modification 60% Design Digital Terrain Model, Metadata Final Report. Prepared by David Evans and Associates, Inc. March 2017. JCLNG Document No. J1-000-MAR-RPT-PCB-00007-00.

OIPCB, 2017b Coos Bay, Oregon, Section 204(f) Channel Modification Project: 60% Engineering Design Report. October 31, 2017. JCLNG Document No. J1-000-MAR-RPT-PCB-00004-00.

Solmar Hydro, Inc., 2016. "JCLNG Slip Access Channel Bathymetry". November 30, 2016. JCLNG Doc No. J1-000-MAR-MAP-KBJ-03001-00.

Tetra Tech, Inc., 2006. Development of the Hydrodynamic and Water Quality Models for the Savannah Harbor Expansion Project. Prepared for USACE – Savannah District, 100 West Oglethorpe Ave Savannah, Georgia 31401, Contract No.: DACA65-99-D-0065, FINAL, January 30, 2006. JCLNG Document No. (currently not available).

U.S. Army Corps of Engineers, Engineer Research and Development Center (USACE/ERDC). 2010. Waves, Hydrodynamics and Sediment Transport Modeling at Grays Harbor, WA. ERDC/CHL TR-10-13. December 2010. JCLNG Document No. (currently not available).

U.S. Army Corps of Engineers, Engineer Research and Development Center (USACE/ERDC). 2013. Regional Sediment Management Studies of Matagorda Ship Channel and Matagorda Bay System, Texas. ERDC/CHL TR-13-10. August 2013. JCLNG Document No. (currently not available).

U.S. Army Corps of Engineers, Northwest Division, Portland District (USACE/NWP), 2014. 2014 USACE NWP Topobathy Lidar: Coos Bay (OR). USACE National Coastal Mapping Program (JALBTCX). Accessed through NOAA Data Access Viewer. https://coast.noaa.gov/dataviewer/#/lidar/search/where:ID=4905/details/4905 JCLNG Document No. J1-000-GEO-MED-NOA-00001-00.

TECHNICAL MEMORANDUM

DATE:	September 19, 2018
ATTENTION:	Drew Jackson, P.E.
COMPANY:	Jordan Cove LNG, LLC (JCLNG)
ADDRESS:	5615 Kirby Drive, Suite 500, Houston, TX 77005
FROM:	Cheng-Feng Tsai, P.E., William Gerken, P.E. – Moffatt & Nichol
SUBJECT:	Sediment Transport Analysis
DEA PROJECT NAME:	Ad Hoc Permitting Support
DEA PROJECT NO:	JLNG0000-0003
M&N PROJECT NO:	9929-03, Task Order MN-1130-002
DOCUMENT #	J1-000-MAR-TNT-DEA-00003-00
COPIES TO:	DEA (Sean Sullivan, Loren Stucker)

1. INTRODUCTION

Jordan Cove Energy Project, LP ("JCEP") is seeking authorization from the Federal Energy Regulatory Commission ("FERC") under Section 3 of the Natural Gas Act ("NGA") to site, construct, and operate a natural gas liquefaction and liquefied natural gas ("LNG") export facility ("LNG Terminal"), located on the bay side of the North Spit of Coos Bay, Oregon. The LNG Terminal, related facilities, temporary construction sites, and other sites/actions associated with LNG Terminal construction are collectively referred to as the "JCEP Project Area" as shown on Figure 1-1.

The JCEP Project Area is made up of the following selected components, among others not listed here because they are not relevant to the scope of this memorandum:

- Slip – a permanent facility between Ingram Yard and the Access Channel. LNG carriers will enter the Slip via the Access Channel, get loaded with LNG, and leave for export. The Slip will include an LNG carrier loading berth and LNG loading facilities, a tug berth, and an emergency lay berth to safely moor a temporarily disabled LNG carrier.
- Access channel – the Access Channel will be dredged north of the Federal Navigation Channel ("FNC") to provide LNG carriers with access from the FNC to the Slip.
- Material Offloading Facility ("MOF") – a permanent facility east of the Slip where fill will be placed to construct a barge berth. Dredging will occur to access the MOF.
- Navigation Reliability Improvements ("NRI") – four permanent dredge areas adjacent to the FNC that will allow for navigation efficiency and reliability for vessel transit under a broader weather window.

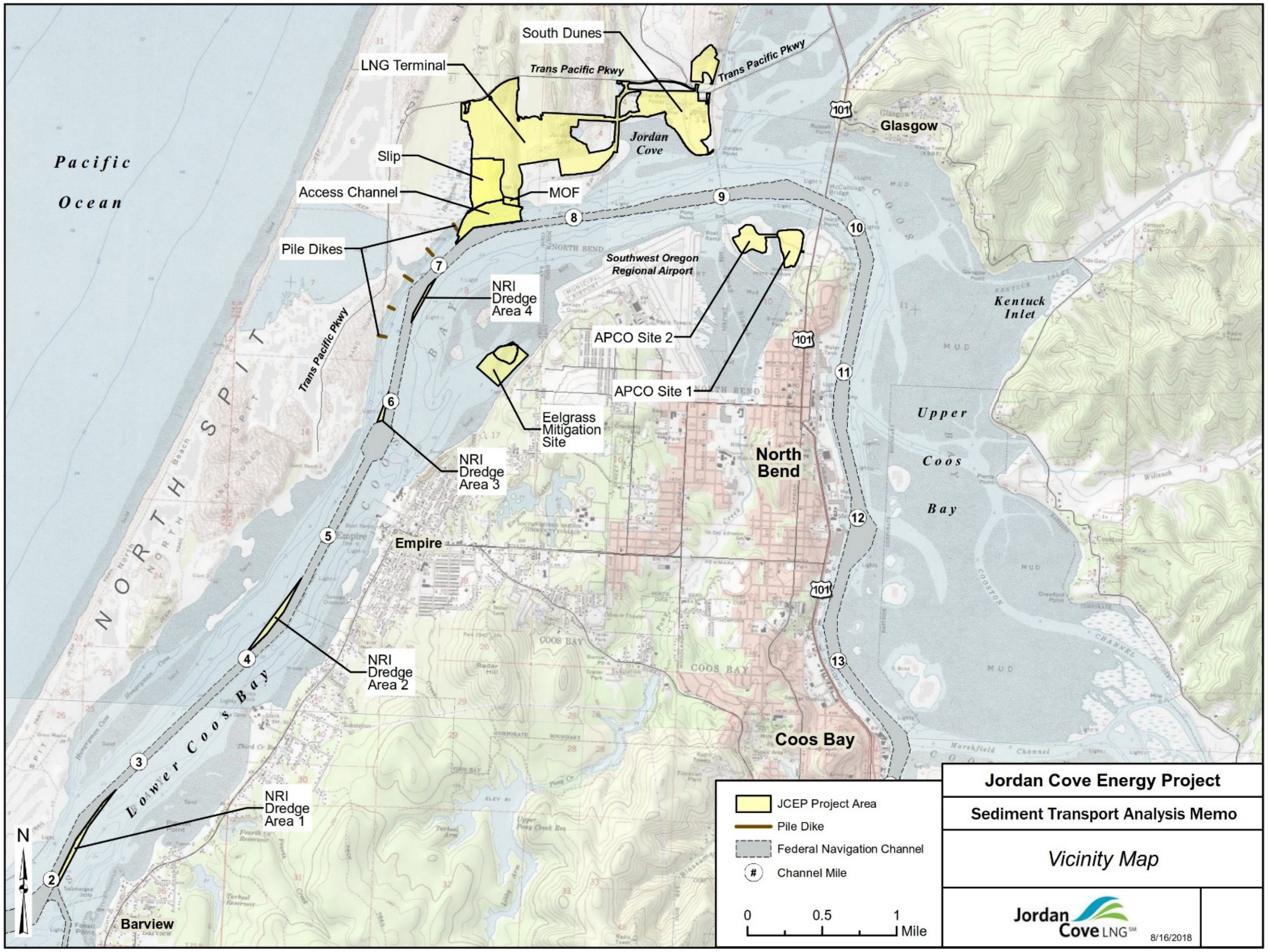

Figure 1-1. JCEP Project Area

In support of the permitting efforts for the JCEP, Moffatt & Nichol ("M&N") has prepared this technical memorandum to summarize the sediment transport analyses performed. The purposes of this study are to assess changes to existing sediment transport patterns due to the project, including the NRI, the Slip and Access Channel, the MOF, and the Eelgrass Mitigation site; to estimate shoaling and/or scour over the project areas and FNC; to assess any potential changes to the existing FNC; and to provide a basis for evaluating potential changes to the pile dikes.

The sediment transport analysis is part of the hydrodynamic studies package, and it is necessary to review this study along with other technical memorandums prepared for the project. Specifically, this study should be considered in parallel with the "Hydrodynamic Analysis Technical Memorandum" (M&N 2018).

Table 1-1 summarizes the two modeling scenarios evaluated, "Without-Project" and "With-Project", and the corresponding design features. The Without-Project scenario is based on the existing FNC with a channel depth of -38' MLLW (-37' navigation depth + 1' advance maintenance dredging). In areas which have historically maintained a depth below -38' MLLW, the existing bathymetry used in the Oregon International Port of Coos Bay's (OIPCB) Section 204(f) Channel Modification Project (OIPCB Project) modeling efforts (OIPCB 2017) was used. The With-Project scenario adopts the same FNC depths used in the Without-Project scenario, and adds the four NRI areas, the Slip and Access Channel, the MOF, and the Eelgrass Mitigation site. This approach allows the changes due to the JCEP to be evaluated.

All elevations in this document are referenced to MLLW tidal datum, unless otherwise noted. Additional details related to hydrodynamic modeling development, such as bathymetric sources and modeling grids, are provided in the "Hydrodynamic Analysis Technical Memorandum" (M&N 2018).

Table 1-1. Summary of Modeling Scenarios

Location	Without-Project	With-Project
Federal Navigation Channel Maintained Depth (ft, MLLW)	≤ -38.0	≤ -38.0*
NRI Dredged Depth (ft, MLLW)	Existing	-39.0
Access Channel Dredged Depth (ft, MLLW)	Existing	-46.7
Slip Dredged Depth (ft, MLLW)	N/A	-45.5
Side Slope for Sand Bottom (OIPCB 2017)	Existing	3H:1V (NRI 1-3) 4H:1V (NRI 4) 3H:1V (Slip & Access Channel)
Side Slope for Rock Bottom (OIPCB 2017)	Existing	1H:1V

* In this study, the water depth of 38 ft is a minimum depth in the FNC. The actual bathymetry used at the entrance and elsewhere is naturally deeper.

Construction side slopes for the Access Channel and NRI areas are used in the With-Project modeling scenario. These construction side slopes are stable against mass failure (sloughing) during and after construction. Stable construction side slopes are based on the analysis completed for the OIPCB Project (OIPCB 2017). Estimations of long-term equilibrated side slopes in non-rock (sand) material will vary. The majority of material to be removed for construction of the Access Channel, NRI 3 and NRI 4 is sand, portions of NRI 1 and NRI 2 are also composed of sandy material overlying rock. In these areas sand side slopes will equilibrate over time to a slope flatter than the initial construction slope. Estimations of long-term equilibrated side slopes in non-rock material can vary significantly. Based on analysis methodology followed on the OIPCB Project (OIPCB 2017b) the conservative long term equilibrated slopes may vary between approximately 5H:1V and 20H:1V

Estimated long-term equilibrated side slopes were not used in the With-Project scenario modeling. After the completion of initial construction dredging, side slopes will continue to evolve over a period of time (estimated 5 to 10 years depending on depth of dredge cut, slope material properties, hydraulic forces acting on slope, and other factors) until they reach a stable slope angle, after which sedimentation patterns may reach a quasi-equilibrium state. There is an inherent level of uncertainty in estimating the long-term equilibrium side slope configuration and the amount of time until long term equilibrium is reached. Construction side slopes were used in the sediment transport analysis to better show the potential changes in sedimentation patterns associated with the JCEP.

The material to be removed for construction of NRI 1 and NRI 2 is primarily rock; rock side slopes will not change from the 1H:1V initial construction slope, and no long-term adjustments for the equilibration process are warranted in these locations.

This revised technical memorandum includes results and analysis based on additional supplemental modeling completed to address issues and questions brought resulting from the U.S. Army Corps of Engineers (USACE), Northwest Division, Portland District (NWP) review of the 408 60% Design Package (Rev. A; JCLNG Document No. J1-000-MAR-TNT-DEA-00003-00). Modifications to the numeric model included matching the With-Project model generated bathymetric grid to the Without-Project model gridded bathymetry outside of the project areas. These corrections provide for a more representative/accurate comparison of results for sediment transport, particularly in the North Jetty Root/Log Spiral Bay and south of Pile Dike 7.3 areas.

2. SEDIMENT TRANSPORT MODELING

2.1 MODEL OVERVIEW

Sediment transport and deposition was modeled using the two-dimensional MIKE-21 Flexible Mesh (FM) model, with coupled hydrodynamic and sediment transport modules (DHI 2014). The sediment transport module considers the erosion, transport, and deposition of sediment due to currents and/or waves.

By coupling the hydrodynamic and sediment transport processes, the model calculates the depth-averaged flow velocity and the corresponding bed shear stress at every time step. The resultant bed shear stress is then internally compared with the critical shear stress, which is a function of the bottom material size. If the calculated bed shear stress exceeds the critical shear stress, the bottom material will be mobilized by the model, resulting in erosion.

Figure 2-1 shows the modeling domain used in both the hydrodynamic analysis and the sediment transport analysis. The model domain included the entire estuary and was not limited to the JCEP areas. A complete discussion of the model domain, modeling grid, and bathymetric sources is provided in the "Hydrodynamic Analysis Technical Memorandum" (M&N 2018).

Strongest ebb currents in the Coos Bay estuary typically occur in winter (Dec to April) because of strong freshwater inflows. Daily freshwater discharge for Coos River for water years (WYs) 2007 to 2012 is shown in Figure 2-2. This figure shows that largest variations (spikes) of freshwater inflow occur in winter as well. To capture the strongest currents and largest variations in freshwater inflow, the modeling period for production runs was selected to be a typical three-month winter tide cycle (January 1, 2011 through March 31, 2011). The year 2011 was selected for production runs because it represented a typical water year, as shown in Figure 2-2. This same period was evaluated by the OIPCB Project (OIPCB 2017) for calibrating their sediment transport model.

The sediment transport model includes a morphological speed-up/repetition factor of 4 for 1-year analysis or 12 for 3-year analysis so that this three-month representative tidal cycle can be repeated to provide a full year or three years of sedimentation, respectively.

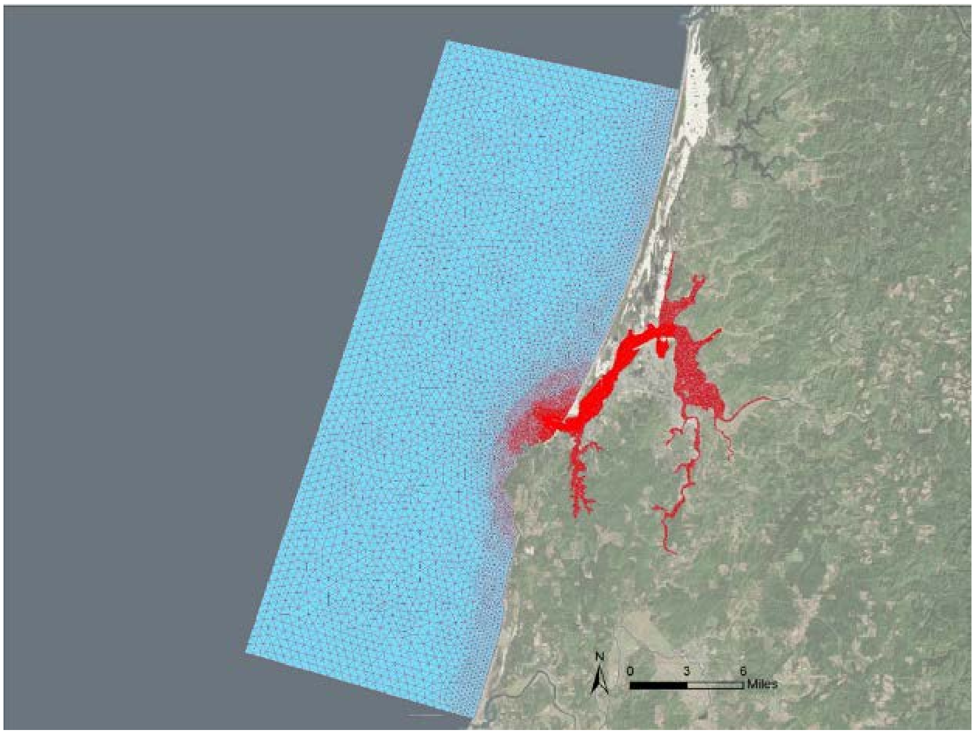

Figure 2-1. Modeling Domain and Elements with Varying Resolution

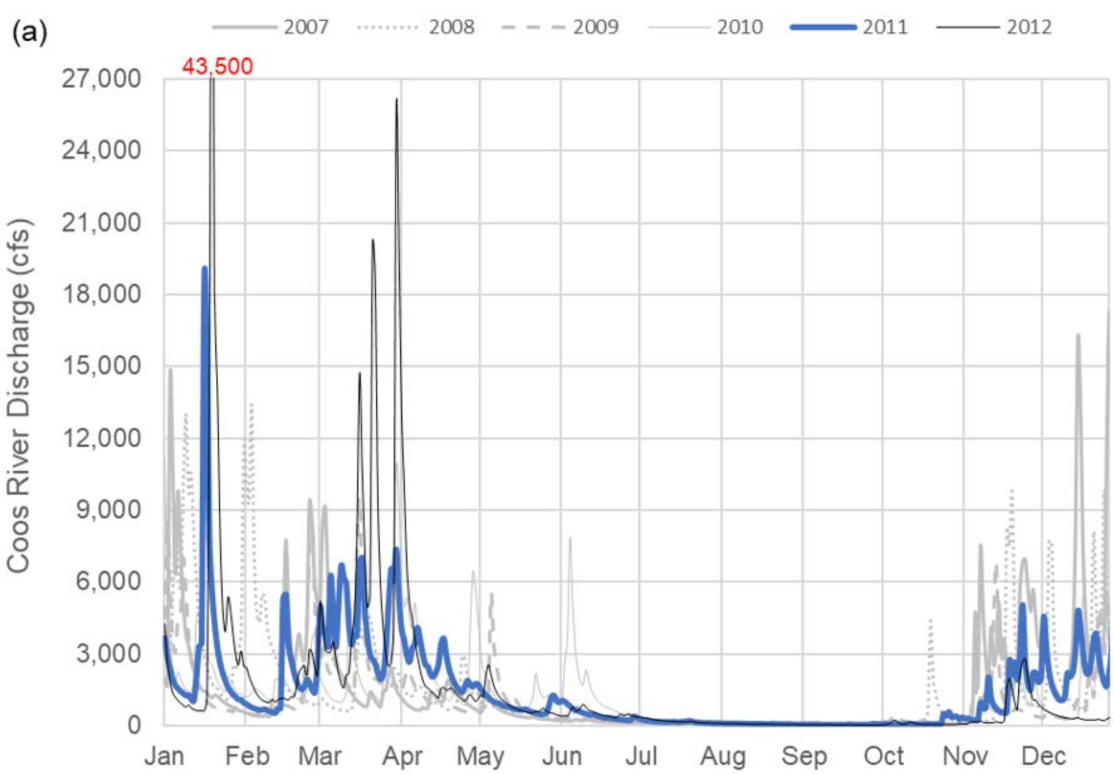

Figure 2-2. Coos River Discharge for Water Years (WYs) 2007 to 2012. WY 2011 is Highlighted.

2.2 MODEL SETUP

2.2.1 MAINTENANCE DREDGING SINCE 1998

Sediment dredged from the FNC, in the area below river mile ("RM") 12, is typically classified by grain size as either silt or sand. Finer sediments originating from the Coos River and other tributaries typically settle out above RM 12 (USACE/USEPA 1986). Therefore, sediment loading from freshwater runoff is not included.

Table 2-1 provides the maintenance dredging quantities of sediment for the federally maintained channel between RM 2.5 and RM 12 from 1998 to 2014 (OIPCB 2017). This table displays the full period since the most recent channel deepening project, which occurred in fiscal year 1996. Figure 2-3 shows the location of each channel range.

Table 2-1. Coos Bay Channel Quantity Dredged in Cubic Yards between RM 2.5 and RM 12

Year	Coos Bay & Empire Ranges RM 2.5 to 6.0	Jarvis Ranges RM 6.0 to 9.0	North Bend Ranges RM 9.0 to 12.0
1998[1]	0	48,911	0
1999	36,138	79,819	95,566
2000	61,923	83,335	31,093
2001	0	128,662	19,141
2002	0	52,764	1,017
2003	28,954	44,075	0
2004	5,718	46,184	44,350
2005	0	23,181	30,435
2006	33,790	34,706	3,953
2007	35,162	81,063	49,655
2008	5,082	59,686	54,584
2009	62,507	44,681	15,226
2010	16,126	69,217	4,080
2011[2]		223,148	
2012		105,495	
2013		269,078	
2014		37,907	
Average[3]	22,000	61,000	29,000

Notes:
1. Data compiled from dredging records provided by the USACE, Portland District.
2. Data provided by the USACE, Portland District, Field Office, not including a breakdown by range. The total quantity includes the amount dredged in the Charleston Channel.
3. Averages above the Entrance Range are based on 1998 to 2010 with minor modifications to match the overall average for the period 1998 to 2014. Values are rounded to the nearest thousands.

2.2.2 GRAIN SIZE MEASUREMENTS

Information regarding sediment grain size within the Coos Bay estuary is available from three sources: USACE 2005 (USACE 2005), SHN Consulting Engineers & Geologists 2007 (SHN 2007), and Geotechnical Resources, Inc. 2011 (GRI 2011). Figure 2-4 shows that the measurements exhibit a mixture of larger grain sizes in the channel, and smaller grain sizes that may be in the channel or in shallow water areas. The larger grain sizes, assumed to reflect channel bottom conditions, vary between 0.30 and 0.44 mm from the entrance to RM 9, and decrease to around 0.2 – 0.25 mm between RM 10 and RM 11. The southern part of the Upper Bay, above RM 12, is characterized by much finer sediments with a typical grain size of 0.04 mm. Near the airport runway, sand samples show a grain size between 0.25 and 0.28 mm. The measurements show variation throughout the channel, including in the FNC. Based on the above information, Figure 2-5 shows the grain size map used for sediment transport modeling. Consistent with the data, the map assumes a grain size of 0.33 mm in a majority of the channel area from the entrance to RM 9. Along the sides in the Coos Bay and Empire Ranges, the same trend observed near the airport runway was extrapolated to reduce grain size to between 0.25 and 0.28 mm. A linear interpolation was used between grain size 0.25 mm near RM 10 to 0.18 mm above RM 12.

2.2.3 GEOPHYSICAL INVESTIGATIONS

Shallow rock underlies much of the FNC, from the entrance to approximately RM 6. When this underlying rock is close to the surface, it limits the potential for erosion. These geophysical investigations were primarily based on the depth to the rock layer compiled by DEA in 2017 (OIPCB 2017) within and close to the FNC. Outside the FNC, areas of shallow rock were estimated based on bathymetric features. Shallow rock was also included – that is, the sand layer was assumed to be thin – along hardened reaches of the shoreline at Roseburg Forest Products, part of the airport runway, and the shoreline close to the FNC in the North Bend Ranges.

In addition, the remaining visible piles within the pile dike structures were modeled as individual piles to capture the changes in flow resistance in the water column imposed by the pile dikes as the flow changes. The remaining identifiable rock features in the area of the pile dikes are designated as nonerodable surfaces in the model. Figure 2-3 indicates the location of pile dike structures and rock aprons.

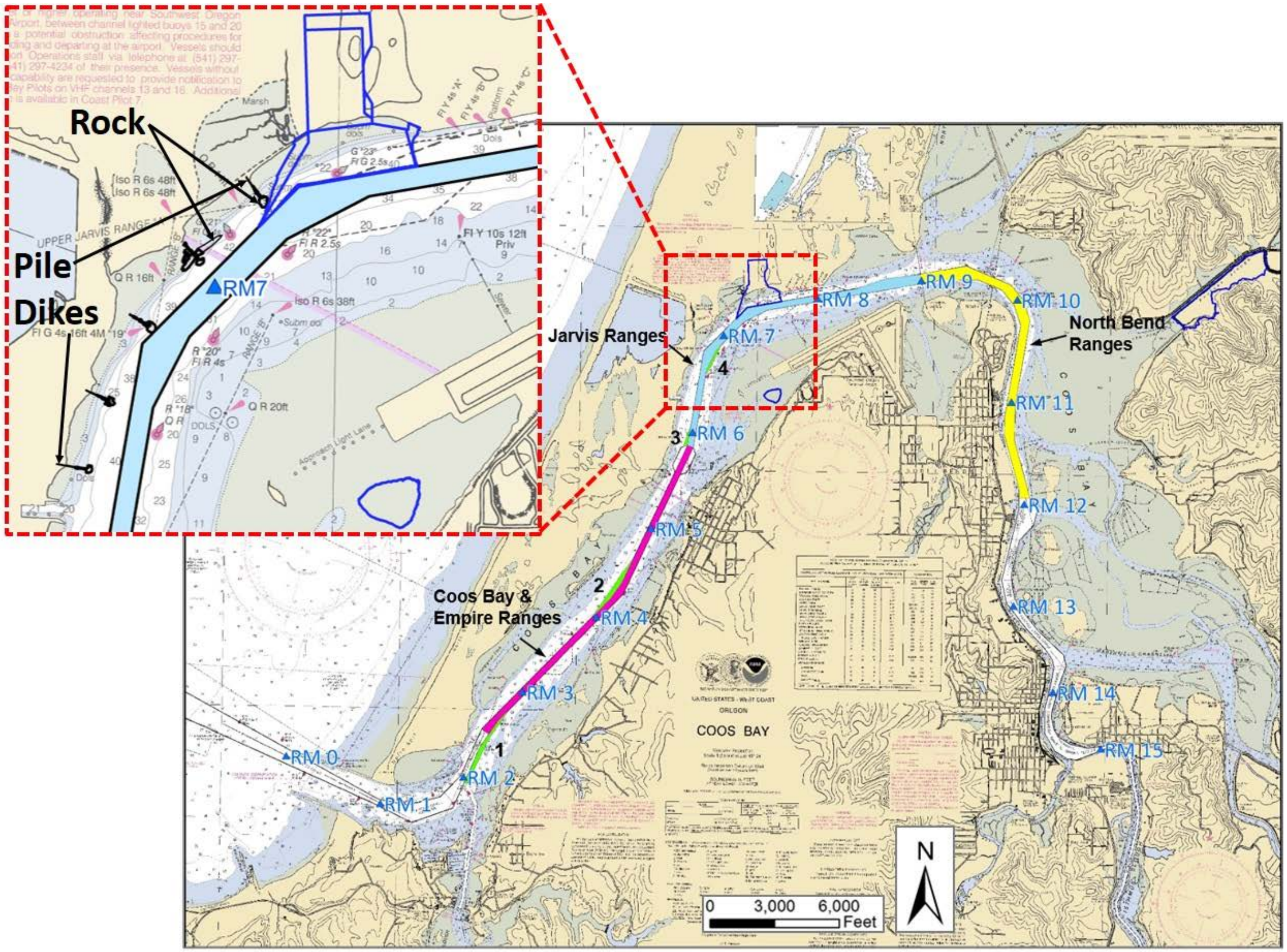

Image source: NOAA Nautical Chart, 18587 Coos Bay

Figure 2-3. Base Map Showing Channel Ranges Used in Shoaling Volume Calibration

Jordan Cove LNG	Hydrodynamic Studies – Sediment Transport Analysis		moffatt & nichol
	Document Number: J1-000-MAR-TNT-DEA-00003-00		
	Rev.: 0	Rev. Date: September 19, 2018	

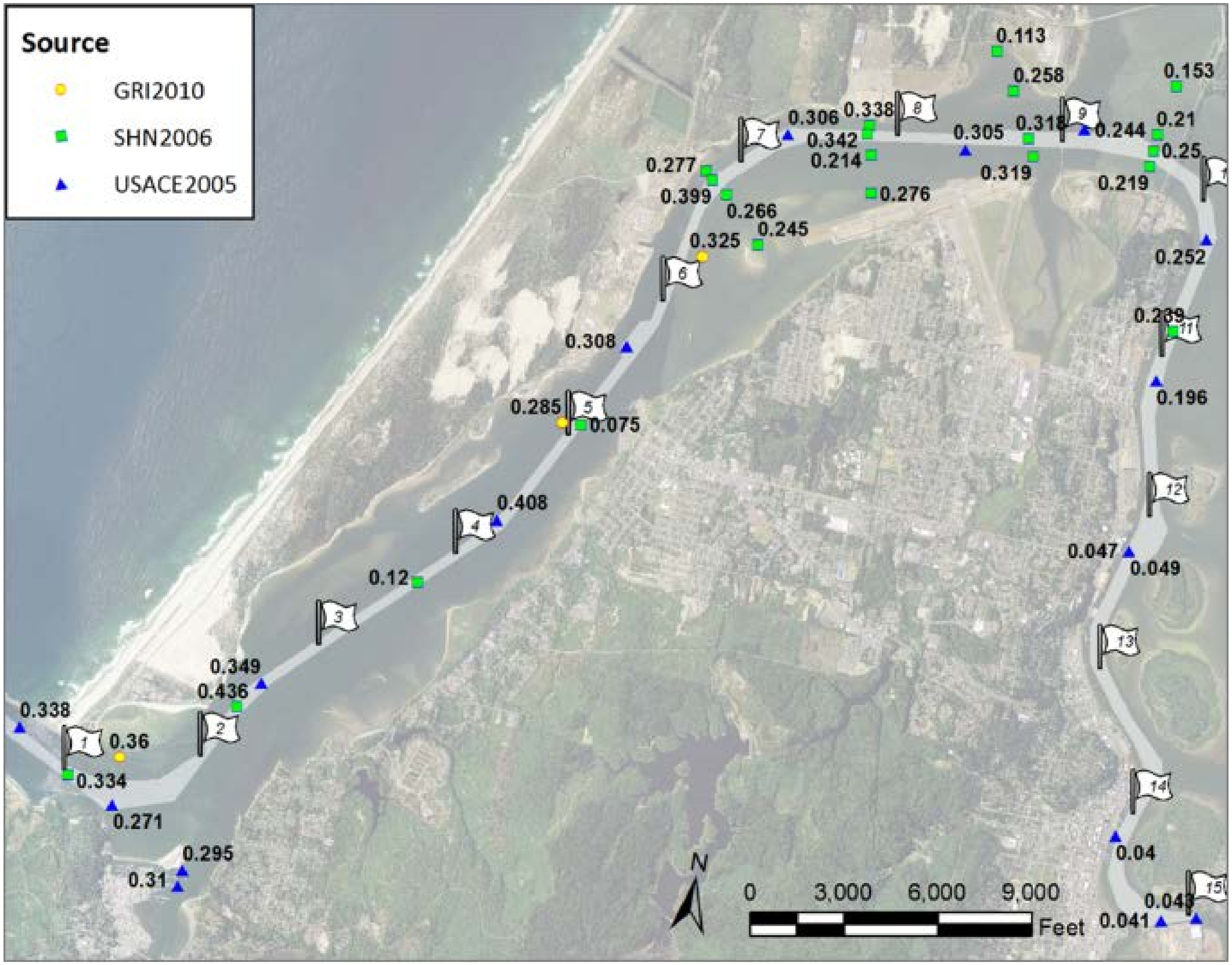

Figure 2-4. Measured Grain Size Map in millimeters

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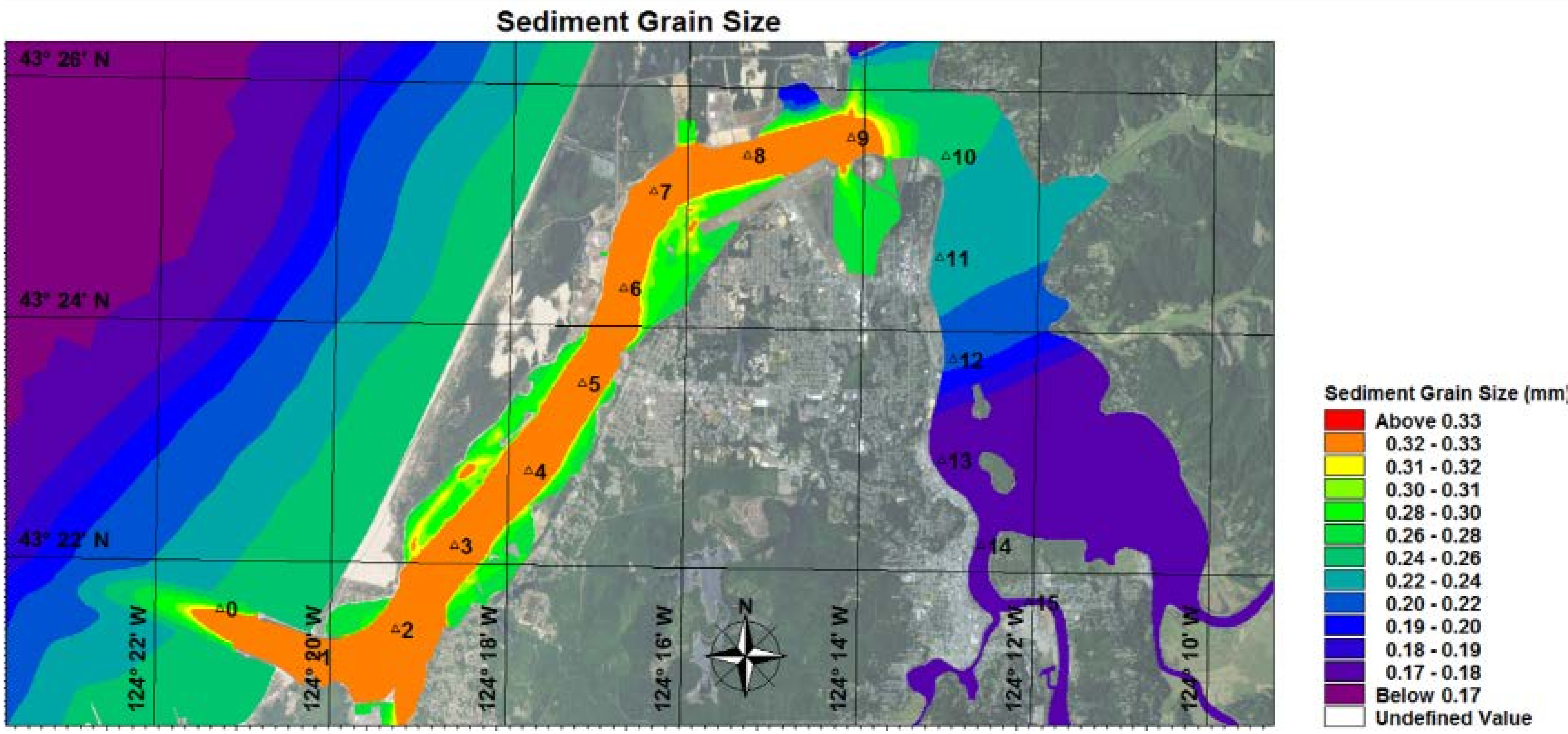

Figure 2-5. Simulated Grain Size Map in millimeters

2.2.4 INPUT PARAMETERS

Table 2-2 lists the primary input parameters used in the sediment transport module. These input parameters were adjusted during model refinement and calibration (described in Section 2.3).

Table 2-2. Input Parameters for Sediment Transport Module

Parameter	Value	Comments
Bedload Formula Suspended Load Formula	Van Rijn	Selected from four formulae available: Engelund & Fredsøe Engelund & Hansen Van Rijn Meyer-Peter and Müller
Bedload to Suspended Load Ratio	1 : 1.7	Relatively large suspended load fraction. Any ratio from entirely bedload to entirely suspended load is possible.
Model description	Non-Equilibrium	Uses advection-dispersion module to track suspended load
Porosity	0.4	Default value
Relative Sediment Density	2.65	Default value
Scaling Factor for Eddy Viscosity	1.0	Default value: dispersion follows hydrodynamic model
Bed Resistance	Manning's n = 0.025	Selected from four bed resistance available: Chezy number Manning's n Alluvial resistance Resistance from Hydrodynamic simulation

2.3 MODEL REFINEMENT AND CALIBRATION

The calibration for sediment transport modeling was based on the existing condition bathymetry (OIPCB 2017) and the annual average quantity of maintenance dredging since 1998 (Table 2-1).

Over an extended period of time, dredging records corroborate the average annual sedimentation rate reasonably well. Although the magnitude and frequency of dredging is dependent on budget and equipment capability on an annual basis, the amount of material removed depends on the sedimentation amounts and is limited by the authorized depths. The cumulative volume removed by dredging activities was deposited over the time between consecutive dredging events, and a deposition rate can be derived from this information. The uncertainty in this method is the exact surface area being dredged, however, the surface area is limited by the authorized dimensions. Therefore, over multiple dredging cycles, all deposited material within critical areas of the channel would be removed.

The approach of using average sedimentation rates over larger areas was selected to calibrate the model because numerical sediment transport models may have difficulty capturing bed level changes accurately in specific areas, such as channel turns and scour areas.

The four sediment theories presently available in the MIKE-21 sediment transport model are listed in Table 2-2. During model calibration, three out of the four were tested. Both the “Engelund & Fredsoe” and the “Engelund & Hansen” theory predict a higher shoaling rate in the Coos & Empire Ranges than the Jarvis Ranges, which is the reverse from the trend observed in the dredging records. Only the “Van Rijn” theory predicts the same trend, leading to the decision to base the analysis on the results predicted by the “Van Rijn” theory.

Using the “Van Rijn” theory, a series of bed load and suspended load combinations was tested during model calibration. The larger the bed load or suspended load, the greater the shoaling rate. The present load combination of 0.1/0.17 was found to best match the dredging records, and this specified load combination was based on model calibration.

Nominal porosity and relative sand density were considered. In this model, sand transport is primarily advective, while diffusive processes (usually not resolved in the model) are of less importance. It was noted that the model has a higher numerical diffusion compared to other similar models, which makes adjustments in diffusivity parameters less impactful.

In the coupled model setup, the hydrodynamic model and sediment transport models use different roughness parameters due to the nature of the numerical solutions. In the hydrodynamic model the roughness represents “apparent” roughness (which represent sediment characteristics, bedforms, and bed content). In the sediment transport model, roughness is used to compute bed shear stresses on the sediment particles only. Therefore, a single roughness value cannot satisfy both hydrodynamic and sediment transport solutions. The applied bed resistance of Manning’s n equal to 0.025 was refined during the model calibration.

Table 2-3 and Figure 2-6 show that the model satisfactorily predicts the annual dredging volumes between RM 2.5 and RM 12.

Table 2-3. Calibration of Annual Shoaling Volume

Location	Average Dredge Volume, CY/year	Simulated Volume, CY/year	Ratio simulated / actual volume
Coos Bay & Empire Ranges	22,000	18,000	0.8
Jarvis Ranges	61,000	61,000	1.0
North Bend Ranges	29,000	30,000	1.0
Total	**112,000**	**109,000**	**1.0**

The modeling result for the existing condition shows sand waves between RM 6 and RM 10, and not much sedimentation beyond RM 11 (Figure 2-7). This is consistent with general USACE observations of sand waves between RM 6 and 7 and not much sedimentation beyond RM 11.

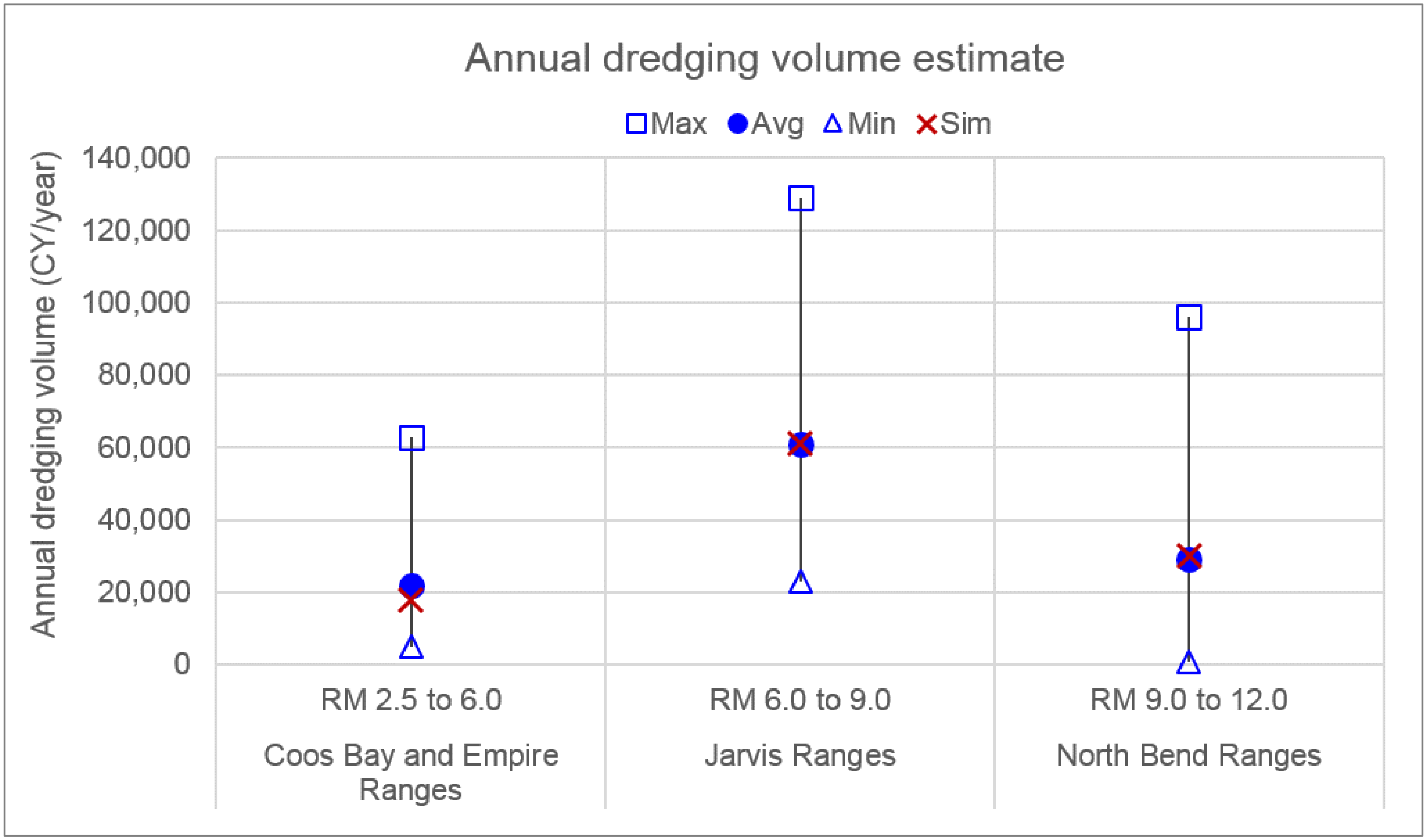

Figure 2-6. Calibration of Annual Shoaling Volume (Dredging Records vs. Simulation)

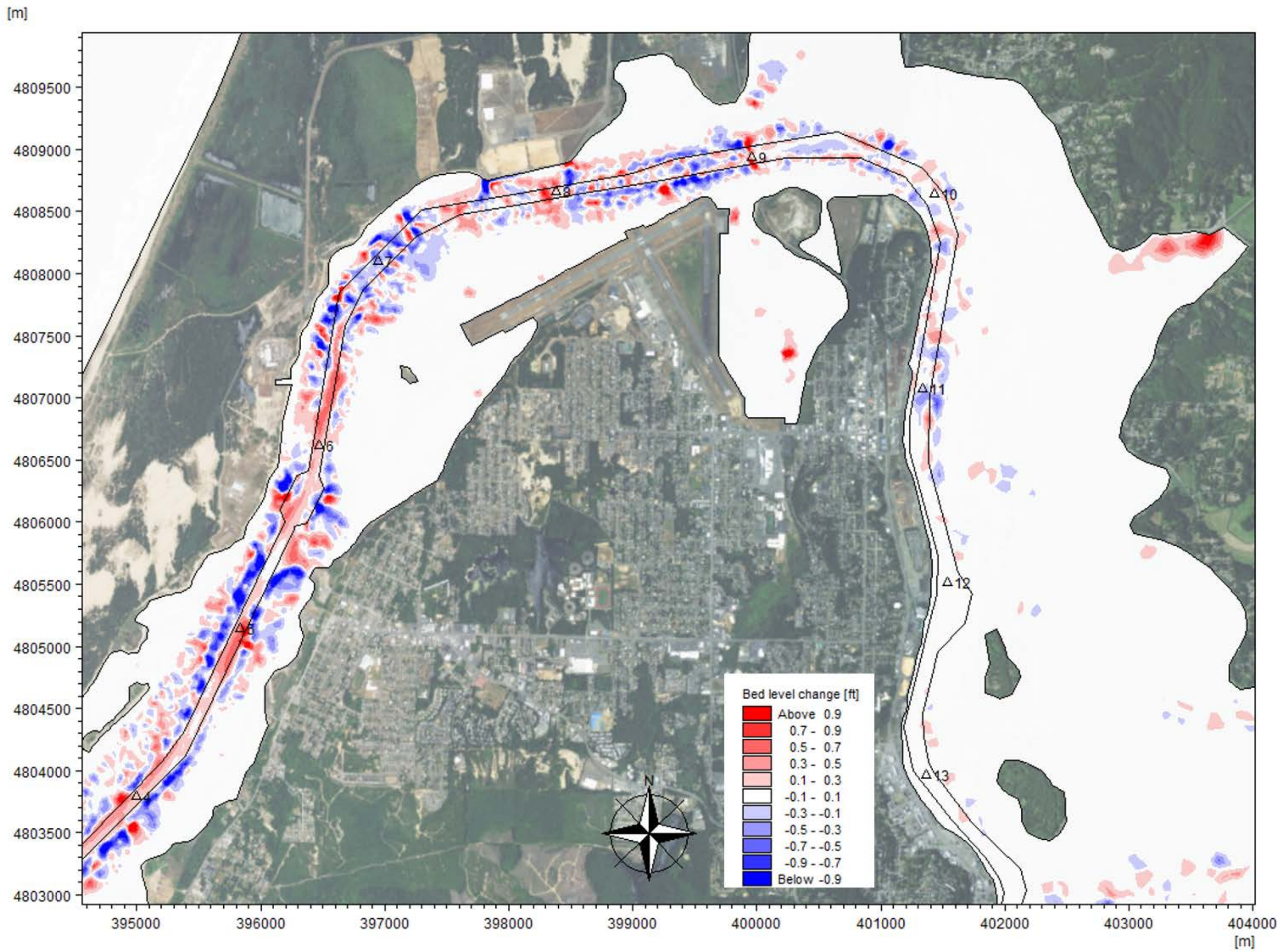

Figure 2-7. Model Result for the Existing Condition; Red – Shoaling, Blue - Erosion (OIPCB 2017)

2.4 MODELING RESULTS

Model results in terms of shoaling rates for "Without-Project" and "With-Project" scenarios were obtained. Comparison of the two scenarios provides an indication of the potential for changes in sedimentation rates resulting from the proposed JCEP Project.

2.4.1 CHANGES TO FEDERAL NAVIGATION CHANNEL

Table 2-4 compares the average shoaling rates at the same three channel ranges inside the FNC (see Figure 2-3) for a one-year and a three-year simulation of sediment transport for With Project and Without Project Conditions. Model results indicate that the average shoaling inside the FNC is not expected to change as a result of the proposed modifications.

Table 2-4. Comparison of Shoaling Rates Inside the Federal Navigation Channel

Location	Average Shoaling After One Year (ft)		Average Shoaling After Three Years (ft)	
	Without-Project	With-Project	Without-Project	With-Project
Coos Bay & Empire Ranges	0.1	0.1	0.2	0.2
Jarvis Ranges	0.3	0.3	0.7	0.7
North Bend Ranges	0.2	0.2	0.4	0.4

Figure 2-8 and Figure 2-12 presents the difference of bed level changes after one year and three years, respectively, between Without-Project and With-Project scenarios. Figure 2-9 through Figure 2-11, and Figure 2-13 through Figure 2-15 provide greater detail of the differences in bed level changes in the Lower Estuary, the Coos and Empire Ranges, and the Jarvis Ranges. Since the JCEP Project areas are dredged in the With-Project scenario, the areas beyond the FNC are removed by shading to avoid distraction from the assessment of changes inside the FNC.

From the results of the one-year run, most of the non-project area shows bed level changes less than 0.2 feet due to the JCEP Project. Some more noticeable changes of up to 1.2 ft in erosion were predicted locally near the intersection of the FNC with the Access Channel, near Pile Dike 7.3, and at the southern end of NRI 3 and NRI 4. Localized shoaling up to 0.4 ft in the FNC adjacent to the Access Channel are in a naturally deep section of the channel. It is noted that the study focuses on the differential sediment transport trend(s) observed in the modeling results, rather than the absolute values predicted by the model. Similar but somewhat greater changes in value and/or extents can be seen in the results of the three-year simulation comparison.

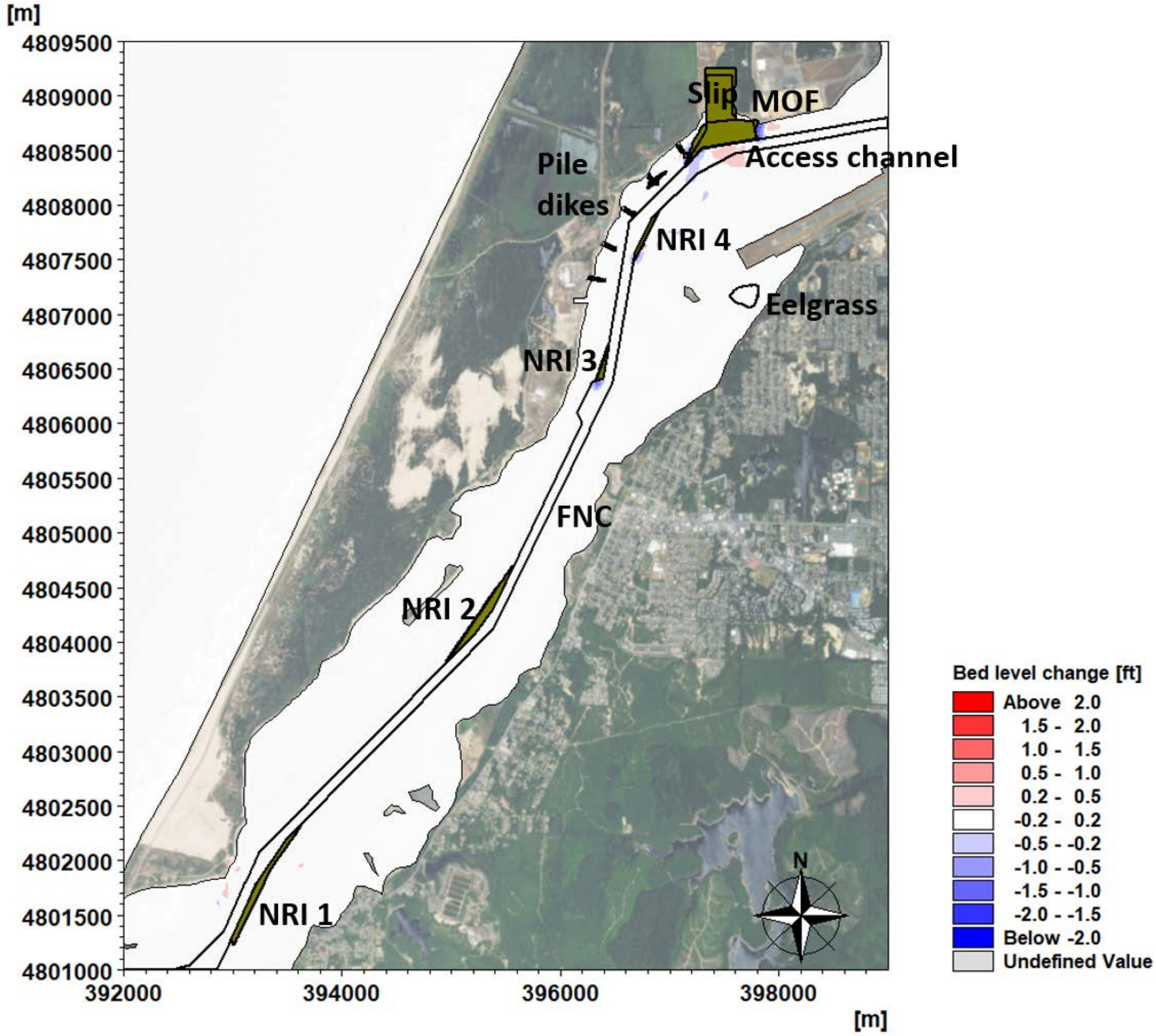

Figure 2-8. Difference of Bed Level Changes after One Year, Without-Project vs. With-Project Scenario; Red – Shoaling, Blue - Erosion

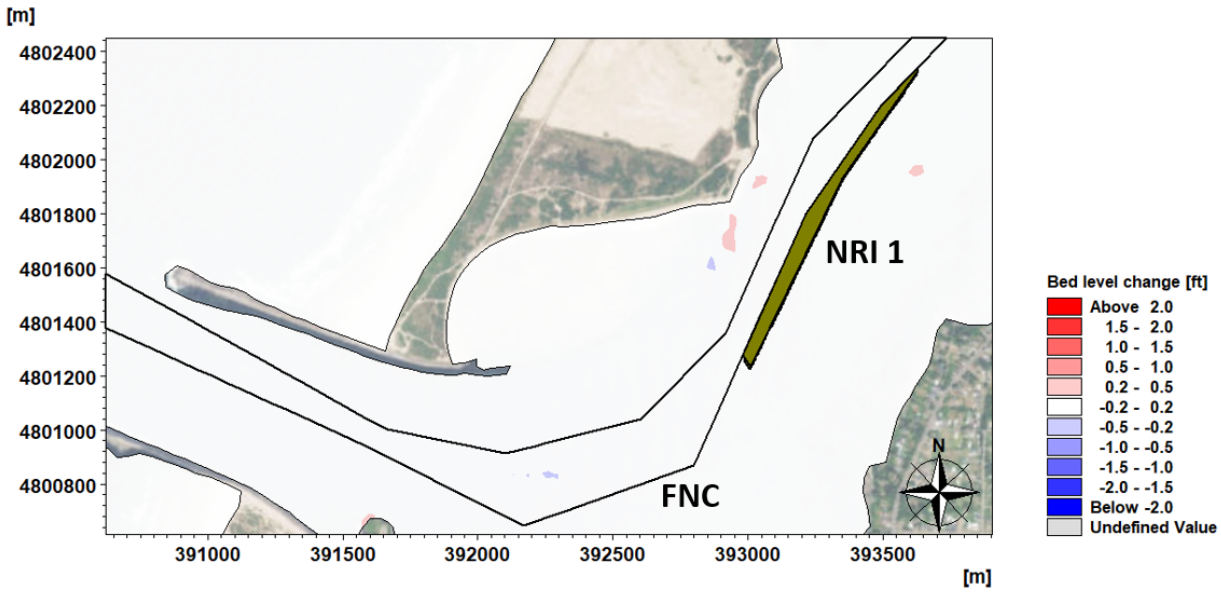

Figure 2-9. Difference of Bed Level Changes after One Year at the Lower Coos Bay Estuary, Without-Project vs. With-Project; Red – Shoaling, Blue - Erosion

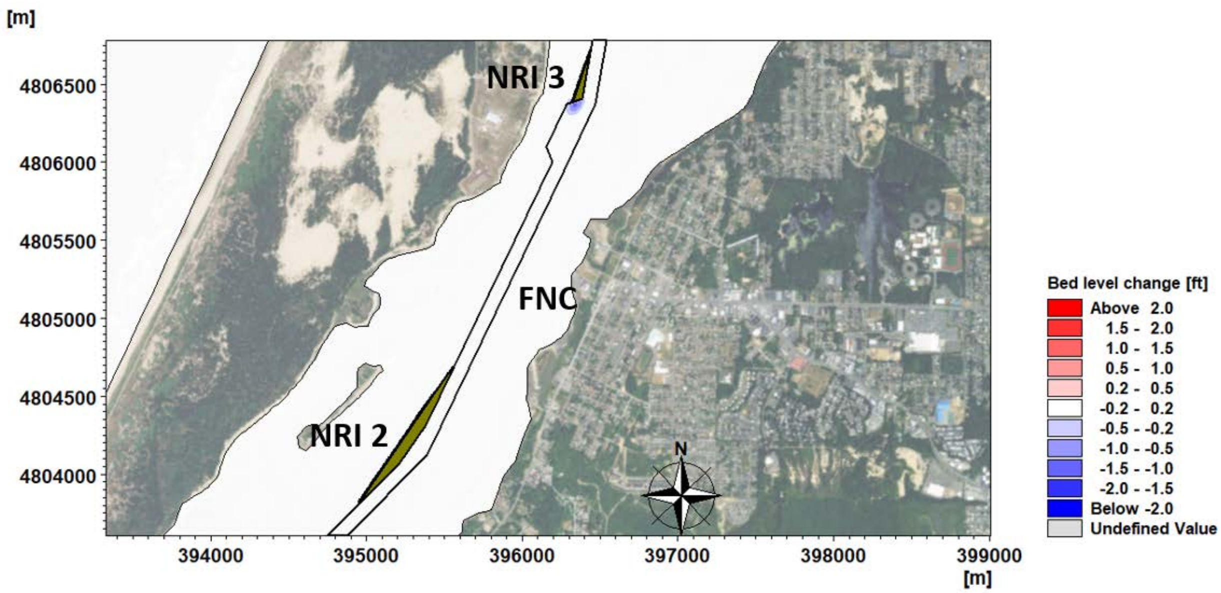

Figure 2-10. Difference of Bed Level Changes after One Year at the Coos & Empire Ranges, Without-Project vs. With-Project; Red – Shoaling, Blue - Erosion

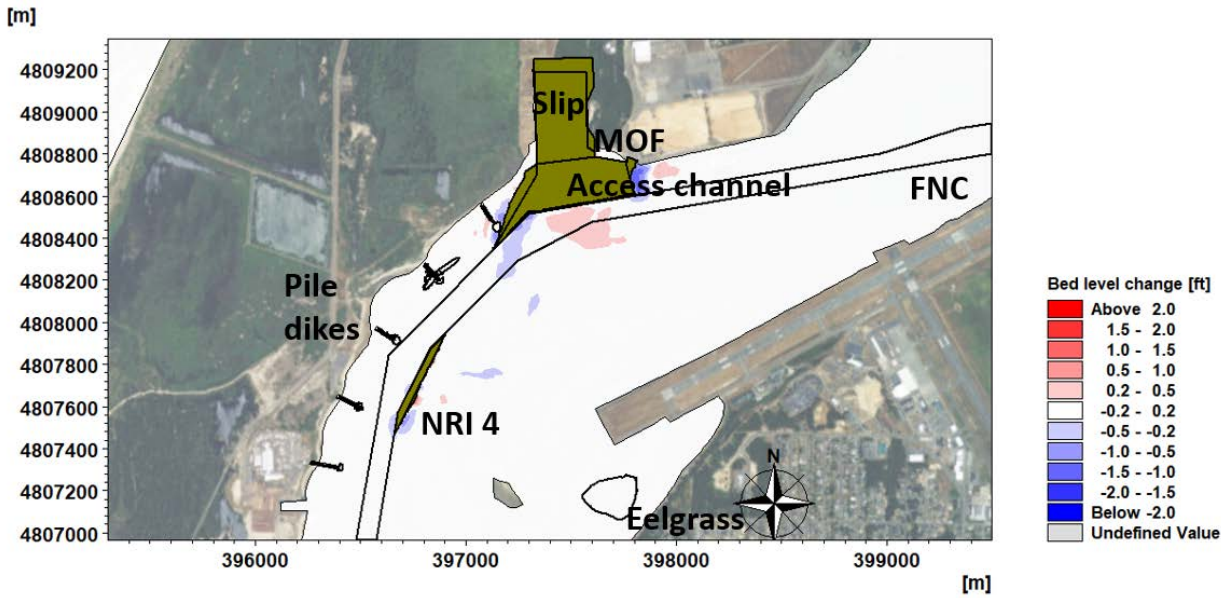

Figure 2-11. Difference of Bed Level Changes after One Year at the Jarvis Ranges, Without-Project vs. With-Project; Red – Shoaling, Blue - Erosion

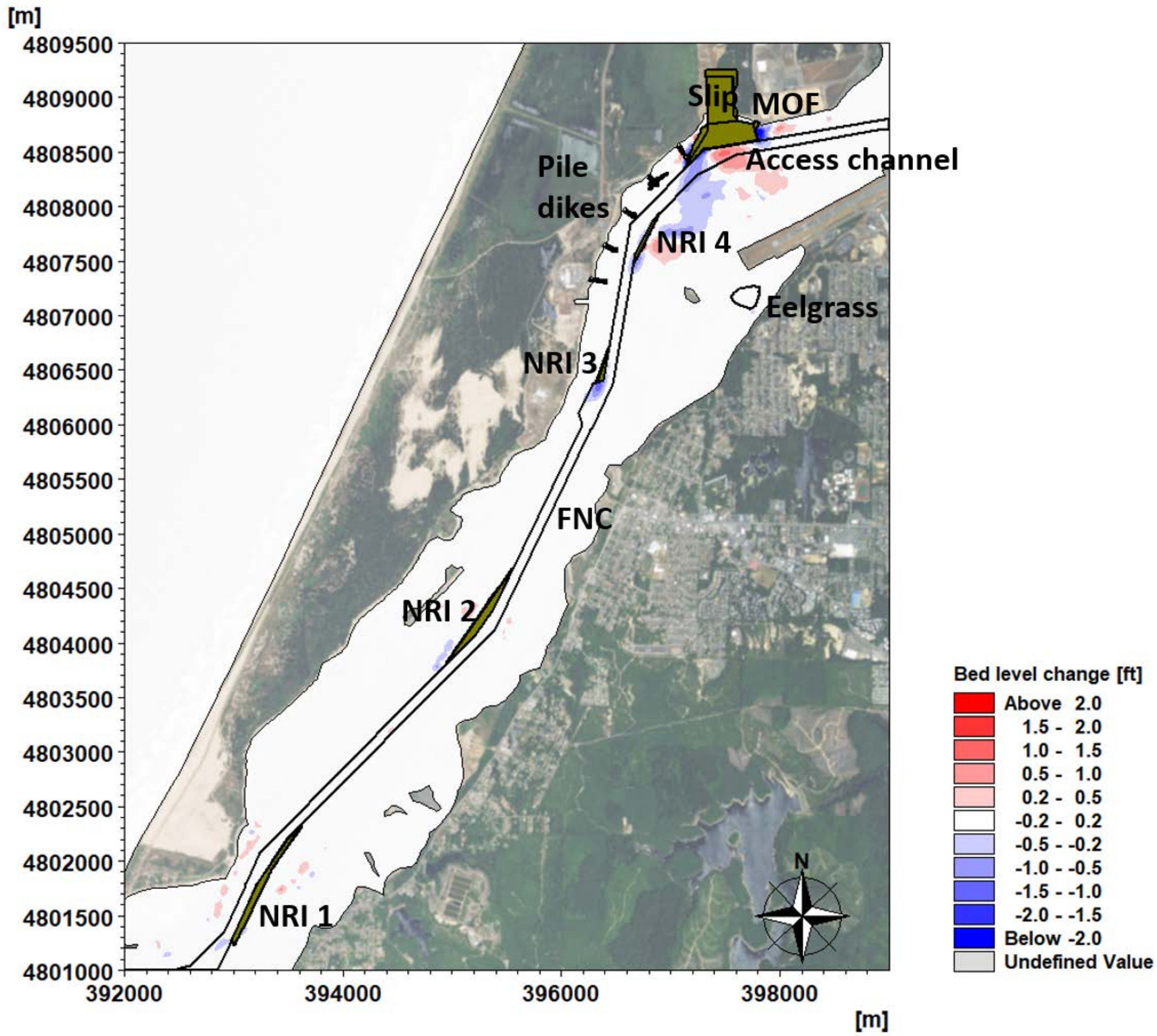

Figure 2-12. Difference of Bed Level Changes after Three Years, Without-Project vs. With-Project Scenario; Red – Shoaling, Blue - Erosion

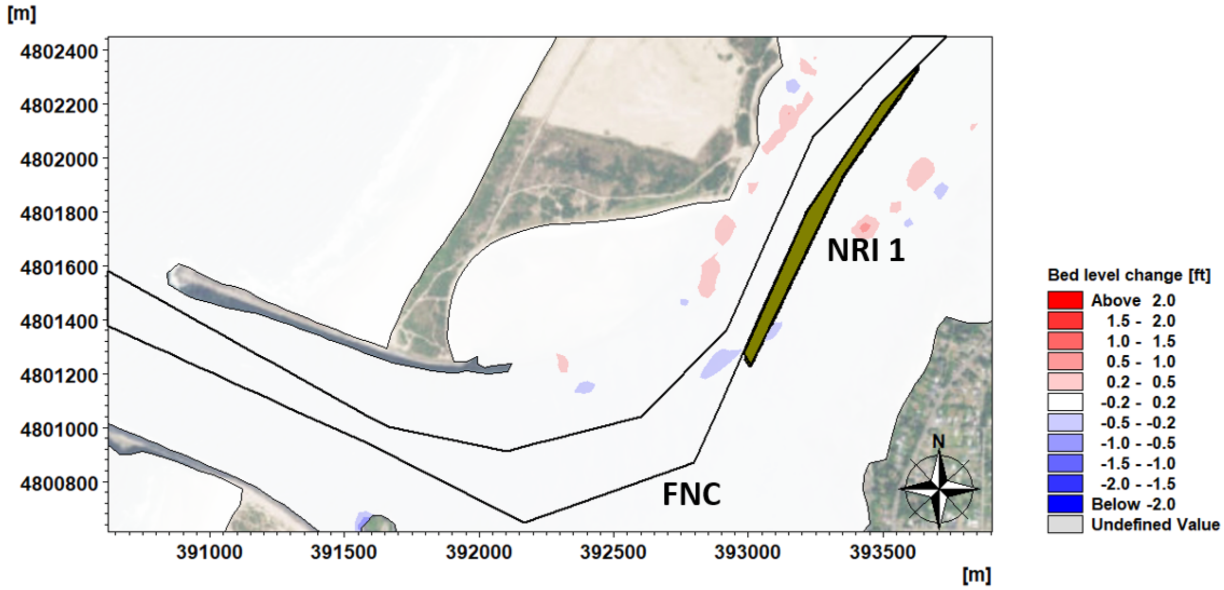

Figure 2-13. Difference of Bed Level Changes after Three Years at the Lower Coos Bay Estuary, Without-Project vs. With-Project; Red – Shoaling, Blue - Erosion

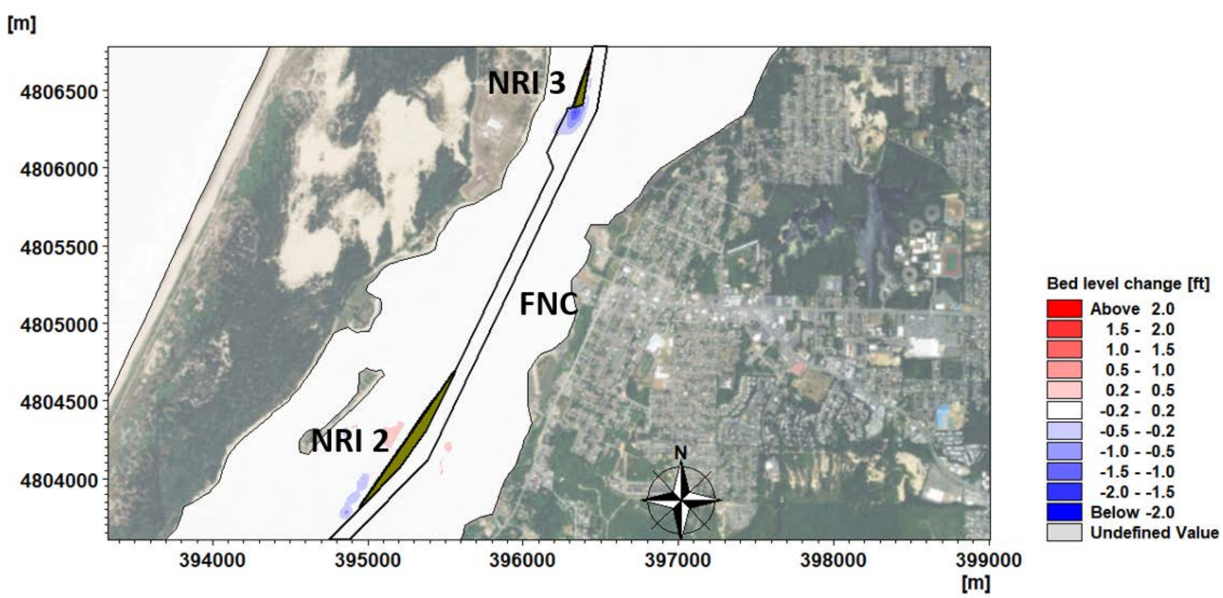

Figure 2-14. Difference of Bed Level Changes after Three Years at the Coos & Empire Ranges, Without-Project vs. With-Project; Red – Shoaling, Blue - Erosion

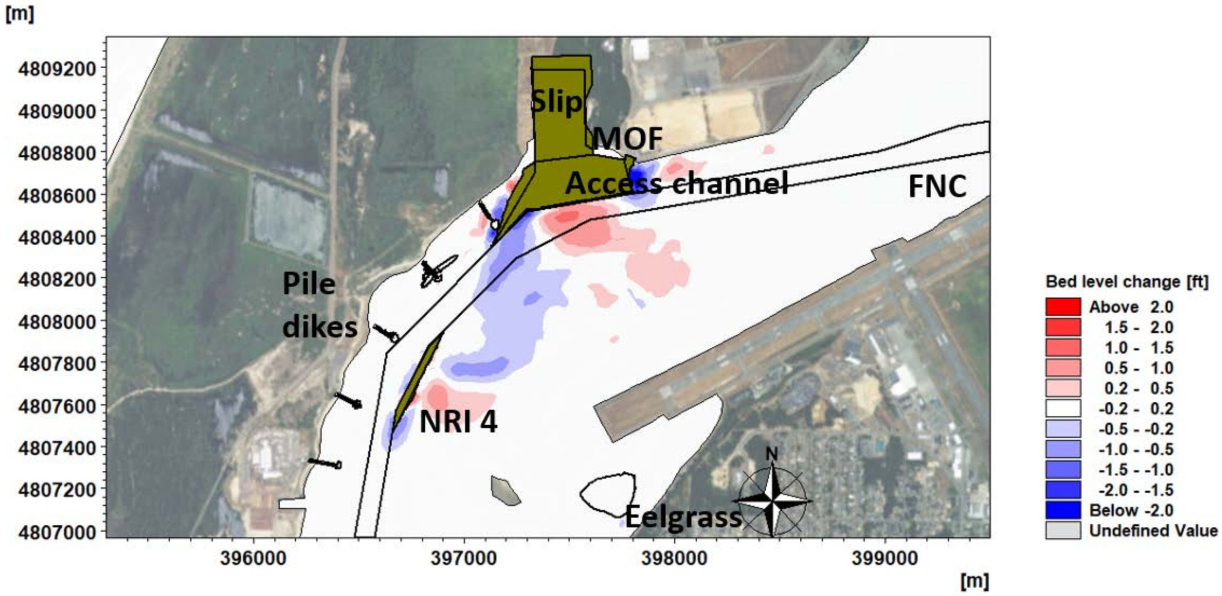

Figure 2-15. Difference of Bed Level Changes after Three Years at the Jarvis Ranges, Without-Project vs. With-Project; Red – Shoaling, Blue - Erosion

Figure 2-15 shows that the model predicts localized comparative erosion of 1.8 feet near the side slope of the Access Channel after three years. This is due to the construction of the Access Channel resulting in larger re-directed currents flowing through this area and re-joining the FNC at the southwest corner of the Access Channel and flow over and/or along the Access Channel dredge slope. The model indicates up to 2 feet of comparative erosion near the offshore end of Pile Dike 7.3. This area will be further analyzed to determine potential effects to Pile Dike 7.3 with results presented in a separate technical memorandum.

The model also predicts some localized shoaling of up to 1.1 feet in the FNC directly adjacent to the Access Channel after 3 years. This potential shoaling is in a historically naturally deep section of the channel where water depths generally range from approximately -39 to -41 feet MLLW and maintenance dredging has not typically been required. Actual sedimentation in this historically naturally deep area will be monitored by hydrographic survey in conjunction with monitoring surveys of the Slip, Access Channel, and NRI areas by the JCEP. Should sedimentation in this area over time result in conditions requiring maintenance dredging, maintenance dredging would be executed by the JCEP in conjunction with maintenance dredging of the NRI areas and access channel.

Figure 2-11 shows the model predicts the same general areas/patterns of erosion and deposition but to a lesser extent after 1 year.

2.4.2 SHOALING ESTIMATES AT THE PROJECT AREAS

Table 2-5 provides the average and maximum shoaling rates after one year and three years for the JCEP Project areas. Figure 2-14 through Figure 2-18 illustrate the results for each project area after one year. Figure 2-19 through Figure 2-23 illustrate the results for each project area after three years. All project areas, except NRI 4, experience a general trend of shoaling. The averaged shoaling of the three-year runs are not a multiple of the shoaling of the one-year runs because the hydraulic gradients, which drive sediment movements, change over time until a dynamic equilibrium state is reached.

Table 2-5. Shoaling Rates for the JCEP Project Areas

Location	RM	Shoaling After One Year (ft)		Shoaling After Three Years (ft)	
		Avg.	Max.	Avg.	Max.
NRI 1	2.0 - 2.5	< 0.1	0.1	0.2	0.4
NRI 2	4.0 - 4.5	0.2	0.6	0.7	1.6
NRI 3	6.0	0.6	1.1	1.5	2.5
NRI 4	6.5	0.2	1.2	0.4	1.3
Access Channel & MOF	7.5	0.1	1.2	0.3	1.5
JCEP Slip	7.5	< 0.1	0.6	< 0.1	0.8

A previous sedimentation analysis completed by Coast & Harbor Engineering (CHE 2011) indicated an annual sedimentation rate of approximately 0.2 ft. in the Slip, and 0.6 ft. in the Access Channel. These sedimentation values are of the same order of magnitude as those predicted by this analysis.

Figure 2-20 and Figure 2-25 indicate localized deposition in front of the MOF, localized erosion at the eastern side of the Slip, erosion of the design slope east of the MOF, and some localized erosion along the southwest side of the Access Channel.

The simulation results also show there are no noticeable sedimentation changes anticipated at the Eelgrass Mitigation site as a result of the proposed improvements.

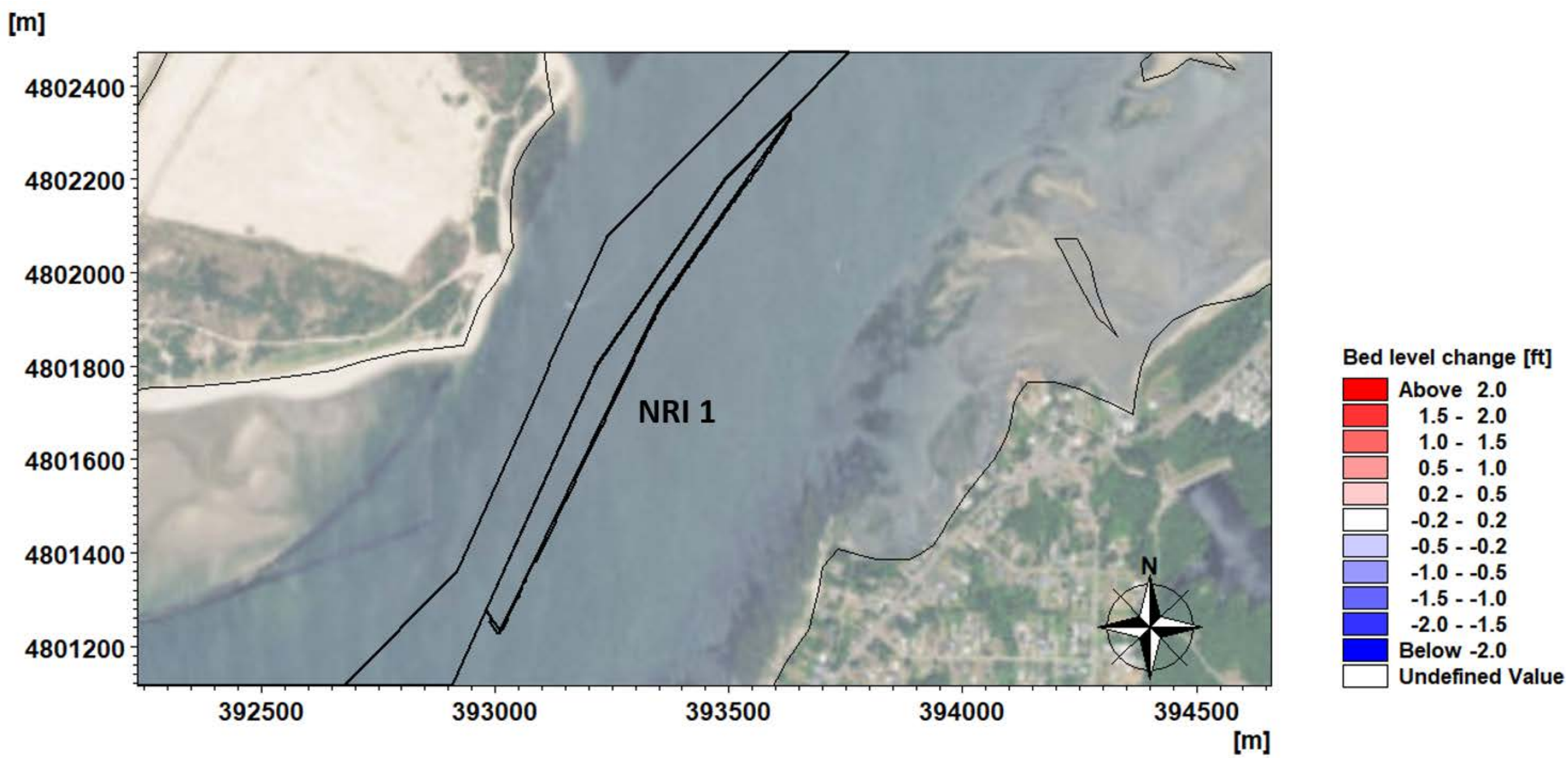

Figure 2-16. Bed Level Changes at NRI 1 after One Year for With-Project; Red – Shoaling, Blue - Erosion

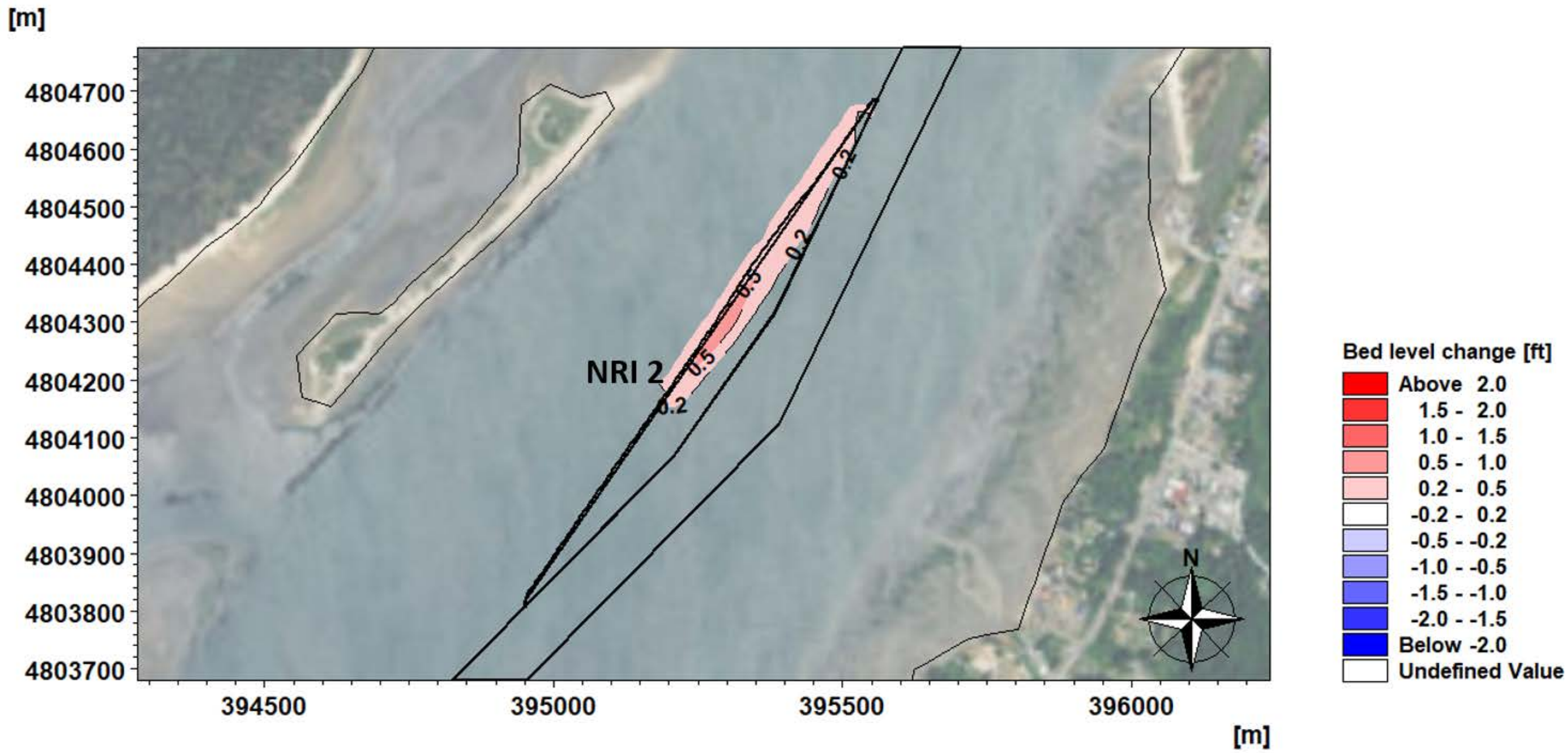

Figure 2-17. Bed Level Changes at NRI 2 after One Year for With-Project; Red – Shoaling, Blue - Erosion

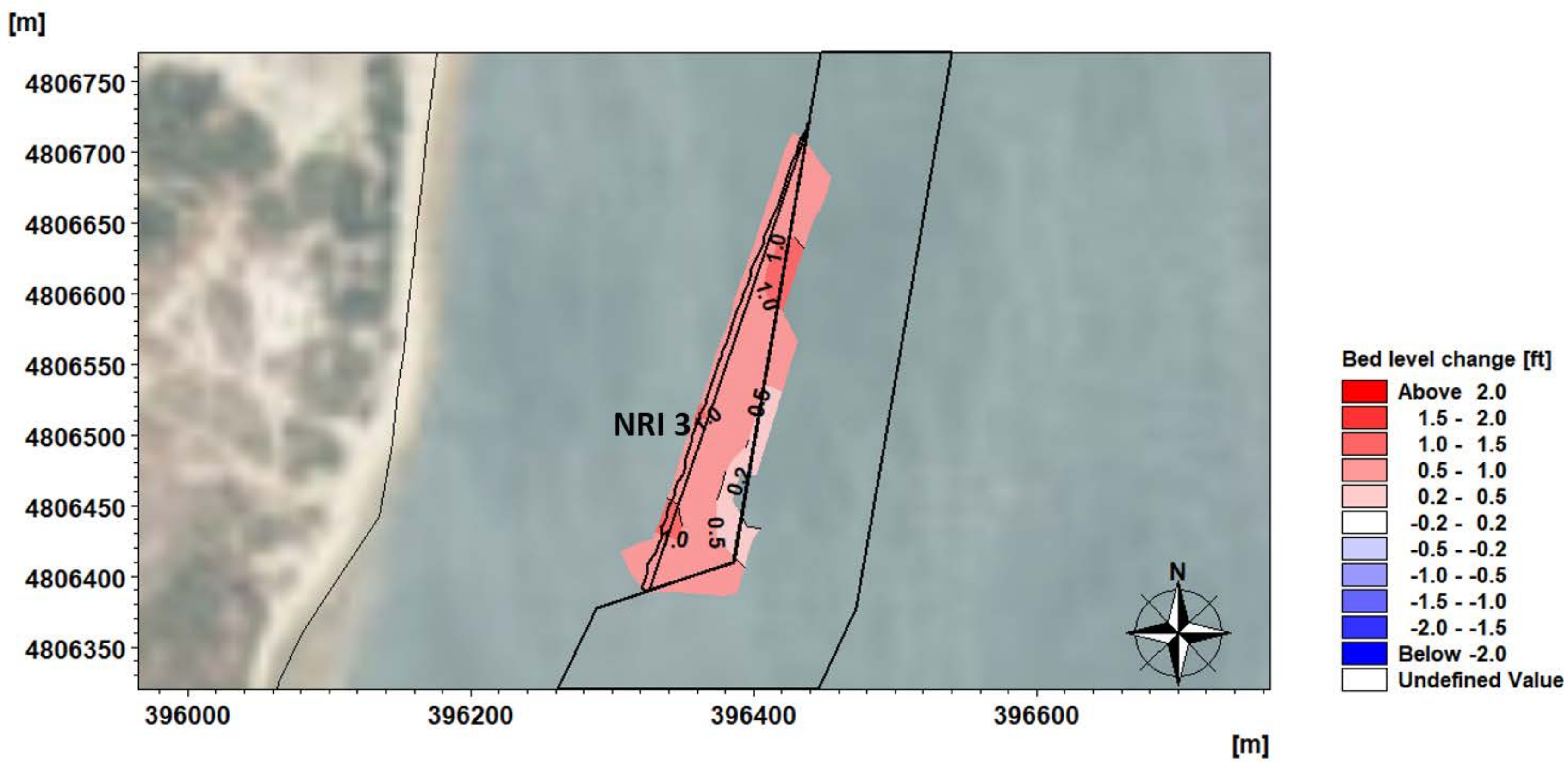

Figure 2-18. Bed Level Changes at NRI 3 after One Year for With-Project; Red – Shoaling, Blue - Erosion

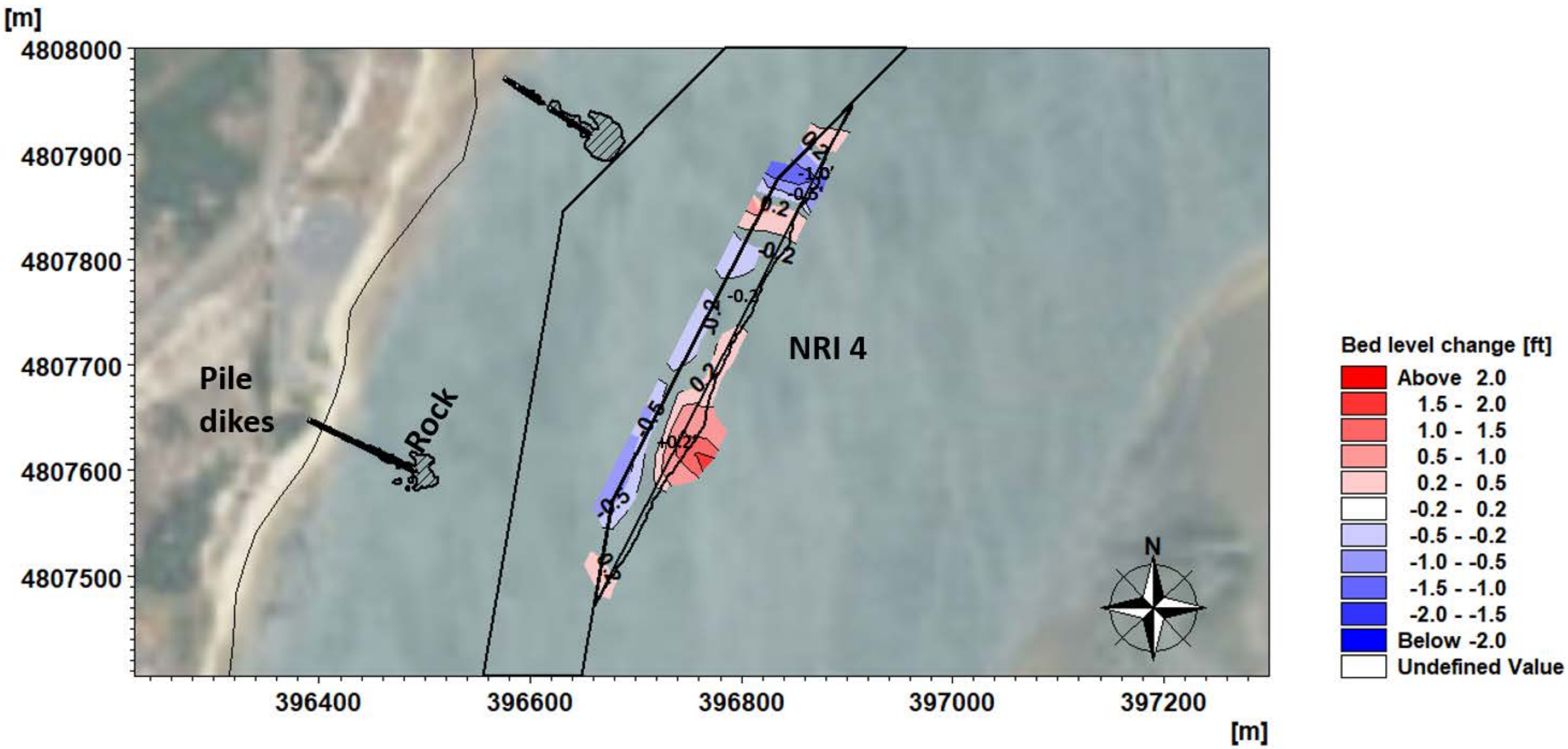

Figure 2-19. Bed Level Changes at NRI 4 after One Year for With-Project; Red – Shoaling, Blue - Erosion

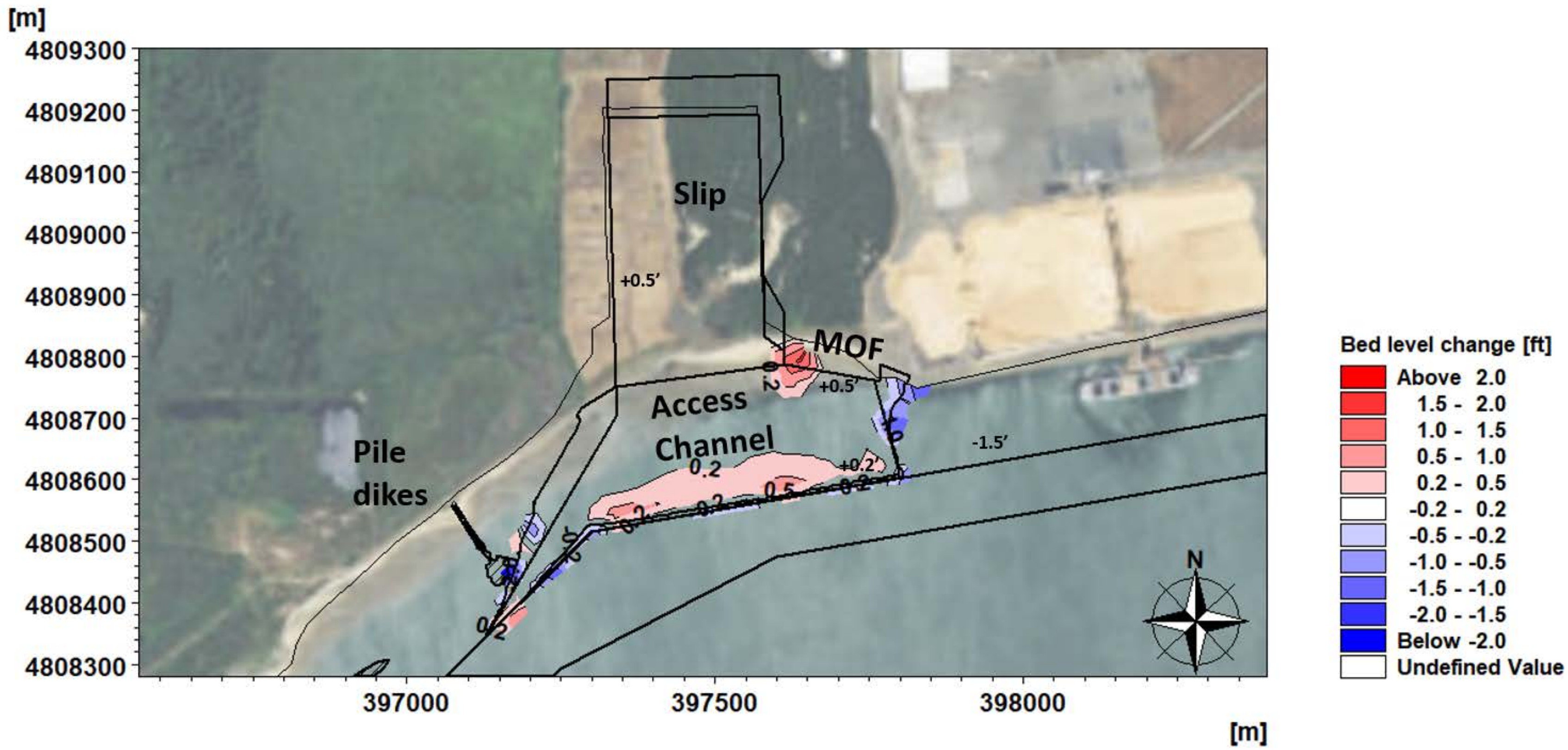

Figure 2-20. Bed Level Changes at the Slip, the Access Channel and the MOF after One Year for With-Project; Red – Shoaling, Blue - Erosion

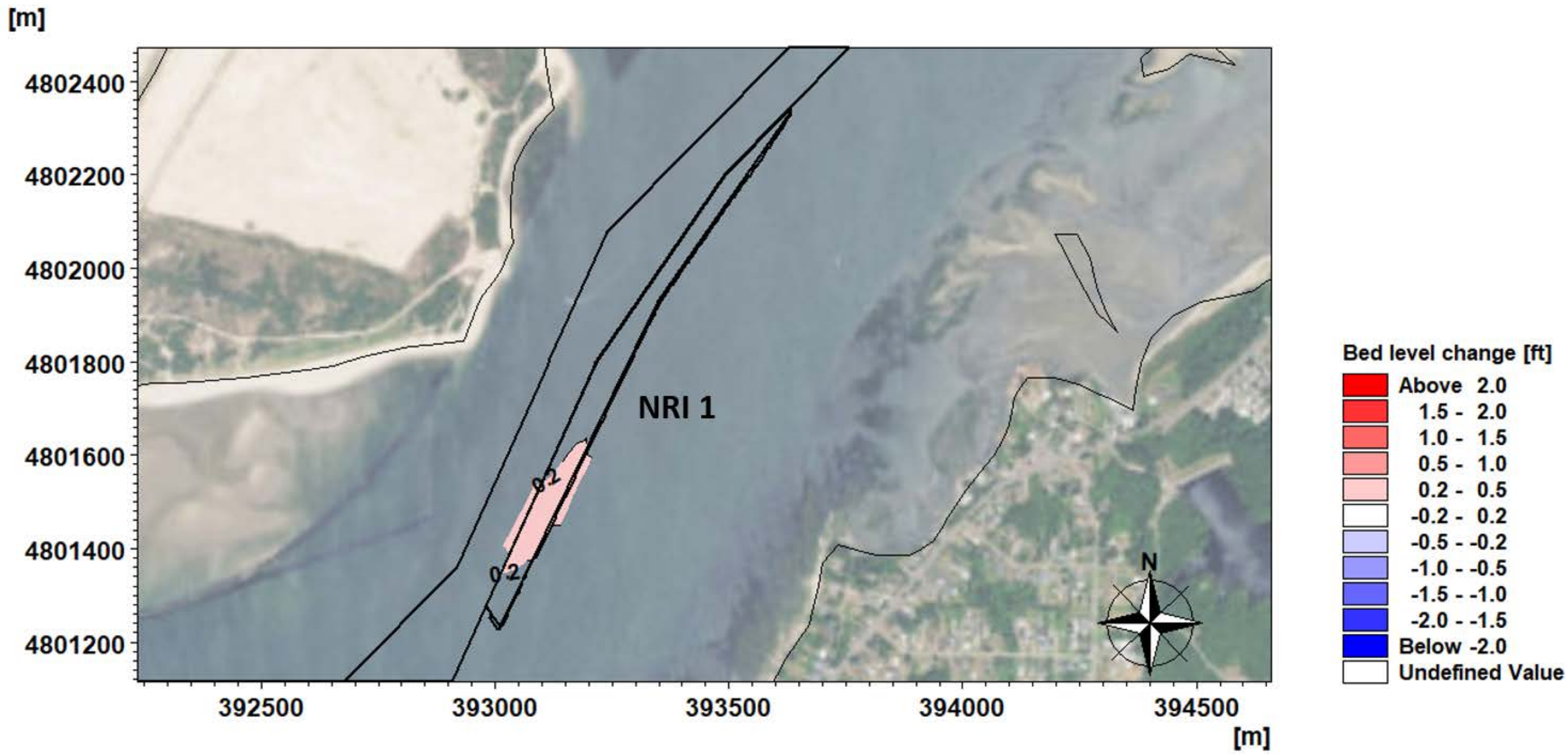

Figure 2-21. Bed Level Changes at NRI 1 after Three Years for With-Project; Red – Shoaling, Blue - Erosion

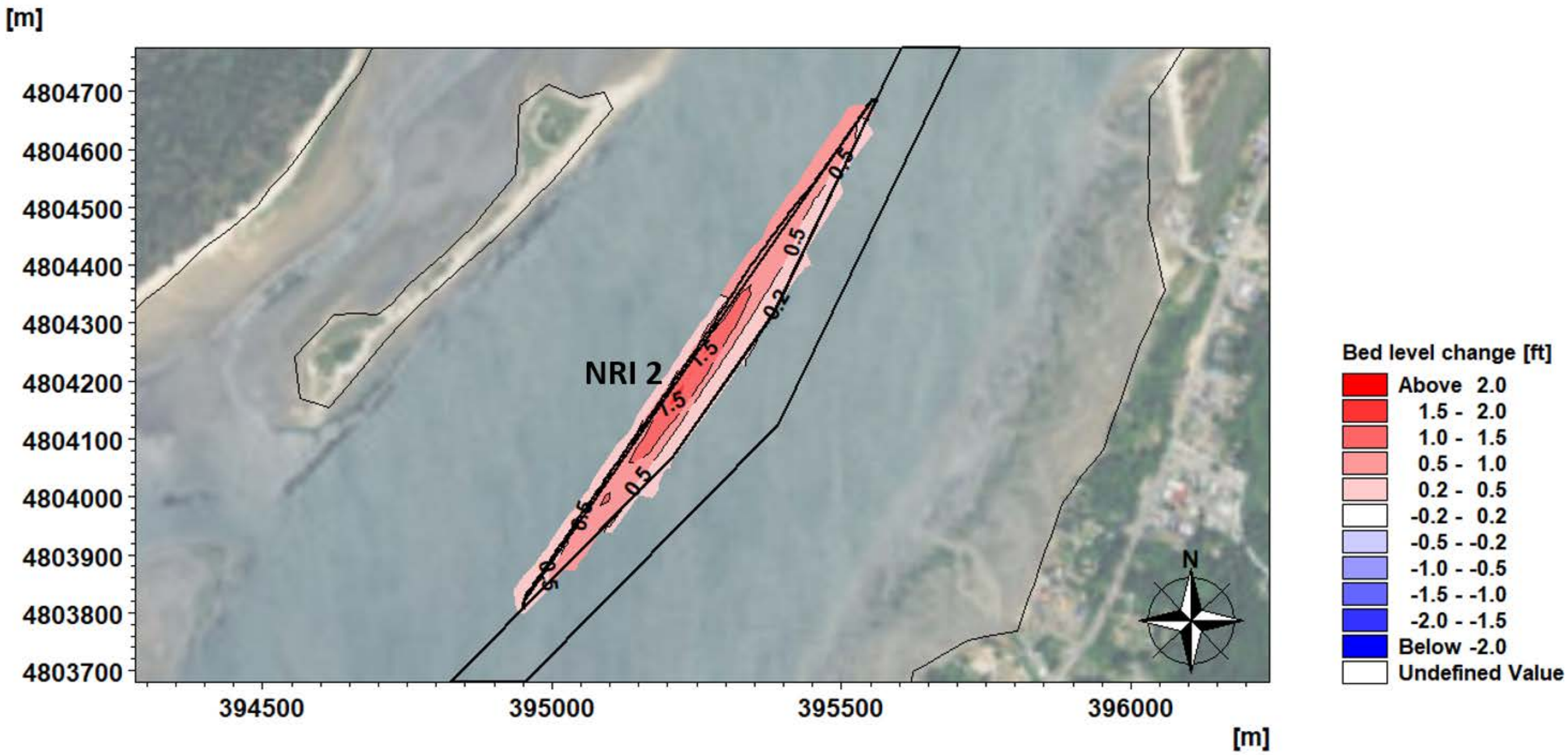

Figure 2-22. Bed Level Changes at NRI 2 after Three Years for With-Project; Red – Shoaling, Blue - Erosion

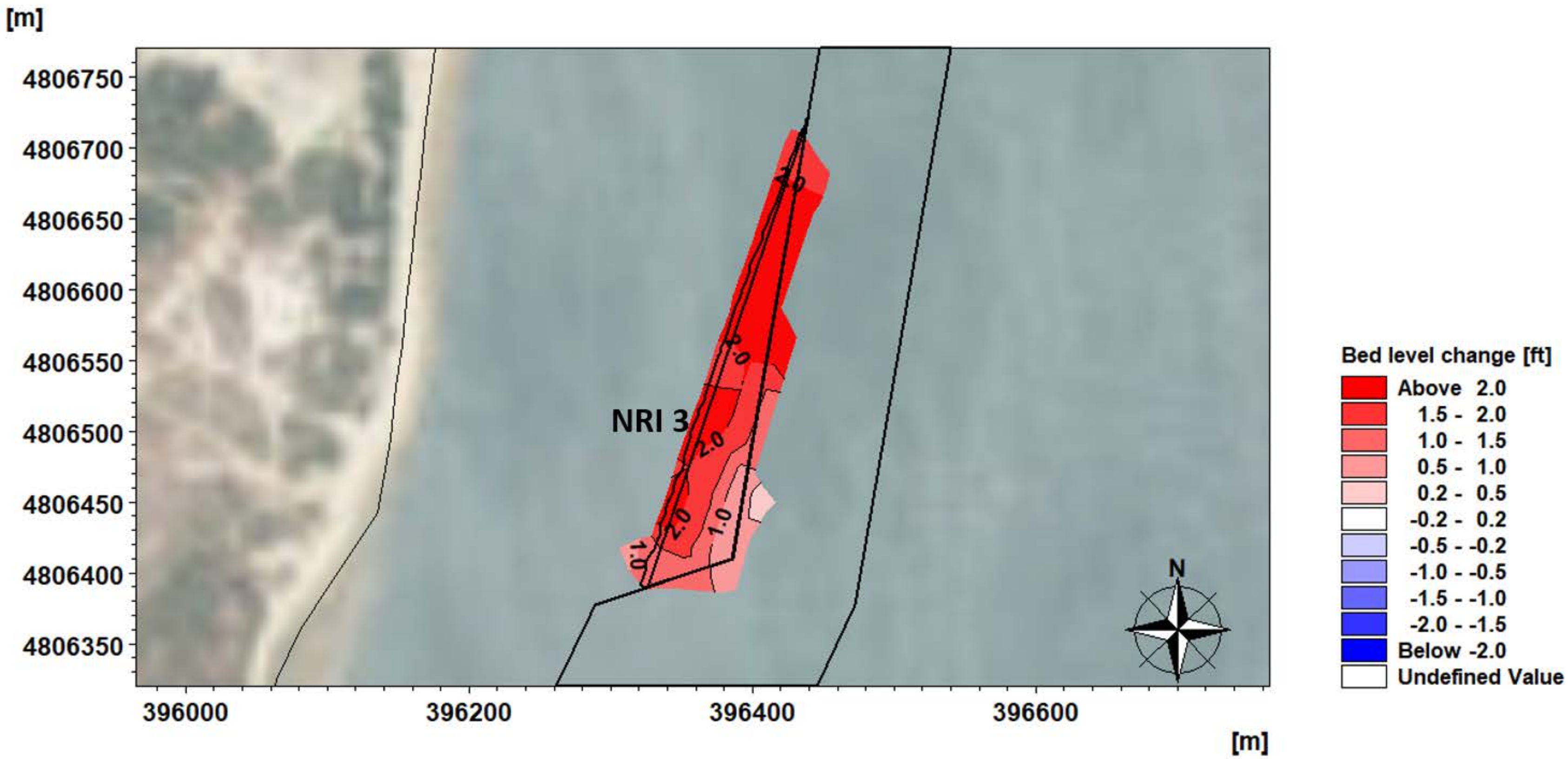

Figure 2-23. Bed Level Changes at NRI 3 after Three Years for With-Project; Red – Shoaling, Blue - Erosion

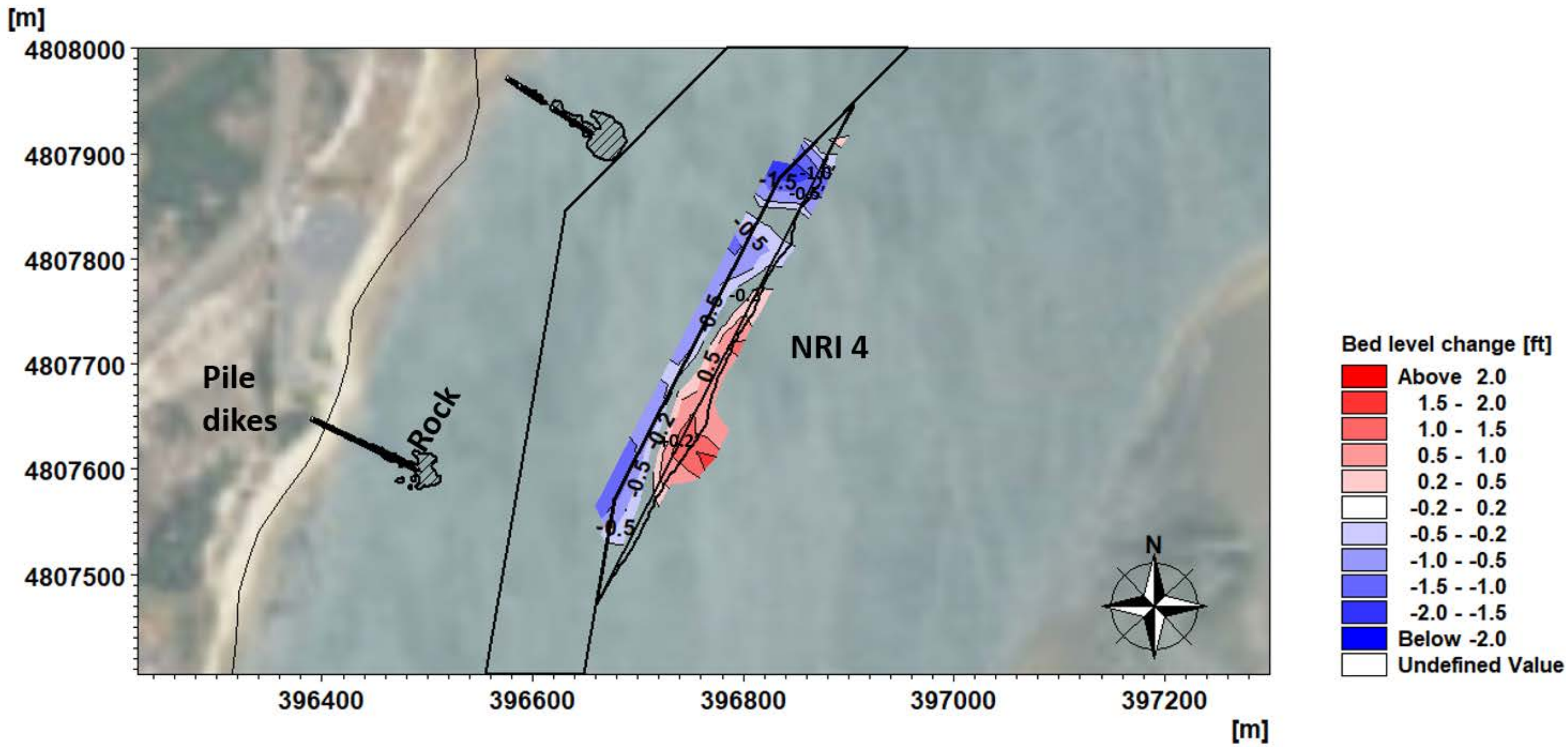

Figure 2-24. Bed Level Changes at NRI 4 after Three Years for With-Project; Red – Shoaling, Blue - Erosion

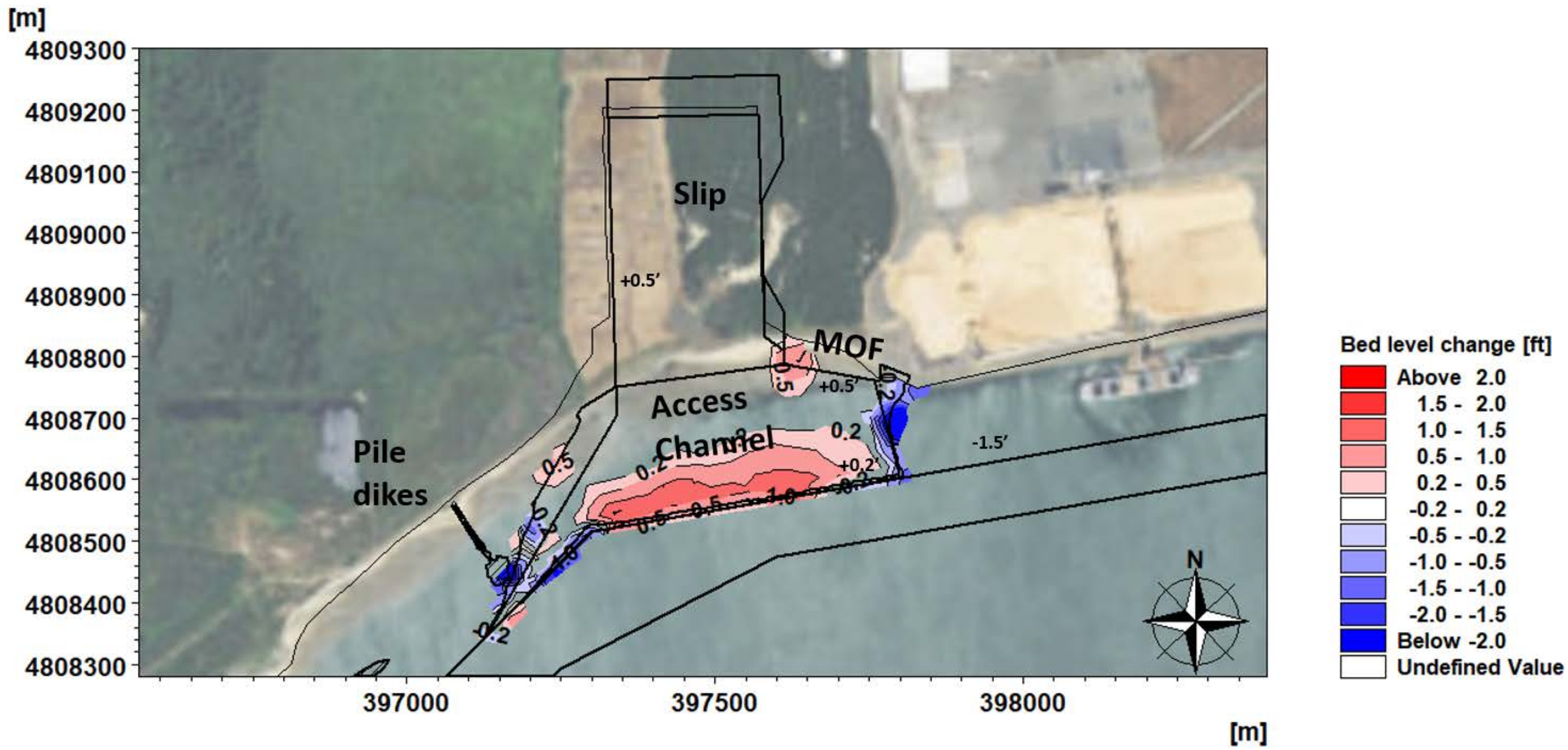

Figure 2-25. Bed Level Changes at the Slip, the Access Channel and the MOF after Three Years for With-Project; Red – Shoaling, Blue - Erosion

3. SUMMARY

M&N conducted a numerical modeling study to evaluate possible changes in sedimentation along the FNC as a result of implementing the With Project Conditions. The model was calibrated against records of annual dredge quantities provided by USACE for the Without Project condition. The model was then used to simulate With-Project condition. Comparison of model results for With-Project and Without-Project conditions indicated potential changes to sedimentation patterns in limited areas within the FNC and adjacent to the offshore end of Pile Dike 7.3.

Results of the one-year and three-year model simulations indicate that comparative (change between With-Project and Without-Project conditions) shoaling and/or erosion rates within the majority of the FNC and most of the non-project areas are less than 0.2 feet. Model results indicated that the JCEP (With-Project condition) could result in limited comparative erosion within the FNC at five locations when compared to the existing (Without-Project) condition. After 3 years, additional erosion of up to 0.4 feet south of NRI 1, 1.5 feet south of NRI 3, 0.7 feet south of NRI 4, 1.8 feet near the intersection of the FNC with the Access Channel, and 1.2 feet near the MOF is indicated.

Up to 2 feet of comparative erosion is indicated near the offshore end of Pile Dike 7.3. These areas of comparative erosion will not increase the overall volume of required maintenance dredging within the FNC or adversely impact navigation. The comparative erosion (bed lowering) near Pile Dike 7.3 will be further analyzed to determine potential effects to Pile Dike 7.3, with results presented in a separate technical memorandum. Only one area within the FNC, adjacent to the Access Channel, indicated comparative deposition (sedimentation) of 1.4 ft. However, this localized change would occur in a historically naturally-deep section of the channel (existing water depth of approximately -39 to -42 feet MLLW which is deeper than the authorized depth of -37 feet MLLW). Actual sedimentation in this historically naturally deep area will be monitored by hydrographic survey in conjunction with monitoring surveys of the Slip, Access Channel, and NRI areas by the JCEP. Should sedimentation in this area over time result in conditions requiring maintenance dredging, maintenance dredging would be executed by JCEP in conjunction with maintenance dredging of the NRI areas and access channel. JCEP will not increase maintenance dredging volumes or dredging intervals.

Modeling results also indicate localized erosion and deposition in the JCEP dredge areas following construction. Anticipated deposition was indicated in the NRI areas, the Access Channel, and the Slip, these areas will be maintained by the JCEP, are outside the FNC, and do not increase maintenance dredging within the FNC. Localized erosion and deposition was indicated adjacent to the MOF outside the FNC.

There are no noticeable sedimentation changes at the Eelgrass Mitigation site.

4. REFERENCES

Coast and Harbor Engineering (CHE), 2011. "Volume 3 – Jordan Cove Terminal & Access Channel Sedimentation and Maintenance Dredging Requirements". Draft Technical Report, March 14, 2010. JCLNG Document No. J1-000-MAR-RPT-CHE-00003-00.

Danish Hydraulic Institute (DHI), 2014. "MIKE 21 Flow Model FM – Sand Transport Module User Guide". JCLNG Document No. J1-000-MAR-PCD-DHI-00003-00.

GRI. 2011. "Coos Bay Channel Modification Section 203 Feasibility Study / Environmental Impact Study". Geotechnical Data Report. Prepared for DEA. JCLNG Document No. J1-000-GEO-RPT-GRI-00054-00.

Moffatt & Nichol (M&N), 2018 "Hydrodynamic Studies – Hydrodynamic Analysis Technical Memorandum". Prepared for JCLNG, May 2018. JCLNG Document No. J1-000-MAR-TNT-DEA-00008-00.

M&N, 2017 "Navigation Reliability Improvement (NRI) Dredge Areas Evaluation Technical Memorandum". Prepared for JCLNG, October 2017. JCLNG Document No. J1-000-MAR-TNT-DEA-00002-00

Oregon International Port of Coos Bay (OIPCB), 2017. "Coos Bay, Oregon, Section 204(f) Channel Modification Project: 60% Engineering Design Report". October 31, 2017. JCLNG Document No. J1-000-MAR-RPT-PCB-00004-00.

SHN, 2007. "Sediment Sampling and Analysis Report, Oregon Marine Gateway Terminal, Coos Bay, Oregon". Prepared for The Port of Coos Bay and Jordan Cove Energy Project, LP. JCLNG Document No. J1-000-RGL-RPT-SHN-00029-00.

U.S. Army Corps of Engineers and U.S. Environmental Protection Agency (USACE/USEPA), 1986. "Coos Bay, Oregon: Dredged Material Disposal Site Designation". JCLNG Document No. J1-000-RGL-RPT-AOE-00001-00.

USACE, 2005. "Coos Bay Sediment Quality Evaluation Report". Prepared by Tim Sherman, Portland District Corps of Engineers, CENWP-EC-HR. March 2005. JCLNG Document No. J1-000-MAR-RPT-AOE-00002-00.

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Acronyms and Abbreviations

ANOVA	Analysis of Variance
BLM	Bureau of Land Management
CHE	Coast and Harbor Engineering, Inc.
CWM Plan	Compensatory Wetland Mitigation Plan
DEA	David Evans and Associates, Inc.
ESRI	Environmental Systems Research Institute
EPA	US Environmental Protection Agency
FERC	Federal Energy Regulatory Commission
GIS	Global Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HARN	High Accuracy Reference Network
HP	Horse Power
JCEP	Jorden Cove Energy Project
kHz	Kilohertz
KMZ	Keyhole Markup language Zipped
LNG	Liquefied Natural Gas
mm	Millimeters
m^2	Square meters
MLLW	Mean Lower Low Water
M&N	Moffatt and Nichol, Inc.
NAD83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
ODSL	Oregon Department of State Lands
RSS	Research Support Services, Inc.
RTK	Real-Time Kinematic
R/V	Research Vessel
SE	Standard Error
SORA	Southwest Oregon Regional Airport
SPCS	State Plane Coordinate System
SSNERR	South Slough National Estuarine Research Reserve
USACE	US Army Corps of Engineers
WDFW	Washington Department of Fish and Wildlife

1. *INTRODUCTION*

1.1 OVERVIEW

Jordan Cove Energy Project, LP (JCEP) is seeking authorization from the Federal Energy Regulatory Commission (FERC) under Section 3 of the Natural Gas Act to site, construct, and operate a natural gas liquefaction and liquefied natural gas (LNG) export facility (LNG Terminal), located on the bay side of the North Spit of Coos Bay, Oregon. Areas encompassing the LNG Terminal, Pacific Connector Gas Pipeline, related facilities, temporary construction sites, and other sites/actions associated with LNG Terminal construction are collectively referred to as the "JCEP Project Area."

As a component of the Project Area, JCEP identified existing eelgrass habitat that will likely be impacted by construction of the LNG Terminal and an eelgrass mitigation site that would be developed to offset those impacts. Specifically, the dredging of a proposed Access Channel that would connect the Coos Bay Federal Navigation Channel with the proposed LNG Terminal slip to be excavated from the North Spit will result in losses of existing eelgrass habitat and hence require compensatory mitigation. The proposed JCEP Eelgrass Mitigation Site currently consists of an elevated shallow sand flat bordered by eelgrass habitat in the Coos Bay estuary, southwest of the Southwest Oregon Regional Airport (SORA). Since site elevations are currently higher than those that would support eelgrass, initial mitigation activities will include lowering the existing grade to match that of surrounding eelgrass beds. Subsequently, the site will be allowed to stabilize before eelgrass stock are transplanted from nearby donor sites. This is the same general approach that was used to conduct the successful SORA eelgrass mitigation effort in the 1980's, which is located nearby. Existing eelgrass within the proposed Access Channel will also be salvaged and transplanted to nearby recipient sites before the channel is dredged to lower the temporal loss of ecological functions and perhaps the total mitigation requirement associated with the proposed JCEP action.

1.2 2018 EELGRASS AND BATHYMETRY SURVEYS

During the period of August 28 – 31 and September 5 – 10, 2018, David Evans and Associates (DEA) conducted eelgrass and bathymetry surveys at several locations within the JCEP Project Area in Coos Bay, Oregon. The objectives of this work are to acquire data in support of the JCEP environmental permitting process, refine the basis for mitigation requirements, and support eelgrass mitigation design and construction planning efforts. DEA collected these additional data, in part, to meet the completeness requirements for the Compensatory Wetland Mitigation Plan (CWM Plan; DEA [2018]) and the Removal/Fill Permit Application for submittal to the Oregon Department of State Lands (ODSL); [ODSL 2018]). The data also have been acquired in response to comments provided on the CWM Plan by the US Army Corps of Engineers (USACE; [USACE 2018a]).

DEA conducted eelgrass and/or bathymetry surveys at the following locations in 2018, as presented in Figure 1. All figures are presented in Appendix A.

- Proposed Access Channel footprint at the LNG Terminal slip entrance (includes Pile Dike work area)
- JCEP Eelgrass Mitigation Site
- Reference Site
- Donor Bed
- Temporary Dredge Material Transfer Pipeline Alignment Between APCO and Kentuck Inlet
- APCO Nearshore
- Jordan Cove Embayment
- SORA Eelgrass Mitigation Site

Survey investigations conducted at each site and related objectives are presented in Table 1.

Table 1: 2018 Site Investigations

	Survey Investigations			
Site	**Eelgrass (Tier 1)**	**Eelgrass (Tier 2)**	**Bathy-metry**	**Objectives**
Access Channel	❖	❖		Update acreage and collect shoot densities of existing eelgrass directly affected by dredging and construction. This acreage represents the JCEP total eelgrass mitigation requirement.
JCEP Eelgrass Mitigation Site	❖		❖	Update the previous eelgrass survey to confirm current site boundaries and to avoid/minimize potential impacts to adjacent eelgrass beds. Bathymetry to refine the engineering design and calculate sediment volume that requires removal.
Reference Site	❖	❖	❖	Eelgrass survey to identify and characterize potential reference sites. Collect shoot densities to establish baseline densities as a basis for measuring performance success of eelgrass transplants at the Eelgrass Mitigation Site over the post-construction monitoring period. Bathymetry to determine optimal elevations of existing eelgrass to refine the design of the Eelgrass Mitigation Site.
Donor Bed	❖	❖	❖	Eelgrass and bathymetry surveys (including shoot densities) to identify donor beds that are healthy, of sufficient size, proximal to, and in similar environmental conditions as the Eelgrass Mitigation Site to best assure they can serve as suitable sources for transplants.
Jordan Cove Embayment	❖		❖	Eelgrass survey conducted at this potential site to assess its suitability for receiving eelgrass salvaged from the Access Channel prior to dredging. Delineation of existing eelgrass to avoid areas already colonized and determine if areas of suitable size are available for transplantation. Bathymetry to determine optimal areas for transplantation.
Temporary Dredge Material Transfer Pipeline Alignment – APCO to Kentuck	❖			Eelgrass survey to adjust the temporary dredge material transfer pipeline alignment to avoid existing eelgrass beds.
APCO Nearshore			❖	Bathymetry to determine suitability as an alternative eelgrass mitigation site and determine if there is available space adjacent to existing eelgrass beds to conduct transplants at optimal elevations.
SORA Mitigation Site	❖		❖	Eelgrass and bathymetry surveys and shoot densities to determine the success or failure of this action. The USACE considers the site to have burial problems and is a failed mitigation action, even though previous surveys have found eelgrass.

2. *METHODS*

In 2018, DEA conducted eelgrass and bathymetry surveys with the assistance of two research vessels, the 19-foot R/V *RiverHawk* operated by the DEA Marine Services Division and the 32-foot R/V *Carolyn Dow*, operated by Research Support Services (RSS; Photo 1). The *RiverHawk* conducted all bathymetric surveys for 2018 field activities; qualitative eelgrass surveys were also conducted using side scan sonar. The hydrographic survey crew consisted of a senior geophysicist, a hydrographer, and the lead biologist from DEA. All quantitative eelgrass surveys were conducted from the *Carolyn Dow* using divers; qualitative eelgrass surveys were also conducted using underwater videography. The crew complement was composed of the vessel captain, two divers, and dive tender from RSS; eelgrass ecologist Dr. Jason Stutes from GeoEngineers; and the lead biologist from DEA. Vessel and instrument specifications are presented in Table 2.

Photo 1: Vessels used in 2018 surveys – R/V* RiverHawk *(left) and R/V* Carolyn Dow *(right)

Table 2: Vessel and scientific instrument specifications

	Vessels	
	R/V *RiverHawk*	**R/V *Carolyn Dow***
Vessel Type	19-ft custom built aluminum survey vessel equipped with integrated navigation and data acquisition system, and custom mounts for single-beam side scan sonar and towed geophysical operations.	Munson 32-ft custom built aluminum research vessel equipped with forward dive ramp, open well deck, and articulated A-Frame for deployment/towing of video camera system. Voice communication system from diver to pilot house for real-time relay of diver observations.
Power type	105 HP jet outboard	Duel 225 HP propeller outboards
Qualitative Remote Sensing	Edgetech 4200DF Single Beam Side Scan Sonar with georeferenced Trimble differential GPS.	SeaAll Underwater Video Camera System with video monitor and recorded audio annotation. Georeferenced Trimble differential GPS.
Quantitative Eelgrass Densities	---	Diver-based, using 0.25m^2 quadrats to collect shoot counts. Number of required quadrats determined by real-time statistical analysis.
Bathymetry	Odom CV100 Echo Sounder with georeferenced differential GPS. Calibrated daily with a Trimble R8 RTK GNSS Rover Check.	---

2.1 EELGRASS SURVEY METHODS (TIER 1 AND TIER 2)

During the period of August 28 – 30, Tier 1 qualitative eelgrass surveys were conducted aboard the DEA R/V *RiverHawk*, using an Edgetech 4200DF single beam side scan sonar system. During the period of September 5 – 10, qualitative surveys were conducted aboard the RSS R/V *Carolyn Dow*, using a SeaAll georeferenced underwater video camera system (Photo 1 and Table 2). During the period of September 5 – 10, Tier 2 quantitative eelgrass surveys were also conducted aboard the *Carolyn Dow*, using diver-based quantitative density estimates. The USACE presents guidelines for conducting Tier 1 qualitative and Tier 2 quantitative eelgrass surveys (USACE 2016; 2018b). Surveys conducted by DEA met both of these requirements.

2.1.1 Tier 1 Qualitative Eelgrass Surveys

Eelgrass surveys of areas potentially affected in Coos Bay by the JCEP were conducted based on the USACE guidance using Method 3 (underwater video), Method 4 (hydroacoustic surveys), and according to the Eelgrass Delineation Detection Method A for defining boundaries (USACE 2018b), which meet Tier 1 requirements. Surveys were conducted during mid to high tide to afford the vessels with enough water to transit across any eelgrass beds and into water depths shallower than where eelgrass grows, thereby delineating the shallow and deep extents of the beds.

For Method 3, the eelgrass survey was initiated using the georeferenced underwater video system deployed off the bow of the *Carolyn Dow* and an on-board eelgrass ecologist to document the extent of eelgrass (*Zostera marina*) and macroalgae in the surveyed areas. The video-based mapping system employed to map submerged vegetation used a combination of underwater digital video and differential GPS complemented by on-board audio annotation. It has a usable georeferenced resolution of less than 1 meter. Macroalgae, eelgrass, benthic substrates, and habitats were viewed and recorded to map potential eelgrass/macroalgae habitat. Large invertebrate fauna and fish visible during the survey were also noted. The survey tracks were oriented perpendicular to shore to detect the presence of eelgrass while compensating for wind and current. Subsequent tracks meandered between the deep and shallow edge of the eelgrass bed to document the extent of the bed on a finer geographic scale. If non-native (and unregulated) *Zostera japonica* was suspected to occur in the area or potentially viewed on the survey transect, divers were deployed to obtain a sample to verify the species of the macrovegetation.

For Method 4, the eelgrass survey was initiated using a georeferenced single beam side scan sonar system deployed off of the bow of the *RiverHawk*, which collected and recorded sonar images of bottom habitats. Within the eelgrass beds, relatively straight transects were run from one end of the eelgrass bed to the other spaced at 50 foot intervals for dense and continuous beds and at 15 to 20 foot intervals for less dense or patchy eelgrass beds. Each transect was run until no eelgrass was observed on the sonar image for approximately 50 feet, or until water elevations were either too shallow or too deep to support eelgrass, as noted on the echo sounder, based on the scientific literature on Coos Bay (Thom et al 2003) and past JCEP eelgrass survey findings.

Tier 1 methods were used to initially map eelgrass within the proposed Access Channel and at the selected eelgrass reference/donor site; mapped beds were then further delineated quantitatively with divers conducting density estimates using shoot count methods (see Section 2.1.2). Tier 1 methods were used to map existing eelgrass beds within Jordan Cove during surveys to identify suitable recipient sites for receiving salvaged eelgrass from the proposed Access Channel. Tier 1 methods also mapped eelgrass within the vicinity of the proposed JCEP eelgrass mitigation site, temporary dredge material transfer pipeline alignment, and at the SORA Mitigation site (Table 1).

2.1.2 Tier 2 Quantitative Eelgrass Surveys

For quantitative Tier 2 eelgrass surveys, divers collected shoot densities where eelgrass was initially mapped using underwater video or single-beam side scan sonar. The *Carolyn Dow* initially plotted eelgrass maps in the field to locate transects within delineated eelgrass bed boundaries for conducting density estimates. Diver-based transects were approximately 300 feet in length. One diver, harnessed to a 300 foot safety line (which also functioned to measure 300 foot transects), dived a straight line transect at an instructed heading within the eelgrass bed. For safety, a second standby diver, partially suited, was always on deck during dives and would be deployed if assistance was necessary. Using randomly placed 0.25-square-meter (m^2) quadrats placed within the delineated bed boundaries, counts at each transect were taken until the requirements for statistical robustness for detecting differences among means ($\alpha = 0.10$ and power $[1 - \beta] = 0.90$) was met or variance around the computed mean remained static. The number of quadrats needed for each transect was determined in real-time as quadrat shoot counts were communicated from the diver to the *Carolyn Dow* and immediately entered into a spreadsheet that ran ongoing tests of statistical robustness. Typically, between 25 and 30 quadrat counts were made at each transect. Average densities were compared between transects and among sample sites. Differences in average density were tested using a one-way Analysis of Variance (ANOVA) to compare means among transects.

Shoot morphology was also sampled as part of the Tier 2 process. Shoot morphology can be attributed to the physical characteristics of each location (Kuo and den Hartog 2007). For example, characteristics such as water clarity and wave exposure (energy) can often be related to the shape and size of leaves for a population of eelgrass. Wider, longer leaves may be characteristic of slow moving more turbid waters while shorter, thinner, and more numerous leaves may indicate clearer, more energetic systems. At sites that could be potential donor or transplant areas, divers retrieved shoots from established beds for basic demography. Shoot morphology data collected from these samples (e.g., abundance of leaves/shoots, leaf lengths and widths) will be used to help match eelgrass donor stock with suitable receiving areas for transplanting.

This approach meets and surpasses the USACE Tier 2 quantitative survey requirements (USACE 2016) for precision and accuracy with respect to eelgrass shoot density measurements. This approach also satisfies the Washington Department of Fish and Wildlife (WDFW) Eelgrass/Macroalgae Habitat Survey Guidelines (WDFW 2008).

Quantitative Tier 2 surveys estimated densities within eelgrass beds at the proposed Access Channel to accurately determine and update the acreage and density of the JCEP eelgrass mitigation requirement. These methods were also used to characterize eelgrass acreage and density at the donor/reference site as the basis for determining appropriate harvest rates for transplanting stock to the eelgrass mitigation site and for establishing the baseline for future performance monitoring (Table 1).

2.2 BATHYMETRY SURVEY METHODS

Field crew aboard the *RiverHawk* conducted bathymetry surveys on an established coordinate system, referenced by monuments. This will enable the survey to be reproduced later with repeatable results. For this survey, hydrographic field operations were conducted using the North American Datum of 1983 (NAD83) High Accuracy Reference Network (HARN) horizontal datum projected to the State Plane Coordinate System (SPCS) Oregon South Zone with units in International Feet. The vertical datum used during data acquisition was the North American Vertical Datum of 1988 (NAVD88) based on the Geoid 2012b separation model. Positioning and vertical control for the survey was provided by a Real-Time Kinematic (RTK) Global Navigation Satellite System (GNSS). RTK GNSS corrections were provided by the Oregon Real-time GPS Reference Network. Opening and closing checks were conducted at the local monument "BLM_RAMP 2007 USACE", a standard USACE 3-inch diameter brass disc. Position checks were conducted each day of the survey using the vessel's Trimble RTK GNSS antenna set on monument "1002", a brass disc located at the top of the BLM boat ramp. The purpose of these checks was to verify system geodetic parameters and unit settings, base station input coordinates, and positional accuracy of the hydrographic survey system. All checks were verified as being better than +/- 0.25 feet from known positions.

2.2.1 Positioning and Navigation

Horizontal positions were acquired with a Trimble SPS851 with a Zephyr model 2 antenna mounted directly above the transducer of the echo-sounder. RTK corrections were broadcast to the survey vessel from the Oregon Real-time GPS reference system via an Inuicom Bridge-X communication device. The positioning data were logged using Hypack 2017a navigation software.

2.2.2 Water Surface Observations

Although not a prime objective of the survey, all bathymetric data were time tagged and recorded relative to the vertical project datum NAVD88 (and later converted to mean lower low water [MLLW], when necessary, using a calculated conversion value of 0.7 feet). Using a fixed vertical reference for both the sonar and GNSS systems, as opposed to using the water surface and making water surface observations, provides improved vertical accuracy as it takes into account dynamic changes in draft and local water surface variations in the vicinity of the survey vessel. The sonar fixed draft relative to the reference point was used to reference the soundings to the project vertical datum.

2.2.3 Data Acquisition

The *RiverHawk* collected bathymetric data equipped with an Odom CV100 Echo Sounder deployed off the bow on the starboard side of the vessel. Locating the RTK GNSS antenna directly over the echo sounder transducers removed the need to apply offsets to the data. Survey operations entailed running relatively straight predetermined track lines over the site at approximate 50 foot intervals. Since bathymetry data were collected within eelgrass beds, track lines were extended over the entire bed, and usually over a distance of at least 50 feet laterally on all sides of the bed. This was conducted at the identified Reference Site/Donor Bed to determine optimal elevations for eelgrass to further inform the Eelgrass Mitigation Site design.

For the Jordan Cove, APCO nearshore, and SORA Mitigation Site, the *RiverHawk* collected bathymetry track lines across these areas until reaching depths unsuitable for eelgrass growth (either too shallow or too deep). Data collected from the Jordan Cove and APCO sites would be used to determine if these areas would be suitable as recipient sites for eelgrass transplants. Therefore it was important to collect bathymetric data in areas both occupied by eelgrass in order to avoid it during potential transplant operations, and in areas unoccupied by eelgrass that are at suitable elevations to determine potential recipient sites. Data were collected at SORA to compare the area of historical excavation with current bathymetries to determine if filling or burial has occurred since the site was created in 1988. Data were recorded using Hypack 2014 software.

The surveys at each of the sites were conducted during mid to high tide to afford the vessel enough water to transit across any eelgrass beds and into water depths shallower than where eelgrass generally grows, thereby delineating the shallow and deep extents of the beds.

2.3 POST-FIELD DATA PROCESSING AND ANALYSIS

2.3.1 Eelgrass Surveys

2.3.1.1 Underwater Video and Density Counts

Macroalgae, eelgrass, benthic substrates, and habitats were reviewed and recorded to map potential subtidal eelgrass/macroalgae habitat. Large invertebrate fauna and fish visible during the survey were also identified and noted either during the survey or during post processing. The review of survey tracks was accomplished over several days where eelgrass presence was compiled in the geospatial database and then imported into the larger ESRI database. Polygons were constructed from eelgrass presence data using a blind review process. This process involved randomly selecting an area of raw data and two technicians developing polygons in tandem and determining the degree of agreement. Polygon agreement was generally within 5 percent of total area. In areas where eelgrass was patchy, sparse in density, or difficult to determine its extent through the transect, a senior scientist was consulted for a third level evaluation.

Eelgrass density data was collected and analyzed for central tendency and precision while in the field. Raw data was reviewed for consistency with field notes in the office for a final level of quality control. Fully reviewed data were then analyzed using ANOVA procedures found in the Sigma Stat portion of Sigma Plot 13.0 (Systat Software, Inc.) to determine if densities within and between beds were statistically different. This approach was useful in identifying sources of potential donor material that have densities similar to those of receiving areas. The similarity also could reflect overall growing conditions likely to be compatible for supporting successful eelgrass transplants.

Eelgrass morphology data was collected in the field and compiled for three variables; total leaf length per shoot, average width, and number of leaves per shoot. Total leaf length is a proxy for the amount of photosynthetic area available for each shoot and is primarily a response to overall turbidity and secondarily to wave energy. Average leaf width tends to vary directly with water clarity with wider leaves occurring in more turbid water. Number of leaves per shoot is used as a proxy to determine the average wave environment where leaves tend to be more numerous (and shorter) in high energy systems and conversely, leaves tend to be less numerous (and longer) in quiescent systems. Though all of these metrics tend to co-vary with wave energy and turbidity to some degree, these morphological characteristics will be used to determine the present environmental conditions of various eelgrass beds within the survey area. Mean values for each characteristic will be compared using ANOVA procedures in the Sigma Stat package found in the Sigma Plot 13.0 (Systat Software, Inc.).

2.3.1.2 Side Scan Sonar

Post-field data processing of eelgrass beds was a multi-step process in which the lateral extents defined from the echogram were overlain on the side-scan geotiff images. Processing of the side-scan sonar data was conducted utilizing Chesapeake Technologies SonarWiz 7 acoustic mapping software. The sonar files were imported and the bottom detection was reviewed and adjusted to improve slant range correction of the images. A general gain was applied to the data. The 413 kHz, high frequency data, produced the sharpest delineation of the eelgrass and was mosaicked to produce and GeoTiff image of all overlapping sonar lines in each area. After mosaicking, the GeoTiff images were used to guide the digitization of various density eelgrass areas. These digitized areas were converted to KMZ files and sent to the diver's in the field who were conducting the Tier 2 surveys. In areas where no side scan data were collected, single beam bathymetric echograms were used to delineate eelgrass areas along each transect. This technique has proven quite effective during past Tier 1 eelgrass surveys in this area.

2.3.2 Bathymetry

Single beam acoustic data from each of the sites were cleaned and fliers and eelgrass removed using Hypack 2018a Single Beam Editor. The final XYZ data were exported at a 10-foot resolution in NAD83 Oregon State Plane South, international feet horizontal datum, and NAVD88, international feet vertical datum.

The soundings were then imported into ArcGIS v. 10.6 using the ASCII to 3DZ tool, converting depth to elevation in the process, and quality checked against the original point data in Hypack. To generate a data set in the MLLW vertical datum, a Z-shift of positive 0.7ft was applied to the NAVD88 data.

A raster surface was generated from the point data using the Kriging interpolation tool. Contours were then generated at one-foot and half-foot intervals using this raster surface and exported as shape files.

3. *FINDINGS*

3.1 PROPOSED ACCESS CHANNEL

One of the primary goals of this survey effort is to update the extent of eelgrass habitat within the proposed Access Channel that may be affected by dredging, armoring, or other project related actions. The *Carolyn Dow* performed both areal and density surveys in the area of the Access Channel on September 5, 2018. Transects were oriented generally perpendicular to shore and were spaced an average of 20 feet apart. The survey limits extended approximately 200 feet west and 220 feet east of the footprints of the proposed Access Channel (Figure 2).

3.1.1 Eelgrass Distribution and Acreage

Data on eelgrass coverage in Coos Bay in the vicinity of the JCEP exists from a series of historical surveys since 2005. Knowing historic locations of eelgrass beds in the area and the proposed locations for the Access Channel and rock apron facilitated the establishment of a focused eelgrass survey effort. The survey extended over approximately 7.70 acres of nearshore benthic habitat using the georeferenced video approach (Tier 1, Method 3). Survey results indicated the presence of 2.39 acres of eelgrass beds within the lower intertidal and shallow subtidal zones (Figure 2). This represents an apparent increase of approximately 1.5 acres of eelgrass coverage compared to the 2016 South Slough National Estuarine Research Reserve (SSNERR) data collected for this same area. The SSNERR data were collected by aerial photography, but underwent validation through ground-truthing with DEA side scan sonar data and additional statistical analyses of the orthophotographic images. SSNERR considers their data to have a high degree of confidence relative to the location and areal extent of eelgrass bed coverage (SSNERR 2017).

The 2.39 acres of eelgrass beds mapped from the 2018 survey is similar in extent to the 2.34 acres mapped in 2017 (DEA 2017) despite being based on different methodologies (Tier 1 Method 3 vs Method 4). This suggests that eelgrass coverage in recent years is relatively stable. Given this similarity in areal coverage between the two surveys, DEA feels confident in establishing the anticipated acreage of eelgrass that would be in jeopardy from the proposed Access Channel dredging and Rock Apron installation. Based on the 2018 survey results, construction of the proposed Access Channel (including the Rock Apron) likely will result in the displacement of 2.26 acres of the 2.39 acres of eelgrass in this area.

To determine shoot density of the delineated eelgrass beds along the proposed Access Channel, three diver-based transects were performed, the results of which are presented in Table 3.

Table 3: Eelgrass density data collected within the Access Channel

Donor Bed Transects	Number of Quadrats	Shoots/m²
West Transect	27	53.8
Center Transect	29	52.6
East Transect	29	55.6
Total Number of Quadrats	85	
Mean Shoots/m²		53.9

The mean densities from each transect were not statistically different from each other so all values were combined for this area. As a result, the average shoot density for the overall area was 53.9 shoots/m^2 ± 1.65 SE (n = 85) with a maximum and minimum density of 88 and 24 shoots/m^2, respectively. The minimal error suggests that eelgrass density is fairly uniform across all areas surveyed.

3.1.2 Eelgrass Morphological Assessment

When examining the morphology of the eelgrass at the Access Channel site, average total length/shoot was 2,779.7 mm/shoot ± 638 SE (average aggregate length of all leaves within the shoot) which was the lowest average of all sites examined. Average width was 9.31 mm/shoot ± 0.9 SE while average leaf abundance per shoot was 6.00 leaves/shoot ± 0.6 SE which was highest of all sites examined. Based on these morphological characteristics, this eelgrass population might experience relatively low turbidity and slightly elevated tidal currents.

3.2 EELGRASS MITIGATION SITE

The JCEP Eelgrass Mitigation Site was surveyed to determine existing elevations of the proposed grading area as well as to determine the proximity of fringing eelgrass communities adjacent to the mitigation site. DEA surveyed the JCEP Eelgrass Mitigation Site for both fringing eelgrass and bathymetry on August 28 and 30, 2018 from the *RiverHawk*. Twenty bathymetry and eelgrass transects (side scan sonar) spaced at approximate 50 foot intervals were aligned across the Site. Transects extended from approximately 180 feet to 600 feet beyond the proposed grading boundaries of the site on all sides to capture fringing eelgrass and determine adjacent elevations. After post processing of the side scan sonar data, the *Carolyn Dow* performed confirmation surveys using georeferenced video transects on September 6, 2018.

3.2.1 Eelgrass Distribution

The results of Tier 1 qualitative eelgrass surveys found only one small eelgrass patch (597 square feet; 0.014 acre) within the proposed grading boundaries of the JCEP Eelgrass Mitigation Site, as presented in Figure 3. This small patch was centrally located in the eastern half of the site at a relatively high elevation near the +2 foot MLLW contour. It was not located near any of the eelgrass detected in historical surveys. Given this small patch of eelgrass was detected for the first time, it may not be permanent and will be monitored before preparing the site for eelgrass transplantation.

Most eelgrass outside the proposed grading area was located in a narrow band that extended in a northeast to southeast direction along the east side of the site at elevations between +0.5 feet and -1.5 feet MLLW. This continuous to near continuous band ran approximately the length of the site along the east shore of Coos Bay. It occupied approximately 1.21 acres with its closest proximity occurring about 45 feet of the southern grading boundary of the JCEP Eelgrass Mitigation Site. An additional moderately large eelgrass patch occupying approximately 0.36 acres was delineated about 400 feet southwest of the Eelgrass Mitigation Site. On the northwest side of the Site, additional small patches of eelgrass were observed with one very small patch near the grading boundary (Figure 3).

For over a decade, the historic distribution of eelgrass in the vicinity of the JCEP Eelgrass Mitigation Site has been very dynamic. In 2018, the areal distribution of eelgrass near the JCEP Eelgrass Mitigation Site was considerably lower than the distribution observed during previous surveys (Figure 4). Surveys conducted in 2016 by the SSNERR, in 2007 by DEA, and in 2005 by the US Environmental Protection Agency (EPA) collectively showed eelgrass distribution within the proposed grading boundaries of the Eelgrass Mitigation Site over an area of approximately 1.7 acres with most occurring along the south, southwest boundary. EPA surveys in 2005 noted the largest area with later surveys conducted by DEA (2007) and SSNERR (2016) documenting considerably less acreage within the Site boundary.

It should be noted that the EPA data were based on bay-wide aerial photography with only selective spot checked ground-truthing to confirm that the distribution did, in fact, involve eelgrass. As such, the 2005 EPA survey is considered to have overestimated eelgrass distribution in many parts of Coos Bay and, therefore, may not be reliable in small scale, site specific applications. While the SSNERR data were also based on aerial photography, the data underwent validation through ground-truthing using DEA side scan sonar and additional statistical analyses of the orthophotographic images. As a result, SSNERR considers their 2016 data to have a high degree of confidence in accurately representing the distribution of eelgrass beds in Coos Bay during that year (SSNERR 2017). The site-specific vessel based data collection conducted by DEA using georeferenced side scan sonar and underwater video is considered the most accurate for site-specific applications.

The EPA (2005), SSNERR (2016), and the DEA (2007) surveys also showed eelgrass on all sides of the grading boundaries. As previously mentioned, DEA's 2018 survey only found significant areas of eelgrass along the eastern side of the boundary near the eastern shore of Coos Bay. This eastern semi-continuous bed, as well as the bed south of the Site, were in similar locations as documented in the 2016 SSNERR and 2014 DEA surveys (Figure 4).

Taken together, historical and present surveys suggest that eelgrass within the vicinity of the JCEP Eelgrass Mitigation Site is contracting. Since 2007, only the 2016 SSNERR survey has indicated the possible presence of eelgrass within the Eelgrass Mitigation Site boundaries. In contrast, eelgrass surveys conducted by DEA in 2010, 2014, and 2018 using vessel-based methods documented no significant eelgrass within the Site. General agreement of eelgrass presence to the east and south of the Site, however, occurs in all surveys since 2014.

3.2.2 Bathymetry

A 2018 bathymetry map of the JCEP Eelgrass Mitigation Site and vicinity is presented in Figure 3. The site's proposed grading boundary is roughly situated at +1 feet MLLW. Existing elevations within this boundary increase reaching a maximum of approximately +3.0 feet MLLW at its southern portion. This maximum elevation and shape of the shoal has remained largely unchanged from the previous bathymetric survey conducted in 2014. Outside of the site's proposed grading boundary, elevations decrease in all directions. To the north, west, and east, elevations lower to between +0.2 to -1.3 feet MLLW before increasing in elevation. Increasing elevations on these sides occur within approximately 180 feet outside of the proposed grading boundary. To the west and northwest, a large shoal is present approaching the runway lights of the airport. A former dredge spoil island also exists due west of the Eelgrass Mitigation Site. To the north and east, increased elevations occur with greater proximity to the airport runway and eastern shore of Coos Bay (Figure 3).

Unlike areas to the north, west, and east of the Site, elevations to the south and southwest deepen for longer distances as a wide channel extends to the southwest. Maximum depths in this area range to approximately -4.3 feet MLLW (Figure 3).

JCEP proposes to excavate the existing shoal at the Eelgrass Mitigation Site to lower elevations to those more optimal for the growth of eelgrass. The current design is to lower the elevations inside of the proposed grading boundary to -1.3 feet MLLW, which is within the elevation range of the selected Reference Site and Donor Bed (see Section 3.3). Bathymetric surveys in 2018 indicate that the volume of material that would need to be removed to obtain this elevation is approximately 46,500 cubic yards (Figure 3).

Bathymetric surveys conducted in 2018 will be used to refine the engineering design of the JCEP Eelgrass Mitigation Site. The proposed grading boundary of the Site may be recontoured from the current design to allow drainage from the Site so it does not become a shallow bowl that retains water at minus low tides. This may be undesirable, particularly if winter storm surges cause the elevated lip of the bowl to collapse into the Site and decrease the effective area at the established elevation for optimizing eelgrass growth. Mid-summer temperatures at daytime minus tides may also warm waters to non-optimal levels for eelgrass. To alleviate this condition and increase site flushing, a short channel may be constructed that extends to deeper waters to the southwest from the site's western boundary at the -1.3 feet MLLW contour. This would slightly increase the volume of sediment that would need to be removed. This and other design modifications are being investigated and will be incorporated into the 75 percent engineering design.

3.3 DONOR BED/REFERENCE SITE

Eelgrass and bathymetry investigations in 2018 identified a suitable Donor Bed and Reference Site southwest of the JCEP Eelgrass Mitigation Site, as presented in Figure 5. The *RiverHawk* conducted a Tier 1 eelgrass survey to determine the Site boundary and acreage on August 28, 2018. In addition, the *Carolyn Dow* conducted a Tier 2 quantitative eelgrass survey on September 6, 2018 to determine eelgrass densities within the bed. Results show that the size and density of the bed make it suitable for providing eelgrass donor stock while also serving as a reference area for comparing performance of the Eelgrass Mitigation Site.

3.3.1 Donor Bed

The donor bed is located approximately 1,500 feet southwest of the JCEP Eelgrass Mitigation Site and occupies approximately 18.6 acres of relatively continuous and dense eelgrass (Figure 5). The donor bed was mapped using a georeferenced single beam side scan sonar system deployed off the bow of the *RiverHawk*; bed boundaries were established based on that portion of the eelgrass bed where shoot densities were highest and continuous. Divers from the *Carolyn Dow* collected eelgrass densities by conducting shoot counts along five, approximately 300 foot-long transects distributed throughout the bed, as shown in Figure 5. In total, shoot counts were conducted at 144 quadrat ($0.25m^2$) locations randomly spaced within the 5 transects, as shown in Table 4.

Table 4: Eelgrass density data collected within the selected Donor Bed

Donor Bed Transects	Number of Quadrats	Shoots/m^2
Northwest Transect	27	63.3
South Transect	29	67.7
Center Transect	28	50.0
East Transect	32	35.5
Southeast Transect	28	51.0
Total Number of Quadrats	**144**	
Mean Shoots/m^2		**53.5**

The mean density within the donor bed was calculated at 53.5 shoots/m^2; shoot counts between transects were somewhat variable, ranging from 35.5 to 67.7 shoots/m^2. Divers collected between 27 and 32 quadrats at each transect to obtain a statistical robustness such that mean shoot densities could be statistically compared. Eelgrass shoots were least dense along the northeast margin of the bed (east transect) with average density statistically lower than all other transects. The center and southeast transect were very similar and statistically distinct from the east transect and western margin transects (northwest and south transects). This intermediate density area can be viewed as a transition habitat from the high density areas to the west to the patchy, uneven habitat along the northeast side of the bed. The western margin exhibited the highest eelgrass densities at nearly double the density of the east transect. Eelgrass at this location tended to occur between 0.0 and -4.0 feet MLLW with highest shoot density concentrated between -1.0 feet and -3.0 feet MLLW (Figure 5; Table 3).

USACE guidelines report that no more than 10 percent of shoots from an existing eelgrass bed may be harvested for donor material. This limitation means that only about 0.15 acre (617 m^2) of eelgrass could be harvested from the donor site (the higher the densities of the potential donor bed, the smaller the acreage that would need to be harvested). As a result, donor shoots would need to be harvested from at least 1.5 acres (6,170 m^2) of intact eelgrass at the donor site to meet the transplant needs of the Eelgrass Mitigation Site (transplant needs, densities and methodologies at the Eelgrass Mitigation Site are presented in the CWM Plan [DEA 2018]). At 18.6 acres, the selected bed is of a size that is sufficient to meet the needs of the mitigation site.

Elevations within the Donor Bed are within the range of the proposed elevations that would be created at the JCEP Eelgrass Mitigation Site. In addition, the donor bed is proximal to the mitigation site which will increase the likelihood that the planting stock will be adapted to local environmental conditions.

3.3.2 Reference Site

A suitable reference site, quantitatively delineated (Tier 2), will be needed to provide the basis for measuring eelgrass growth performance, or mitigation success, over time. Optimally, reference sites should be within the general vicinity of the Eelgrass Mitigation Site with similar elevations, salinity regimes, current velocities, light penetration, sediment characteristics, and other water quality parameters that naturally affect eelgrass growth. As described in Section 3.3.1, the donor bed will also serve as the reference site for the Eelgrass Mitigation Site. At 18.6 acres and 1,500 feet from the mitigation site, it is both large enough and proximal to the Site, meeting the requirements of both a donor bed and reference site. The area within this site that will be established as the reference area will be restricted from any harvest of transplant material.

In the event future eelgrass distribution and/or density at the mitigation site declines coincident with measurements of these parameters at the reference site, the mitigation performance standard will be correspondingly adjusted to reflect baseline conditions at the reference site. However, if eelgrass production increases in the future at the reference site, performance of the mitigation site will only be compared to baseline conditions at the reference site established prior to construction, consistent with USACE guidance (USACE 2018b).

3.3.3 Eelgrass Morphological Assessment

Morphologically, eelgrass within the donor bed site had the highest total length per shoot of any of the sites sampled at 5,140.5 mm/shoot ± 638 SE (average aggregate length of all leaves within the shoot). Average width was not significantly different from any of the other sites sampled at 9.2 mm/shoot ± 0.53 SE while leaves per shoot was lower than the eelgrass present in the access channel at 4.2 leaves/shoot ± 0.30 SE. This means that leaves tended to be longer and less numerous which may indicate higher turbidity and lower current velocity conditions.

3.4 JORDAN COVE

Available eelgrass salvaged from the proposed Access Channel prior to dredging will be transplanted to a suitable recipient site. As currently planned, the selected recipient site is the Jordan Cove embayment located 0.5 miles east of the Access Channel. The *Carolyn Dow* conducted a Tier 1 eelgrass survey on September 7, 2018 to carefully delineate the existing eelgrass boundaries so these areas can be avoided during transplantation, and so that monitoring events will only delineate transplants rather than existing eelgrass. In addition, on August 10, 2018 the *RiverHawk* conducted a bathymetric survey within the Cove to identify optimal areas away from existing eelgrass beds to transplant (Figure 6).

3.4.1 Eelgrass Surveys

The *Carolyn Dow* and crew surveyed approximately 3.43 acres of subtidal habitat in the Jordan Cove embayment at the periphery of where existing eelgrass beds. Three general areas were investigated based on bathymetry and the historical occurrence of eelgrass in previous surveys (west, center, and east)

The opening of Jordan Cove has a shallow shoal with a top elevation of approximately +3.0 feet MLLW extending 2,100 feet from east to west. Eelgrass occurs at the edges of the shoal on the north, west, and south sides. Eelgrass on the landward north side of the shoal occurred at a much higher elevation (approximately +2 feet MLLW) than the south main channel side of the shoal (approximately -1 foot MLLW). Adjacent to the shoal on the west side is a shallow tidal channel where eelgrass was found on either side of the channel between 0 and -2 feet MLLW.

The western edge of the shallow shoal was investigated, first without recording data, using underwater video. No eelgrass were observed except at the southeast edge. Subsequently, a formal Method 3 survey was initiated to document eelgrass adjacent to the shoal. Approximately 0.28 acres of eelgrass was observed over a very narrow depth range (approximately -1.5 to -2.0 feet MLLW). Eelgrass observed via video was very patchy in distribution.

Along the western edge of the shoal, there appeared to be a natural break in eelgrass coverage based on the 2016 SSNERR data set which became the focus of our survey. Approximately 1.5 acres of benthic habitat was surveyed which yielded only 0.26 acres of eelgrass coverage concentrated at the south edge. Eelgrass observed via video was very patchy in distribution.

On the outer edge of the shoal, a narrower steeper sloped area of approximately 1.0 acres of benthic habitat was surveyed (1,250 by 45 feet). Of that area, only 0.12 acres was covered with eelgrass.

Eelgrass densities were surveyed at both the north and south side of the shoal. As seen in Table 5, eelgrass was denser north of the shoal than south of the shoal. It was also more even and less patchy as evidenced by the number of quadrats taken to maintain statistical power. Also note that the density of the eelgrass north of the shoal was similar to that measured within the Access Channel.

Table 5: Eelgrass density data collected within Jordan Cove

Jordan Cove Bed Transects	Number of Quadrats	Shoots/m^2
North Transect	24	55.0
South Transect	30	46.8
Total Number of Quadrats	**54**	
Mean Shoots/m^2		**50.4**

3.4.2 Bathymetry

Bathymetric survey results along with the above described underwater videography confirm that the Jordan Cove embayment is very shallow and dominated by sandy sediments. As reported, an elevated shoal is present along much of the eastern half of the outer bay with maximum elevations of approximately +3 feet MLLW. Much of the eelgrass within the bay is situated along the landward edge of this shoal at relatively high elevations of between 0 feet and +3 feet MLLW, with most along the +2 foot MLLW contour. Landward of the shoal within the mid-bay, elevations deepen slightly to between 0 and +2 feet MLLW. A broad inner flat with an elevation of +2 feet MLLW is largely unvegetated and exists within mid-bay reaches. The waterward edge of the outer shoal deepens rapidly as the main channel is approached. As noted in Section 3.4.1, eelgrass in this region is patchy and in a narrow sparse band (Figure 6).

3.4.3 Potential Transplant Recipient Sites

Dr. Jason Stutes and DEA selected potential transplant recipient sites based on the elevation of existing eelgrass and the pattern of eelgrass distribution within Jordan Cove. As reported, most existing eelgrass was relatively high in elevation, with most between the +1 and +2 foot MLLW contours; however, there was no eelgrass on the + 2 foot MLLW broad mid-bay flat within middle reaches of the Cove (Figure 6). It is not known why eelgrass is not present in this area, despite elevations where it is prevalent, but there is an apparent preference along the inner and outer edges of the outer shoal. This distributional preference, as well as a lack of eelgrass within inner portions of the bay, has been observed in multiple eelgrass surveys conducted since 2005. Transplant survival will likely be higher if this distributional trend is followed. Consideration was also given to areas on the main channel side of the outer shoal. Here, elevations where eelgrass was found were in a narrower band because slopes steepen approaching the main channel. During 2018 surveys, eelgrass was sparse and patchy. In this area, underwater video also showed the presence of sand waves on surface sediments, suggestive of higher tidal water velocities mobilizing sediments in the area. Water velocities greater than optimal for eelgrass may be the reason for the patchy distribution along the outer edge of the shoal and provides some doubt that transplant survival will be acceptable in this area.

Taking these observations into account, two areas were selected along the west side of the outer shoal to transplant eelgrass from the proposed Access Channel. The first is a broad square-shaped polygon at the end of the existing eelgrass bed along the landward side of the outer shoal. This area occupies elevations between +1 foot and +2 foot MLLW, similar to existing eelgrass in the Cove. The area occupies approximately 1.3 acres. The second proposed eelgrass recipient area occupies a rectangular polygon farther west and occupies approximately 0.9 acres. This area is somewhat deeper, at elevations between 0 and -2 feet MLLW, but is well within elevations of eelgrass in this portion of Coos Bay and in particular, the Access Channel (Figure 6). This polygon may be adjusted by field personnel upon further examination of the habitats along the shoreline. The two areas combined provide sufficient area to receive eelgrass salvaged from the Access Channel.

3.5 KENTUCK TEMPORARY DREDGE PIPELINE ALIGNMENT

3.5.1 Eelgrass Survey

The original alignment of the Temporary Dredge Material Transfer Pipeline between APCO and Kentuck Inlet used eelgrass data from EPA (2005) to avoid impacts to substantial areas of eelgrass. Eelgrass surveys conducted in 2018 were used to update the current distribution of eelgrass in the vicinity of the current alignment, confirm the alignment avoids direct impacts to eelgrass, and inform design engineers of any additional environmental requirements. On September 8, 2018, a Tier 1 eelgrass survey was conducted with georeferenced underwater video aboard the *Carolyn Dow* within the buffer of the existing transfer pipeline along its entire alignment. A single Tier 2 survey transect was performed near the beginning of the alignment where eelgrass coverage was most continuous.

The *Carolyn Dow* and crew surveyed approximately 20.72 acres of subtidal habitat east of North Point, around Glasgow Point, into Kentuck Inlet. Survey transects were approximately 30 feet apart and were broken up into three general segments of the transfer pipeline alignment (northwest, center, and southeast). These segments were investigated based on the proposed alignment and the historical occurrence of eelgrass based on previous surveys.

The northwest segment of the alignment starts at the edge of the navigation channel offshore of the APCO sites. The survey started at the top edge of the navigation channel and immediately encountered eelgrass (Figure 7). The decision was made to delineate the north/south extent of this eelgrass to determine if there was a gap in coverage. The eelgrass was determined to be continuous north of the alignment, but became patchier south of the alignment. Eelgrass became absent approximately 290 feet south of the proposed alignment. As DEA continued the survey along the northwest segment, eelgrass coverage varied between patchy to continuous. No eelgrass free path was apparent for the northwest segment of the dredge pipeline alignment in the area surveyed except for the area south of the beginning of the proposed alignment. Eelgrass did become patchier as the survey continued east passed the midpoint.

A single Tier 2 density transect was performed to determine density in the area. This transect targeted the beginning of the northwest segment of the Tier 1 survey (Figure 7). The surveyed yielded an average density of 36.4 shoots/m^2 ± 2.19 SE from 32 quadrat samples. The number of quads and variability indicates that density varied within the bed along the transect.

The center segment of the survey began by turning southeast and was surveyed for approximately 1,350 feet over several parallel transects. Eelgrass coverage was much diminished compared to the northwest segment. Only isolated patches occurred throughout the segment. Several areas of oyster culturing were within the survey area. Numerous PVC poles were present which presumably marked active oyster beds. Also noted were several areas of high density oyster culture subtidally while surveying for eelgrass.

The final southeast segment began as the alignment turned east toward Kentuck Inlet. This segment of the alignment was surveyed for approximately 2,200 feet over several parallel transects. At 640 feet from the beginning of the transect, a continuous eelgrass bed of approximately 0.42 acres in size was encountered.

The lateral extent of this eelgrass bed was not fully delineated and is likely larger. Beyond this point, eelgrass that was encountered showed two distinct forms, larger less dense shoots mixed with a dense, short leafed variant. The shorter leafed variant was later positively identified as *Zostera japonica*. This portion of the area surveyed is suspected to have a mix of the two species where eelgrass is encountered (Figure 7).

3.5.2 Eelgrass within the Existing Alignment

In general, there was more eelgrass present than was expected along the proposed alignment, especially along the northwestern segment nearest to the APCO Sites. Attempts to find a clear path through the eelgrass suggested that the beginning of the alignment should shift south to avoid the near continuous bed present at the eastern edge of the navigation channel. Patchy eelgrass dominated the remaining portion of the northwestern segment. The center segment of the survey had very little eelgrass, mainly isolated patches that could be avoided. This result is complicated by the observation of active aquaculture existing in this area. The first half of the southeast segment had one continuous eelgrass bed located toward the center of the segment. All eelgrass noted in this was *Z. marina*. The second half of the segment had distinct mixed (both *Z. marina* and *Z. japonica*) eelgrass patches located just outside Kentuck Inlet (Figure 8). It is suspected that eelgrass dominance will likely shift to *Z. japonica* where eelgrass occurs upon entering Kentuck Inlet, given its shallow nature.

Modifying the current alignment to take a more southerly route at the northwestern insertion is recommended, if possible, as it crosses the navigation channel. Observations by field crew from the deck of the *Carolyn Dow* indicates that eelgrass coverage of the general area is patchy, but expansive. To minimize impacts to eelgrass within this relatively expansive area of eelgrass it is recommended that additional low tide surveys be conducted using a drone to finalize an alignment. Eelgrass at the northwestern segment, if it remains continuous, may need to be carefully crossed. Given the narrow extent of this eelgrass band, laying the temporary dredge material transfer pipeline over existing eelgrass with minimal disturbance will impact a relatively small area of the resource.

3.6 APCO NEARSHORE

DEA conducted a bathymetric survey of the APCO nearshore on August 28, 2018 aboard the *RiverHawk* to determine shallow water bathymetry in relation to existing eelgrass resources. The survey was conducted in an effort to determine whether existing eelgrass is limited by optimal elevations in which eelgrass can grow and whether the area can be used as an alternative mitigation site for JCEP.

Figure 9 presents a 2018 bathymetric map with DEA 2017 eelgrass survey data within the APCO nearshore. Bathymetry is characterized as a relatively narrow intertidal shelf followed by a steep dropoff into the Coos Bay main channel. In 2017, a relatively continuous band of eelgrass was documented between elevations of approximately 0 feet and -6 feet MLLW, with the majority occurring between -1 and -3 feet MLLW. On the west side of the site, this band was determined to be up to approximately 250 feet wide between elevations of 0 feet and -6 feet MLLW. The grade within the lower intertidal and shallow subtidal zones was flattest in this area. On the east side of the site, the eelgrass distribution became much narrower (less than 50 feet wide), most of which was located at depths of between -2 feet and -3 feet MLLW. Bathymetry drops relatively steeply beyond -2 feet MLLW. At the time of the survey, no eelgrass was observed above 0 feet MLLW along the entire length of the site.

Bathymetry data and eelgrass presence indicates that most all of the usable habitat is occupied by existing eelgrass beds. For reasons that are not known, eelgrass does not appear to inhabit areas higher in the intertidal zone (+1 to +3 feet MLLW) like that observed in other areas of Coos Bay. These areas would be available as potential transplant sites, but the lack of existing eelgrass at these elevations suggests that transplants may not have acceptable survival rates. In contrast, offshore areas below -3 feet MLLW drop off rather steeply to the main channel, limiting further offshore expansion.

These data indicate that optimal elevations and habitats for eelgrass in the APCO nearshore is near fully utilized by existing eelgrass resources. DEA has concluded that significant eelgrass transplantation and survival would be unlikely in this area; hence is not recommended as an alternative eelgrass mitigation site.

3.7 SORA EELGRASS MITIGATION SITE

In 1988, SORA extended Runway 4/22 into Coos Bay, which eliminated existing intertidal and eelgrass habitat. As compensatory mitigation for this runway extension, SORA excavated a nearby existing dredge spoil island by creating elevations optimal for eelgrass growth. Subsequently, eelgrass was transplanted onto the recontoured island in 1989 (M&N 2018). A review of DSL records shows a site visit by DSL staff in 1997 noting the success of eelgrass establishment at the site. The baywide eelgrass surveys by EPA and SSNERR have also documented eelgrass at the site (additional site monitoring discussion provided in Section 3.7.4). Despite this, the USACE considers the site to have extensive burial problems, such that the project has not met compensatory mitigation requirements. The USACE views this project, and its similarities to the JCEP Eelgrass Mitigation Site, as evidence that the JCEP Site may not remain viable in the long-term eventually and fail to meet its compensatory mitigation requirements (USACE 2018a).

For these reasons, the *RiverHawk* conducted a bathymetric survey on August 30, 2018 and the *Carolyn Dow* conducted a Tier 1 eelgrass survey on September 9, 2018 to estimate the excavation prism and determine the current eelgrass resource within the mitigation site. These data were used, in part, to address USACE reservations regarding the potential for success of the JCEP Eelgrass Mitigation Site.

Overall, the 2018 eelgrass and bathymetric surveys show that the SORA Mitigation Site has successfully met compensatory mitigation requirements for eelgrass.

3.7.1 Eelgrass Survey

The *Carolyn Dow* and crew surveyed approximately 12.66 acres of subtidal habitat northwest of the current SORA runway (Figure 10). The *Carolyn Dow* approached the survey area from the north gaining access through a tidal channel. Survey transects, aligned approximately 30 feet apart, were first oriented along the long axis of the survey area with a second set oriented perpendicular to the long axis to maximize survey resolution.

Eelgrass was noted on the shoal outside of the survey area and within the entrance tidal channel of the survey area. This was consistent with the SSNERR (2016) survey results. It was obvious through the bathymetric and video surveys that a majority of the survey area occurred within a depression with distinct sidewalls. This appears consistent with the understanding that the depression was created by excavation methods. The surrounding tideflat outside of the depression was situated at approximately +2 feet MLLW with the base of the depression ranging from -1 to +1 foot MLLW. Approximately 6.83 acres of eelgrass was mapped within the assumed SORA Mitigation Site (Figure 10). Eelgrass was continuous throughout its coverage (i.e. no patchiness).

Eelgrass densities were surveyed at two locations near the center of the bed (north and south transects). As seen in Table 6, eelgrass density was remarkably similar between the transects (Table 6). Statistical analysis confirms that the average estimates were not statistically different from one another ($P = 0.5$). This average density is within the range presented for the center and southeast transects of the proposed Donor Bed/Reference Site and lower than the existing average shoot density recorded for the Access Channel site.

Table 6: Eelgrass density data collected within SORA mitigation site

SORA Mit. Bed Transects	Number of Quadrats	Shoots/m^2
North Transect	31	47.4
South Transect	32	45.1
Total Number of Quadrats	**63**	
Mean Shoots/m^2		**46.2**

3.7.2 Eelgrass Morphological Assessment

Eelgrass at the SORA Mitigation Site had an average total length/shoot of 3,066.7 mm/shoot ± 431 SE (average aggregate length of all leaves within the shoot) which is intermediate relative to the sites examined. Average shoot width was 10.66 mm/shoot ± 0.6 SE while average leaf abundance was 4.25 leaves/shoot ± 0.8 SE which was very similar to the Access Channel site, but lower than the Reference/Donor site. This suggests that the population may experience relatively clear water but potentially lower current velocities. In many ways, the character of the eelgrass beds at the SORA Mitigation Site more closely resembled the Access Channel eelgrass as oppose to the relatively close by Reference/Donor site.

3.7.3 Bathymetry

The SORA Mitigation Site is a relatively narrow lower intertidal channel between two higher elevation sandy shoals. Elevations within the Site range from approximately +3 feet to -1 foot MLLW with most of the area (approximately 7 acres) between +1 and -1 foot MLLW (Figure 10). The +1 foot MLLW contour extends over the length of the site, with the north end deepening to -1 foot MLLW providing a narrow channel for water exchange.

3.7.4 Mitigation Site Success/Failure

For the extension of Runway 4/22 at SORA (then called the North Bend Municipal Airport), the USACE (Permit No. 071-OYA-2-006326) and ODSL (Permit No. RF-4460) required the creation of approximately 0.6 acres of saltmarsh and 5.0 acres of eelgrass to compensate for lost intertidal and eelgrass habitat (CH2M Hill 1990a). DEA was unable to acquire construction drawings for the SORA Eelgrass Mitigation Site with the exception of a few sketches and concept drawings. The Site is located at a former dredge spoil island to the immediate north and west of the new runway. The island was excavated to provide fill for the runway extension and was re-graded to create a new intertidal zone at optimal elevations for eelgrass. Both eelgrass transplantation and areas intended for natural colonization were a part of the mitigation site. Concept sketches show that 4.85 acres of the excavated and graded area was planted with eelgrass and an additional 3.2 acres were graded to elevations that would naturally recruit eelgrass resulting in a total of 8.1 total acres.

Monitoring in 1989 and 1990 showed an approximate three-fold increase in eelgrass density at 3 of 4, 0.25 acre transplanted plots within the Site. The fourth plot showed lower densities during this period, attributed to substrate instability and sedimentation. Mean elevations at the 4 plots in 1989 ranged from -0.3 feet to -2.2 feet MLLW, with slightly lower elevations measured in 1990, except for the one plot where sedimentation was apparent (CH2M Hill 1990b). DEA could not identify additional monitoring reports beyond 1990, but site visit notes taken by ODSL in 1997 indicated that eelgrass was present and the original plots were identified on the site. ODSL concluded that eelgrass mitigation was apparently successful, though no quantitative monitoring was undertaken at that time (McCabe, M., site visit notations and photographs for R/F Permit No: 4460, April 1997).

DEA eelgrass and bathymetric surveys conducted in August and September 2018 indicate that 29 years after the original eelgrass transplants, relatively dense and continuous eelgrass is still present within the original site boundaries. As reported, eelgrass occupies 6.83 acres within the site. Two, 300 foot transects taken within central portions of the site show moderately dense eelgrass with mean densities of 47.4 and 45.1 shoots/m^2 (Table 6). This is well in excess of the mean of 10.7 shoots/m^2 found in 1990 after one year of growth (CH2M Hill 1990b).

Bathymetric data in 2018 indicates that some filling has occurred. The lowest elevations within the mitigation site are currently at -1 foot MLLW, while the lowest elevation reported in 1990 was -2.6 feet MLLW. As built construction drawings were not available to make direct comparisons, but the original permitting documents reported that a total of 8.1 acres was originally slated for either eelgrass transplantation or graded for natural colonization. This information and data may be the reason why the USACE considers the site to have burial issues. However, a robust eelgrass bed has largely colonized the entire mitigation site at the +1 foot MLLW contour and lower (Figure 8). The current total area of 6.83

acres of eelgrass coverage also exceeds the original permit requirement of 5.0 acres thirty years after the permit was issued.

The 2018 data indicate that the SORA Mitigation Site has successfully met compensatory mitigation requirements for eelgrass. Dynamic estuarine processes that are present within Coos Bay were expected to modify the site somewhat over time; however, the degree of eelgrass coverage documented after nearly three decades has shown a long-term resilience. Contrary to comments by the USACE, these data provide quantitative evidence that proposed activities at the JCEP Eelgrass Mitigation Site will likely not be subject to long-term burial issues. In addition, these data results are consistent with sediment transport modeling (M&N 2018b; CHE 2014) and historical geomorphic analyses presented in the JCEP CWM Plan that show there are no apparent estuarine processes that would cause long-term burial. Hydrodynamic modeling and review of historic aerial photographs indicate the processes that likely created the original shoal have been substantially altered or blocked by the new runway (DEA 2018; Appendix D [M&N 2018a]).

4. *SUMMARY CONCLUSIONS AND PATH FORWARD*

4.1 SUMMARY AND CONCLUSIONS

Results of the 2018 eelgrass investigations surveyed a combined total of 56 acres of benthic habitat with 14.21 acres of eelgrass delineated to at least the Tier 1 standard. In the process of surveying the area, DEA determined the following:

- Historical eelgrass data show a high degree of variability over time in the surveyed portions of Coos Bay; some areas of eelgrass coverage have contracted over time, though others areas appear to have similar distributions or have expanded.
- Eelgrass that would be at risk from proposed dredging and construction of the JCEP Access Channel was determined to extend over 2.26 acres. This eelgrass acreage and distribution was the same as was determined in 2017, despite using different survey methods (single beam side scan sonar in 2017 and georeferenced underwater video in 2018). In 2018, quantitative Tier 2 eelgrass surveys were conducted for the first time revealing the presence of moderately high and uniform densities at the Site.
- The JCEP Eelgrass Mitigation Site has no large areas of eelgrass within the proposed excavation and grading boundaries (i.e, one small patch of 597 square feet was identified; 0.014 acre). This was confirmed by both side scan sonar and georeferenced underwater video in 2018. Compared with historical survey data collected since 2005, eelgrass distribution appears to have contracted at this site. Survey data over time is somewhat contradictory, with different surveys showing different degrees of eelgrass intrusion within Site boundaries. However, DEA surveys have not documented significant eelgrass within the Site boundaries since 2010 based on three separate surveys. Only one survey conducted by SSNERR in 2016 detected a significant amount of eelgrass within the site boundary.
- Investigations in 2018 identified and delineated a large and continuous nearby eelgrass bed, southwest of the Eelgrass Mitigation Site that is suitable as both a Reference Site and Donor Bed. Quantitative Tier 2 surveys have determined that there is adequate acreage and donor stock to transplant to the JCEP Eelgrass Mitigation Site. Adequate metrics (area, density, morphology) have been collected at the impact, donor, and salvage sites to track mitigation success over time.
- Eelgrass and bathymetry surveys at the Jordan Cove embayment show continuous to semi-continuous eelgrass between elevations of approximately -2 feet and +2 feet MLLW, most along the edges of an intertidal shoal located in outer portions of the cove. Surveys conducted in 2018 identified two areas within the cove that are at suitable elevations and large enough to relocate salvaged eelgrass from the proposed Access Channel.
- The alignment of the Kentuck Temporary Dredge Material Transfer Pipeline was surveyed revealing the presence of a greater area of eelgrass coverage and distribution than anticipated. Adjustment to the alignment will be investigated during the design development process to assess alternative alignments that could avoid or minimize direct impacts to eelgrass, particularly near the APCO Dredge Disposal Site where eelgrass is relatively continuous along the edge of the

navigation channel. Significant eelgrass resources were also identified near the alignment just outside of Kentuck Inlet; alignment adjustments also will be investigated for this area.

- Bathymetric investigations at the APCO nearshore found that existing eelgrass occupies nearly all optimal habitats. Nearshore elevations drop steeply into the main channel. For these reasons, DEA does not recommend the area as an alternative eelgrass mitigation site.
- Eelgrass and bathymetry investigations in 2018 indicate a substantial, healthy, and continuous eelgrass bed within the SORA Eelgrass Mitigation Site, first excavated in 1988 and planted in 1989. Eelgrass occupies nearly the entire area between elevations of +1 foot and -1 foot MLLW, nearly 30 years after the mitigation site was created. Though some filling has occurred, the current acreage of eelgrass surpasses the original permit requirements, indicating that the site has met its compensatory mitigation requirements. The site does not provide scientific evidence that long-term longevity or burial will be an issue at the JCEP Eelgrass Mitigation Site.
- Eelgrass morphological assessments conducted at the proposed Access Channel, Donor/Reference Site, and SORA Mitigation Site show relatively long leaves between 2 and 4 feet in length. Substantial differences were not observed between the three areas, suggesting relatively similar environmental conditions. In general, the long and wide leaves suggest that currents in the habitats are lower and surface waters more turbid, which is consistent with the relatively shallow depths at which eelgrass is found in Coos Bay. There were, however, small scale differences between sites that might indicate small regional variation in conditions, especially in tidal current velocities. The long and numerous leaves also suggests that the eelgrass shoots are producing leaves over the entire growing season with leaf shedding likely dominated by senescence as oppose to wave action or currents. The resultant in-water eelgrass canopy in continuous beds and the shade it produces may be a limiting factor in controlling overall shoot density.

4.2 PATH FORWARD

Eelgrass and bathymetric surveys conducted in 2018 provide supplemental information necessary for updating the eelgrass sections of the CWM Plan (Rev H) responding to comments and data requests from the USACE and ODSL, and furthering permitting and mitigation design. DEA recommends the following as next steps in the eelgrass mitigation process:

- Engage JCEP Environmental and Engineering Leads to discuss the implications of survey results to project design and permitting. Further refine the permitting schedule and develop specific milestones for progress. Develop/update permitting strategy for eelgrass mitigation.
- Develop a comprehensive planting plan with the objective of gaining approval from ODSL, USACE, and other interested agencies. Another objective will be to provide sufficient detail to enable a further refinement of costs. The planting plan will cover all aspects of proposed eelgrass mitigation:
    - Harvest from the proposed donor bed including harvest techniques, eelgrass processing, holding times, and vessel and personnel requirements

  - Transplantation to the Eelgrass Mitigation Site including transplantation techniques, holding times, transplant locations, and initial transplantation densities
  - Eelgrass salvage from the proposed Access Channel including vessel and equipment used to successfully remove large areas of eelgrass efficiently and maintain survival, salvage sequencing
  - Transplantation to recipient sites in Jordan Cove including planting densities and GPS measurement guidelines
  - Transplantation schedules and seasons
  - Monitoring schedules and performance criteria
  - Defining Adaptive Management
- Use existing eelgrass and bathymetry data to bring the Eelgrass Mitigation Site to the 75% design level and beyond
- Engage the ODSL and USACE on final JCEP mitigation design
  - Discuss design, monitoring requirements, performance criteria, and adaptive management
  - Discuss SORA mitigation success and lessons learned
  - Discuss/negotiate any further agency requirements
- Concurrently engage the Coquille Indian Tribe and other area tribes with jurisdiction

5. *PREPARERS AND CONTRIBUTORS*

Jim Starkes, DEA Senior Biologist and Jason Stutes, PhD, GeoEngineers Senior Eelgrass Ecologist were the primary authors of this report. Nick Lesnikowski, DEA Senior Geophysicist and Victoria Price-Doucet, DEA Senior Oceanographer conducted field activities or post-processing of bathymetry and eelgrass data. Sean Sullivan DEA Project Manager, Ethan Rosenthal, DEA Ecologist, and Mike Wert, DEA Senior Biologist conducted QA review. Shay Witten, DEA Project Assistant, prepared report drafts. Sara Gilbert, DEA GIS Manager and Lydia Baldwin, GeoEngineers GIS Specialist prepared geo-referenced eelgrass habitat maps and graphics.

6. *LITERATURE CITATIONS*

Coast and Harbor Engineering (CHE) 2014. Technical Memorandum. Evaluation of Stability of Subgrade Material for Proposed Eelgrass Mitigation Site at North Bend Airport. Prepared for David Evans and Associates and Jordan Cove LNG. August 2014.

CH2M Hill 1990a. North Bend Airport Runway Extension Status Report. Prepared for the City of North Bend, Oregon. March 1990

CH2M Hill 1990b. Mitigation Monitoring Report Technical Memorandum. Prepared for the City of North Bend, Oregon. July 1990.

David Evans and Associates (DEA) 2018. Jordan Cove Energy Project and Pacific Connector Gas Pipeline Project. Compensatory Wetland Mitigation Plan, Rev H. Prepared for Jordan Cove LNG. J1-000-TEC-PLN-DEA-00002-00.

David Evans and Associates (DEA) 2017. 2017 Jordan Cove Eelgrass Mapping Hydrographic Survey Report. Prepared for Jordan Cove LNG. September 2017.

David Evans and Associates (DEA) 2014. DEA hydrographic (side scan sonar) eelgrass survey meta data.

David Evans and Associates (DEA) 2010. DEA hydrographic (side scan sonar) eelgrass survey meta data.

David Evans and Associates (DEA) 2007. DEA hydrographic (side scan sonar) eelgrass survey meta data.

Kuo, J.; den Hartog, C. (2007). Seagrass morphology, anatomy, and ultrastructure, *in*: Larkum, A.W.D. *et al.* (Ed.) *Seagrasses: biology, ecology and conservation.* pp. 51-87 In: Larkum, A.W.D.; Orth, R.J.; Duarte, C.M. (Ed.) (2006). Seagrasses: biology, ecology and conservation. Springer: Dordrecht. ISBN 1-4020-2942-X. XVI, 691 pp.

Moffatt & Nichol (M&N) 2018a. Eelgrass Site Geomorphic History and Analysis. Technical Memorandum prepared for Jordan Cove LNG. J1-740-TEC-TNT-DEA-00002-00.

Moffatt & Nichol (M&N) 2018b. Hydrodynamic Analysis Memorandum. Rev 0. November 8, 2018. J1-000-MAR-TNT-DEA-00008-00.

Oregon Department of State Lands (ODSL) 2018. Removal-Fill Permit Application, Rev F. Prepared for the Oregon Department of State Lands. November 6, 2018.

South Slough National Estuarine Research Reserve (SSNERR) 2017. Orthophotography and eelgrass feature extraction technical data Report – Revised.

South Slough National Estuarine Research Reserve (SSNERR) 2016. SSNERR remote sensing eelgrass survey meta data.

Thom, R.M. *et al.* 2003. Factors influencing spatial and annual variability in eelgrass (*Zostera marina*) meadows in Willapa Bay, Washington, and Coos Bay, Oregon, estuaries. Estuaries, Vol. 26, No. 4B, p. 1117-1129, August 2003.

U.S. Army Corps of Engineers (USACE). 2018a. A review of the Jordan Cove Energy Project and Pacific Connector Gas Pipeline Project Compensatory Wetland Mitigation Plan. Prepared by Deborah Nelson, PhD., US Army Corps of Engineers, Seattle District, Seattle, WA.

U.S. Army Corps of Engineers (USACE). 2018b. Components of a complete eelgrass delineation report. U.S. Army Corps of Engineers, Seattle District, Seattle, WA.

U.S. Army Corps of Engineers (USACE). 2016. Components of a complete eelgrass delineation and characterization report. Prepared by the Seattle District, US Army Corps of Engineers, Seattle, Washington.

U.S. Environmental Protection Agency (EPA). 2005. US EPA remote sensing eelgrass survey meta data.

WDFW 2008. Eelgrass/Macroalgae Habitat Interim Survey Guidelines. Prepared by the Washington Department of Fish and Wildlife

7. *APPENDIX A - FIGURES*

Figure 1. 2018 Site Locations

Figure 2. 2018 Eelgrass Distribution Within The Access Channel

Figure 3. Jcep Eelgrass Mitigation Site And 2018 Eelgrass Distribution And Bathymetry

Figure 4. Jcep Eelgrass Mitigation Site Eelgrass Distribution – 2005 To 2018

Figure 5. Jcep Referred Eelgrass Donor/Reference Bed

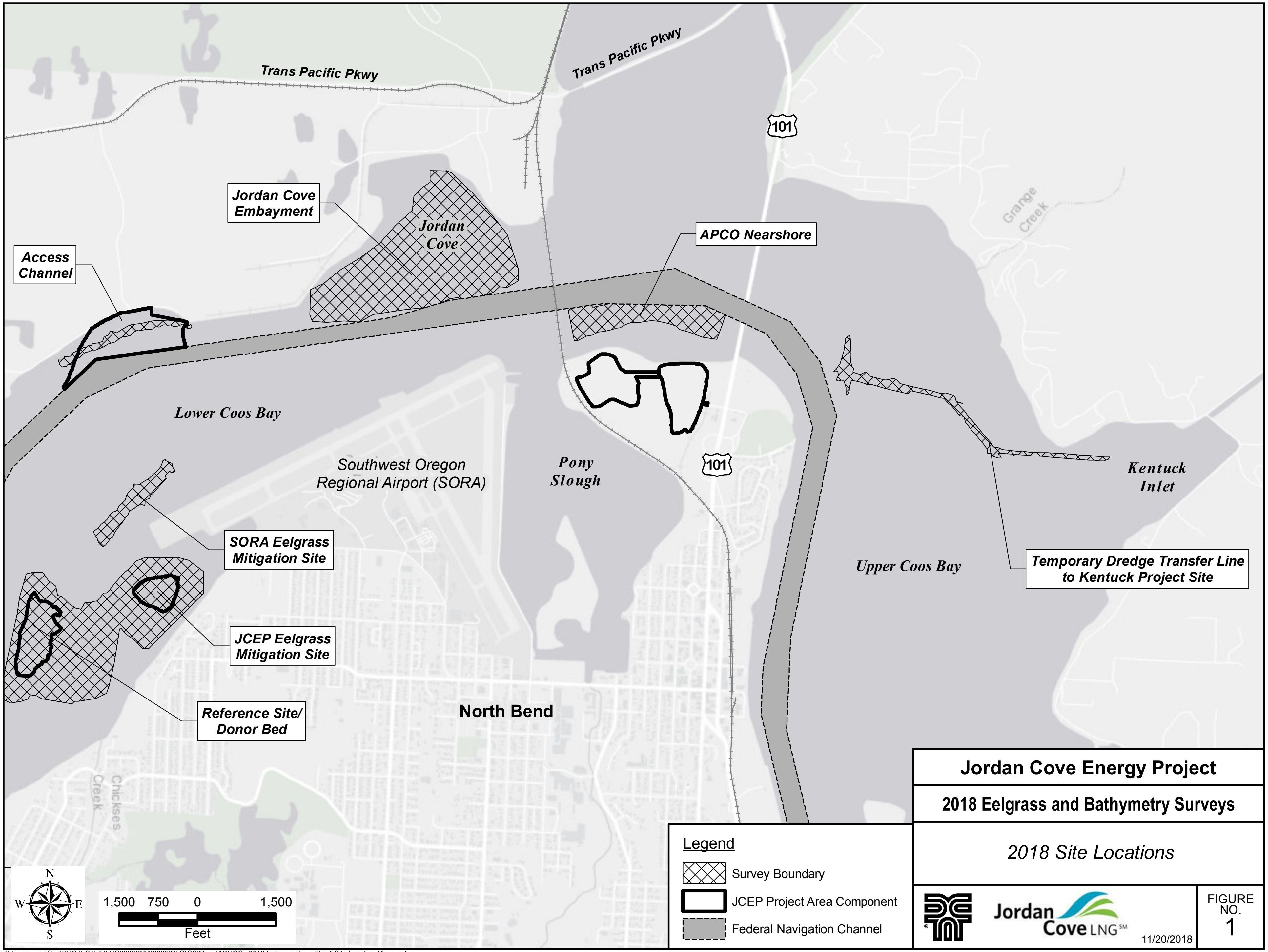
Figure 6. Eelgrass Distribution In Jordan Cove And Proposed Eelgrass Transplant Recipient Sites

Figure 7. Eelgrass Distribution In The Vicinity Of The Proposed Temporary Dredge Transfer Line

Figure 8. Area Of Mixed Eelgrass – Z. Marina And Z. Japonica Near Kentuck Inlet

Figure 9. Apco Nearshore Bathymetry And Existing Eelgrass Resources

Figure 10. 2018 Eelgrass Distribution Within The Sora Eelgrass Mitigation Site


Trans Pacific Pkwy
Trans Pacific Pkwy
101
Jordan Cove Embayment
Jordan Cove
Access Channel
APCO Nearshore
Grange Creek
Lower Coos Bay
Southwest Oregon Regional Airport (SORA)
Pony Slough
101
Kentuck Inlet
SORA Eelgrass Mitigation Site
Upper Coos Bay
Temporary Dredge Transfer Line to Kentuck Project Site
JCEP Eelgrass Mitigation Site
Reference Site/ Donor Bed
North Bend
Chickses Creek
Jordan Cove Energy Project
2018 Eelgrass and Bathymetry Surveys
2018 Site Locations
Legend
Survey Boundary
JCEP Project Area Component
Federal Navigation Channel
N
W
E
S
1,500 750 0 1,500
Feet
Jordan Cove LNG℠
11/20/2018
FIGURE NO.
1
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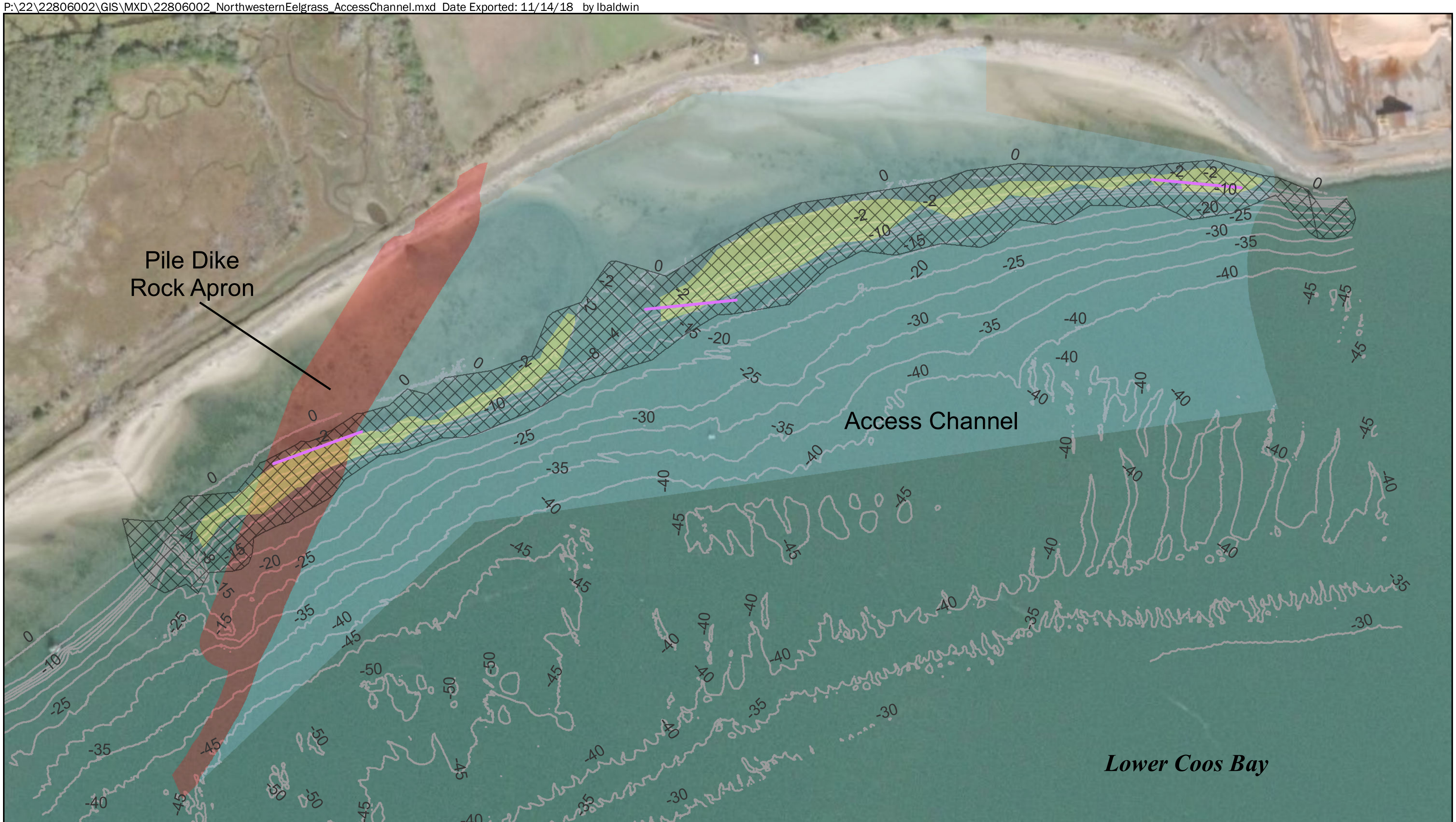

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Data Source: Aerial image from ESRI Data Online.

Projection: NAD 1983 StatePlane Oregon South FIPS 3602 Feet

Legend

- DEA Eelgrass Survey (2018)
- DEA Survey Boundary
- Rock Apron
- Access Channel
- Transect
- Bathymetric Contour (Intl Ft, MLLW)

(0.0 ft MLLW = -0.72 ft NAVD88)

N W E S

100 0 100

Feet

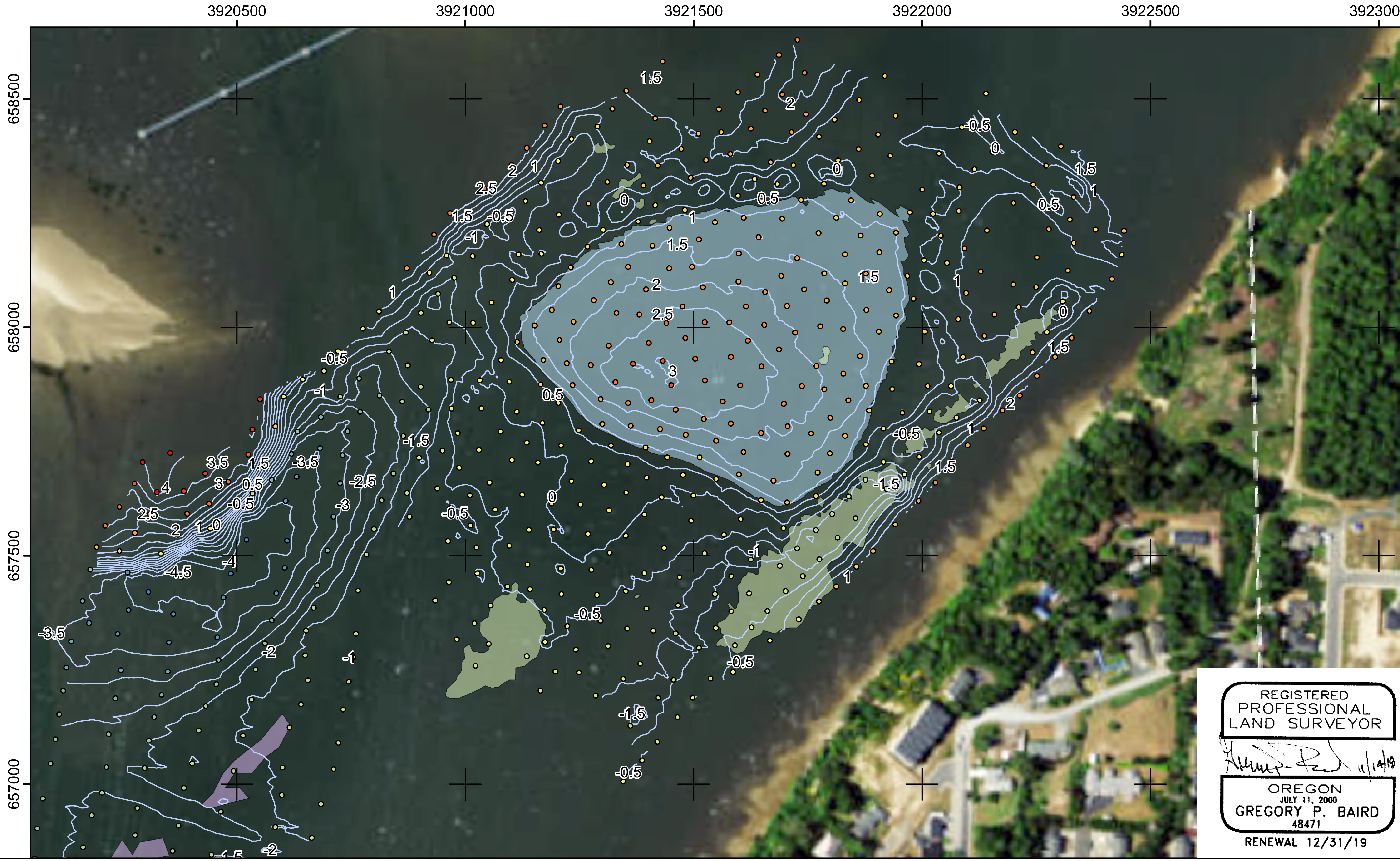
Jordan Cove Energy Project

2018 Eelgrass and Bathymetry Surveys

2018 Eelgrass Distribution within the Access Channel

GeoEngineers Jordan Cove LNG

FIGURE NO.
2



Elevation (feet) (MLLW)

-4.5 - -4.0	-2.5 - -2.0	-0.5 - 0	1.5 - 2.0	3.5 - 4.0
-4.0 - -3.5	-2.0 - -1.5	0 - 0.5	2.0 - 2.5	4.0 - 4.5
-3.5 - -3.0	-1.5 - -1.0	0.5 - 1.0	2.5 - 3.0	
-3.0 - -2.5	-1.0 - -0.5	1.0 - 1.5	3.0 - 3.5	

(0.0 ft MLLW = -0.72 ft NAVD88)

0.5 ft Contour
Oregon South Graticule
Isolated Eelgrass
High Density Eelgrass
Mitigation Site Boundary

N S W E

0 100 200
UNITS IN FEET

JCEP Eelgrass Mitigation Site and 2018 Eelgrass Distribution and Bathymetry

COOS BAY, OREGON

DAVID EVANS AND ASSOCIATES INC
MARINE SERVICES

SURVEY BY:
David Evans and Associates, Inc

DATE OF SURVEY:
August 2018

HORIZONTAL DATUM:
North American Datum of 1983 (NAD83), State Plane Coordinate System, OregonSouth Zone, Intl. Feet

VERTICAL DATUM:
Mean Lower Low Water (MLLW)

THIS HYDROGRAPHIC SURVEY WAS COMPLETED UNDER THE DIRECTION OF A NATIONAL SOCIETY OF PROFESSIONAL SURVEYORS/THE HYDROGRAPHIC SOCIETY OF AMERICA, CERTIFIED HYDROGRAPHER

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NSPS/THSOA CERTIFIED HYDROGRAPHER (206)

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CHECKED:
REVISION NUMBER: 0

SCALE: 1" = 200'

CONTRACT NUMBER:

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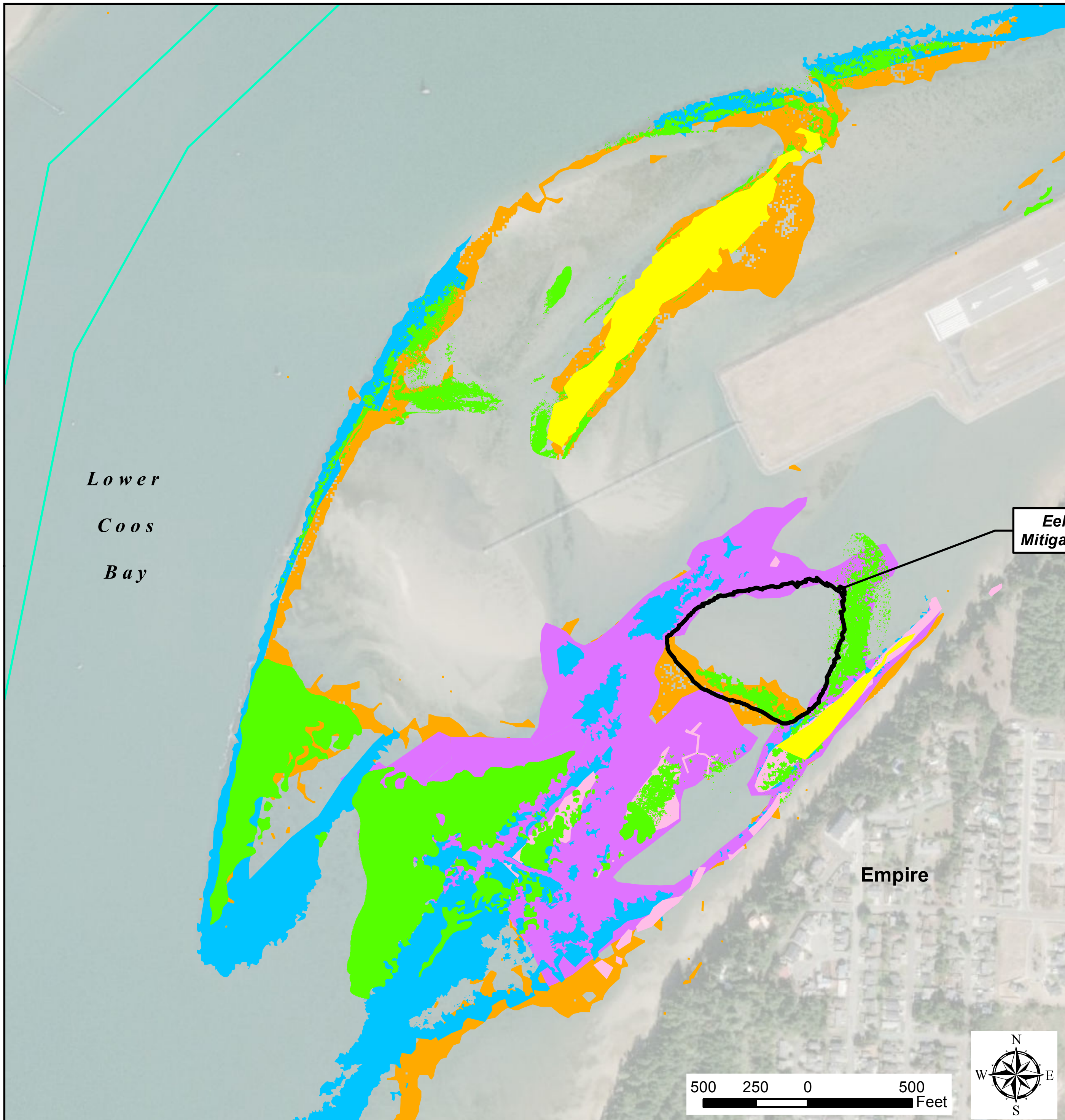
FIGURE
3



Jordan Cove Energy Project

2018 Eelgrass and Bathymetry Surveys

JCEP Eelgrass Mitigation Site Eelgrass Distribution – 2005 to 2018

Jordan Cove LNG℠

11/14/2018

FIGURE NO. 4

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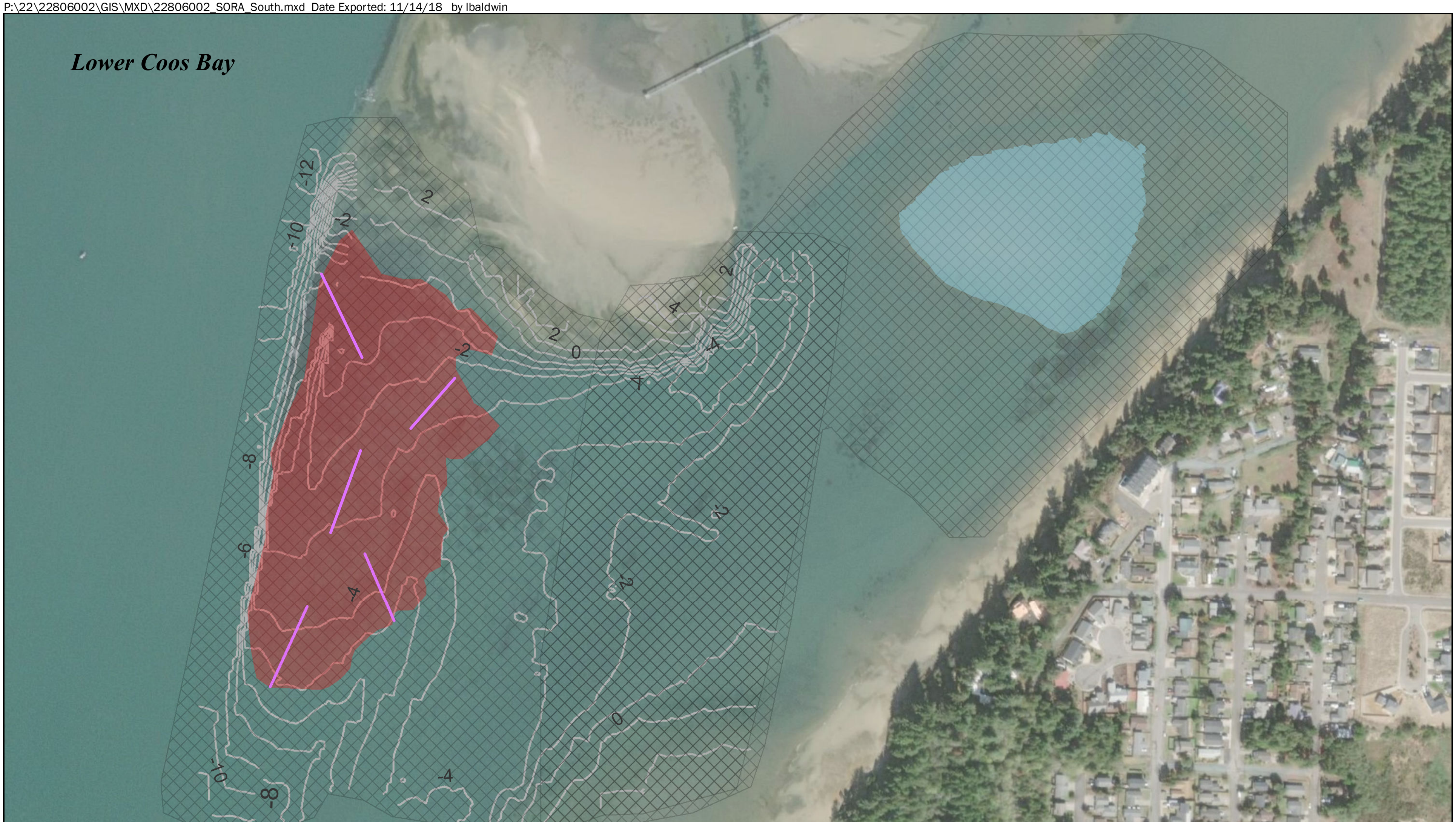

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Data Source: Aerial image from ESRI Data Online.

Projection: NAD 1983 StatePlane Oregon South FIPS 3602 Feet

Legend

- DEA Survey Boundary
- JCEP Eelgrass Mitigation Site
- Donor Bed
- Transect
- Bathymetric Contour (Intl Ft, MLLW) (0.0 ft MLLW = -0.72 ft NAVD88)

N W E S

150 0 150
Feet

Jordan Cove Energy Project

2018 Eelgrass and Bathymetry Surveys

JCEP Preferred Eelgrass Donor/Reference Bed

GEOENGINEERS Jordan Cove LNG

FIGURE NO.
5

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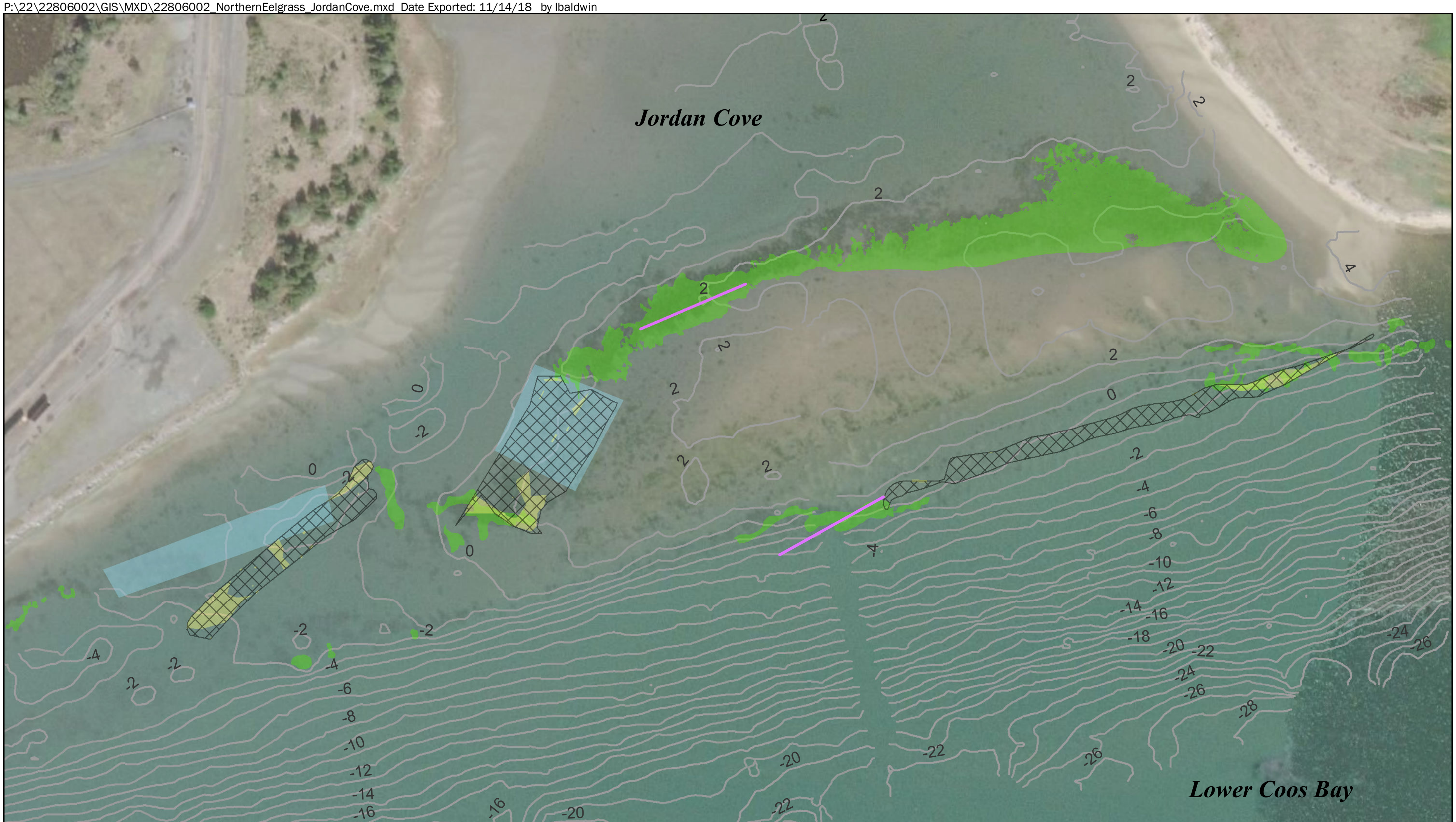

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Data Source: Aerial image from ESRI Data Online.

Projection: NAD 1983 StatePlane Oregon South FIPS 3602 Feet

Legend

- SSNERR Eelgrass Survey (2016)
- DEA Eelgrass Survey (2018)
- DEA Survey Boundary
- Transplant Area
- Transect
- Bathymetric Contour (Int Ft, MLLW) (0.0 ft MLLW = -0.72 ft NAVD88)

N W E S

100 0 100
Feet

Jordan Cove Energy Project

2018 Eelgrass and Bathymetry Surveys

Eelgrasss Distribution in Jordan Cove and Proposed Eelgrass Transplant Recipient Sites

GeoEngineers Jordan Cove LNG℠

FIGURE NO.
6

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Data Source: Aerial image from ESRI Data Online.

Projection: NAD 1983 StatePlane Oregon South FIPS 3602 Feet

Legend

- Transect
- DEA Survey Boundary
- Zostera marina
- Confirmed Z. marina and japonica mix
- Suspected Z. marina and japonica mix
- Dredge Line and Buffer

N E S W

200 0 200
Feet

Jordan Cove Energy Project

2018 Eelgrass and Bathymetry Surveys

Eelgrass Distribution in the Vicinity of the Temporary Dredge Transfer Line to Kentuck

GEOENGINEERS Jordan Cove LNG℠

FIGURE NO.
7

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Data Source: Aerial image from ESRI Data Online.

Projection: NAD 1983 StatePlane Oregon South FIPS 3602 Feet Intl

Legend

- Zostera marina Eelgrass
- Confirmed Z. marina and Z. japonica mix
- Suspected Z. marina and Z. japonica mix
- DEA Survey Boundary
- Temporary Dredge Transfer Line to Kentuck with Buffer

N W E S

50 0 50 Feet

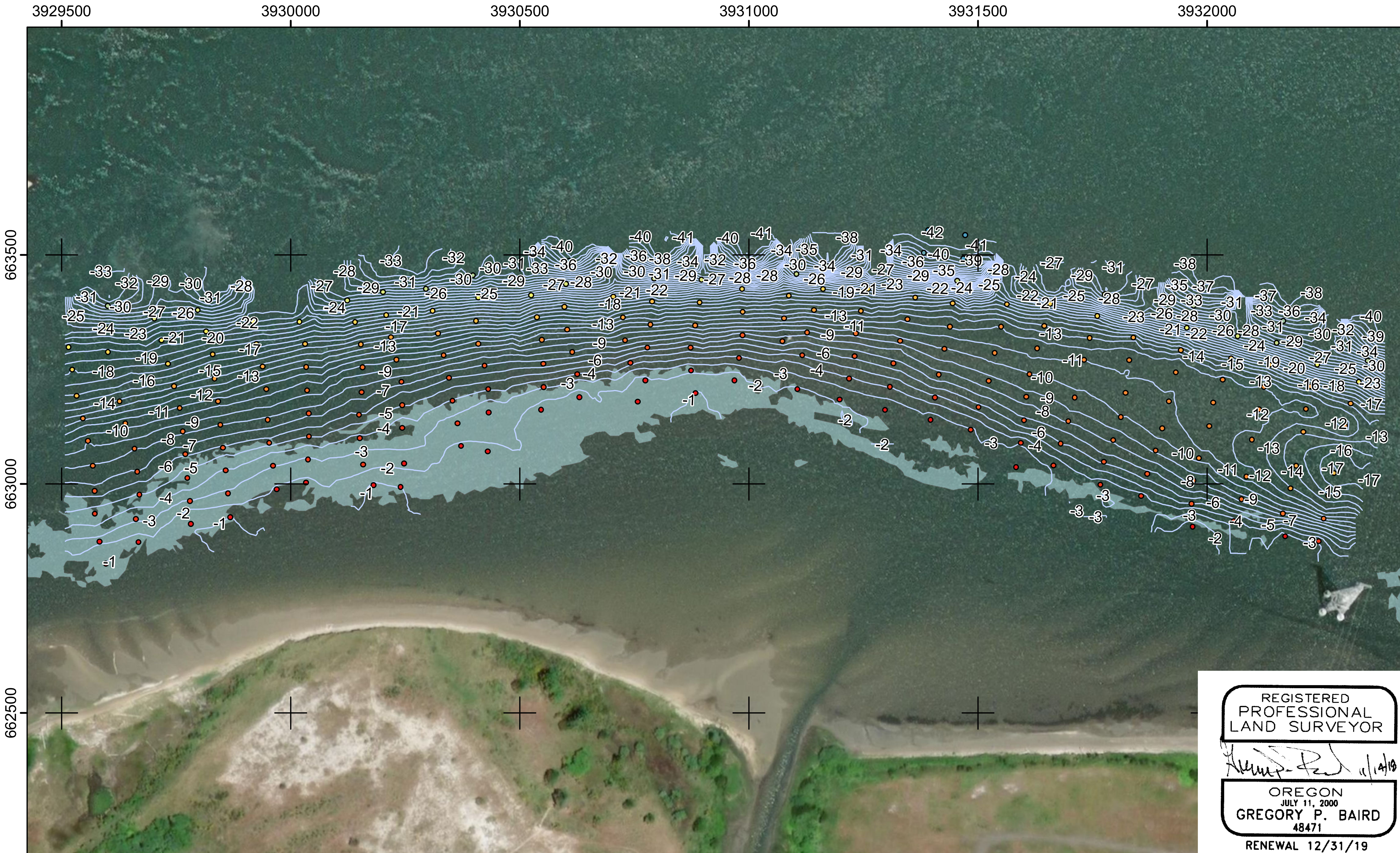
Jordan Cove Energy Project

2018 Eelgrass and Bathymetry Surveys

Area of Mixed Eelgrass - Z. marina and Z. japonica near Kentuck Inlet

GeoEngineers Jordan Cove LNG

FIGURE NO. 8



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OREGON
JULY 11, 2000
GREGORY P. BAIRD
48471

RENEWAL 12/31/19

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(MLLW)

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- -42.5 - -40.0
- -40.0 - -37.5
- -37.5 - -35.0
- -35.0 - -32.5
- -32.5 - -30.0
- -30.0 - -27.5
- -27.5 - -25.0
- -25.0 - -22.5
- -22.5 - -20.0
- -20.0 - -17.5
- -17.5 - -15.0
- -15.0 - -12.5
- -12.5 - -10.0
- -10.0 - -7.5
- -7.5 - -5.0
- -5.0 - -2.5
- -2.5 - -0.8

(0.0 ft MLLW = -0.72 ft NAVD88)

- One Foot Contour
- Oregon South Graticule
- 2017 Eelgrass Boundary

N W E S

0 100 200
UNITS IN FEET

APCO Nearshore Contour Elevation Map and Existing Eelgrass Resources

COOS BAY, OREGON

DAVID EVANS AND ASSOCIATES INC. MARINE SERVICES

SURVEY BY:
David Evans and Associates, Inc

DATE OF SURVEY:
August 2018

HORIZONTAL DATUM:
North American Datum of 1983 with 2011 adjustment (NAD83/11), State Plane Coordinate System, OregonSouth Zone, Intl. Feet

VERTICAL DATUM:
Mean Lower Low Water (MLLW)

THIS HYDROGRAPHIC SURVEY WAS COMPLETED UNDER THE DIRECTION OF A NATIONAL SOCIETY OF PROFESSIONAL SURVEYORS/THE HYDROGRAPHIC SOCIETY OF AMERICA, CERTIFIED HYDROGRAPHER

NICHOLAS LESNIKOWSKI
NSPS/THSOA CERTIFIED HYDROGRAPHER (206)

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FIGURE 9

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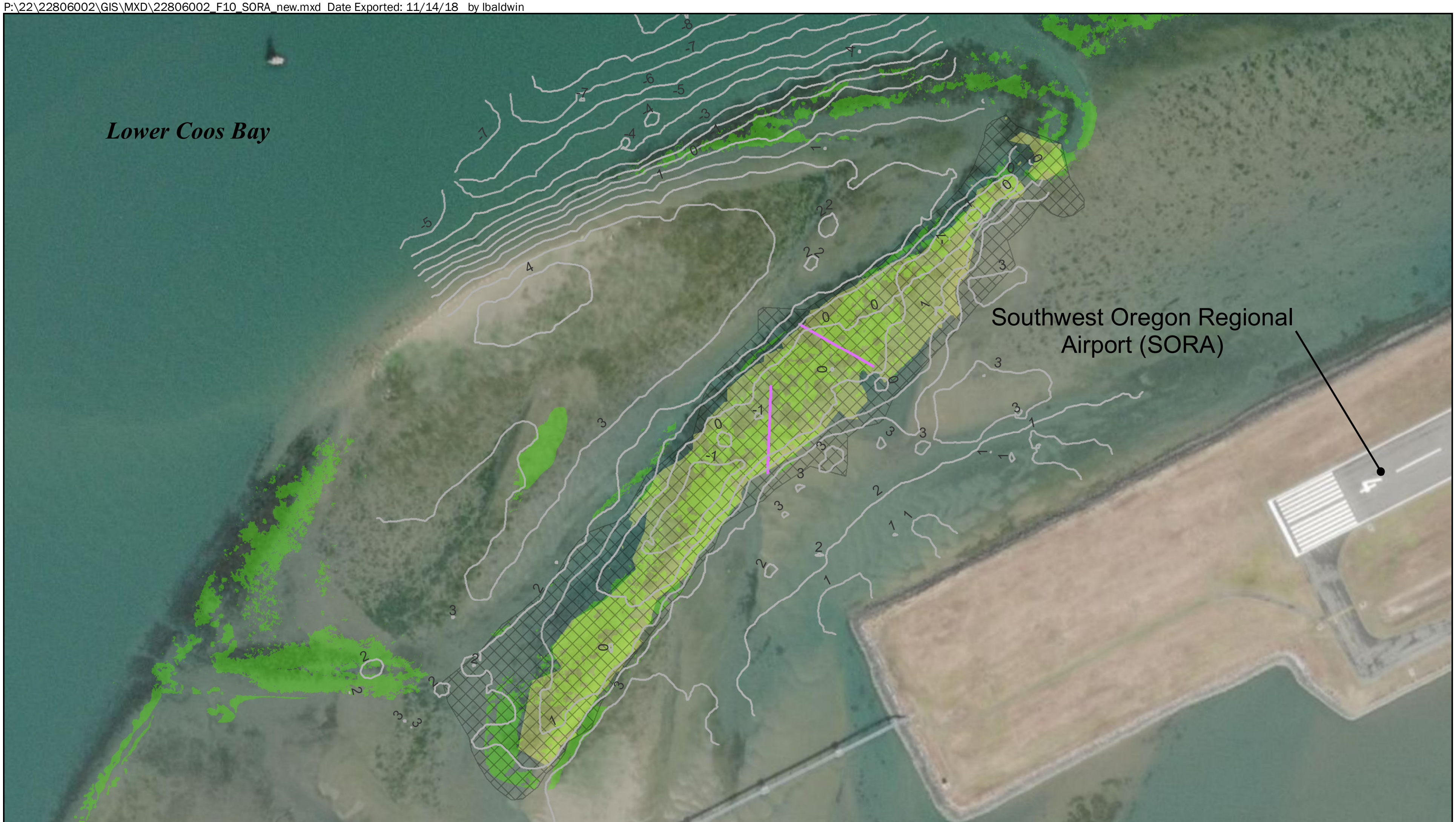

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Data Source: Aerial image from ESRI Data Online.

Projection: NAD 1983 StatePlane Oregon South FIPS 3602 Feet Intl

Legend

- SSNERR Eelgrass Survey (2016)
- DEA Eelgrass Survey (2018)
- DEA Survey Boundary
- Transect
- Bathymetric Contour (Intl Ft, MLLW) (0.0 ft MLLW = -0.72 ft NAVD88)

N W E S

100 0 100
Feet

Jordan Cove Energy Project

2018 Eelgrass and Bathymetry Surveys

2018 Eelgrass Distribution within the SORA Eelgrass Mitigation Site

GeoEngineers | Jordan Cove LNG

FIGURE NO.
10

Csw

OREGON BAY CLAM DISTRIBUTION, ABUNDANCE, PLANTING SITES AND EFFECTS OF HARVEST

ANNUAL REPORT

October 1, 1977 to September 30, 1978

by

Thomas F. Gaumer
Gregory P. Robart
Anne Geiger

Oregon Department of Fish and Wildlife

National Marine Fisheries Service
National Oceanic and Atmospheric Administration
United States Department of Commerce
Commercial Fisheries Research and Development Act
Project Number 1-122-R Segment 2
Contract Number 820840 RAB

November, 1978

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OREGON BAY CLAM DISTRIBUTION, ABUNDANCE, PLANTING SITES AND EFFECTS OF HARVEST

ABSTRACT

Studies were continued on the distribution and abundance of bay clams in Oregon's estuaries. Maps showing distribution of clams, substrate type and vegetation type in Tillamook, Netarts and Salmon River estuaries are presented.

Experimental releases of juvenile butter and gaper clams were made in an attempt to evaluate feasibility of supplementing natural clam stocks. Only one of three experimental plantings produced surviving clams one year after release.

In 1977 six commercial clam harvesting permits were issued (five in Yaquina Bay and one in Coos Bay). A total of 69,057 pounds (31.3 mt) were taken from Yaquina Bay and 11,931 pounds (5.4 mt) were harvested from Coos Bay. Over 99% of the total harvest was on gaper clams. In Yaquina Bay catch per effort averaged 229 pounds/hr (103.9 kg/hr) whereas in Coos Bay the catch/effort averaged 157 pounds/hr (71.2 kg/hr). In both bays the fishery was primarily on clams five years in age and older.

In 1978 five permits were issued to commercially harvest subtidal clams in Oregon's estuaries (4 in Yaquina Bay and one in Coos Bay). Approximately 155,400 pounds (70.5 mt) were harvested in Yaquina Bay and 27,505 pounds (12.5 mt) were taken from Coos Bay. As in 1977, gaper clams were the target species. In Yaquina Bay the suction pump was the primary method of harvest while the water jet was used entirely in the harvest from Coos Bay. Catch per effort in Yaquina Bay averaged 420 pounds/hr (190.7 kg/hr) and in Coos Bay, 262 pounds/hr (118.9 kg/hr).

Studies on water turbidities adjacent to the suction pump surface discharge showed that all detectable particulate material had settled out of the water column within 175 feet (53.3 m) of the discharge. No evidence of turbidities was observed near the jet harvesting operation.

We continued to monitor the growth of laboratory produced clams planted in Netarts and Yaquina bays.

INTRODUCTION

During the year we continued our studies on the clam resources in Oregon's estuaries. The objectives were: (1) to continue our intertidal and subtidal clam distribution and abundance surveys in Oregon's estuaries; (2) to locate and assess intertidal clam planting sites; (3) to monitor the commercial harvest of subtidal clams in Yaquina and Coos bays and evaluate the effects of mechanical harvest on subtidal clam populations and habitat; (4) to monitor growth of laboratory reared clams released in Netarts and Yaquina bays.

DISTRIBUTION AND ABUNDANCE STUDIES

During the year we completed our clam surveys on Tillamook, Netarts and Salmon River estuaries. Surveys were completed on Yaquina Bay in 1973 (Lukas and Gaumer, 1974), Alsea Bay in 1974 (Gaumer and Lukas, 1975), and Nestucca and Siletz bays in

1975 (Gaumer and Halstead, 1976). In addition to the completed studies, we continued our clam assessment surveys on Coos and Siuslaw estuaries.

Methods

Using techniques developed in 1973 (Osis and Gaumer, 1973), we continued to evaluate the distribution and abundance of intertidal and subtidal clams.

Results and Discussion

Tillamook Bay

Subtidal and intertidal surveys were completed for Tillamook Bay. In total we have examined 387,600 feet (118,140 m) of transect line and made 2,095 observations.

Eleven species of clams were observed. Of the recreationally or commercially important clams, cockles and gapers were the principal species observed in the lower bay while the softshell was the most prevalent clam species in the upper bay. Figures 1 to 11 shows the distribution of Baltic, bentnose, butter, California softshell, cockle, gaper, irus, native littleneck, piddock, sand and softshell clams. Elevations of islands on each map are shown at the 0.0 tide level. Ghost and mud shrimp also inhabited much of the tideflats (Figure 12).

Substrate in the lower bay channel consisted primarily of gravel and rock, much of it cemented together. The intertidal area adjacent to Garibaldi was mainly pure sand whereas the up-bay tideflats and channels were primarily a mixture of sand and mud (Figure 13).

Vegetation covered extensive areas of the mid- and up-bay tideflats. Eelgrass was the main species observed although other species of brown and green algae were scattered throughout the estuary (Figures 14 to 17).

Netarts Bay

Our surveys of Netarts Bay, started in 1973, were completed this year and included making 1,335 observations along 259,580 feet (79,120 m) of transect line.

Eleven species of clams were observed during our studies (Figures 18 to 28). Mud and ghost shrimp were also well distributed over the tideflats (Figure 29).

Tideflats in Netarts Bay consisted mainly of combinations of sand and mud (Figure 30). The down-bay channel areas were primarily of rock, gravel and sand; the up-bay channels were covered with sand and shell sediments.

Eelgrass was the prinicpal vegetation observed on the tideflats and channels (Figure 31). Several species of brown and green algae were noted in addition to the eelgrass beds (Figures 32 and 33).

Salmon River Estuary

Our completed surveys of the Salmon River Estuary included making 151 observations along 33,423 feet (10,187 m) of transect. These surveys were started in 1975. Sparse populations of softshell and Baltic clams were observed throughout the survey area (Figures 34 and 35). Mud and ghost shrimp were widely distributed over much of the intertidal areas of the bay (Figure 36).

Most of the substrate consisted of mud, sand, or mud mixed with sand (Figure 37). Rock and gravel covered much of the northern tideflat near the mouth of the bay.

Sparse *Fucus* and *Enteromorpha* were scattered throughout most of the survey area (Figure 38). Eelgrass was especially prevalent along the north shore of the bay (Figure 39).

ASSESSMENT OF CLAM PLANTING SITES

Three experimental releases of clams were made during the year on selected tideflats of Yaquina Bay. Primary purpose was to evaluate suitability of the release sites for future clam plants with our ultimate goal to enhance or supplement the natural populations of clams.

Methods

Ore-Aqua, a private salmon rearing facility on Yaquina Bay, while cleaning their raceways encounter large numbers of young clams. Working with Ore-Aqua, we salvaged 31,500 young butter clams that averaged 22.2 mm and 2.3 gms. These clams were released in July 1977 at a density of 11.8/ft^2 (127.4/m^2) on a selected area of Idaho Flat of Yaquina Bay. In addition, two releases of gaper clams were made in 1977; one on Idaho Flat where 1,050 1975 year-class clams averaging 53.2 mm were planted at a density of 12/ft^2 (129.6/m^2), and the other on the ODFW shellfish preserve in Yaquina Bay where 1,350 1975 year-class gapers averaging 58.1 mm were planted at a density of 6.8/ft^2 (73.4/m^2). Clams for both of these plants were collected by Department personnel, using a suction pump, during routine population assessment studies.

Results and Discussion

The experimental butter clam plant on Idaho Flat was sampled in July 1978 and no butter clams were located. Examination of the screenings showed no evidence of clam mortality (no dead shells were found). The lack of clams and/or shell suggest predation by crabs, fish or starfish.

We sampled the gaper plant on Idaho Flat one year after release. No live clams were recovered. No explanation for the total mortality is available except possibly habitat type or location was unsuitable.

Gaper clams planted in the Department shellfish preserve on the Yaquina Bay breakwater produced a survival rate of 5.9%, 14 months after release. The clams averaged 70.7 mm, an increase of 12.6 mm since release.

COMMERCIAL HARVEST OF CLAMS

Six permits were issued to commercial clam diggers to harvest subtidal clams in Oregon's estuaries in 1977 (five in Yaquina Bay and one in Coos Bay). Permits were required since the use of mechanical means to harvest clams in Oregon is unlawful. The permits specified the pounds of clams that could be harvested, season, area and harvest equipment. Quotas were established by allowing the fishery a maximum of 10% of the available biomass. The season started July 1, 1977 and ended December 31, 1977. The harvest area in Yaquina Bay was in the main ship channel up-bay from the U.S. highway 101 bridge (Figure 40). The Coos Bay fishery was allowed adjacent to and up-bay of Pigeon Point on the east side of the channel (Figure 41).

In 1978 five permits were issued to commercially harvest clams in Oregon's estuaries (four in Yaquina Bay and one in Coos Bay). Seasons were the same as in 1977. Area of harvest in Yaquina Bay was up-bay and adjacent to the U.S. highway 101 bridge (Figure 42). The Coos Bay permit area was the same as in 1977 (Figure 41).

Two types of harvest were permitted; in Yaquina Bay both a suction pump and a high pressure water jet were allowed and in Coos Bay only a high pressure jet was used.

Methods

Yaquina Bay, 1977

Two adjacent 2.1 acre (0.8 ha) plots were selected in Yaquina Bay for the commercial harvest of clams (Figure 40). The down-bay plot (A) was restricted to the use of a high pressure water jet; plot (B) was restricted to the use of a suction pump. Each of the 300 x 300-foot (91.4 x 91.4 m) plots was further subdivided by polypropylene rope into 100 x 100-foot (30.5 x 30.5 m) sub-sections.

Two commercial clam harvesting permits were issued for sub-sections in the jet approved area and three for the suction pump site (each permit holder was assigned a specific sub-section). Sub-sections 2-A-4 and 2-A-7 were "jet" areas and 2-B-1, 2-B-3 and 2-B-4 were "pump" areas. A quota of 400,000 pounds (181.4 mt) was set for the 1977 season; 200,000 pounds (90.7 mt) for each of the jet and pump approved areas. Each of the permittees' catch was periodically sampled for age, size and weight composition data.

Following the 1977 commercial season, those portions of sub-sections 2-A-4 and 2-B-4 that were harvested were resurveyed to evaluate effectiveness of the harvest equipment. We did not resurvey sub-sections 2-A-7, 2-B-1 and 2-B-3 since little harvest effort was expended in these areas.

Yaquina Bay, 1978

Two 1.4 acre (0.6 ha) plots of area 2 in Yaquina Bay were approved for clam harvesting in 1978 (Figure 42). Plot C was designated a suction pump area and was shared by two operators. Plot D was restricted to a water jet/hand harvesting method. of the two permittees approved to work in the area, only one harvested clams.

Prior to and following the commercial season, dredge samples were taken to determine population and biomass estimates of clams in the permit areas. Data collected included information on species, age, size and weight. At the same time we collected sediment core samples to assess the impact of the two harvesting methods on the substrate.

A quota of 400,000 pounds (181.4 mt) was approved for the 1978 season; 200,000 pounds (90.7 mt) for each of the jet and pump approved areas. During the commercial season we sampled the clams harvested for species, age, size and weight composition. Following the 1978 season, we resurveyed the harvested areas in plots C and D to evaluate effectiveness of the harvesting equipment.

In addition to the assessment of clam stocks occurring in the two permit areas, we collected meat recovery data from clams that were processed for market. Gaper clams were weighed monthly before, during and following processing to determine meat recovery through the commercial season.

During the season we also collected water samples adjacent to and downstream of the dredging operations to assess turbidities created during the surface discharge of dredge spoils. Turbidities in all water samples were analyzed using a Jackson Turbidimeter.

<u>Coos Bay, 1977</u>

In 1977 one request was received to commercially harvest clams from Coos Bay. A permit was issued allowing the use of a water jet to harvest clams from within the same 48 acre (19.4 ha) permit area approved for the 1975 season (Figure 41). A harvest quota of 100,000 pounds (45.4 mt) was placed on the area. As with the Yaquina Bay clam harvesters, the permittee was required to submit monthly summaries of his harvest records to the ODFW.

<u>Coos Bay, 1978</u>

A single permit was issued to commercially harvest clams by a hand held jet in Coos Bay (Figure 41). A harvest quota of 150,000 pounds (68 mt) was established for the 48 acre (19.4 ha) area.

Results and Discussion

<u>Yaquina Bay, 1977</u>

Population estimates were calculated for the commercial clam digging plots of Yaquina Bay and revealed that 12.7 million clams inhabited the areas (Table 1). Of this total, 6.6 million occurred in plot A and 6.1 million inhabited plot B. Over nine million of the total clams were gapers that weighed in excess of 1.2 million pounds (584.7 mt); 0.9 million pounds (385.9 mt) occurred in plot A and 0.4 million pounds (198.8 mt) inhabited plot B.

Table 1. Summary of Subtidal Clams in Commercial Clam Harvesting Plots of Yaquina Bay, 1977-78.

Plot No.	Year	Species	Population Estimates	Biomass Estimates	90% Confidence Interval of Biomass (±%)
A	1977	Gaper	4,500,000	850,986	50.7
		Butter	11,250	not calculated	-
		Littleneck	33,750	" "	-
		Irus	2,070,000	" "	-
		Total	6,615,000	850,986	50.7
B	1977	Gaper	4,713,750	438,383	68.0
		Irus	1,361,250	not calculated	-
		Total	6,075,000	438,383	68.0
A + B	1977	Grand Total	12,690,000	1,289,369	
C	1978	Gaper	384,000	358,900	75.7
		Cockle	18,000	not calculated	-
		Butter	36,000	" "	-
		Littleneck	18,000	" "	-
		Irus	846,000	" "	-
		Total	1,296,000	358,900	75.7
D	1978	Gaper	918,000	516,592	44.4
		Butter	48,000	not calculated	-
		Irus	1,416,000	" "	-
		Total	2,376,000	516,592	44.4
C + D	1978	Grand Total	3,672,000	875,492	29.1

Population and biomass estimates were calculated for the individual permit areas within plots A and B (Table 2). A total of 1.6 million clams weighing 282,600 pounds (128.2 mt) inhabited the five areas. Biomass estimates ranged from 11.1 mt in sub-section 2-B-1 to 36.5 mt in unit 2-A-4.

Over 104,000 clams weighing 69,057 pounds (31.3 mt) were taken in the commercial harvest in 1977 (Table 3). Gaper clams comprised 68,074 pounds (30.9 mt) or 98.6% of the total harvest. Of this total, 36,852 pounds (16.7 mt) or 53.4% came from sub-section 2-A-4. Original estimates of gaper clam biomass for this sub-section revealed 80,200 pounds (36.5 mt) available to be harvested. Approximately 20% of the permit area was worked. Production from permit areas 2-A-7 and 2-B-3 was low because of the little effort expended in 2-A-7 and the inability of the harvester to maintain his boat in position in 2-B-3.

Table 2. Summary of Subtidal Gaper Clams in Commercial Clam Harvesting Sub-Sections of Yaquina Bay, Oregon, 1977.

Sub-Section No.	Population Estimates	Biomass Estimates (Pounds)	Biomass Estimates (Metric Tons)	95% Confidence Interval of Biomass (±%)
2-A-4 (Jet)	362,400	80,200	36.5	98.9
2-A-7 (Jet)	100,900	43,500	19.7	83.4
2-B-1 (Pump)	135,000	24,500	11.1	65.2
2-B-3 (Pump)	465,100	62,300	28.3	100.0
2-B-4 (Pump)	540,000	72.100	32.6	100.0
Total	1,603,400	282,600	128.2	53.8

Catch per effort values ranged from 100 pounds/hr (45.4 kg/hr) in pump permit unit 2-B-1 to 314 pounds/hr (142.4 kg/hr) in jet permit area 2-A-4 (Table 3). For all areas combined, the C/E was 229 pounds/hr (103.9 kg/hr).

Table 3. Summary of Subtidal Clams Harvested in the Yaquina Bay Commercial Fishery, 1977.

Species		2-A-4 "Jet"	2-A-7 "Jet"	2-B-1 "Pump"	2-B-3 "Pump"	2-B-4 "Pump"	Salvage "Jet & Pump"	Total
		Yaquina Bay Sub-Section						
Gaper	Pounds	36,852	1,083	4,159	774	10,506	14,700	68,074
	N	46,681	1,164	4,568	1,010	13,370	18,230	85,023
Cockle	Pounds	1	0	0	0	4	5	10
	N	2	0	0	0	22	13	37
Butter	Pounds	516	9	1	4	43	18	519
	N	1,296	33	5	33	181	89	1,637
Littleneck	Pounds	45	<1	0	1	3	0	49
	N	176	1	0	5	15	0	197
Irus	Pounds	0	0	91	0	14	229	334
	N	0	0	6,300	0	115	11,577	17,992
Softshell	Pounds	0	<1	0	0	0	0	<1
	N	0	5	0	0	0	0	5
Total	Pounds	37,413	1,092	4,251	779	10,570	14,952	69,057
	N	48,155	1,203	10,873	1,048	13,703	29,909	104,891
Hours of Effort		119.1	6.3	42.5	7.0	79.7	47.0	301.6
C/E (Pounds/hr)		314	173	100	111	133	318	229

The age composition of subtidal gaper clams before, from and following the commercial harvest is shown in Figure 43. Subtidal surveys revealed that the 1975 year class was prominant in each area prior to the commercial fishery whereas samples of the commercial harvest showed this year class of clams was generally ignored except in sub-section 2-B-4. The fishery was primarily on older clams with 82.7% of the harvested clams being five years of age or older.

The length frequency of subtidal gaper clams from each of the four main permit areas is shown in Figure 44. Mean size of clams before harvest ranged from 62.5 mm in 2-B-4 to 86.1 mm in 2-A-7. Mean size of harvested clams ranged from 107.0 mm in 2-B-4 to 117.7 mm in 2-B-1.

Results of our assessment of the effects of commercial clam harvest on the clam stocks and surrounding habitat showed that only a small portion of each of the 100 x 100-foot (30.5 x 30.5 m) sub-sections was actually harvested. Only in sub-sections 2-A-4 and 2-B-4 were there appreciable numbers of clams taken; 36,852 pounds (16.7 mt) in 2-A-4 and 10,570 pounds (4.8 mt) in 2-B-4.

In sub-section 2-A-4 we estimated that an area 20 x 100-feet (6.1 x 30.5 m) had been worked. Age composition of gapers remaining in the harvested area revealed that only clams of the 1973, 1975 and 1976 year class remained. All older clams had been removed. Prior to the harvest, gaper clams averaged 36.2/ft^2 (391/m^2) whereas post-harvest samples revealed that gaper densities were 0.8/ft^2 (8.6/m^2).

An area similar in size to 2-A-4 was harvested in 2-B-4. Age composition of gaper clams was generally similar in each area prior to harvest. Post harvest observations revealed that mainly younger clams remained although some older clams were missed by the suction pump operator. Gaper clam densities in 2-B-4 prior to harvest averaged 54.0/ft^2 (583.2/m^2) whereas post-harvest densities were 5.3/ft^2 (57.2/m^2).

Yaquina Bay, 1978

We estimated that 3.7 million clams inhabited the commercial clam digging plots C and D (Table 1). Of this total 1.3 million inhabited plot C and 2.4 million occurred in plot D. Approximately 1.3 million of the total clams were gapers that weighed in excess of 0.8 million pounds (397.0 mt); 0.4 million pounds (162.8 mt) occurred in plot C and 0.5 million pounds (234.3 mt) inhabited plot D.

Preliminary figures showed that approximately 181,400 clams weighing 155,403 pounds (70.5 mt) were harvested in the commercial fishery in 1978 (Table 4). Of this total, 155,337 pounds (70.4 mt) or 99.9% were gaper clams. Of the total clams harvested 148,371 pounds (67.3 mt) or 95.5% came from the pump plot C. We originally estimated that 358,900 pounds (162.8 mt) were available in the area for harvest. Production from plot D was 7,032 pounds (3.2 mt). The low harvest was primarily due to the inefficiency of the water jet in dislodging clams. Total effort expended by the operator in the area was also low.

Catch per effort for plot C was 480.2 pounds/hr (218.0 kg/hr) and 176.3 pounds/hr (80.0 kg/hr) in plot D. For all areas combined, the C/E was 420.0 pounds/hr (190.7 kg/hr).

The age composition of gaper clams before, from and following the commercial harvest is shown in Figure 45. As in 1977, the 1975 year class was the predominant age group of clams in area 2 prior to the commercial harvest. In plots C and D of area 2, the 1971 and 1973 year classes, respectively, were predominant suggesting that many of the 1975 year class clams occurred outside the two plots. Age composition data from the commercial harvest in plot C revealed that the 1971 year class was the principal age group taken contributing 31% of the clams. Ninety-eight percent of the gaper harvest was five years of age or older. In jet plot D, 72.6% of the gaper harvest was on the 1975 year class. Only 19% of the harvest was on clams five years of age or older.

Table 4. Summary of Subtidal Clams Harvested in the Yaquina Bay Commercial Fishery, 1978.

		Yaquina Bay Plot		
Species		2-C "Pump"	2-D "Jet"	Total
Gaper	Pounds	148,371	6,966	155,337
	N	168,280	10,970	179,250
Butter	Pounds	0	22	22
	N	0	93	93
Littleneck	Pounds	0	<1	<1
	N	0	7	7
Irus	Pounds	0	44	44
	N	0	2,035	2,035
Total	Pounds	148,371	7,032	155,403
	N	168,280	13,105	181,385
Hours of Effort		309	61	370
C/E (Pounds/hr)		480.2	176.3	420.0

Figure 46 shows the length frequency of subtidal gapers in plots C and D of area 2 prior to and from the commercial fishery. Mean size of gapers before harvest was 100.0 mm in plot C and 118.8 mm in plot D. Mean size of harvested clams from plot C was 123.5 mm and plot D 96.9 mm.

Following the commercial season, both plots C and D were resurveyed to assess effectiveness of the suction pump and water jet in removing clams. We removed 32 ft^2 (3.0 m^2) of substrate in plot C and found 41 clams of which five were gapers. The 0.2 gapers/ft^2 (2.2/m^2) found in the post-harvest area when compared to 6.4 gapers/ft^2 (69.1/m^2) prior to the fishery showed the area to be thoroughly harvested. In plot D we removed 20 ft^2 (1.9 m^2) of bottom material and located 237 clams of which 190 were gapers. The 9.5 gapers/ft^2 (102.6/m^2) recovered in the post-harvest area was only a slight reduction in the preharvest abundance of 15.3 clams/ft^2 (165.2/m^2). Surface observations revealed that nearly all clams had been removed from the worked area of plot C whereas little evidence of harvest effort could be seen in plot D.

Sediment samples collected prior to and following the commercial fishery have not been analyzed yet. Diver observations of the suction pump area revealed that strong water currents have effectively spread the redeposited spoils out over the original area of harvest. No visual evidence of harvest operation could be detected in the jet-worked area.

Meat recovery for gaper clams by 10 mm size intervals is shown in Table 5. In July the recovery was lowest (19%) for gapers in the 90-99 mm range and highest (28%) for gapers 100-109 mm in length. In contrast to this, the August through October recovery rates were highest for the smallest clams in the sample (90-99 mm). The unusually high recovery of 32% in September is unexplained. All clams were processed by industry personnel.

Table 5. Summary of Meat Weight Recovery Study for Subtidal Gaper Clams, Yaquina Bay, July-October, 1978.

		Size Range in mm					Sample
		90-99	100-109	110-119	120-129	130-139	Average
Average round weight per clam in ounces	July	7.70	9.25	11.25	13.00	18.05	11.85
	Aug.	7.07	11.06	12.35	16.75	20.45	14.36
	Sept.	6.80	9.80	12.75	16.05	19.80	14.14
	Oct.	6.90	10.45	12.75	15.70	18.65	12.89
Average shucked weight of meat per clam in ounces	July	2.55	3.45	4.15	5.05	6.65	4.37
	Aug.	-	-	-	-	-	-
	Sept.	3.60	4.25	5.25	6.35	9.10	6.08
	Oct.	3.10	4.25	5.35	6.50	7.65	5.37
Average cleaned weight (final product) per clam in ounces	July	1.45	2.50	2.60	3.30	4.35	2.84
	Aug.	1.93	2.81	2.85	3.45	4.10	3.11
	Sept.	2.20	2.30	2.90	3.55	4.60	3.27
	Oct.	1.55	2.05	2.50	3.40	3.35	2.57
Percent recovery of clam meat in weight	July	19%	28%	23%	25%	24%	24%
	Aug.	27%	25%	21%	21%	20%	22%
	Sept.	32%	23%	23%	22%	23%	23%
	Oct.	22%	20%	20%	22%	18%	20%
Percent of all marketed gaper clams in size category	July	2%	8%	34%	32%	14%	

Turbidity samples, taken on two occasions in plot C adjacent to and downbay of the commercial operations revealed that all detectable particulate matter had settled out of the water column within 175 feet (53.3 m) of the discharge. Thirty feet (9.1 m) downstream of the discharge the mean value of three turbidity samples was 56.1 "Jackson Turbidity Units" on August 1, 1978 and 57.2 units on September 27, 1978. No evidence of turbidity was observed in the jet harvest operation.

Coos Bay, 1977

We estimated that of the 1.9 million pounds (849.9 mt) of clams occurring in the permit area of Coos Bay (Table 6), 1.5 million pounds (694.2 mt) were gaper clams.

The commercial harvest reported for Coos Bay totaled 11,931 pounds (5.4 mt) of gapers. Catch per effort averaged 157.0 pounds/hr (71.2 kg/hr).

Age composition for the 1977 harvest is shown in Figure 47. The 1969-72 year classes were well represented in the take.

Length frequency data revealed the gapers averaged 132.9 mm (Figure 48). The harvest was entirely on 108-157 mm size clams.

Table 6. Summary of Subtidal Clams in Commercial Clam Harvesting Area of Coos Bay, Oregon, 1975.

Species	Population Estimates (N)	Biomass Estimates (Pounds)	Biomass Estimates (Metric Tons)	95% Confidence Interval of Biomass (±%)
Gaper	5,648,700	1,530,800	694.2	44.8
Cockle	202,200	23,000	10.5	100.0
Littleneck	843,000	71,600	32.6	49.7
Butter	809,200	248,200	112.6	58.2
Total	7,503,100	1,873,600	849.9	34.7

Coos Bay, 1978

The 1978 commercial harvest of clams from Coos Bay totaled 27,505 pounds (12.5 mt). Only gaper clams were taken. Catch per effort averaged 262 pounds/hr (118.9 kg/hr) which is nearly double the 1977 rate.

Age composition for the 1978 harvest is shown in Figure 47. The fishery was primarily on the 1973 and 1971 year-classes of gapers.

Length frequency of gaper clams taken in the commercial fishery is shown in Figure 48. The gapers averaged 121.1 mm.

LABORATORY CLAM STUDIES

Although our laboratory clam studies were terminated in 1975, we have continued to monitor the growth of clams planted in Netarts and Yaquina bays.

Methods

Two studies were continued in Netarts Bay. One compared the growth characteristics of Manila littleneck clams that were selected for their fast growing ability *vs* normal growing clams (Gaumer and Lukas, 1975); the other compared growth of clams in a screened enclosure *vs* unscreened areas.

The only study continued in Yaquina Bay compared the growth and survival of butter clams planted in a natural substrate *vs* artificial substrate (Lukas, 1972).

Results and Discussion

Netarts Bay

Manila littleneck clams spawned in August 1974 from fast growing parent stock grew 3.7 mm since June 1977 and averaged 35.2 mm in length, whereas progeny from the "normal" clams grew 3.1 mm and averaged 32.3 mm (Figure 49). Due to the mobility of Manila clams, it was impossible to calculate survival rates for the released clams.

Manila clams planted in the screened test plot averaged 34.9 mm whereas clams planted in an adjacent unscreened test plot averaged 35.6 mm. Manilas planted adjacent to an eelgrass bed and at a slightly lower elevation, were 42.4 mm in average length (Figure 50). Clams in all three releases averaged 13.1 mm when planted.

Yaquina Bay

Butter clams sampled from a natural type substrate averaged 62.9 mm (Table 7). Clams of this sample were 2.5 mm smaller than clams sampled in 1977. The clams averaged 20.0 mm when planted in 1970 as 22-month-old clams and 62.9 mm when sampled in 1978.

Growth and survival of butter clams planted in artificial substrate test plots is shown in Table 8. Our sampling in April 1978, 112 months after the clams were released, showed a survival ranging from 0% (for clams planted in natural substrate and 19 mm minus river rock) to 0.8% for clams planted in 19 mm minus crushed rock.

Table 7. Growth and Survival of Butter Clams Planted on the Yaquina Bay Breakwater, 1978.

Date Sampled	Mean Shell Length (mm)	Percentage survival	Age of Clams (months)	Months in Plot
7-13-72	37.0	31.7	44.5	22.0
7-30-73	46.7	46.7	57.0	34.5
7-19-74	48.4	59.2	68.0	46.0
7-9-75	53.7	65.0	80.0	58.0
7-27-76	60.0	68.3	92.0	70.0
8-2-77	65.4	51.7	105.0	83.0
7-20-78	62.9	60.0	116.0	94.0

Tab[illegible] 8. Growth and Survival of Butter Clams Planted [illegible] Artificial Substrate Plots, Yaquina Bay Breakwat[illegible] 1968-78.

Substrate type	Date sampled	Months after release	Survival (%)	Mean size (mm)
Control	12/15/68	0	100.0	2.9
	6/8/69	6	1.5	11.1
	12/26/69	12	0.0	-
Crushed rock 19mm to 38mm	12/15/68	0	100.0	2.9
	6/8/69	6	3.3	10.3
	12/26/69	12	0.0	-
	3/25/70	15	2.0	24.4
	12/9/70	24	0.8	38.6
	4/12/73	52	0.1	56.1
	4/25/74	64	0.1	59.1
	4/28/75	76	0.1	63.0
	4/16/76	88	0.1	64.9
	4/6/77	100	0.1	71.4
	4/25/78	112	0.1	72.1
River Run 19mm	12/15/68	0	100.0	2.9
	6/8/69	6	1.0	7.9
	12/26/69	12	0.0	-
	3/25/70	15	0.5	23.8
	12/9/70	24	0.2	41.0
	4/12/73	52	0.0	-
Crushed 19mm -	12/15/68	0	100.0	2.9
	6/8/69	6	4.5	10.5
	12/26/69	12	1.0	20.8
	3/25/70	15	4.5	23.8
	12/9/70	24	3.4	38.8
	4/12/73	52	2.4	61.2
	4/25/74	64	1.7	62.2
	4/28/75	76	1.6	64.7
	4/16/76	88	1.1	65.6
	4/6/77	100	0.9	69.1
	4/25/78	112	0.8	72.7
River Run 19mm to 38mm	12/15/68	0	100.0	2.9
	6/8/69	6	0.8	7.4
	12/26/69	12	1.8	20.7
	3/25/70	15	0.9	23.3
	12/9/70	24	0.7	36.5
	4/12/73	52	0.2	61.0
	4/25/74	64	0.3	63.2
	4/28/75	76	0.3	65.3
	4/16/76	88	0.3	-
	4/6/77	100	0.3	67.0
	4/25/78	112	0.3	71.8
Crushed 38mm to 76mm	12/15/68	0	100.0	2.9
	6/8/69	6	7.3	9.2
	12/26/69	12	1.5	19.6
	3/25/70	15	2.4	22.2
	12/9/70	24	2.5	38.2
				49.9 1972
	4/12/73	52	1.7	58.5
	4/25/74	64	1.4	60.3
	4/28/75	76	1.3	62.3
	4/16/76	88	0.9	63.6
	4/6/77	100	0.9	69.1
	4/25/78	112	0.4	71.7

Where survival occurred, growth of the butter clams were generally similar for each type of substrate. After 119 months the clams averaged 71.8 mm (Figure 51).

ACKNOWLEDGMENTS

We wish to thank Dennis Wise, Jerry Lukas, Laimons Osis and Darrell Demory of the Oregon Department of Fish and Wildlife for their assistance in the study.

We also wish to thank Connie Morehouse, illustrator for the Oregon State University Sea Grant Program, for the many hours she expended preparing the base maps for the study.

LITERATURE CITED

Gaumer, Thomas F. and Bruce G. Halstead. 1976. Methods of Supplementing Clam and Abalone Production. Comm. Fish. Res. and Devel. Act. July 1, 1975 to June 30, 1976. Ore. Dept. of Fish and Wildlife Proc. Rept. 65 pp.

Gaumer, Thomas F. and Gerald Lukas. 1975. Methods of Supplementing Clam and Abalone Production. Comm. Fish. Res. and Devel. Act. July 1, 1974 to June 30, 1975. Fish Comm. of Ore. Proc. Rept. 34 pp.

Lukas, Gerald. 1972. Clam-Abalone Spawning and Rearing. Comm. Fish. Res. and Devel. Act. July 1, 1971 to June 30, 1972. Fish Comm. of Ore. Proc. Rept. 16 pp.

Lukas, Gerald and Thomas F. Gaumer. 1974. Clam-Abalone Stock Supplementation Feasibility Study. Comm. Fish. Res. and Devel. Act. July 1, 1973 to June 30, 1974. Fish Comm. of Ore. Proc. Rept. 20 pp.

Osis, Laimons and Thomas F. Gaumer. 1973. Estuary Resource Survey, Subtitle: Clam Inventory Techniques Study. Comm. Fish. Res. and Devel. Act. Completion Rept. July 1, 1971 to June 30, 1973. Fish Comm. of Ore. Proc. Rept. 11 pp.

APPENDIX 1

(Figures 1 through 51)

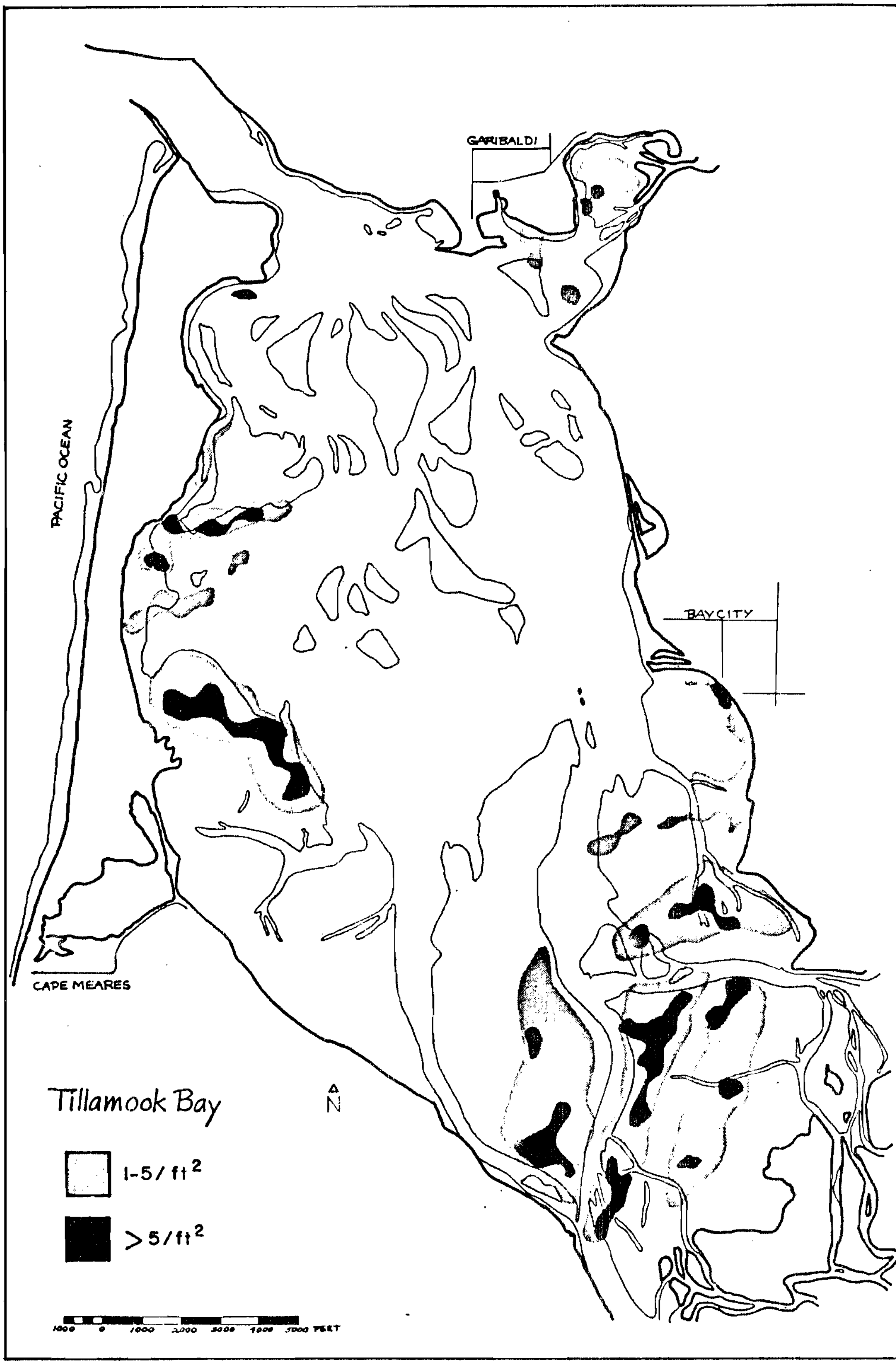

Figure 1. Distribution of Baltic Clams in Tillamook Bay

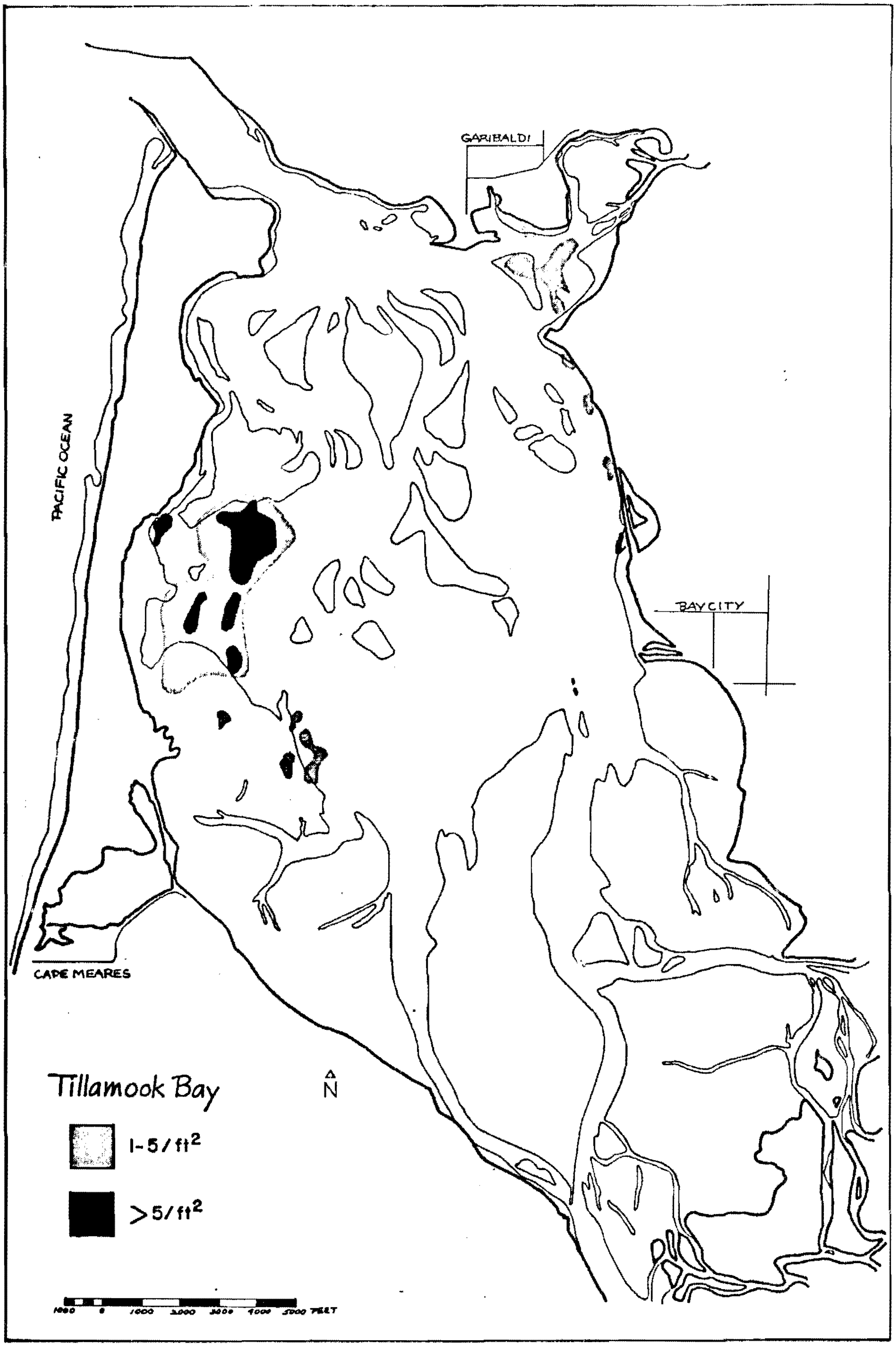

Figure 2. Distribution of Bentnose Clams in Tillamook Bay.

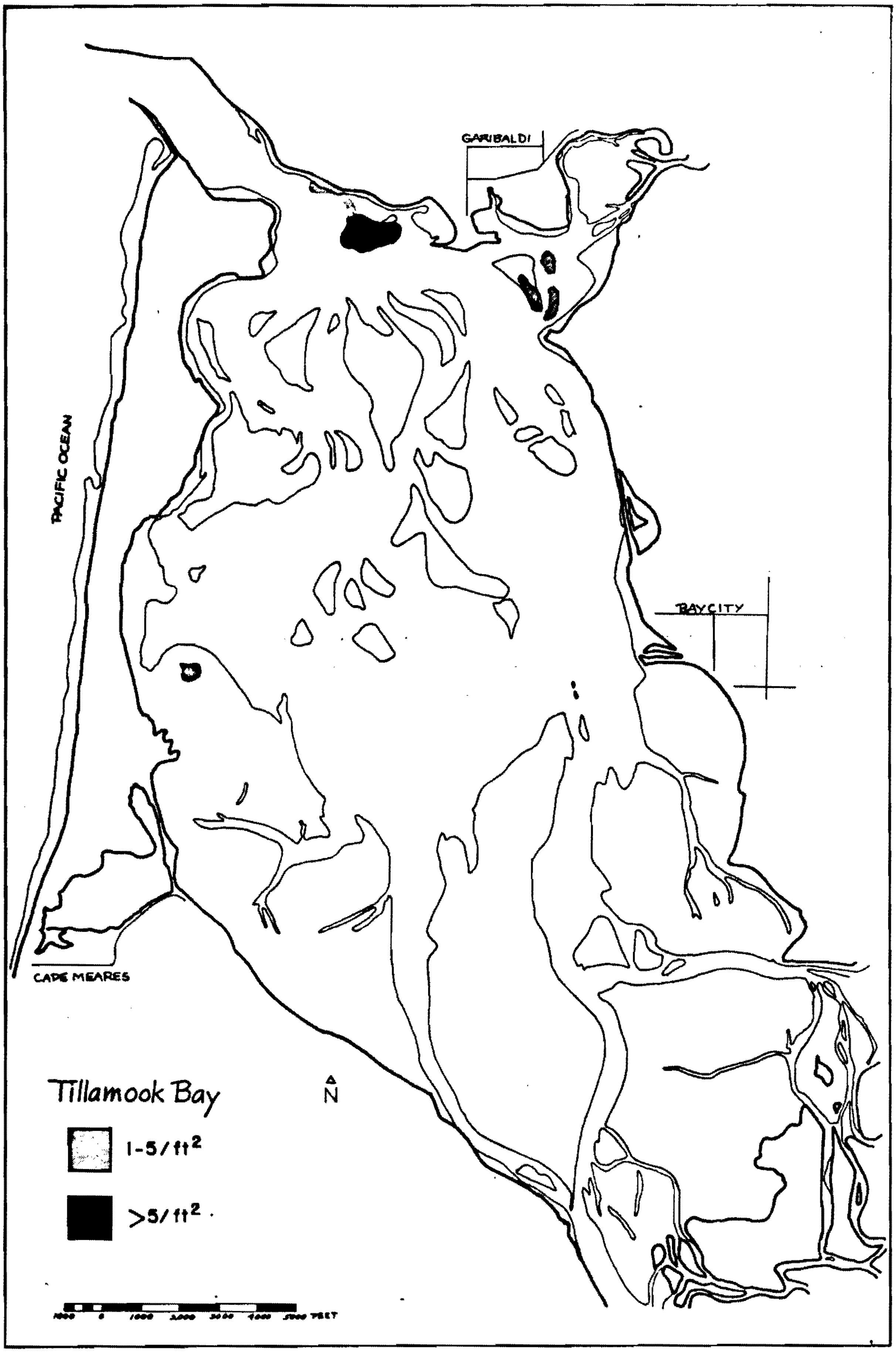

Figure 3. Distribution of Butter Clams in Tillamook Bay.

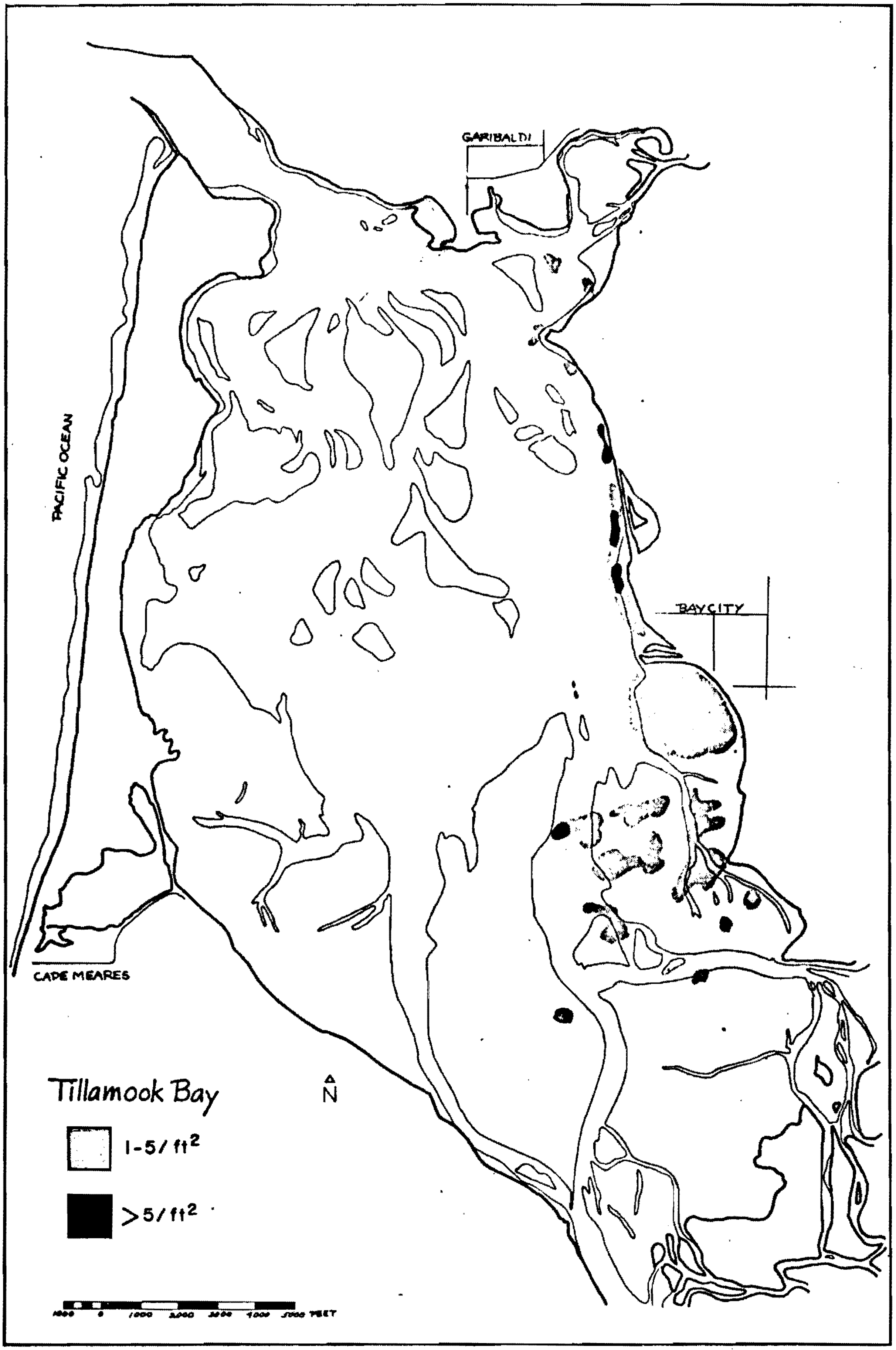

Figure 4. Distribution of California Softshell Clams in Tillamook Bay.

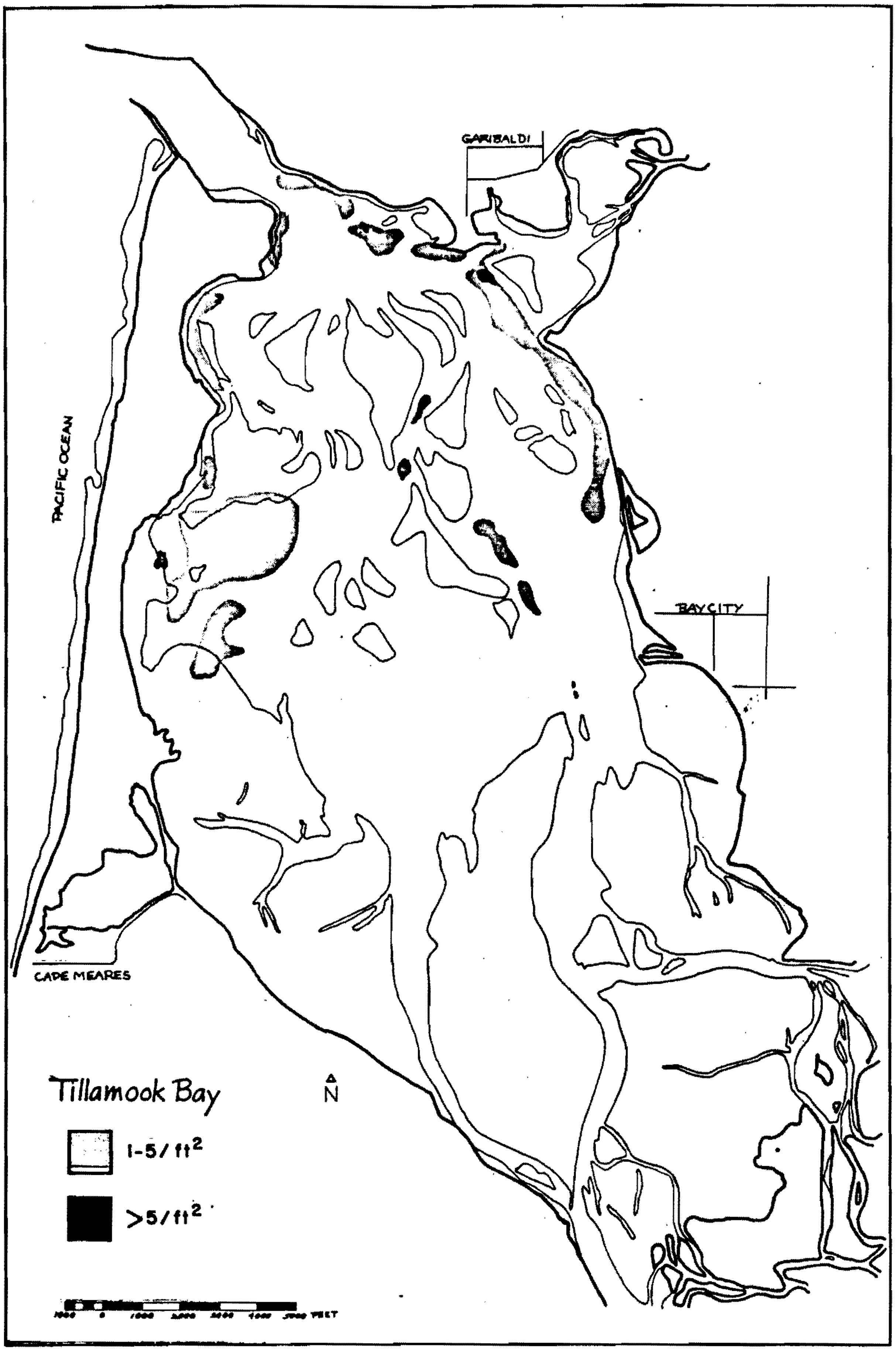

Figure 5. Distribution of Cockle Clams in Tillamook Bay.

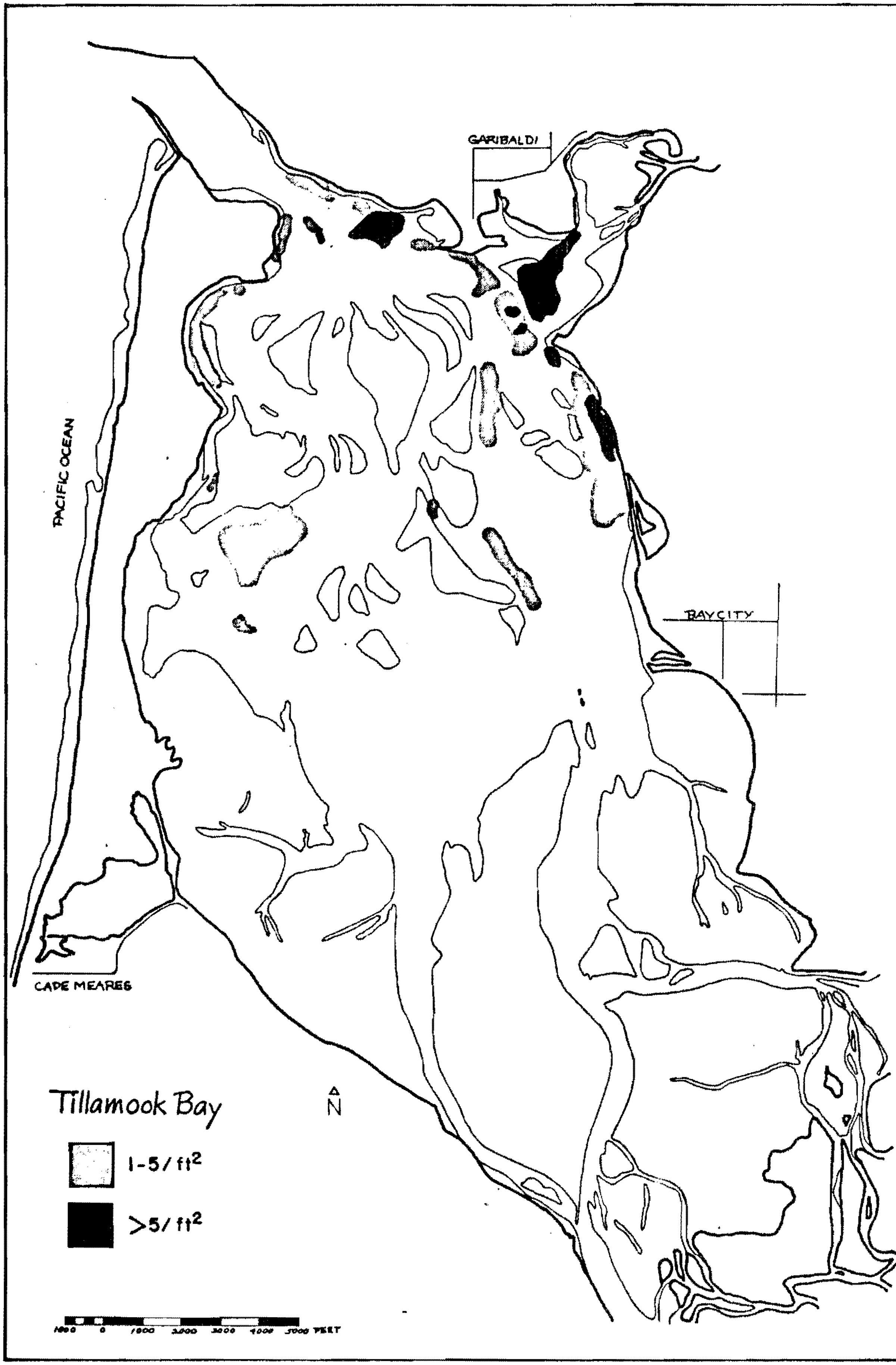

Figure 6. Distribution of Gaper Clams in Tillamook Bay.

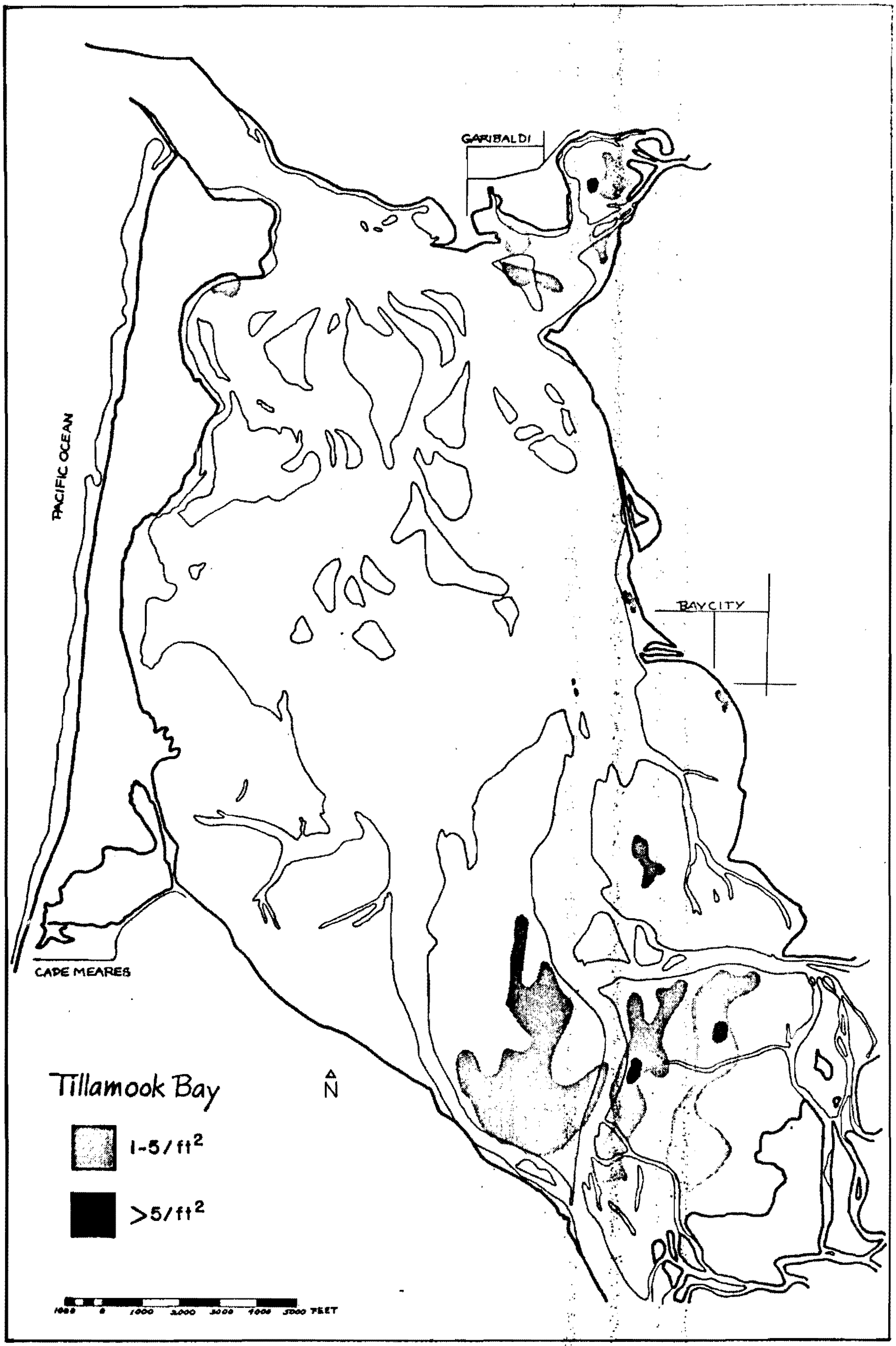

Figure 7. Distribution of Irus Clams in Tillamook Bay.

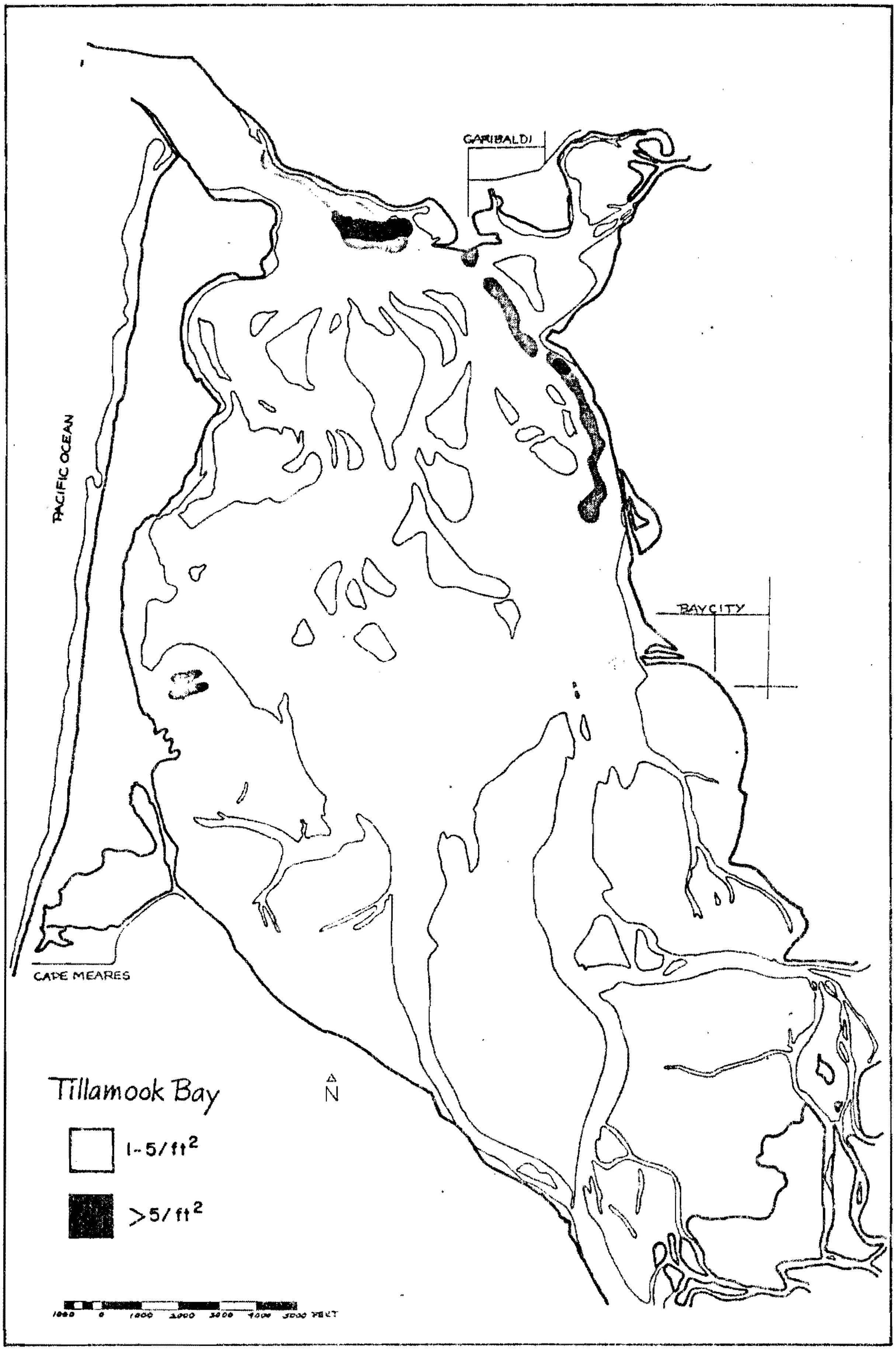

Figure 8. Distribution of Native Littleneck Clams in Tillamook Bay.

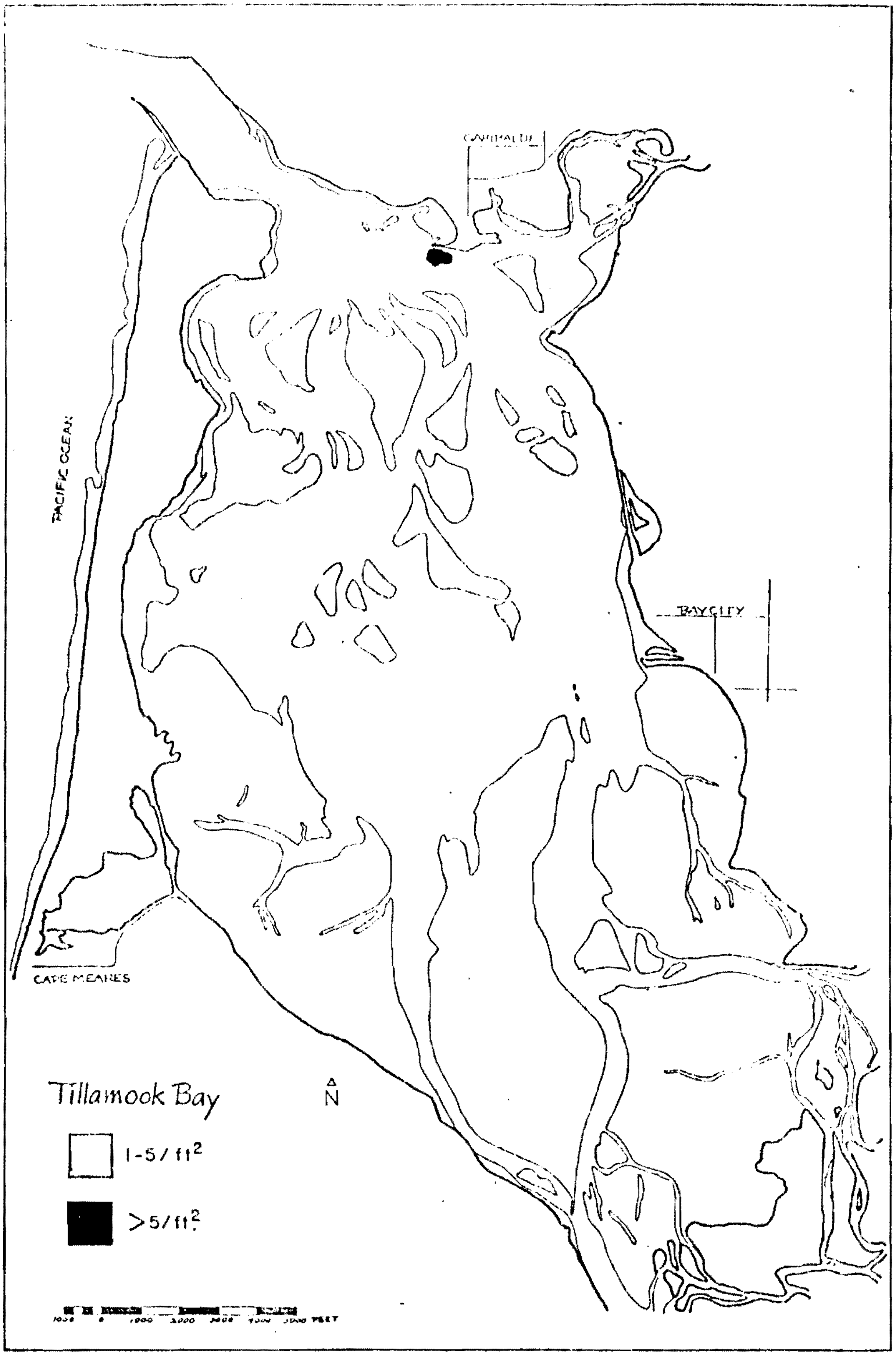

Figure 9. Distribution of Piddock Clams in Tillamook Bay.

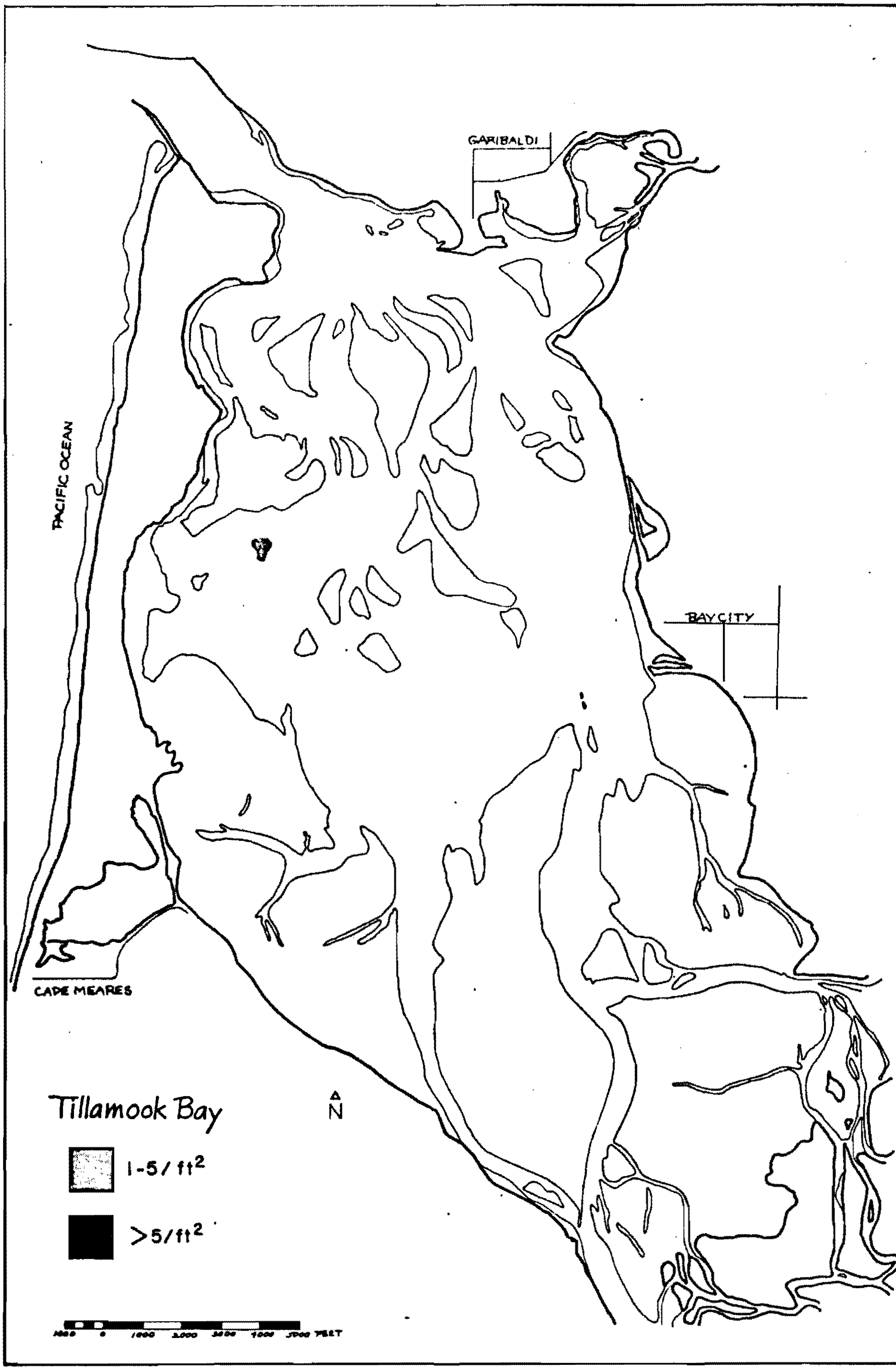

Figure 10. Distribution of Sand Clams in Tillamook Bay.

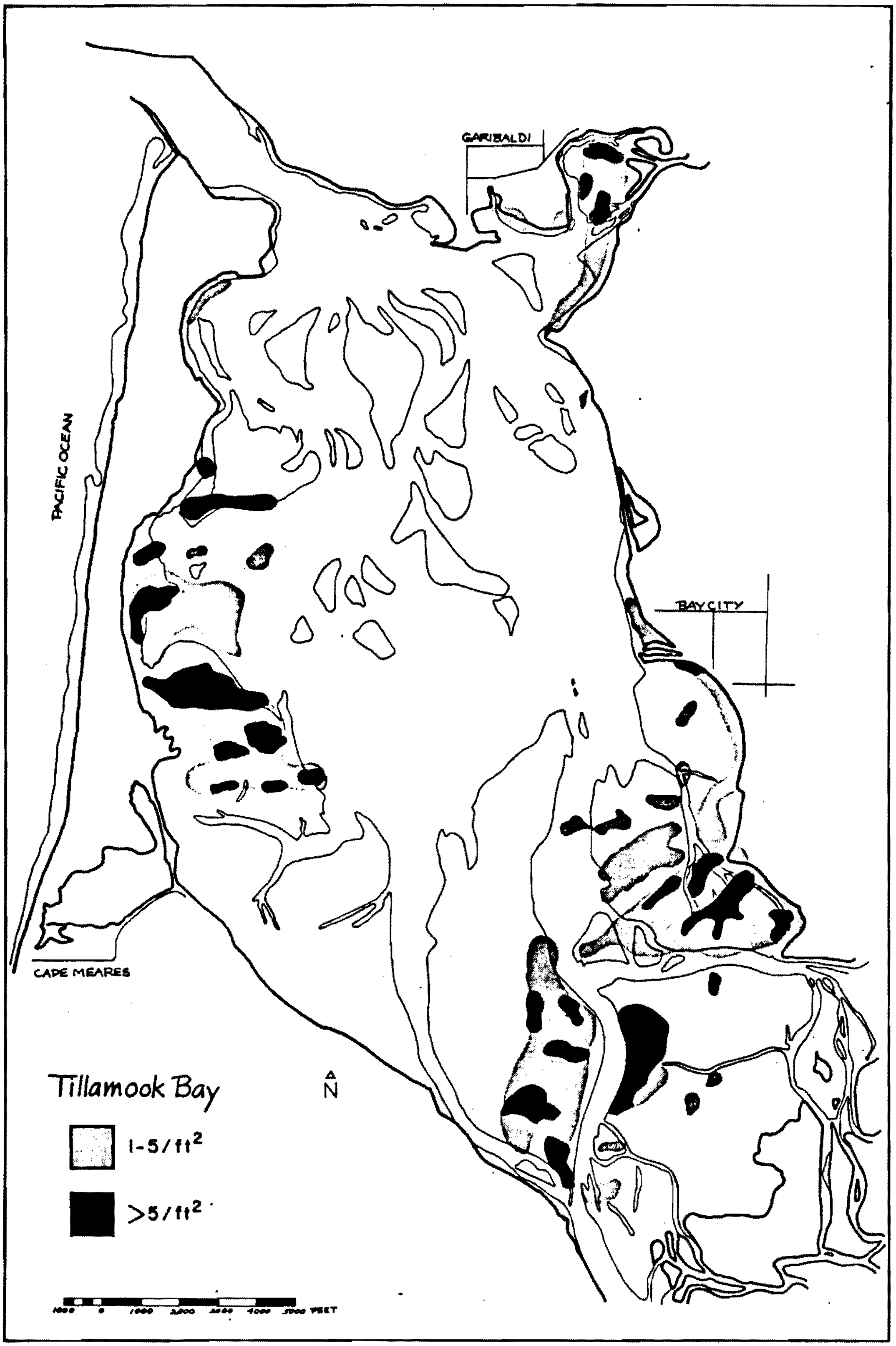

Figure 11. Distribution of Softshell Clams in Tillamook Bay.

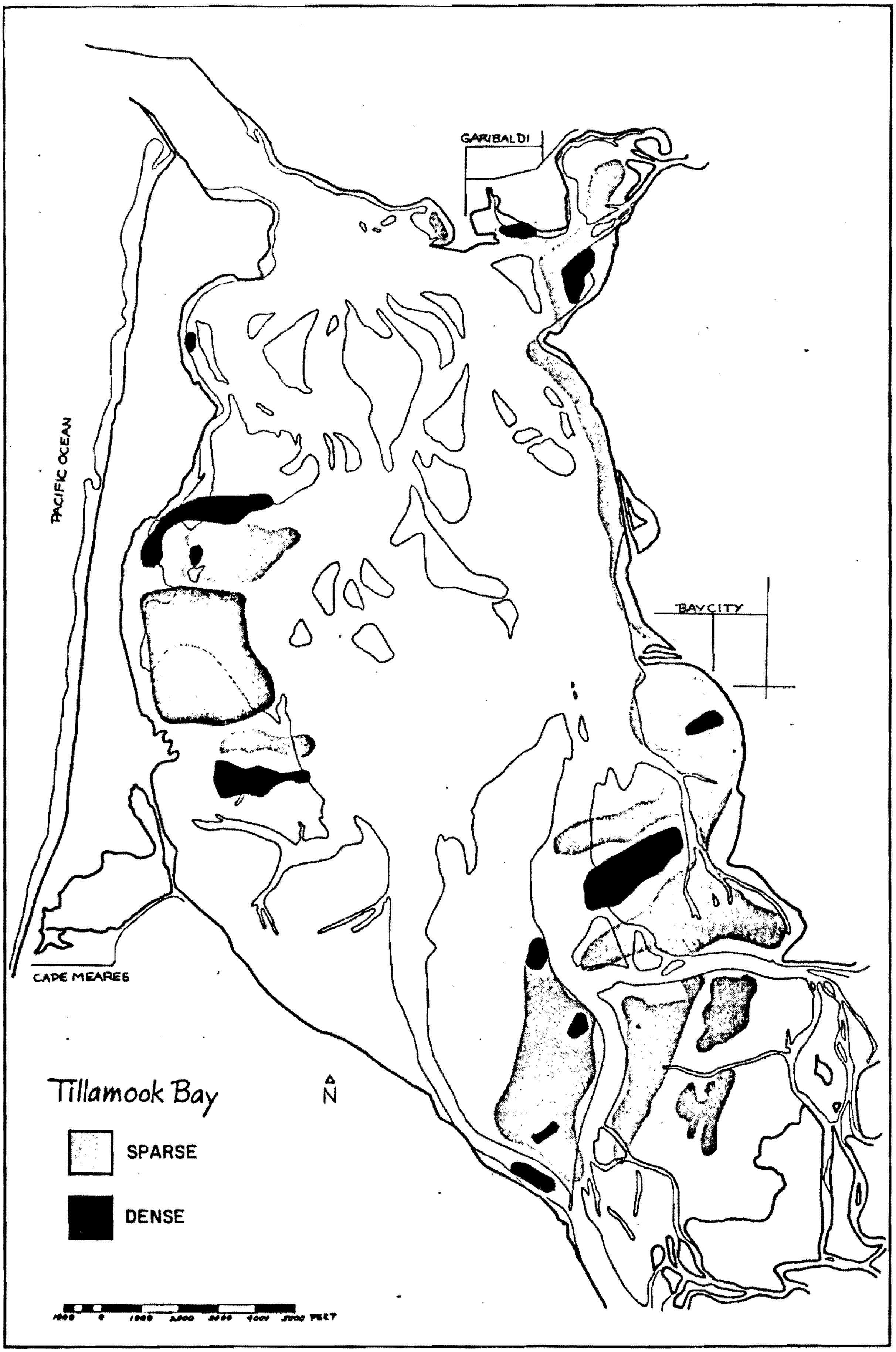

Figure 12. Distribution of Shrimp in Tillamook Bay.

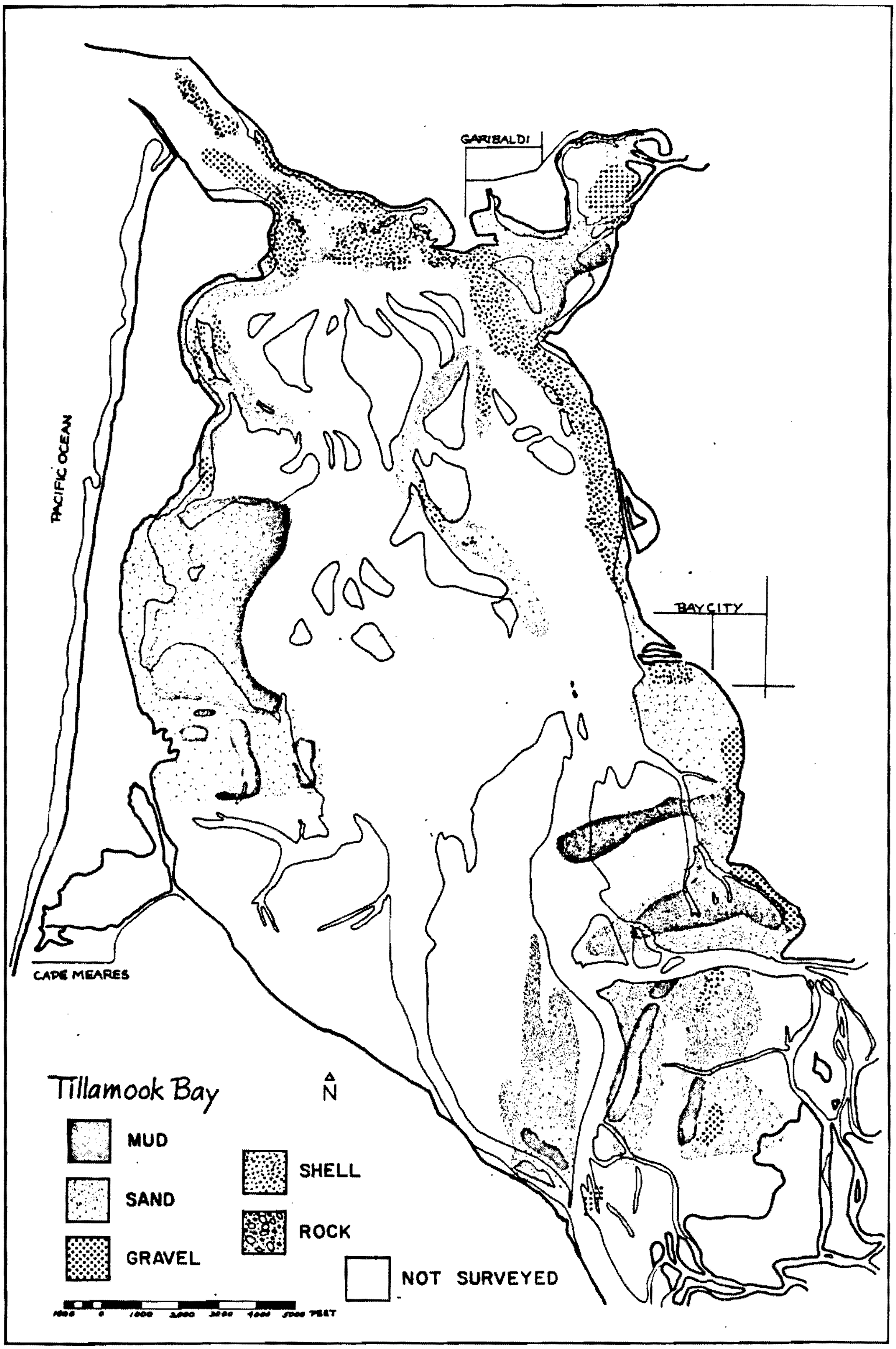

Figure 13. Substrate Material in Tillamook Bay.

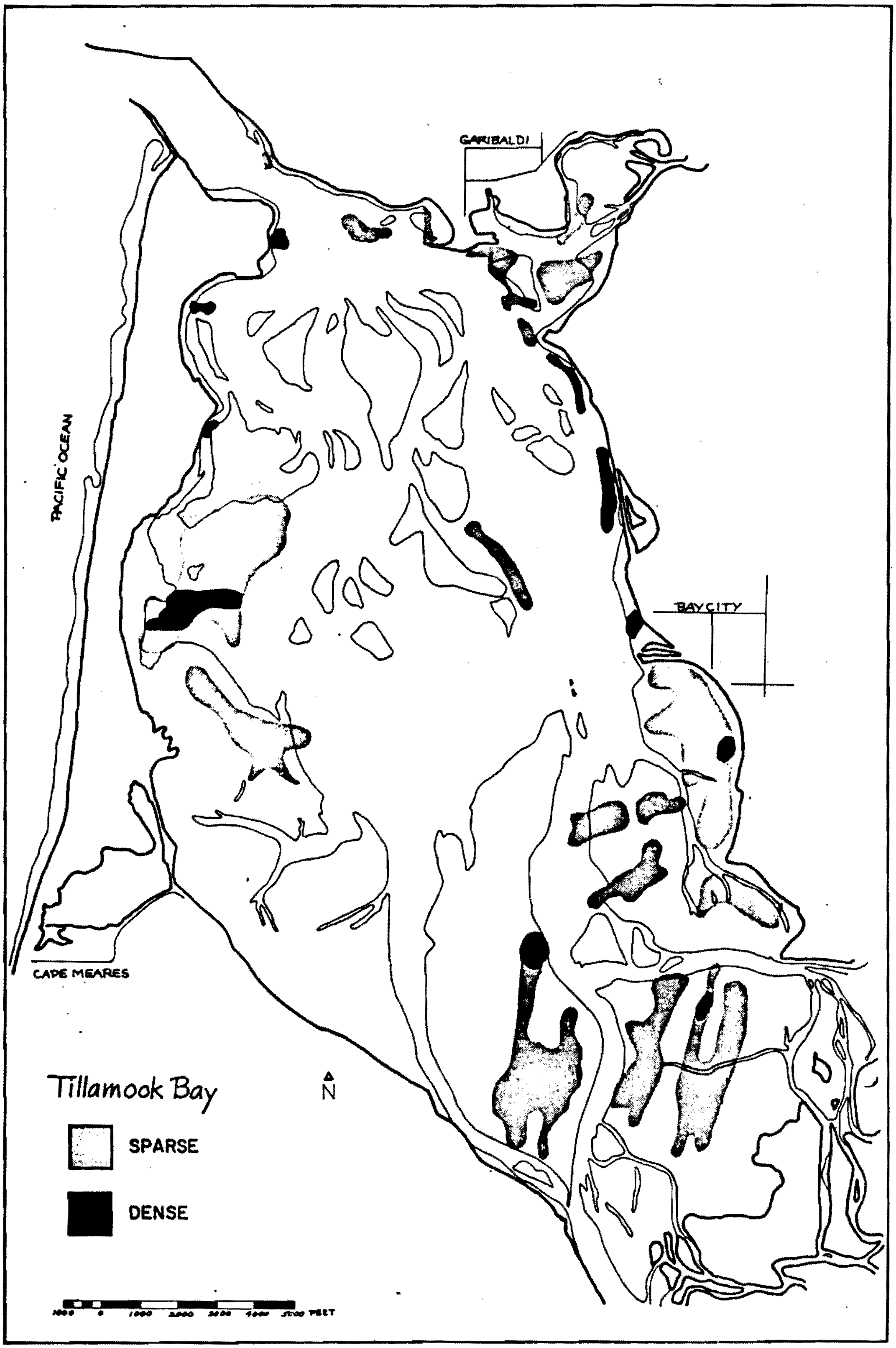

Figure 14. Distribution on Eel Grass in Tillamook Bay.

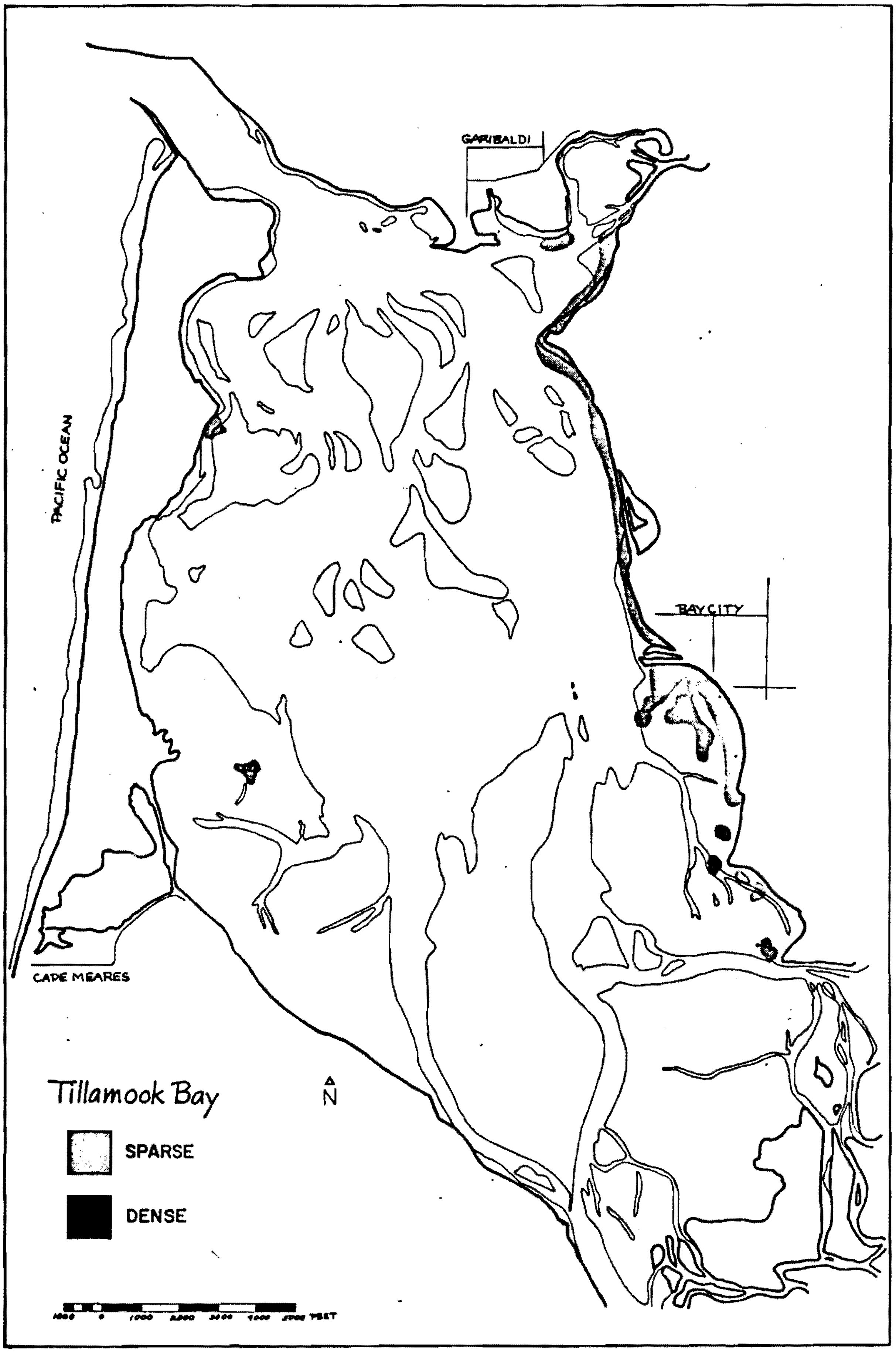

Figure 15. Distribution of *Fucus* in Tillamook Bay.

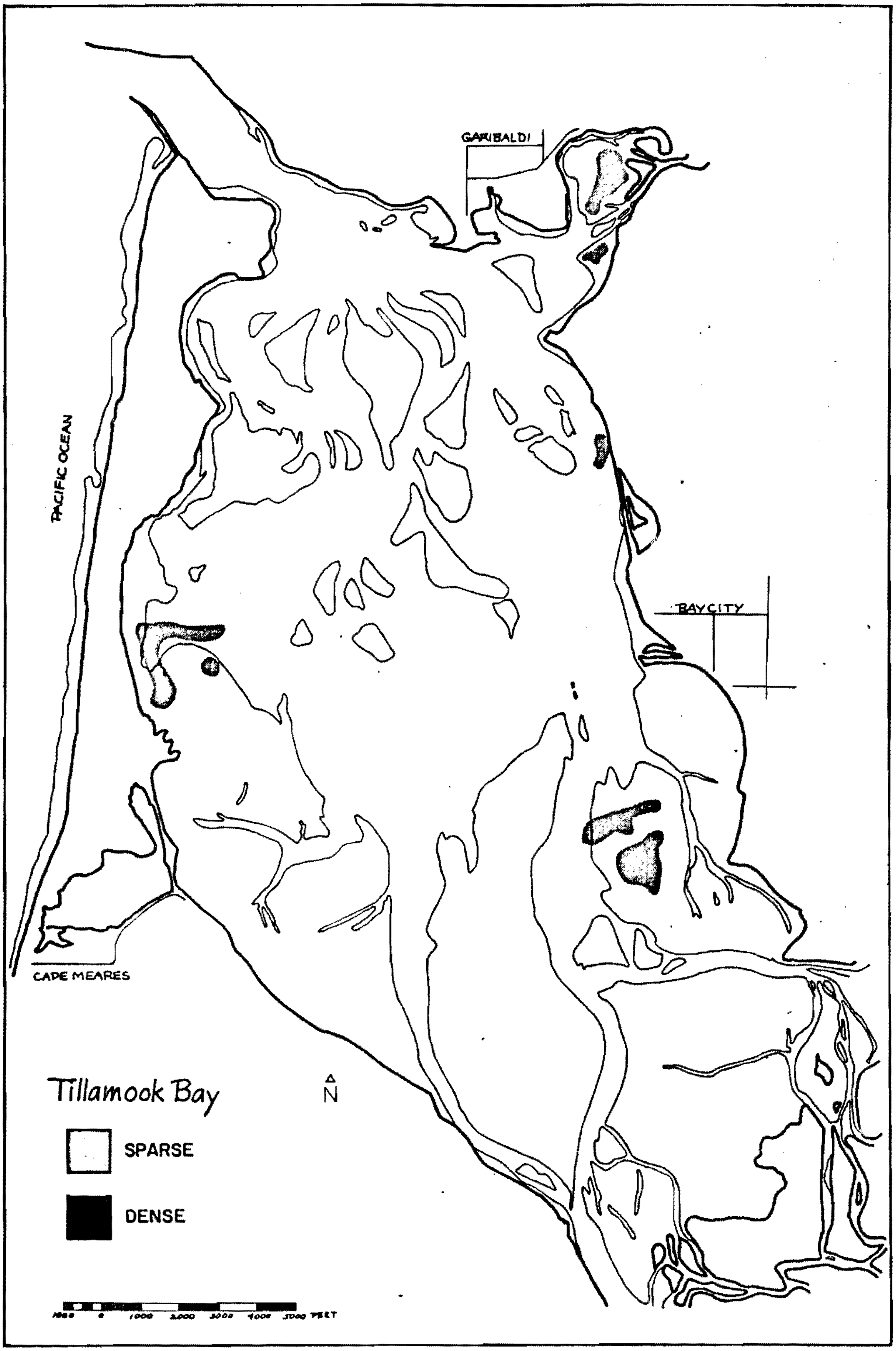

Figure 16. Distribution of *Enteromorpha* in Tillamook Bay.

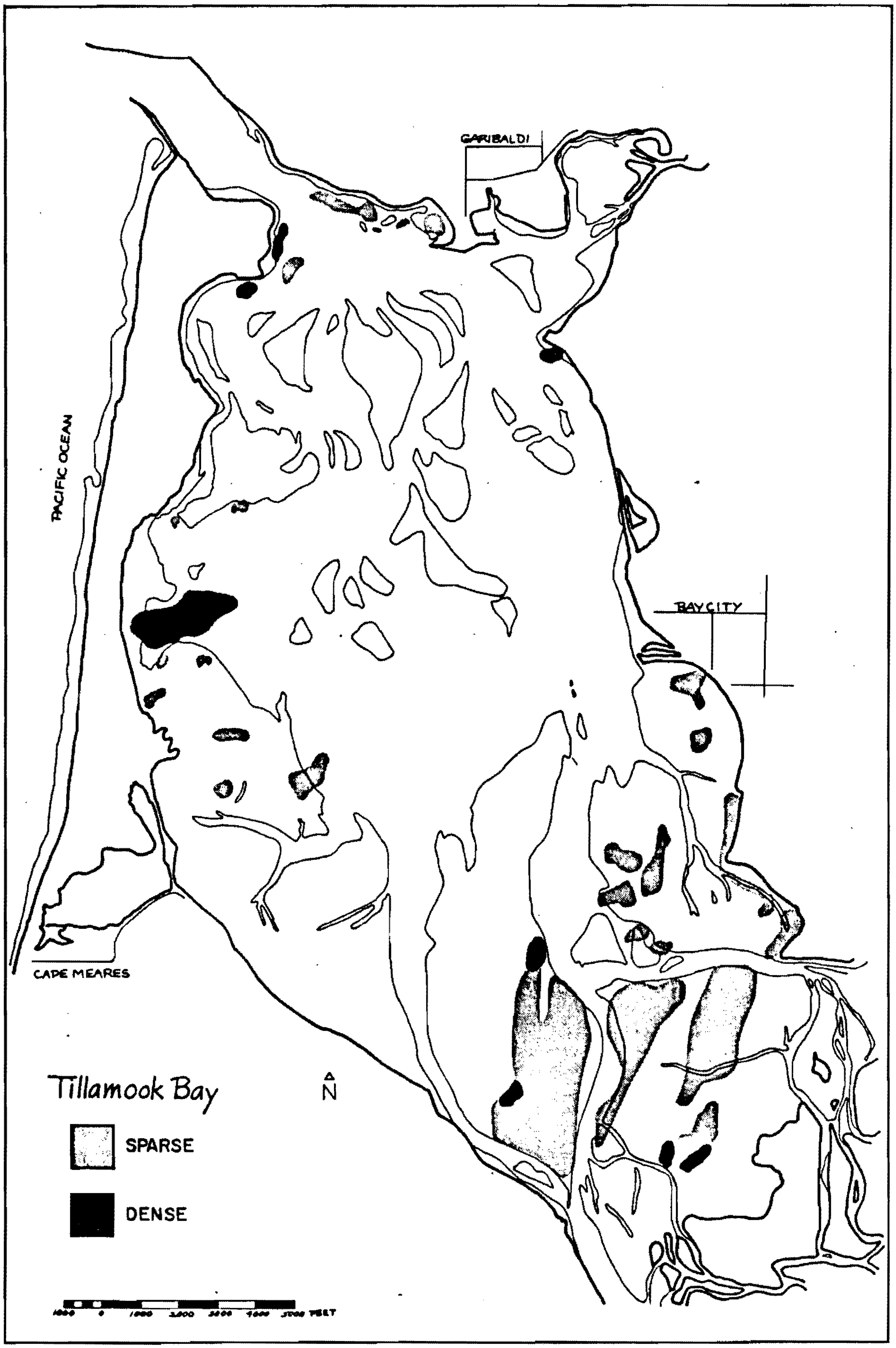

Figure 17. Distribution of Ulva in Tillamook Bay.

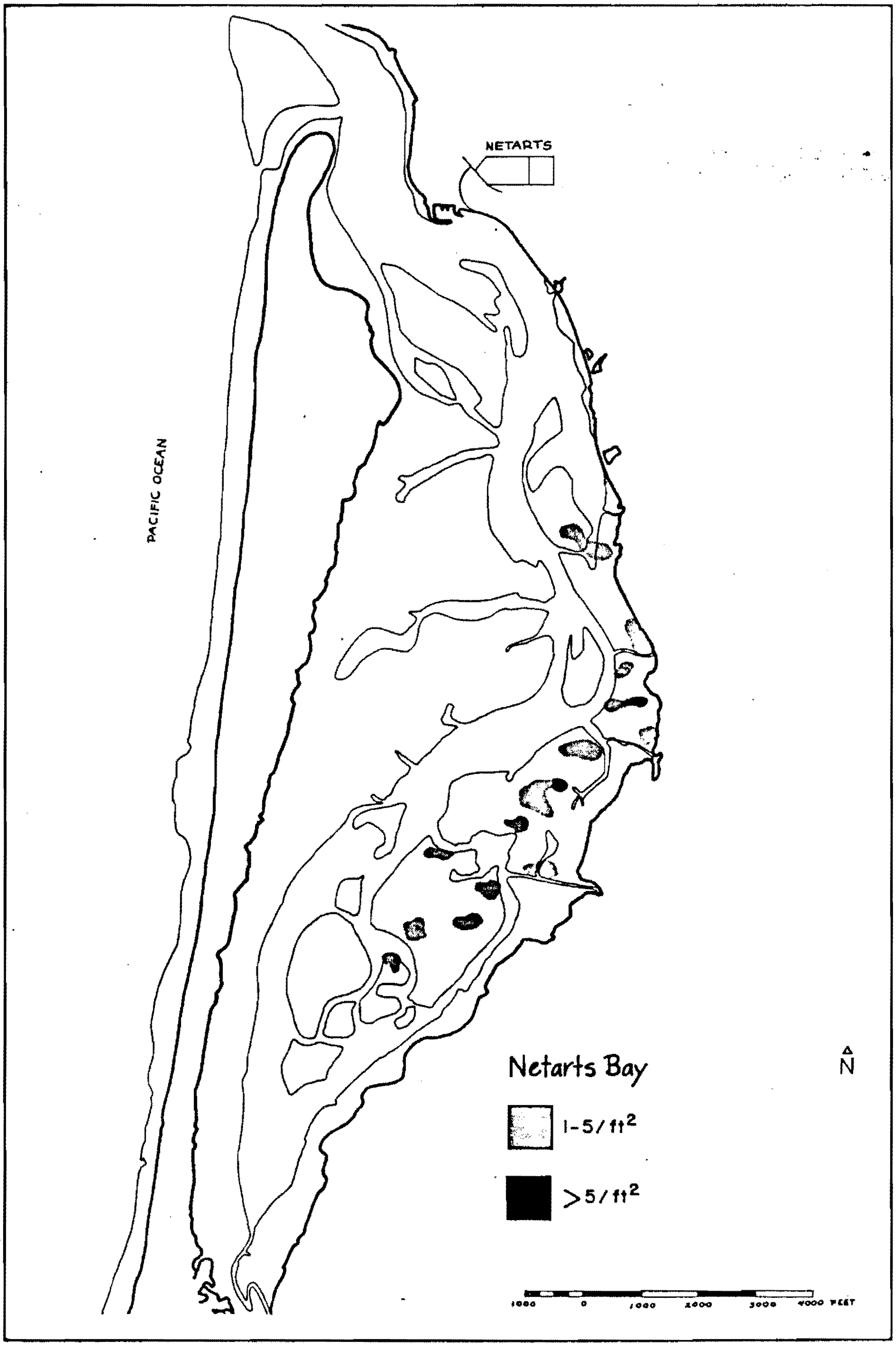

Figure 18. Distribution of Baltic Clams in Netarts Bay.

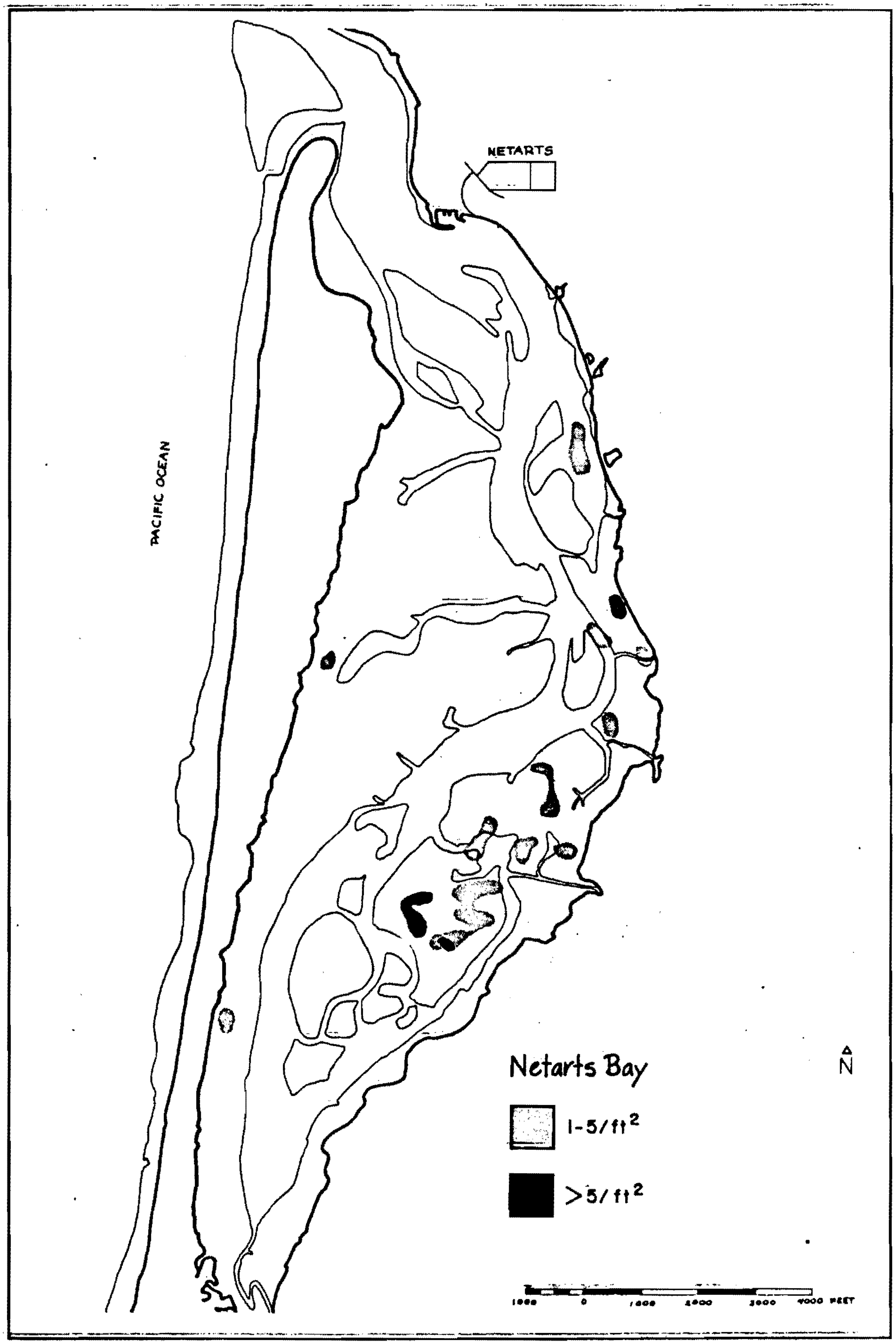

Figure 19. Distribution of Bentnose Clams in Netarts Bay.

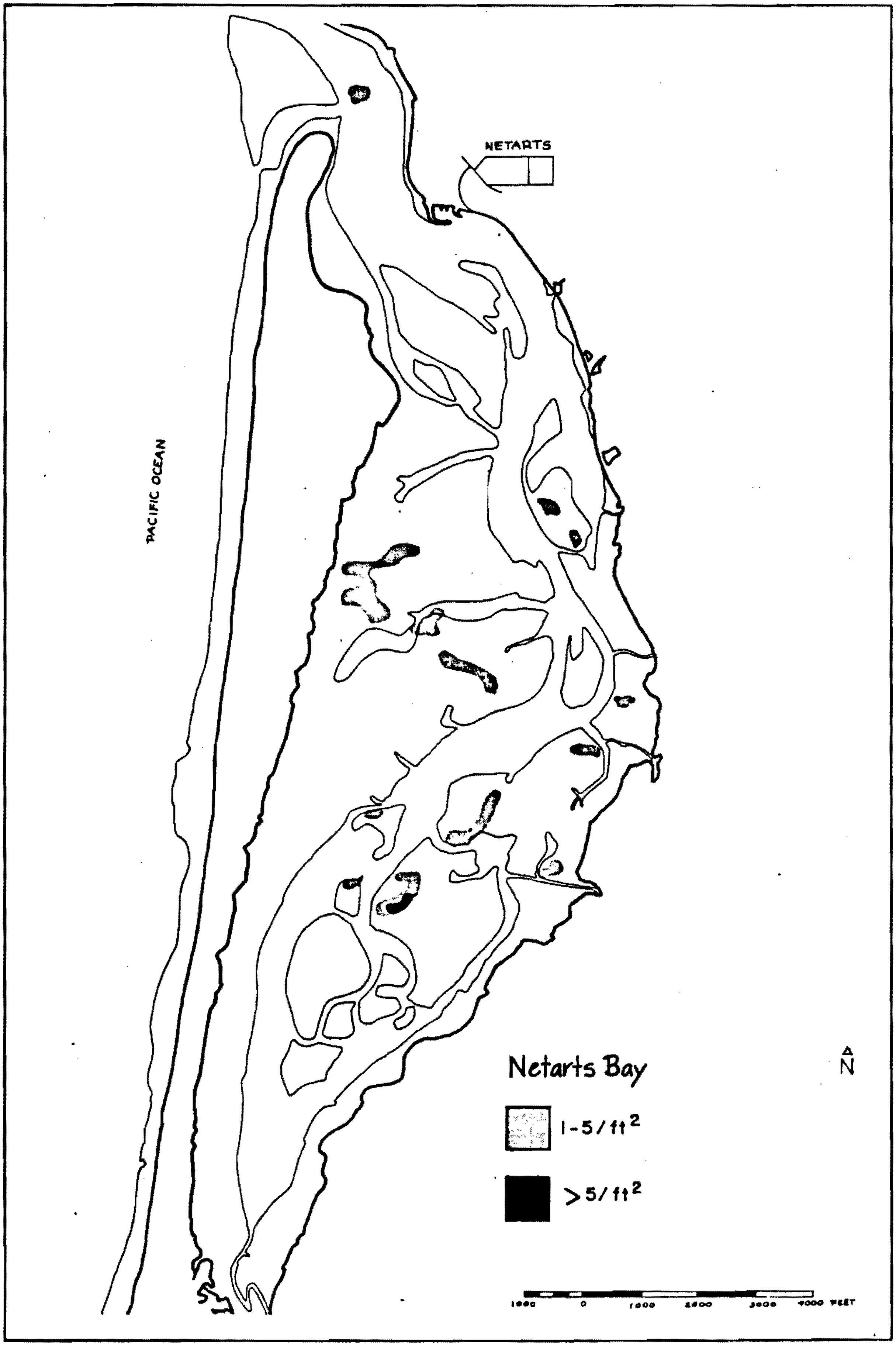

Figure 20. Distribution of Butter Clams in Netarts Bay.

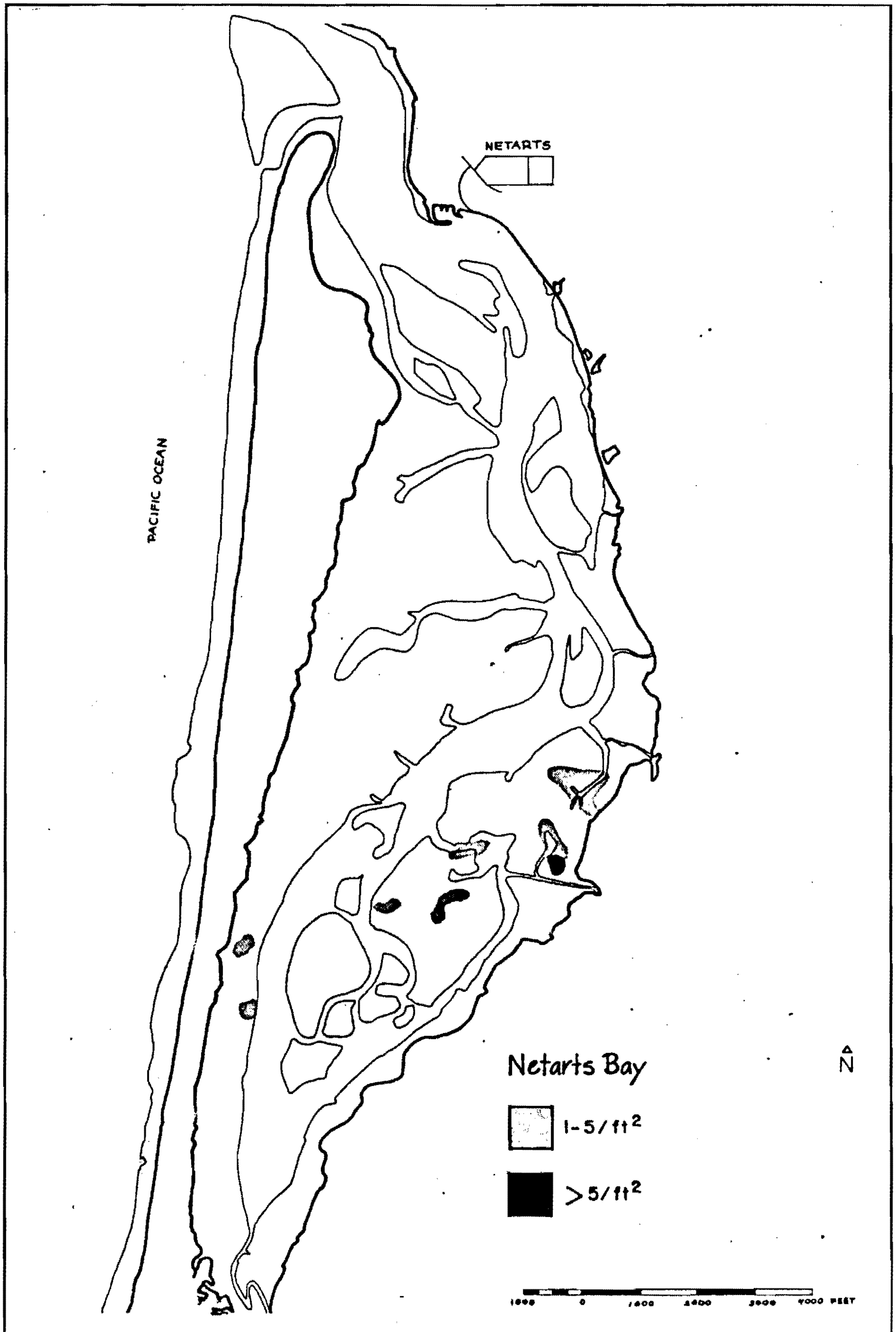

Figure 21. Distribution of California Softshell Clams in Netarts Bay.

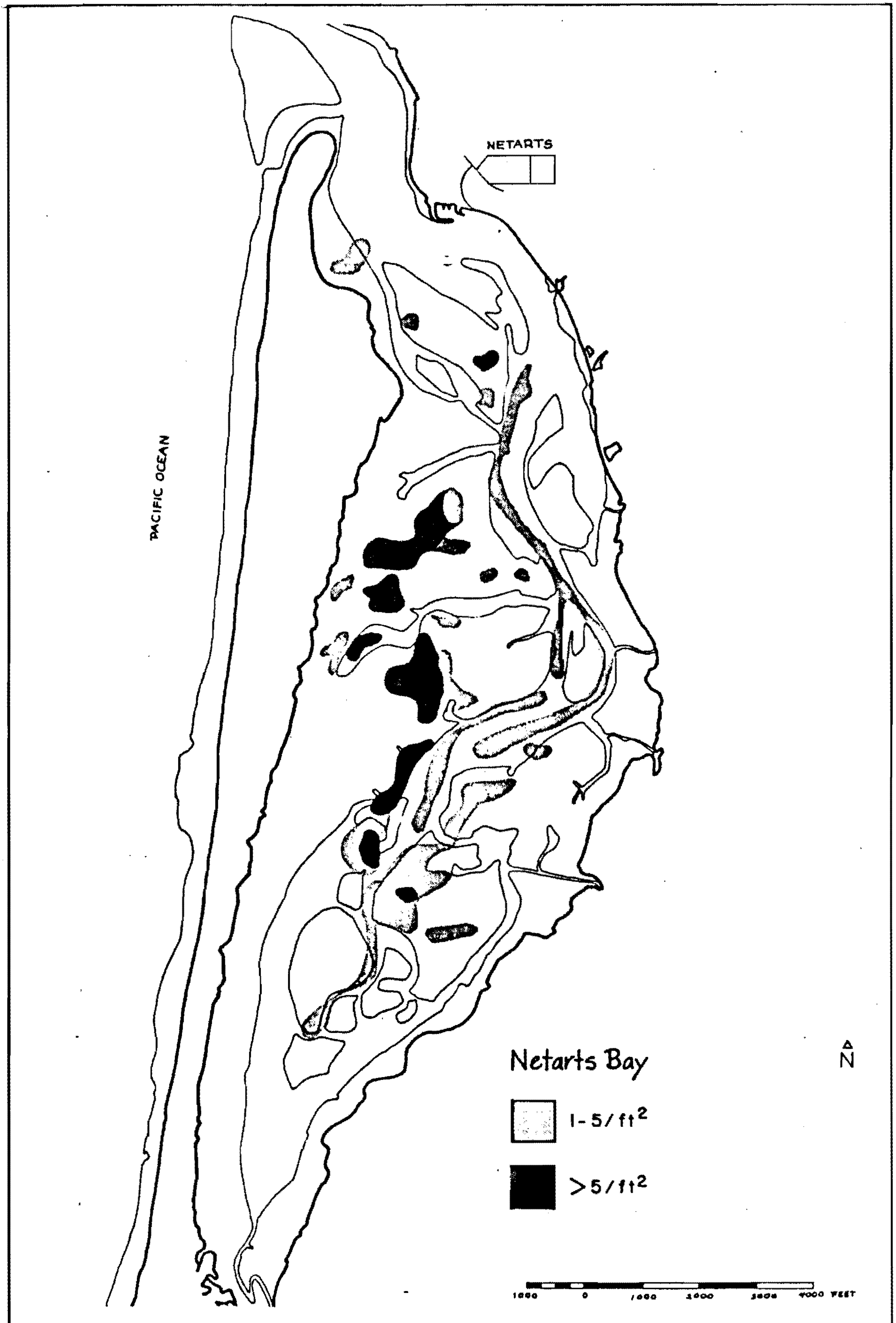

Figure 22. Distribution of Cockle Clams in Netarts Bay.

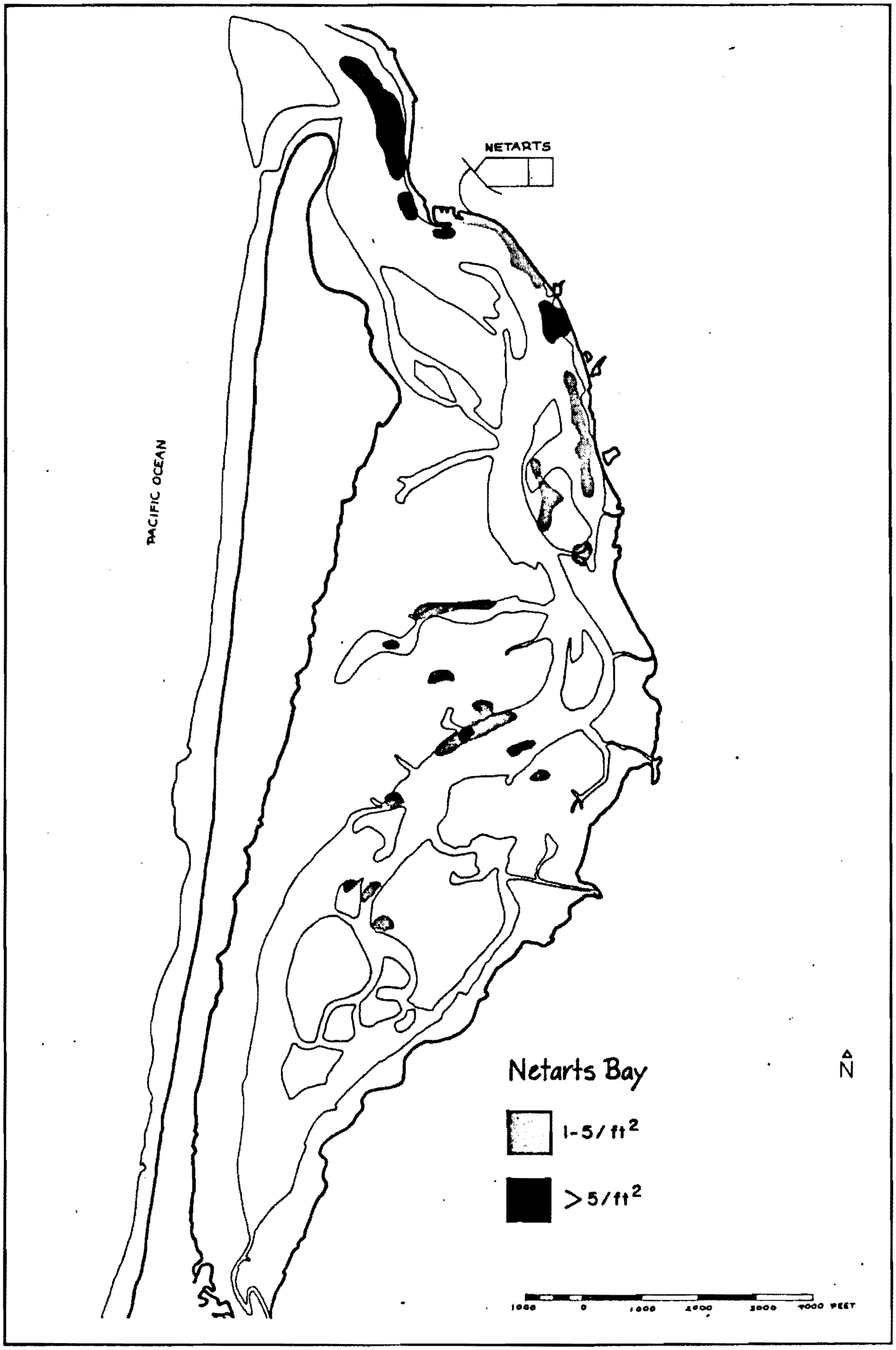

Figure 23. Distribution of Gaper Clams in Netarts Bay.

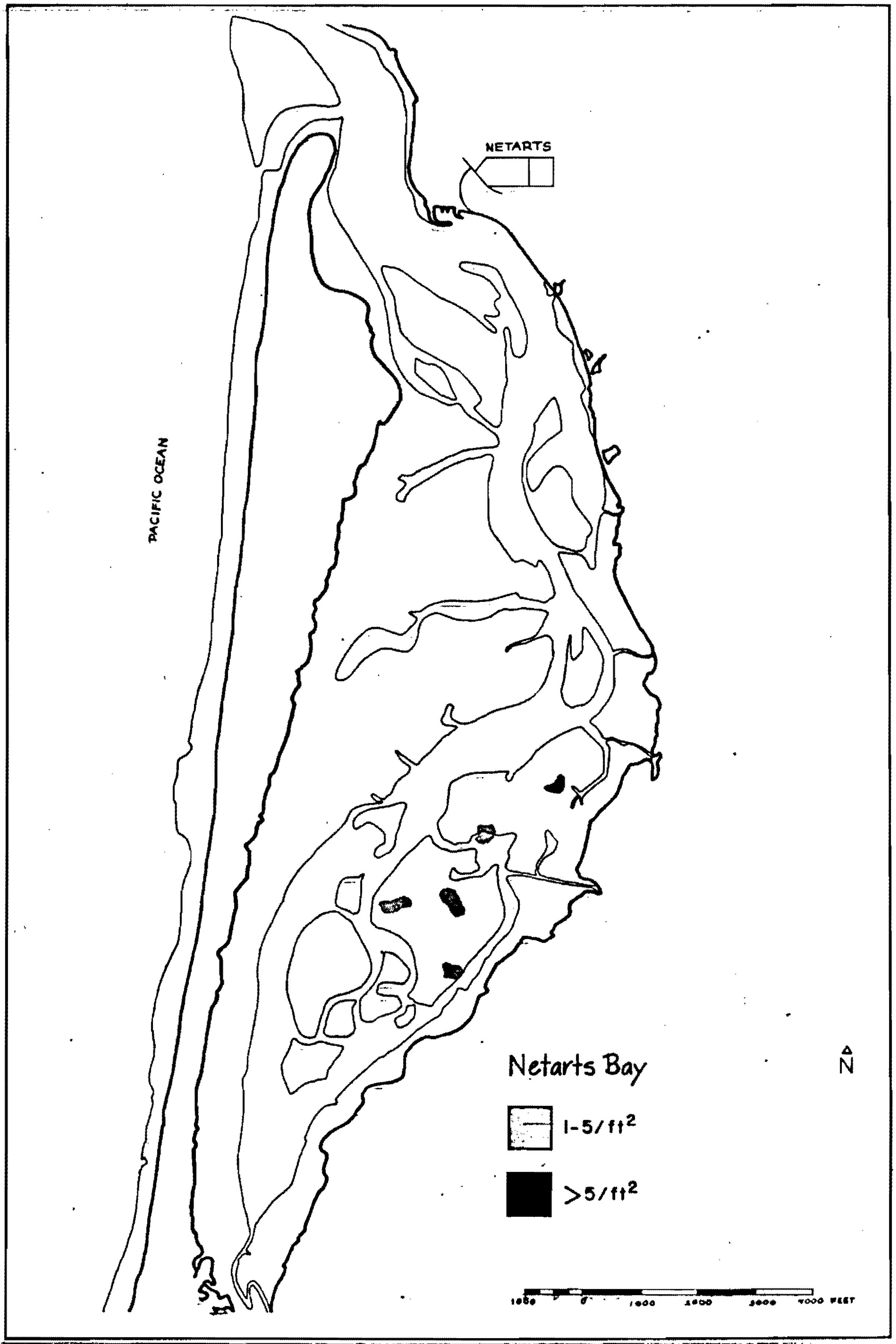

Figure 24. Distribution of Irus Clams in Netarts Bay.

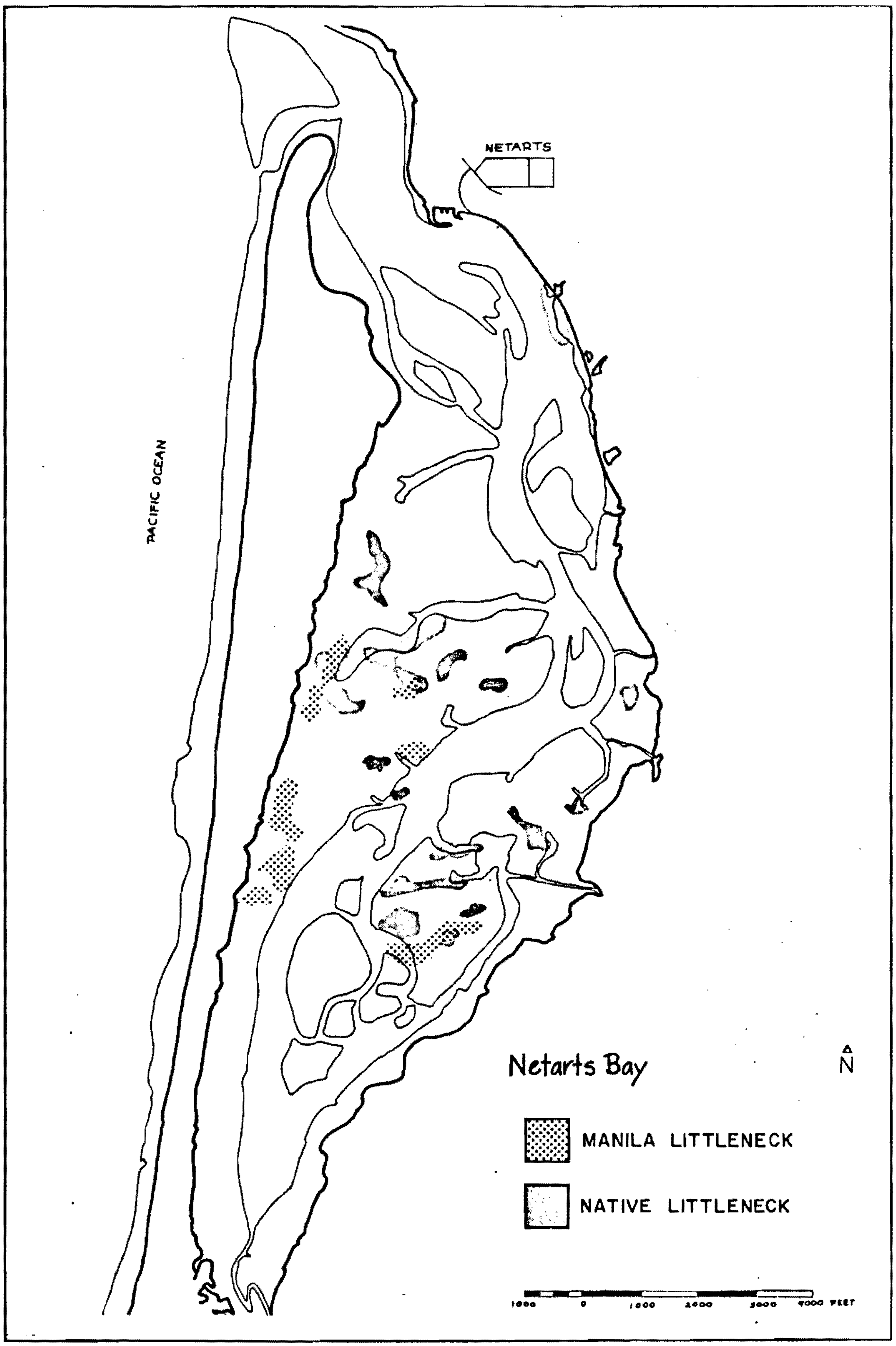

Figure 25. Distribution of Native Littleneck and Manila Littleneck Clams in Netarts Bay.

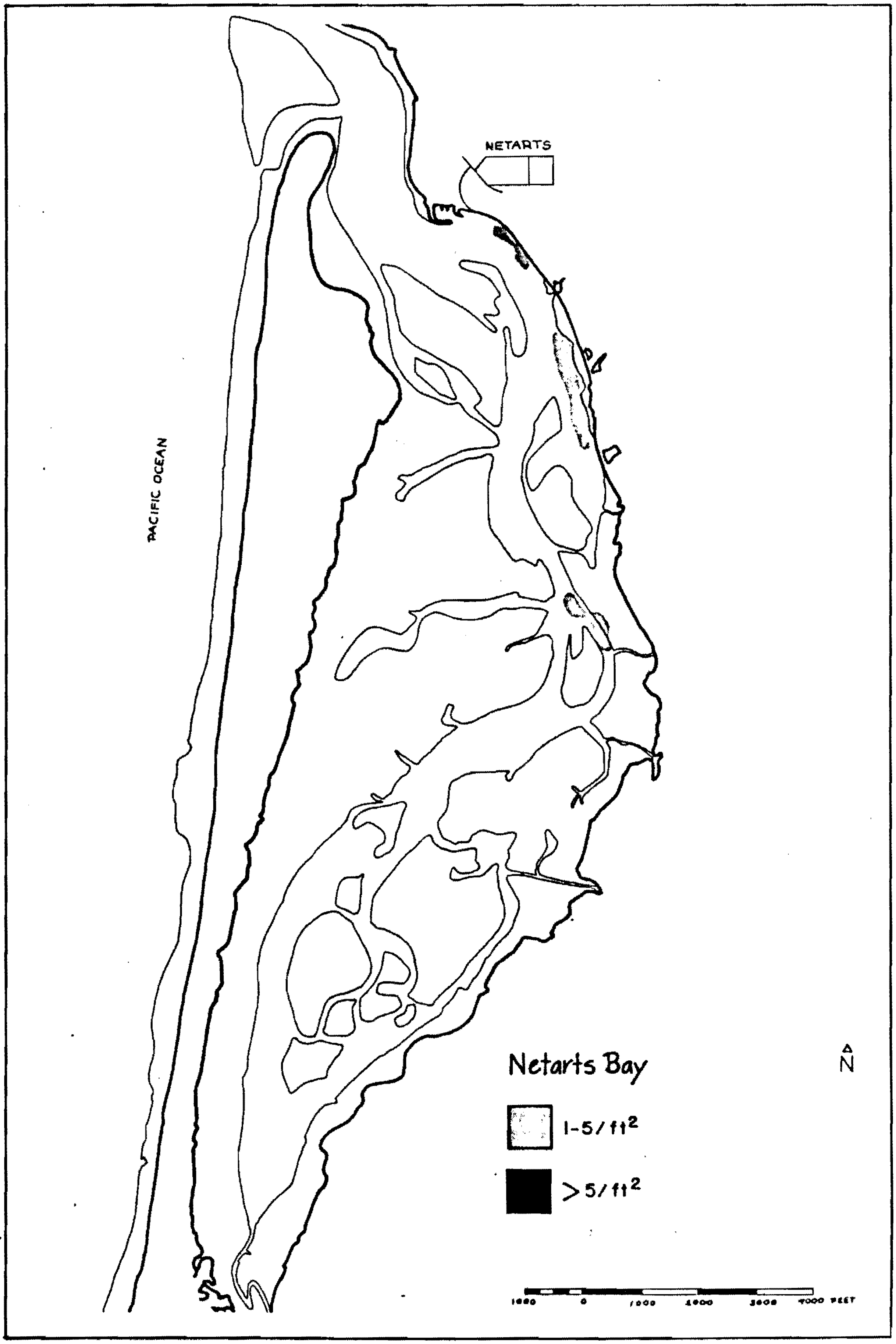

Figure 26. Distribution of Piddock Clams in Netarts Bay.

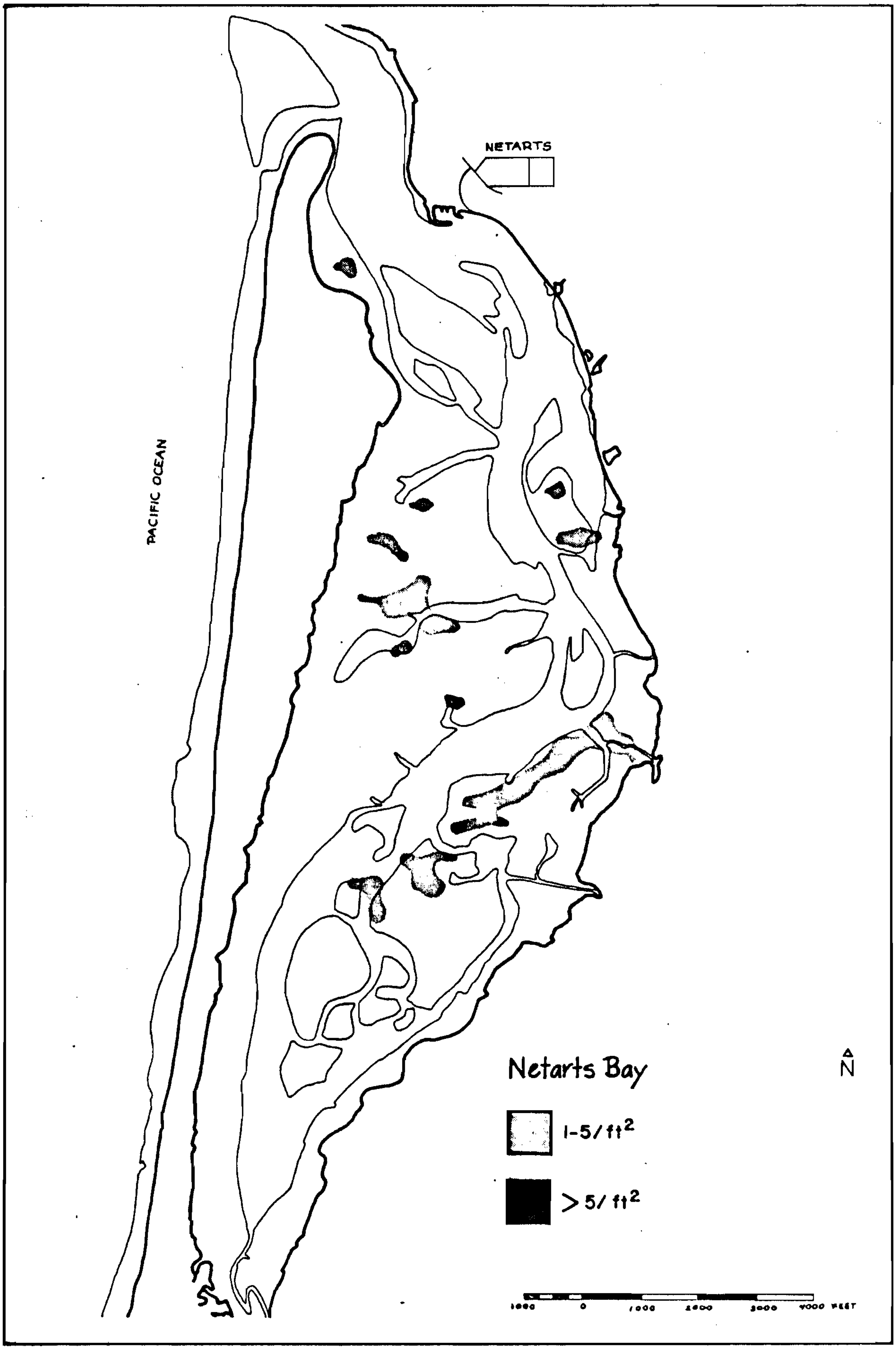

Figure 27. Distribution of Softshell Clams in Netarts Bay.

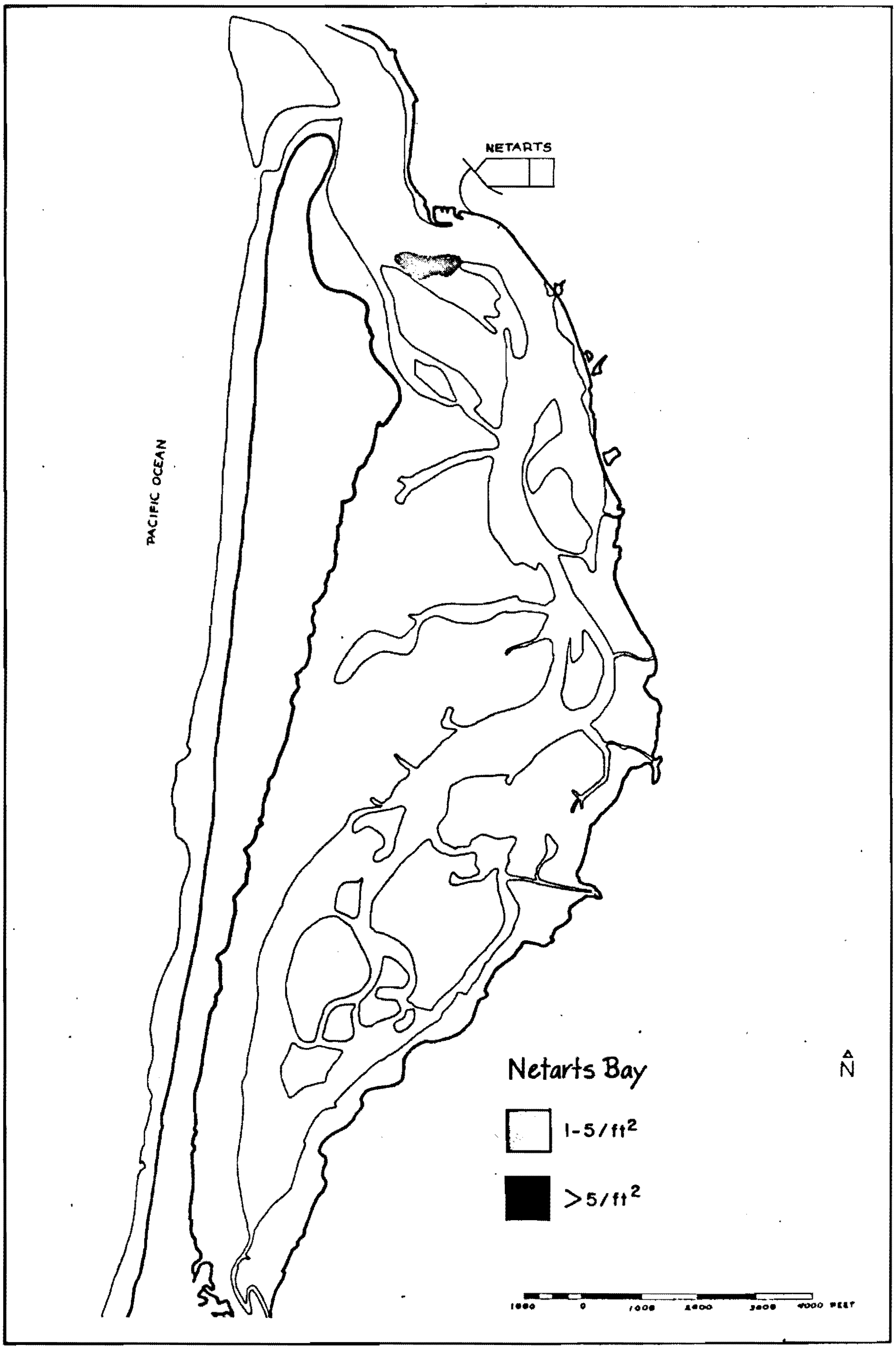

Figure 28. Distribution of Bodega Tellen Clams in Netarts Bay.

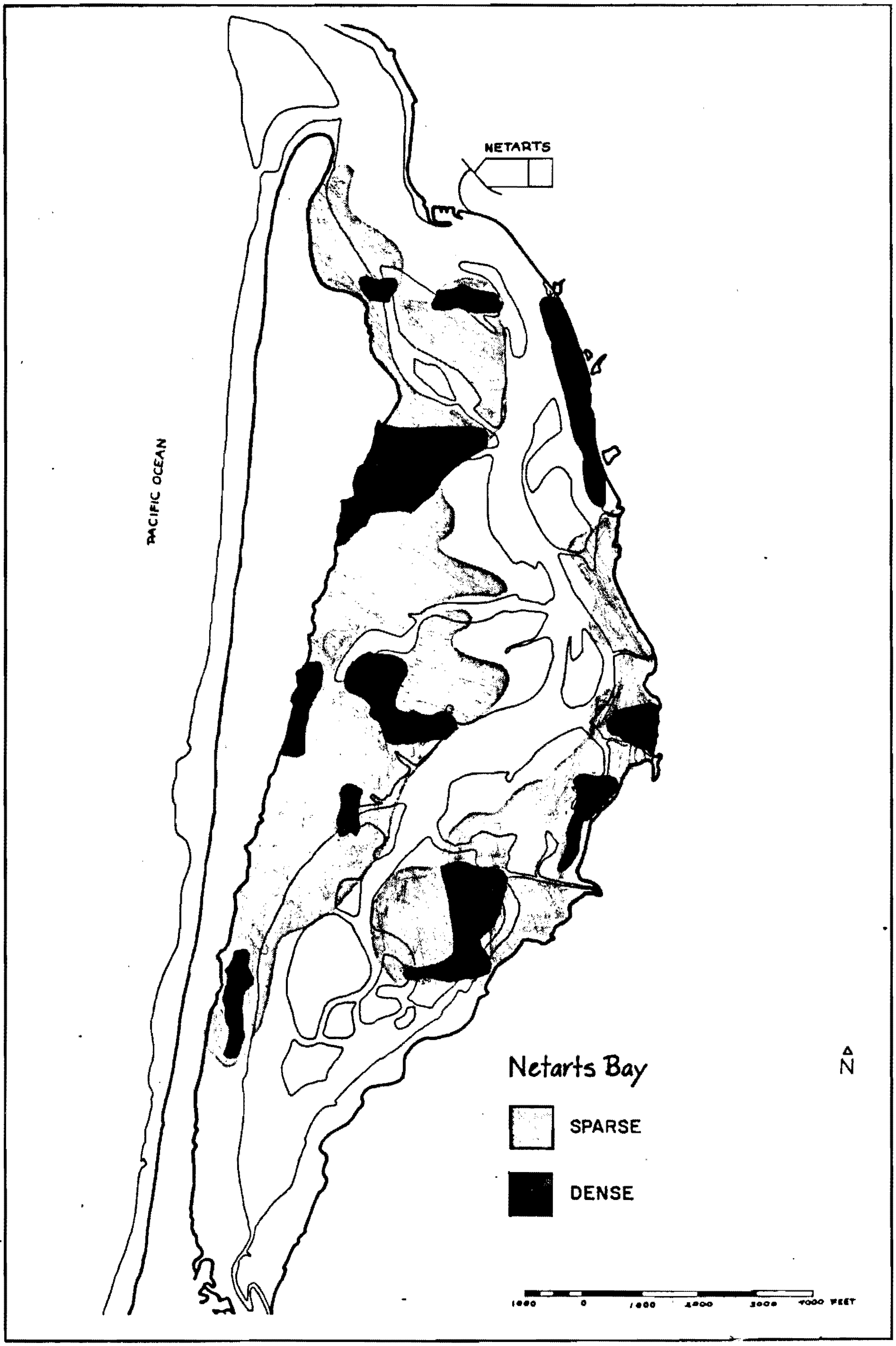

Figure 29. Distribution of Mud and Ghost Shrimp in Netarts Bay.

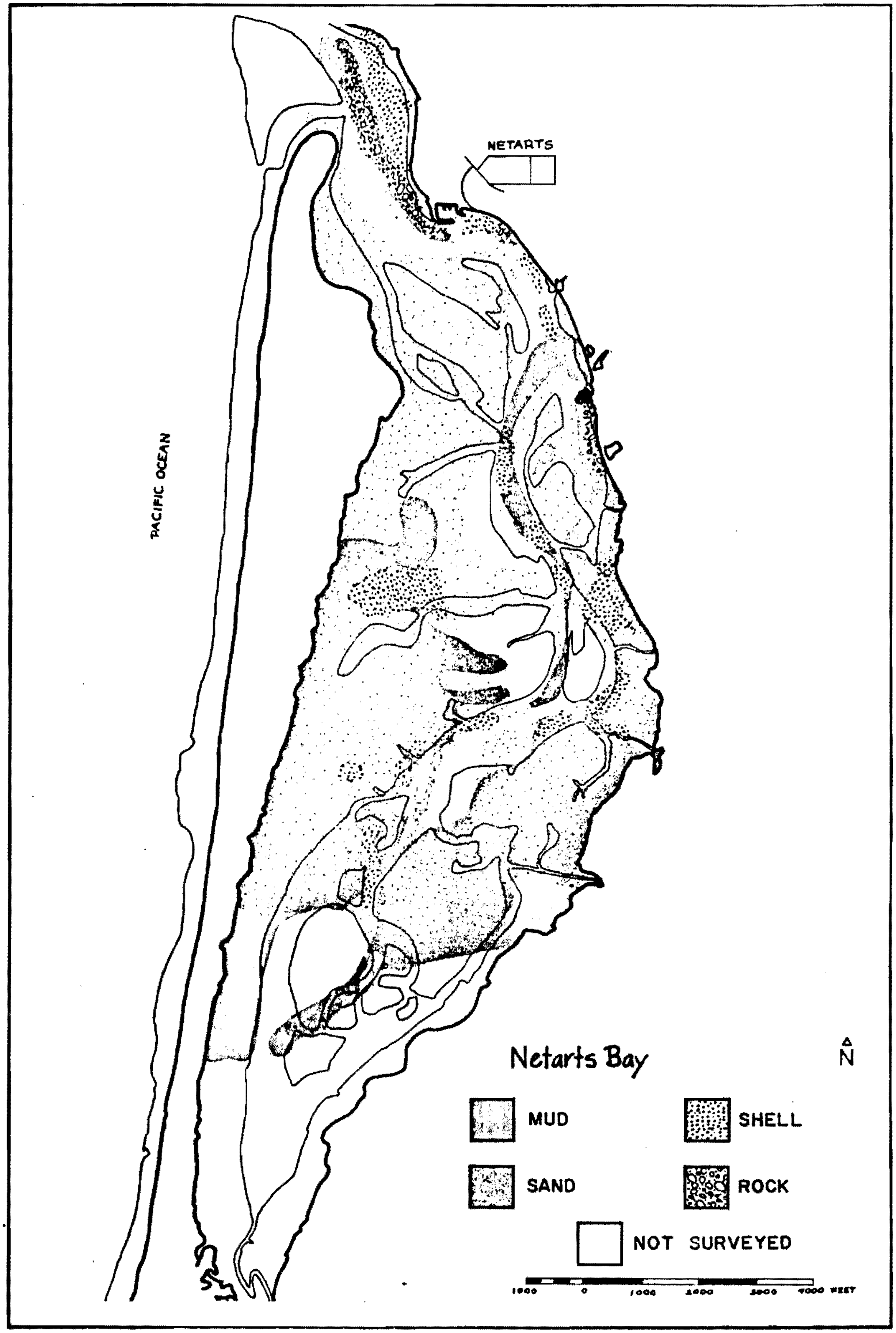

Figure 30. Substrate Materials in Netarts Bay.

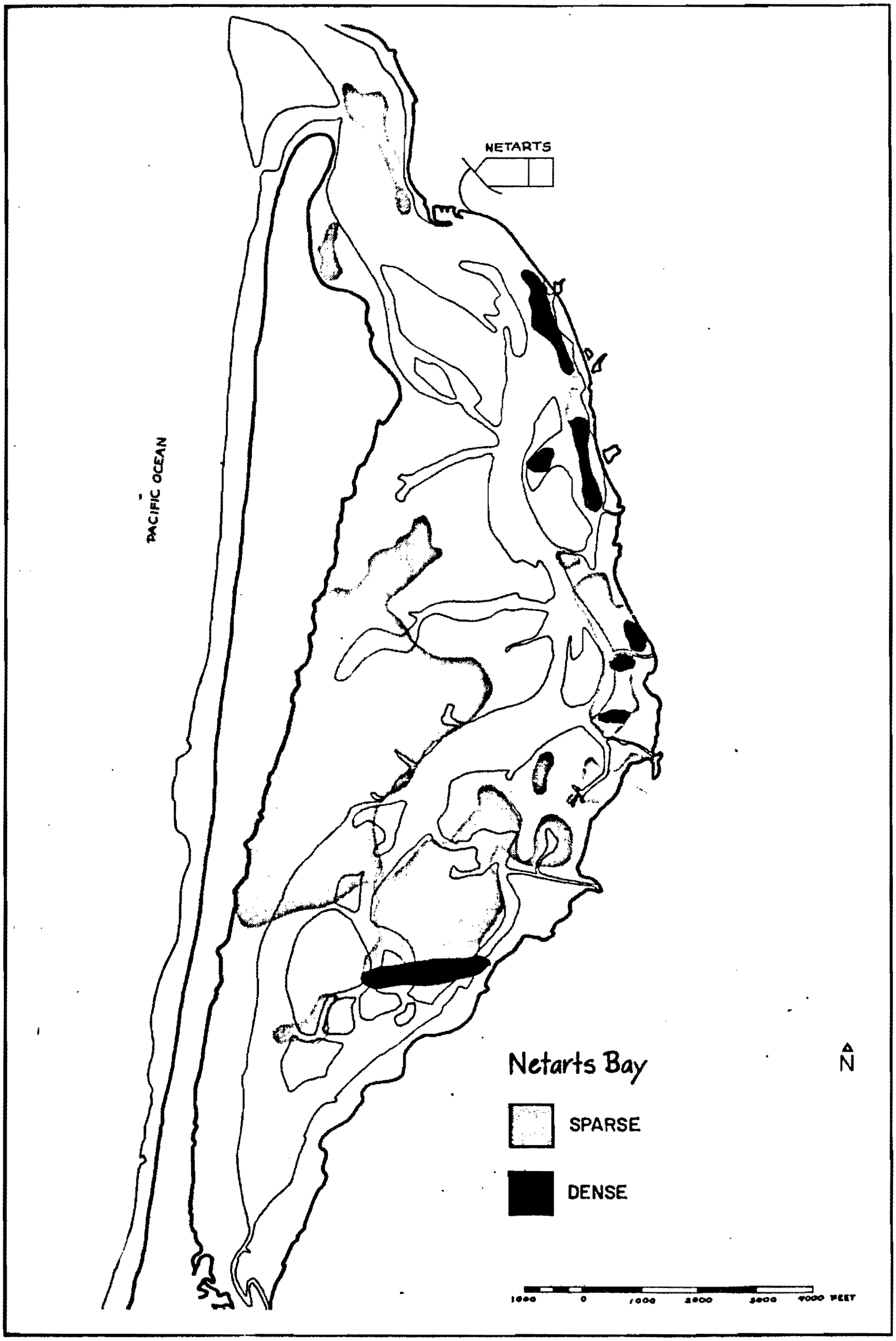

Figure 31. Distribution of Eel Grass in Netarts Bay.

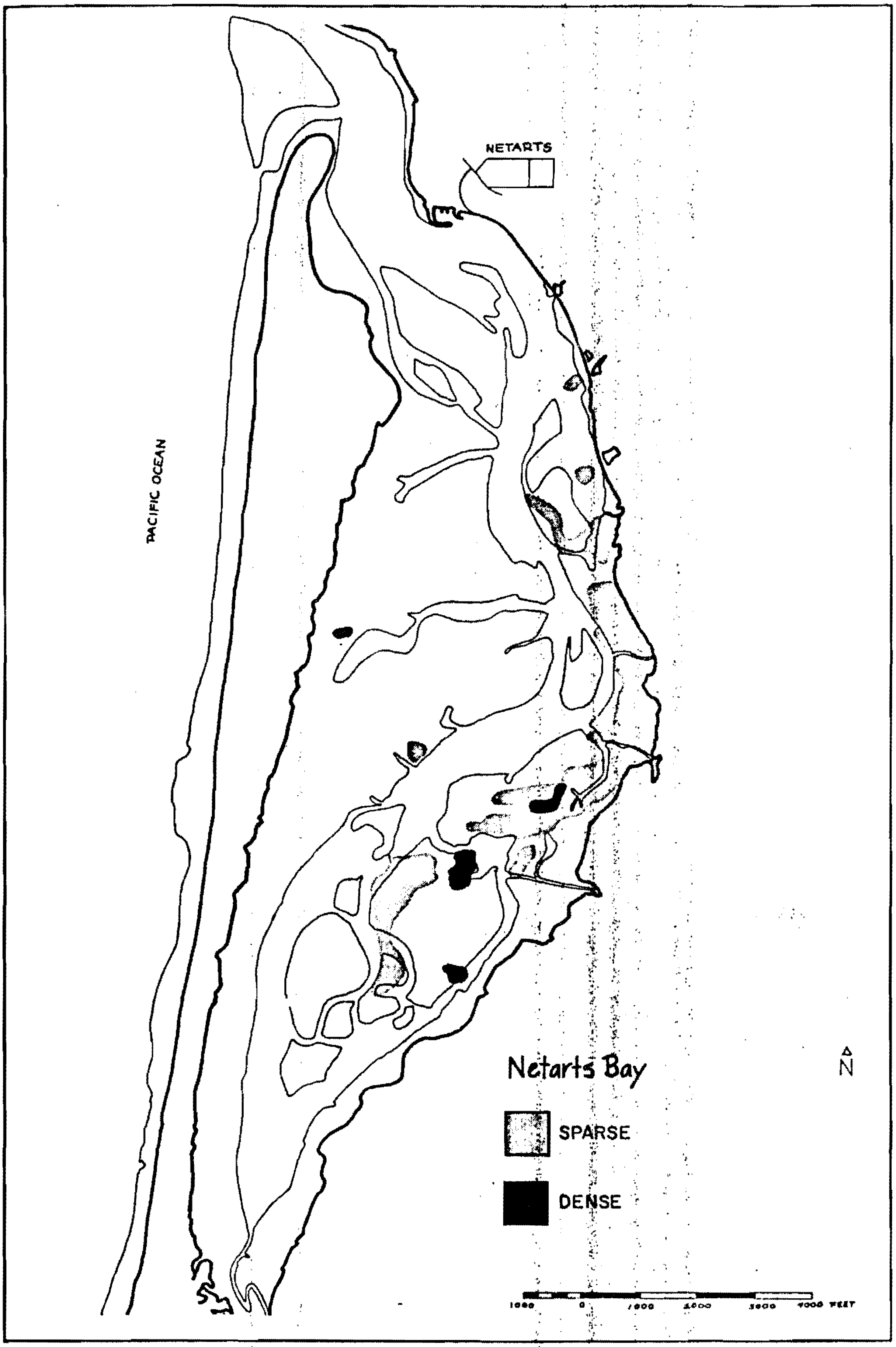

Figure 32. Distribution of *Enteromorpha* in Netarts Bay.

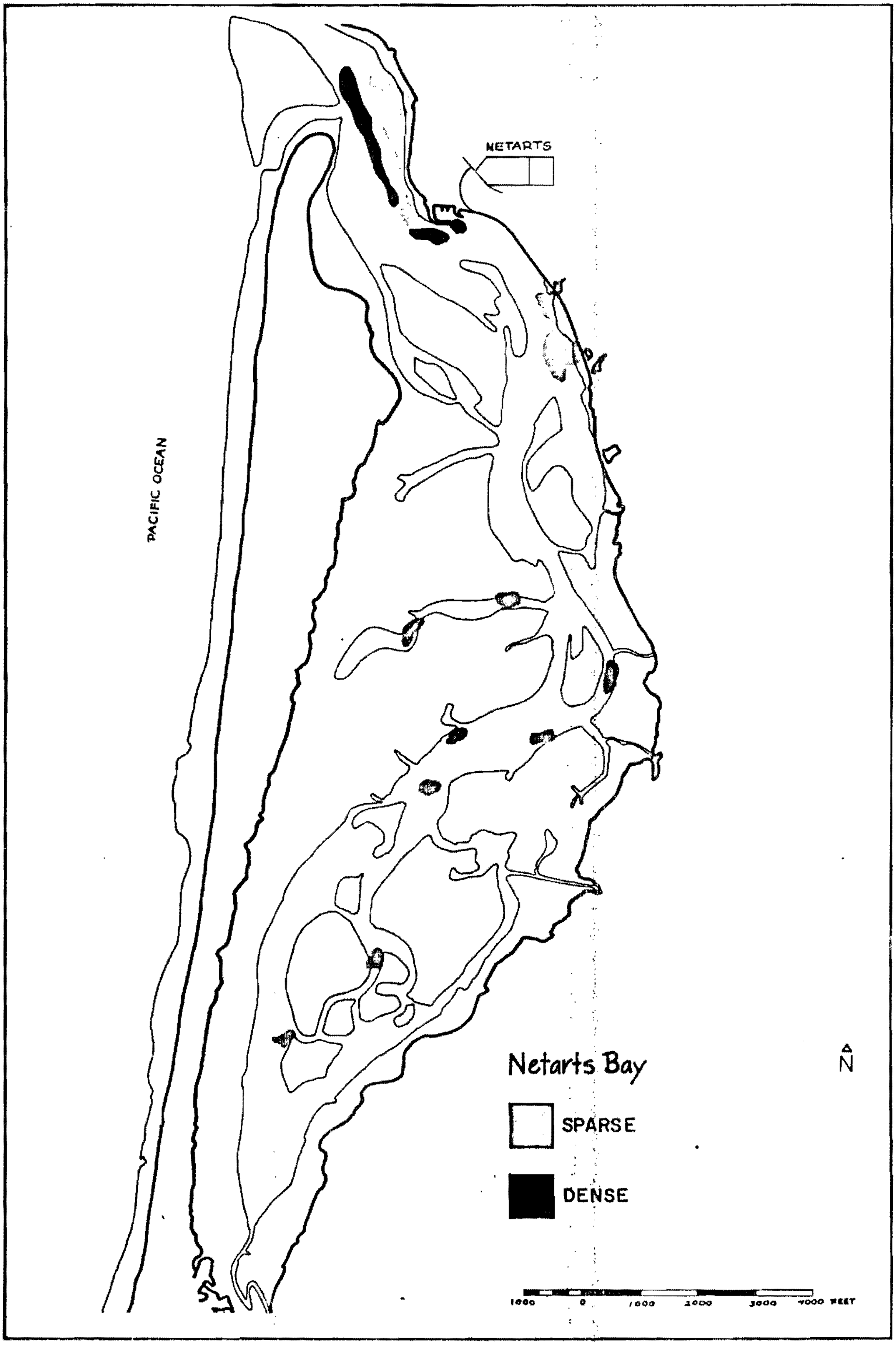

Figure 33. Distribution of Green Algae in Netarts Bay.

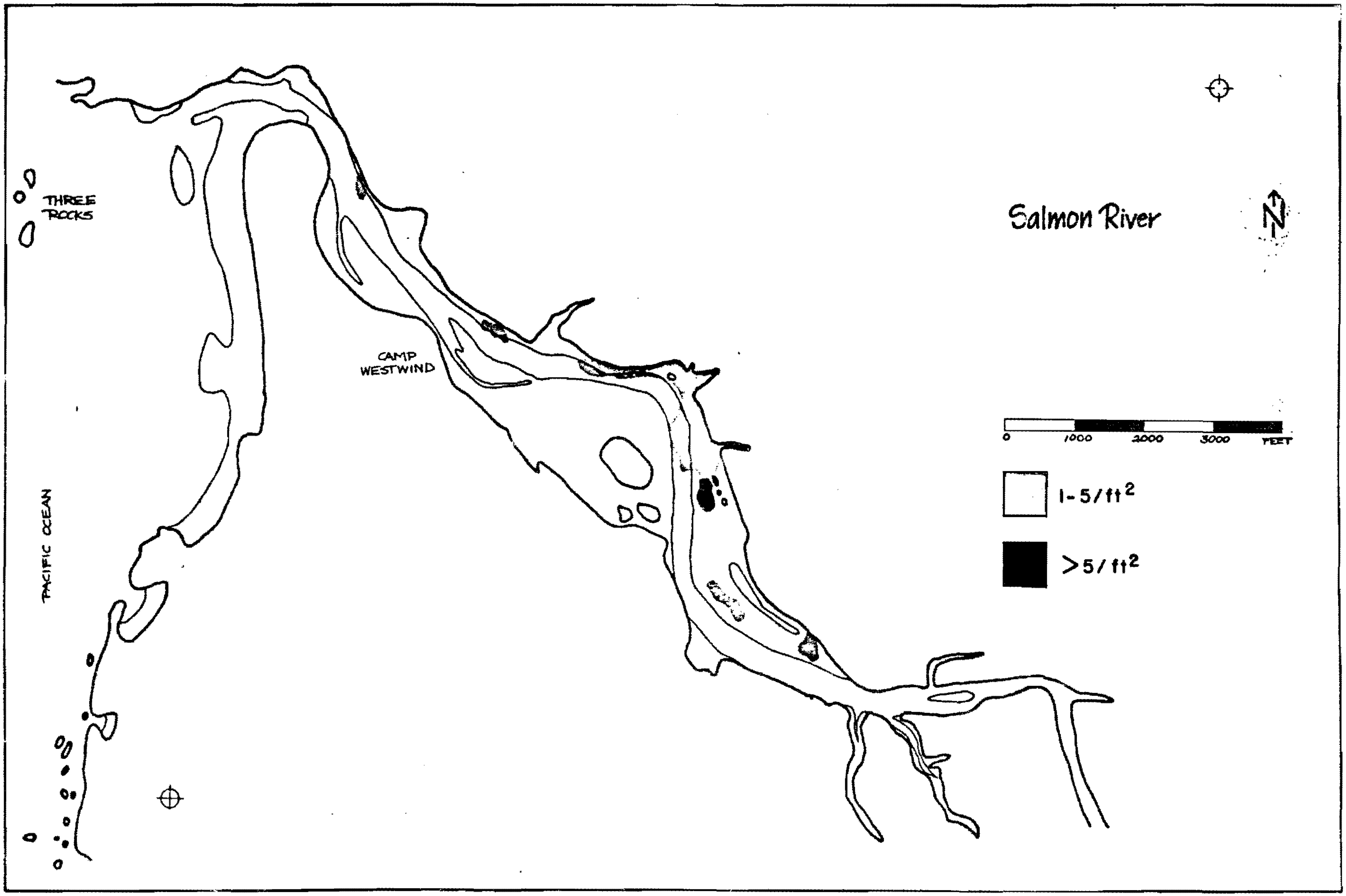

Figure 34. Distribution of Softshell Clams in the Salmon River.

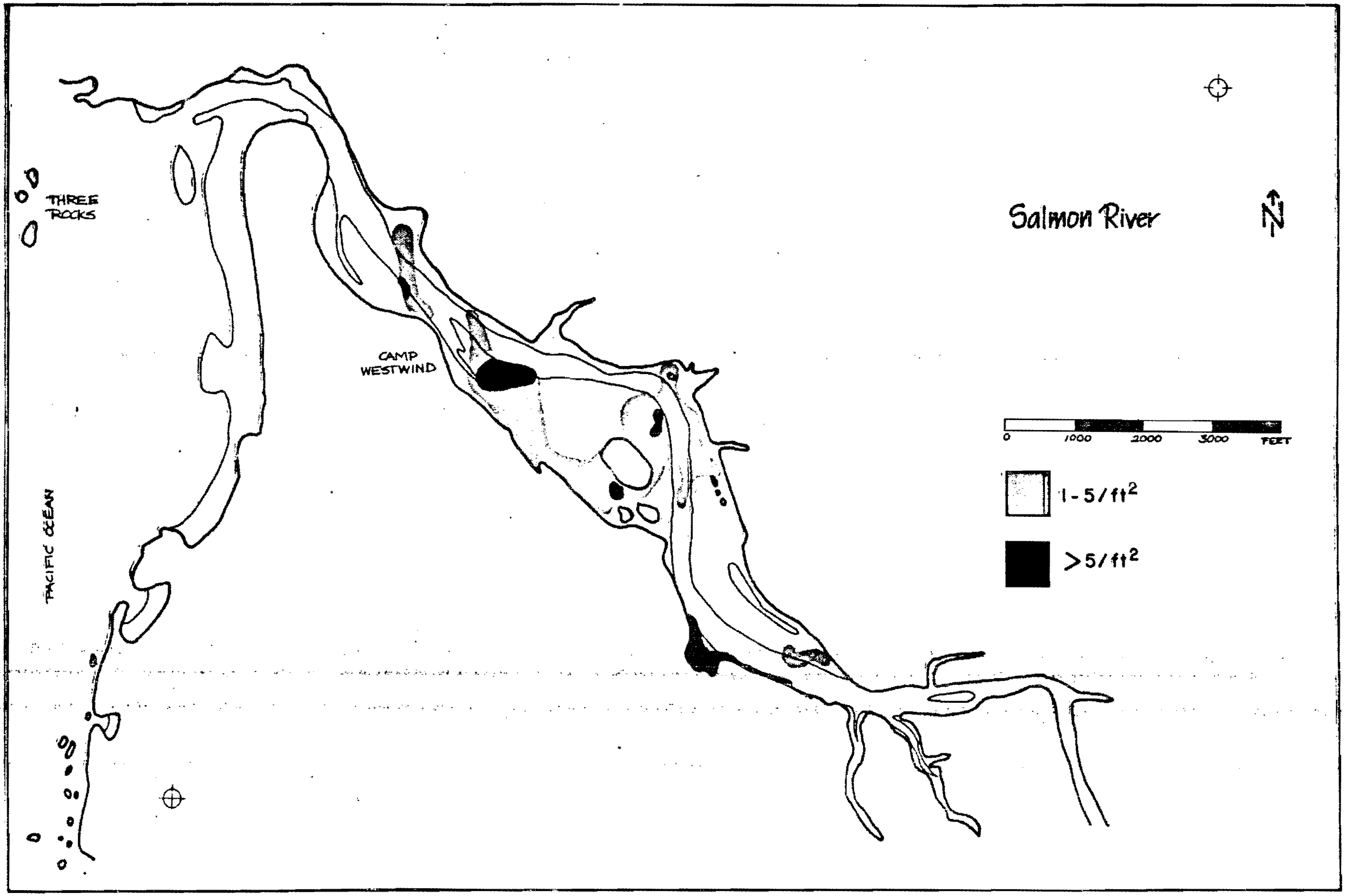

Figure 35. Distribution of Baltic Clams in The Salmon River.

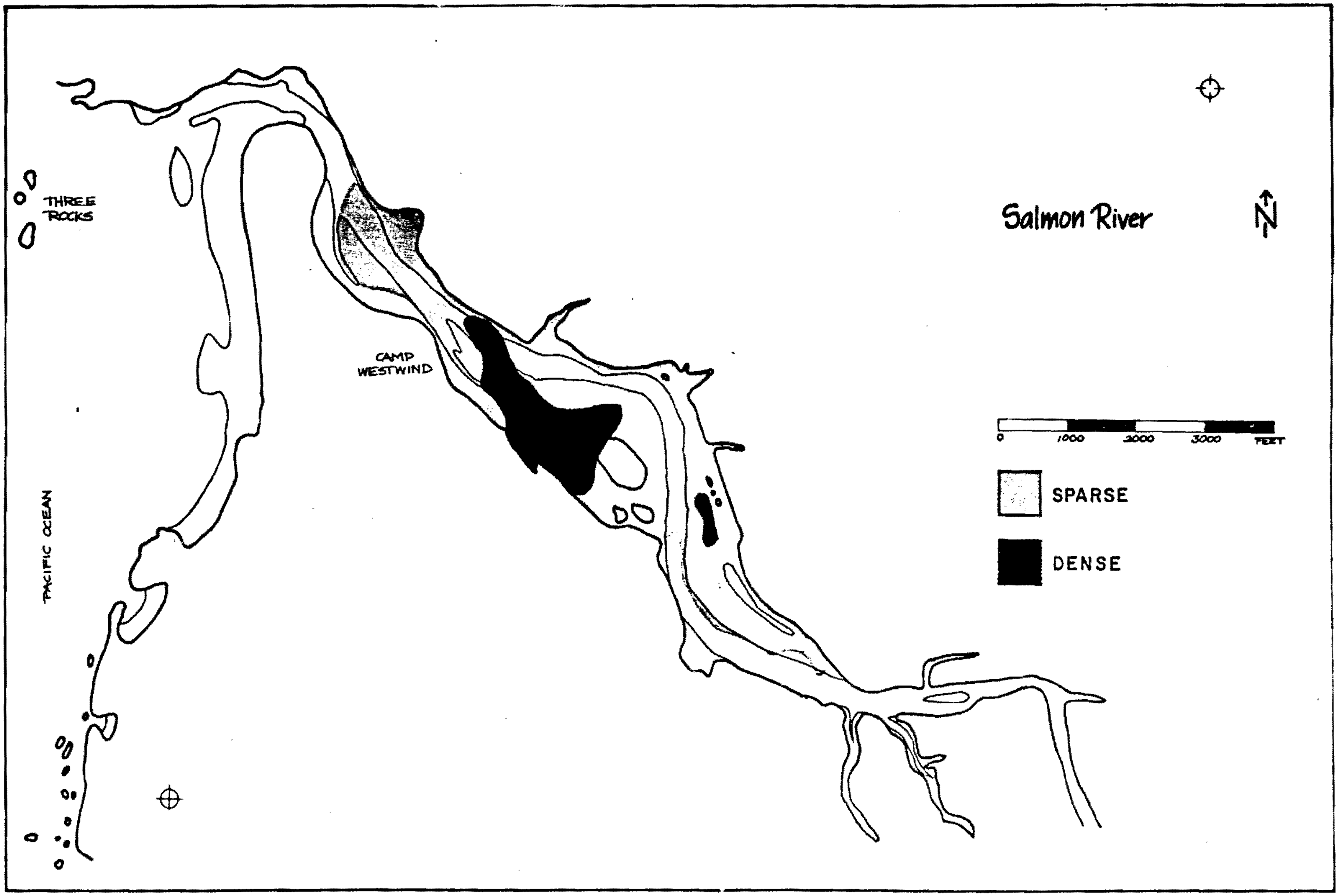

Figure 36. Distribution of Mud and Ghost Shrimp in The Salmon River

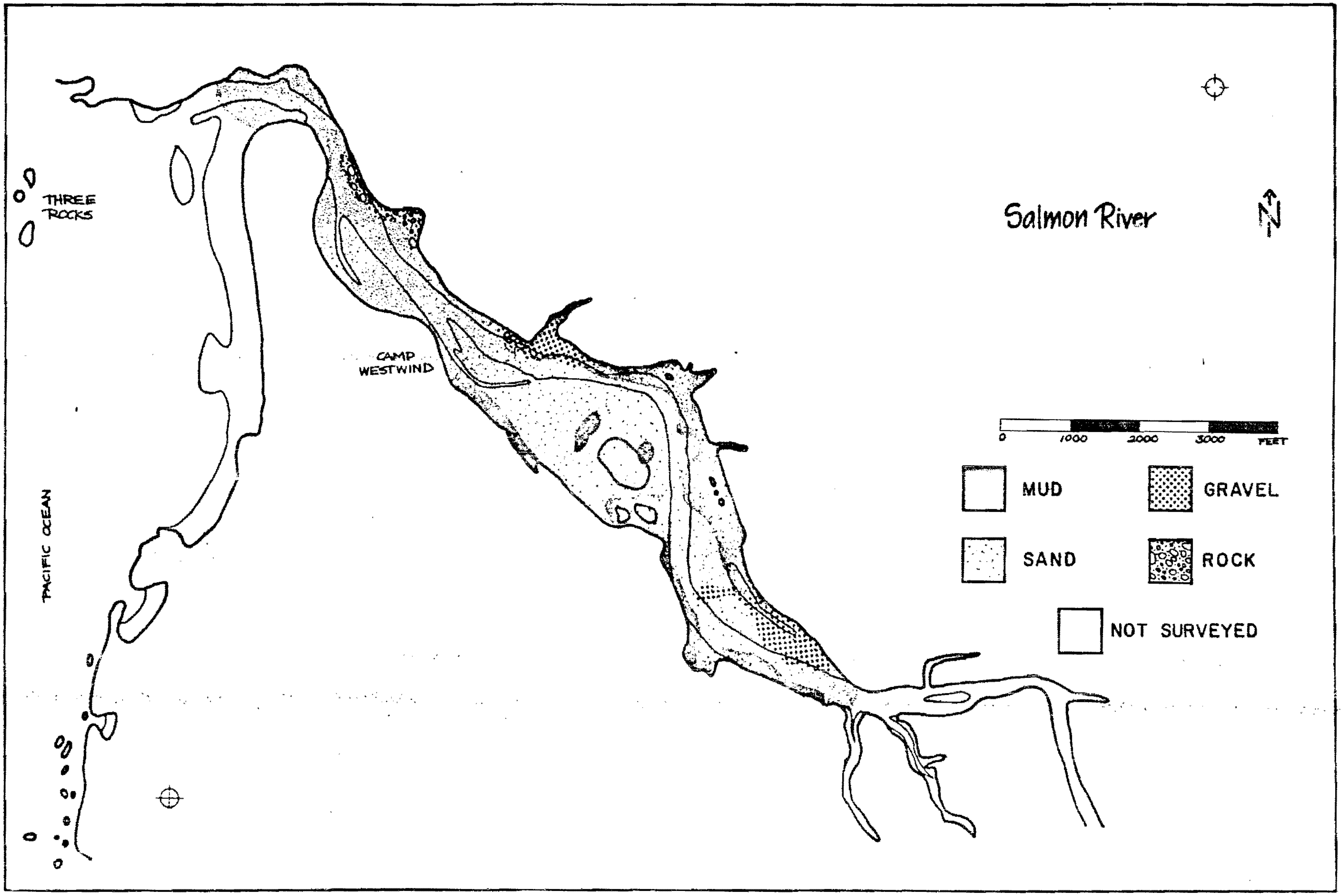

Figure 37. Substrate Material in The Salmon River.

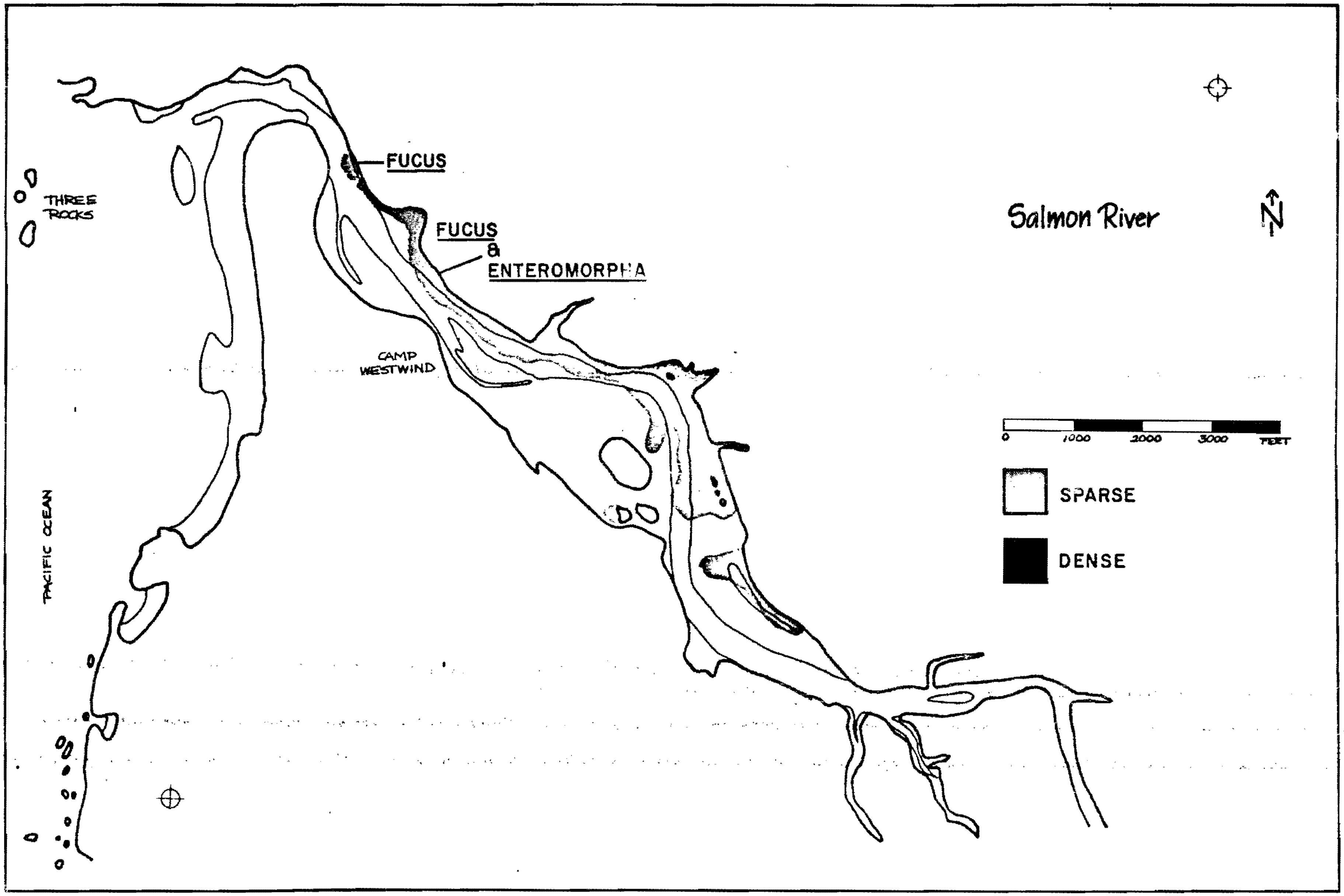

Figure 38. Distribution of *Fucus* and *Enteromorpha* in The Salmon River.

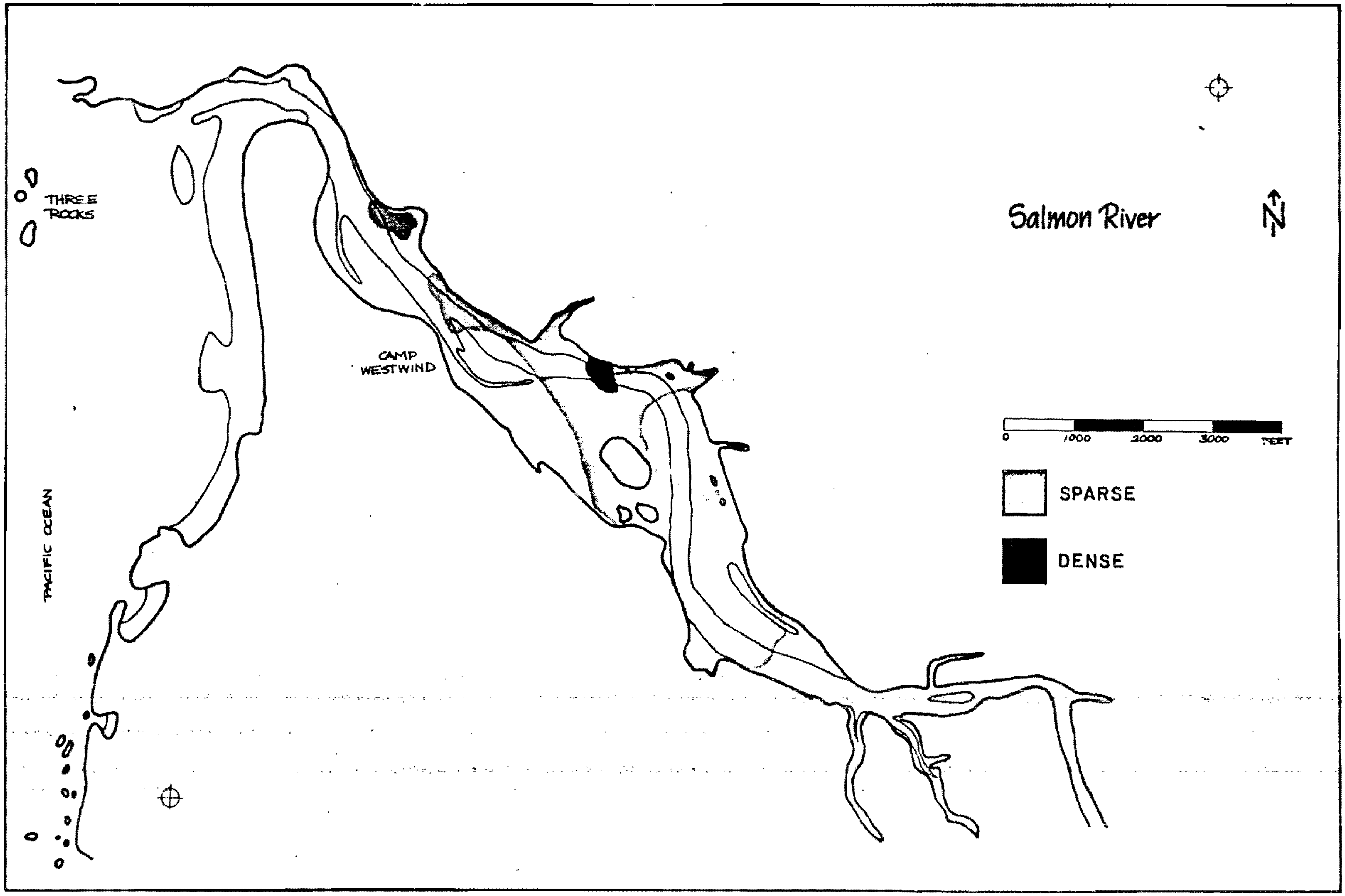

Figure 39. Distribution of Eel Grass in The Salmon River.

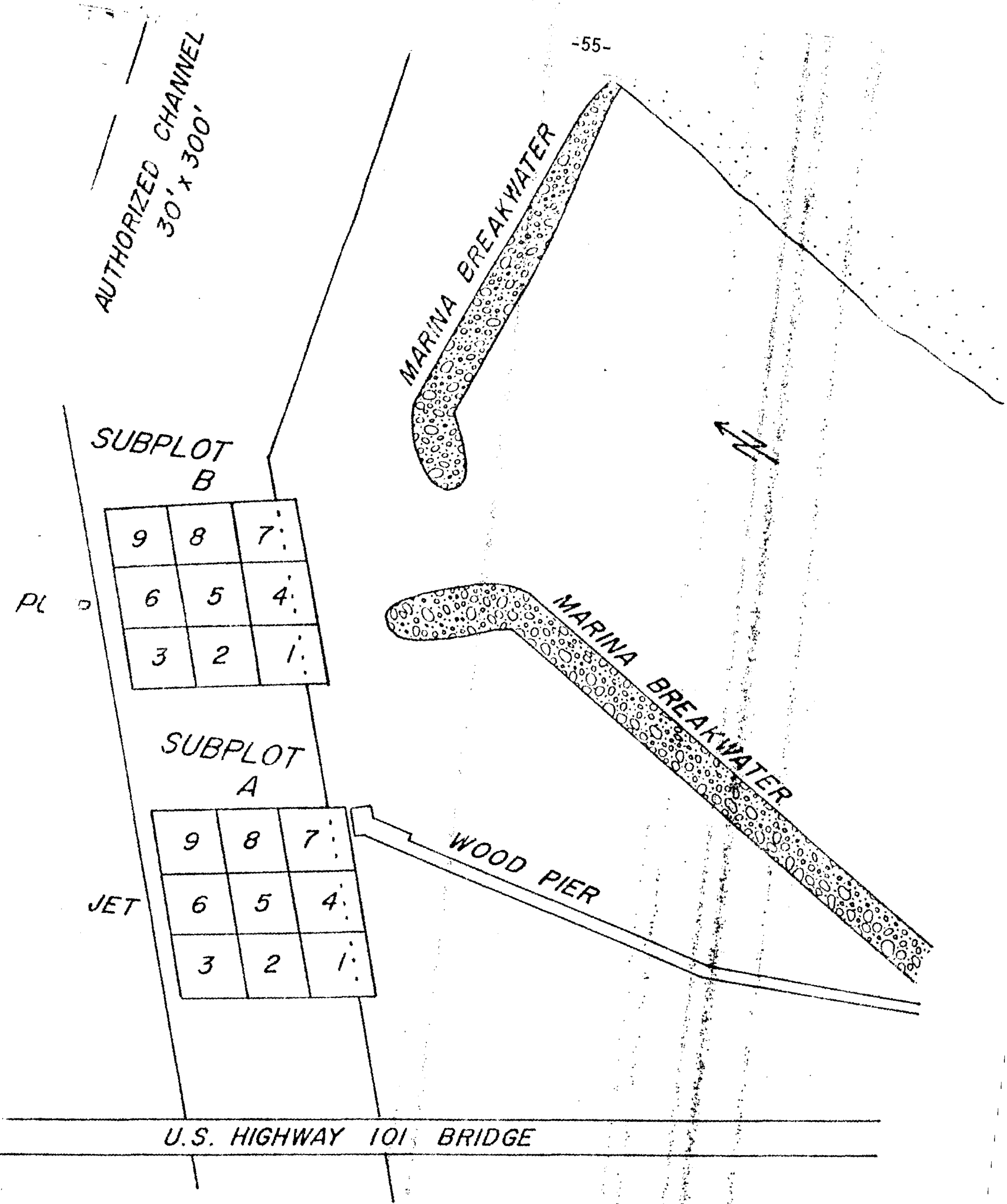

Figure 40. Commercial Clam Harvesting Areas of Yaquina Bay, 1977.

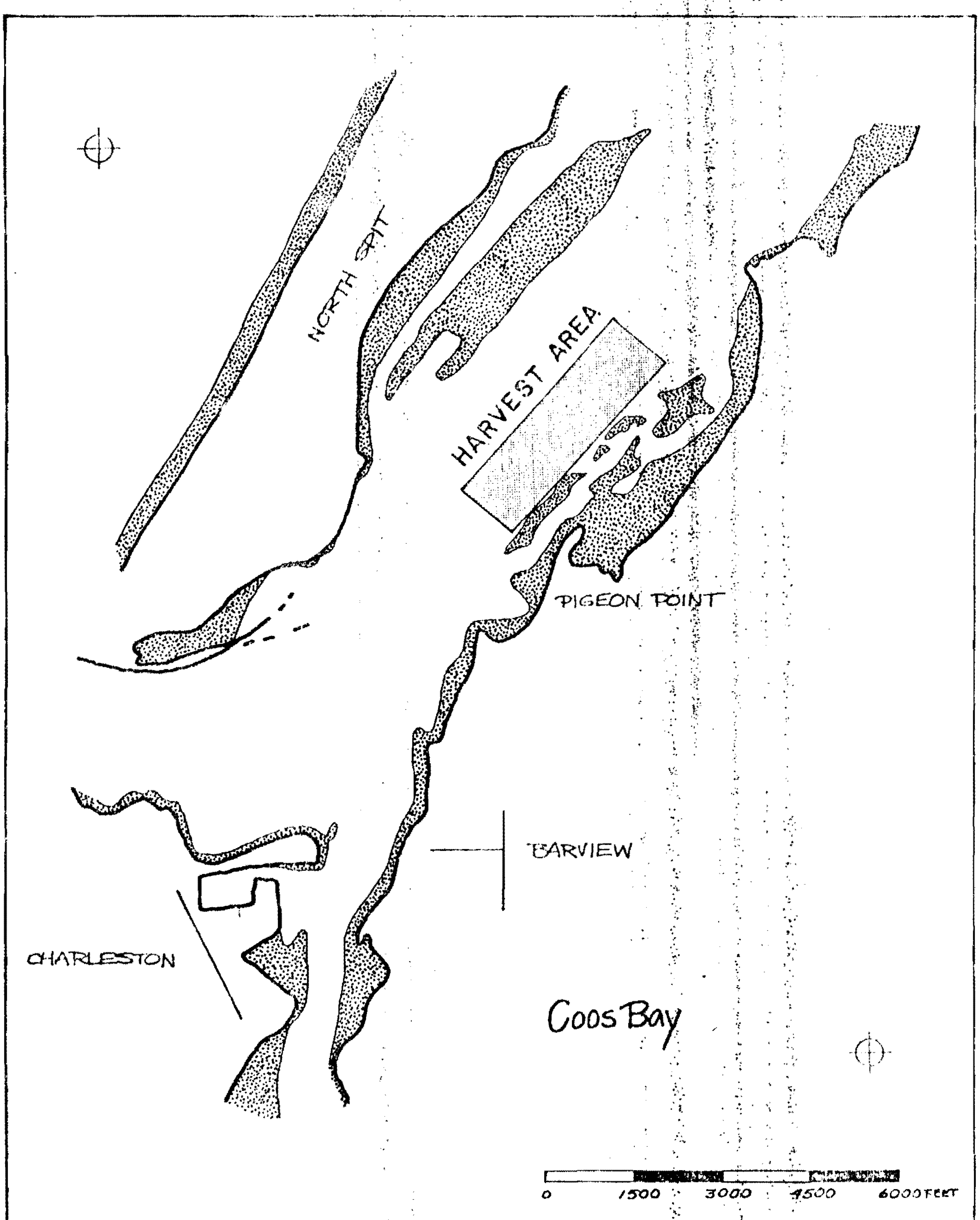

Figure 41. Commercial Clam Harvesting Areas of Coos Bay, 1977.

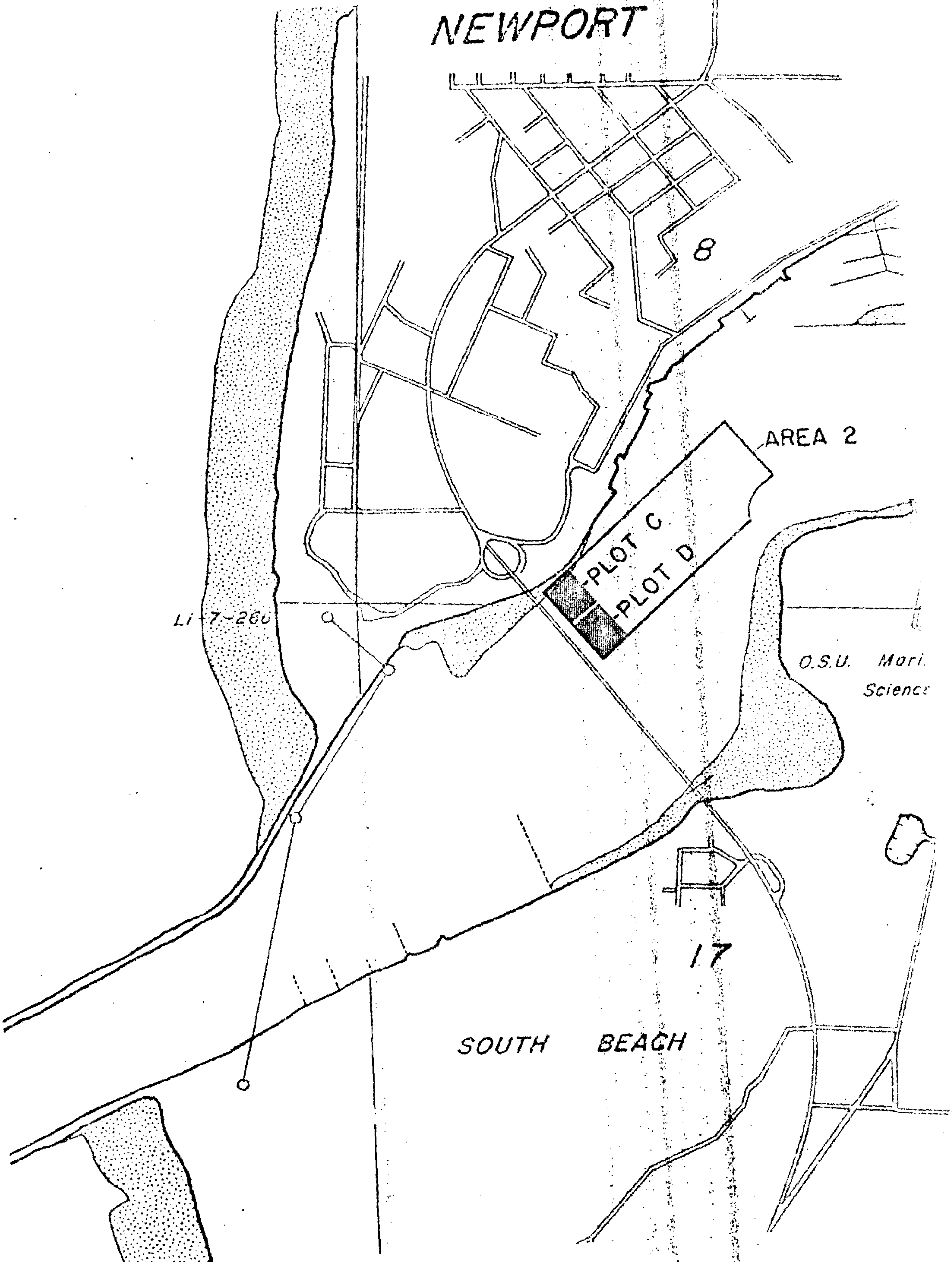

Figure 42. Commercial Clam Harvesting Areas of Yaquina Bay, 1978.

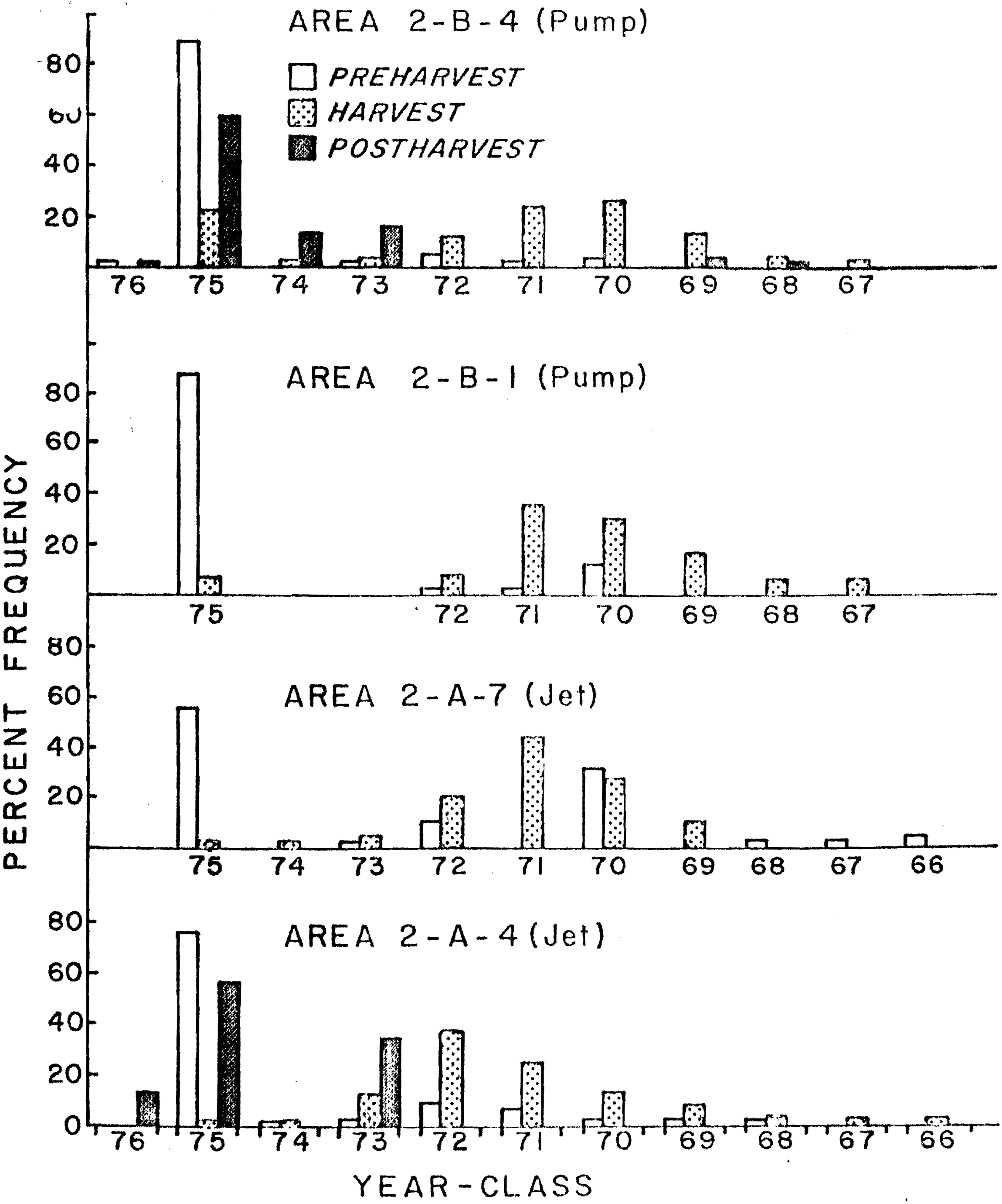

Figure 43. Year-class Composition of Subtidal Gaper Clams of Commercially Harvested Sub-plots, Area 2, Yaquina Bay, 1977.

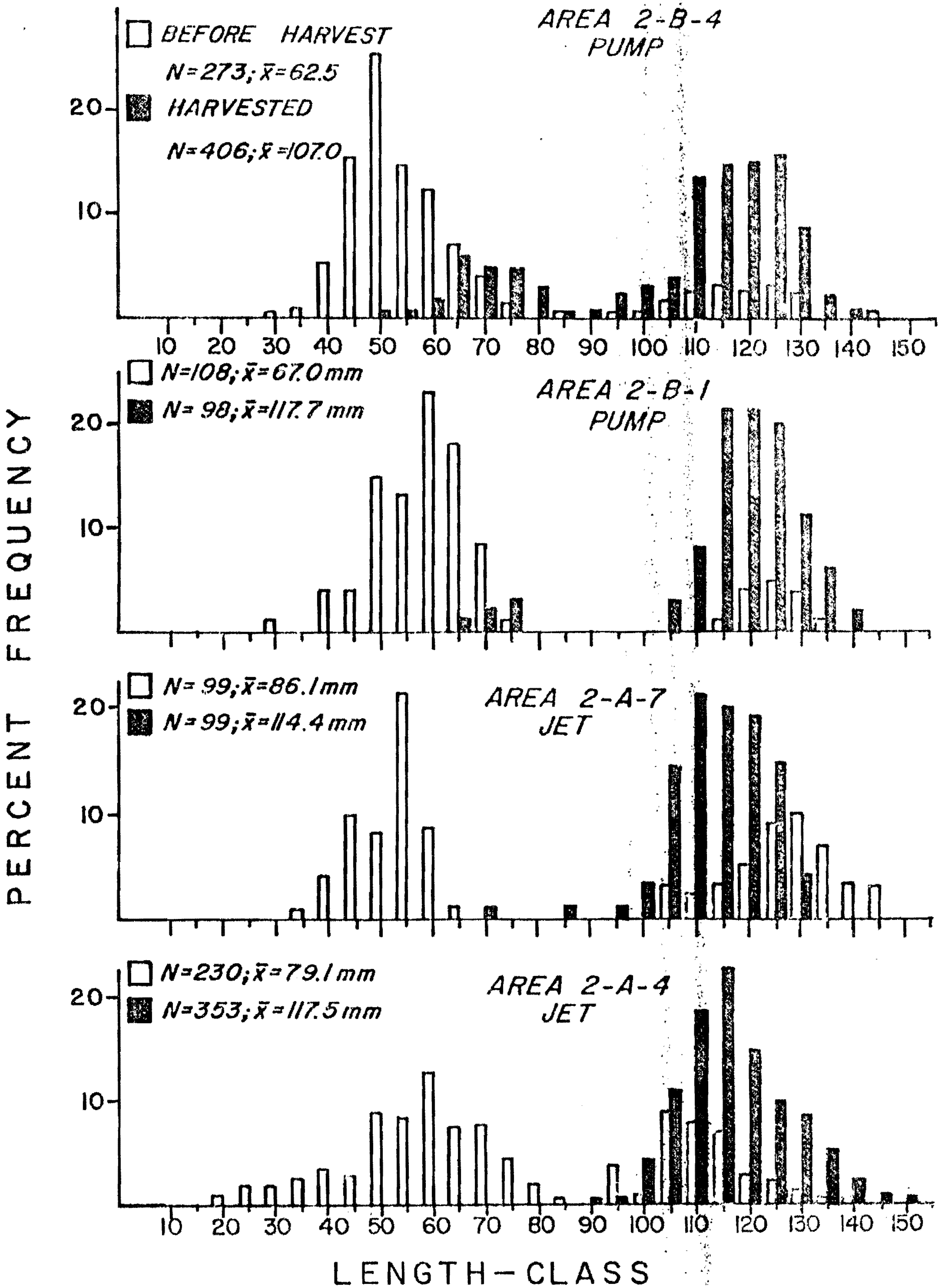

Figure 44. Size-class Composition of Subtidal Gaper Clams from Commercially Harvested Sub-plots of Area 2, Yaquina Bay, 1977.

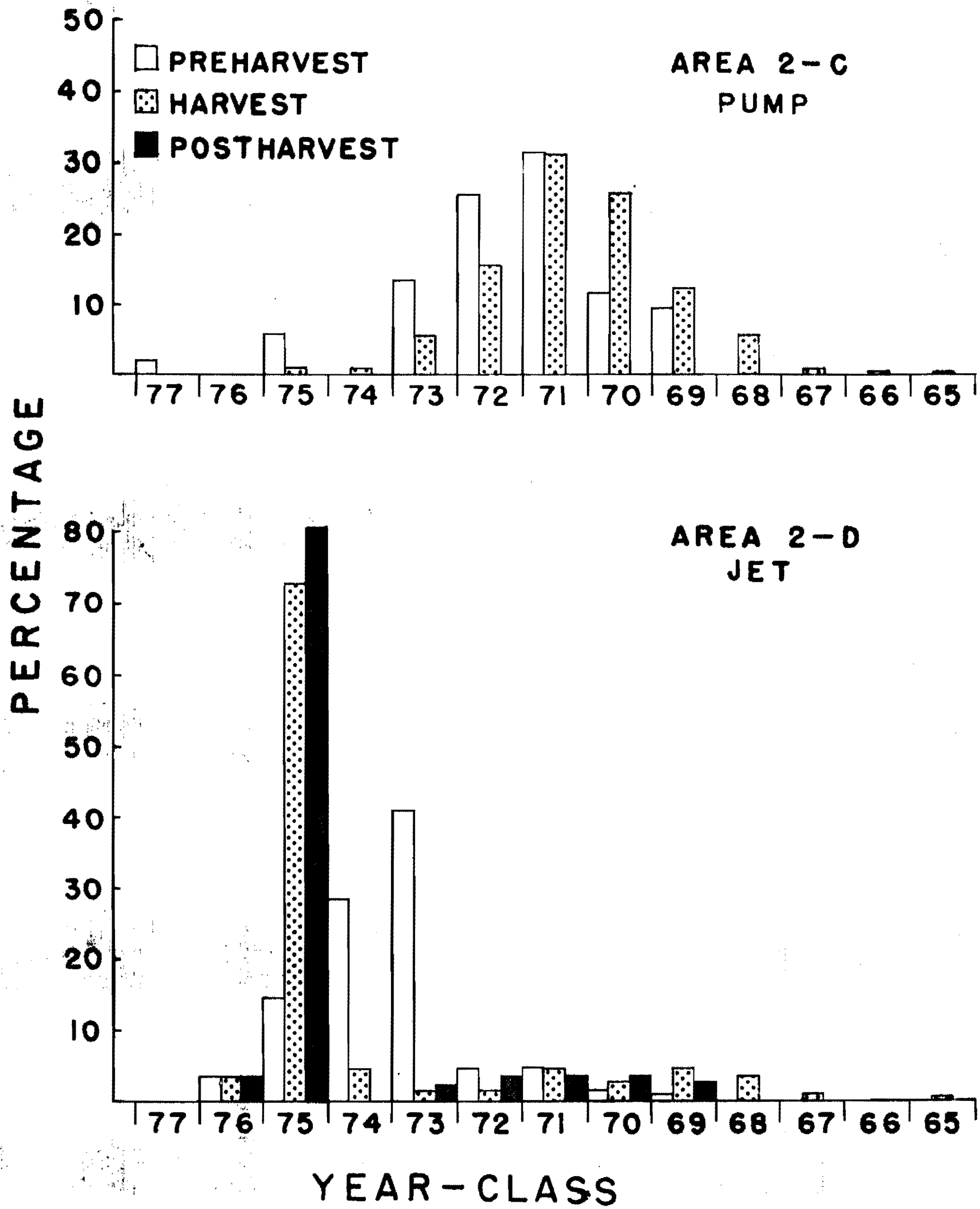

Figure 45. Year-class Composition of Subtidal Gaper Clams from Commercially Harvested Plots of Yaquina Bay, 1978.

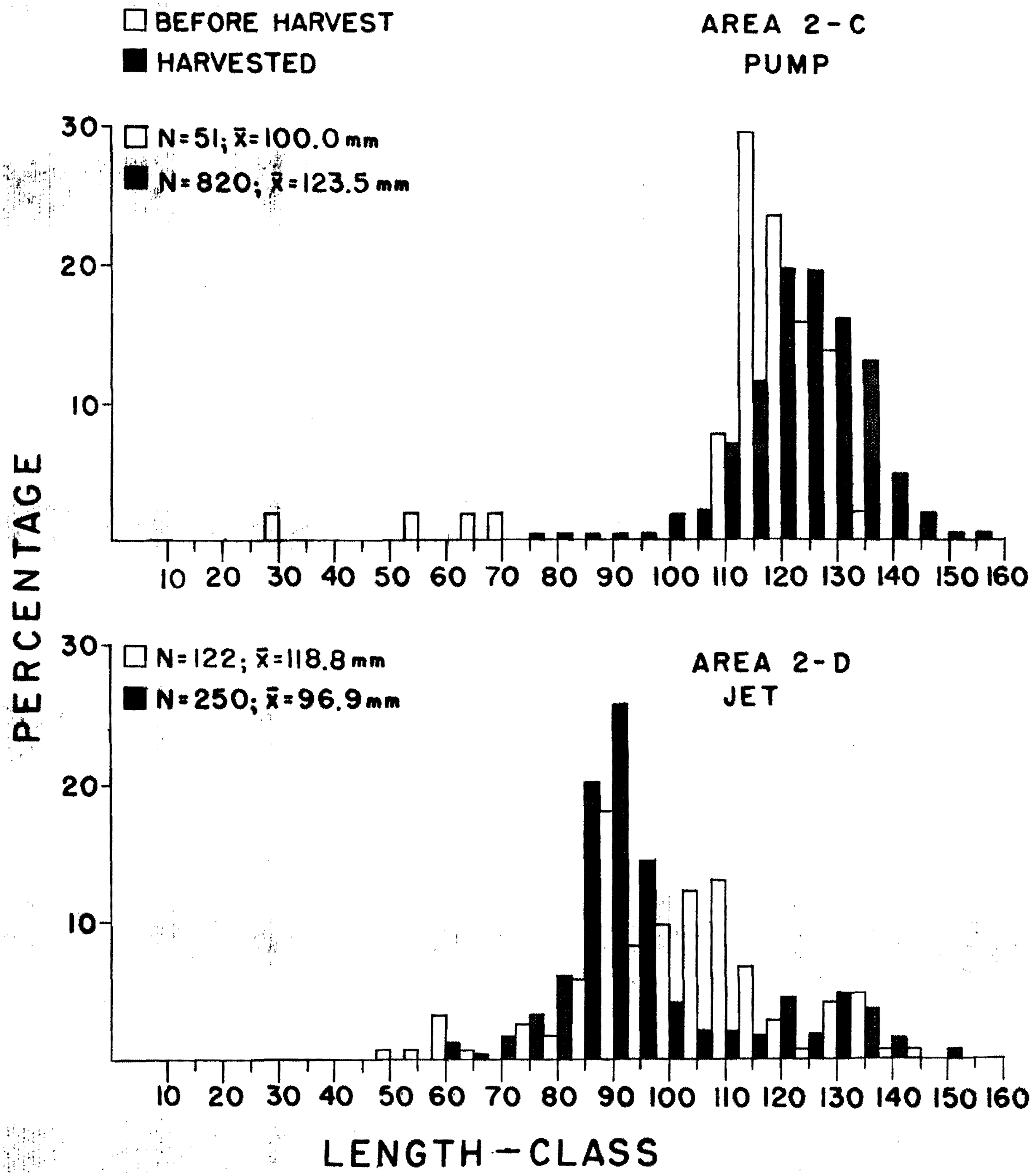

Figure 46. Size-class Composition of Subtidal Gaper Clams from Commercially Harvested Sub-plots of Yaquina Bay, 1978.

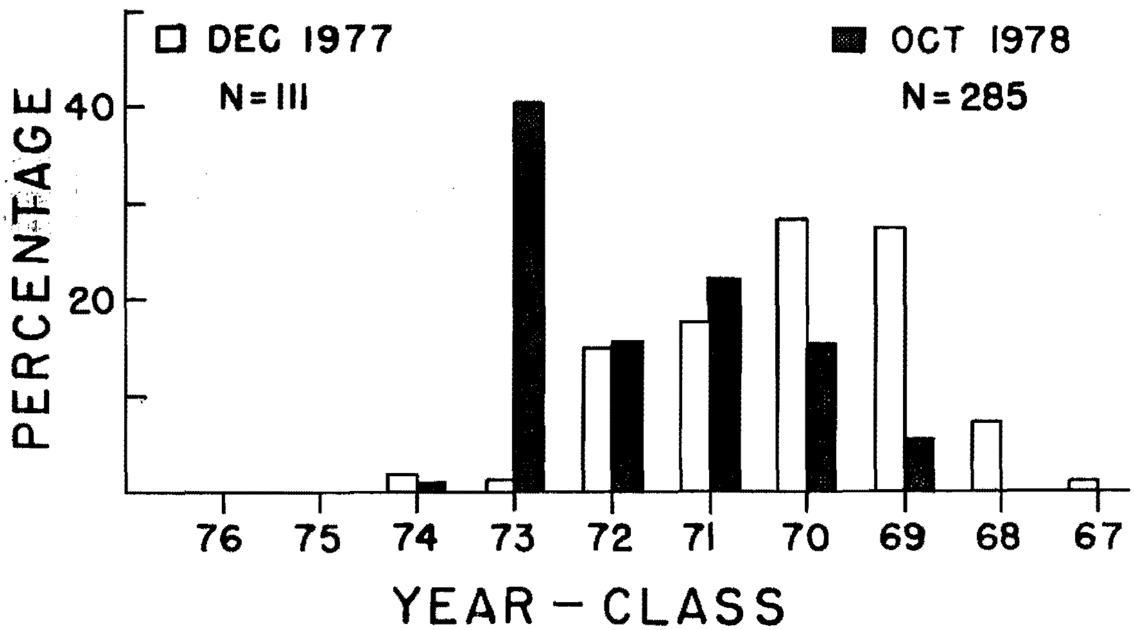

Figure 47. Year-class Composition of Subtidal Gaper Clams Commercially Harvested from Pigeon Point, Coos Bay, 1977-78.

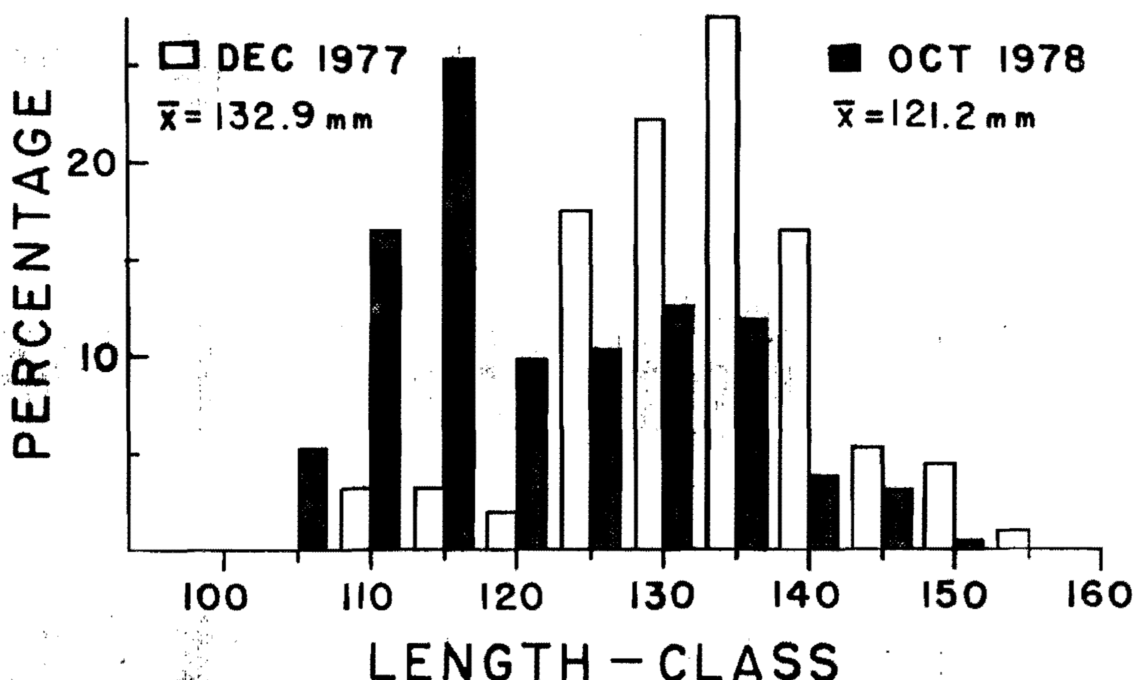

Figure 48. Size-class Composition of Subtidal Gaper Clams Commercially Harvested from Pigeon Point, Coos Bay, 1977-78.

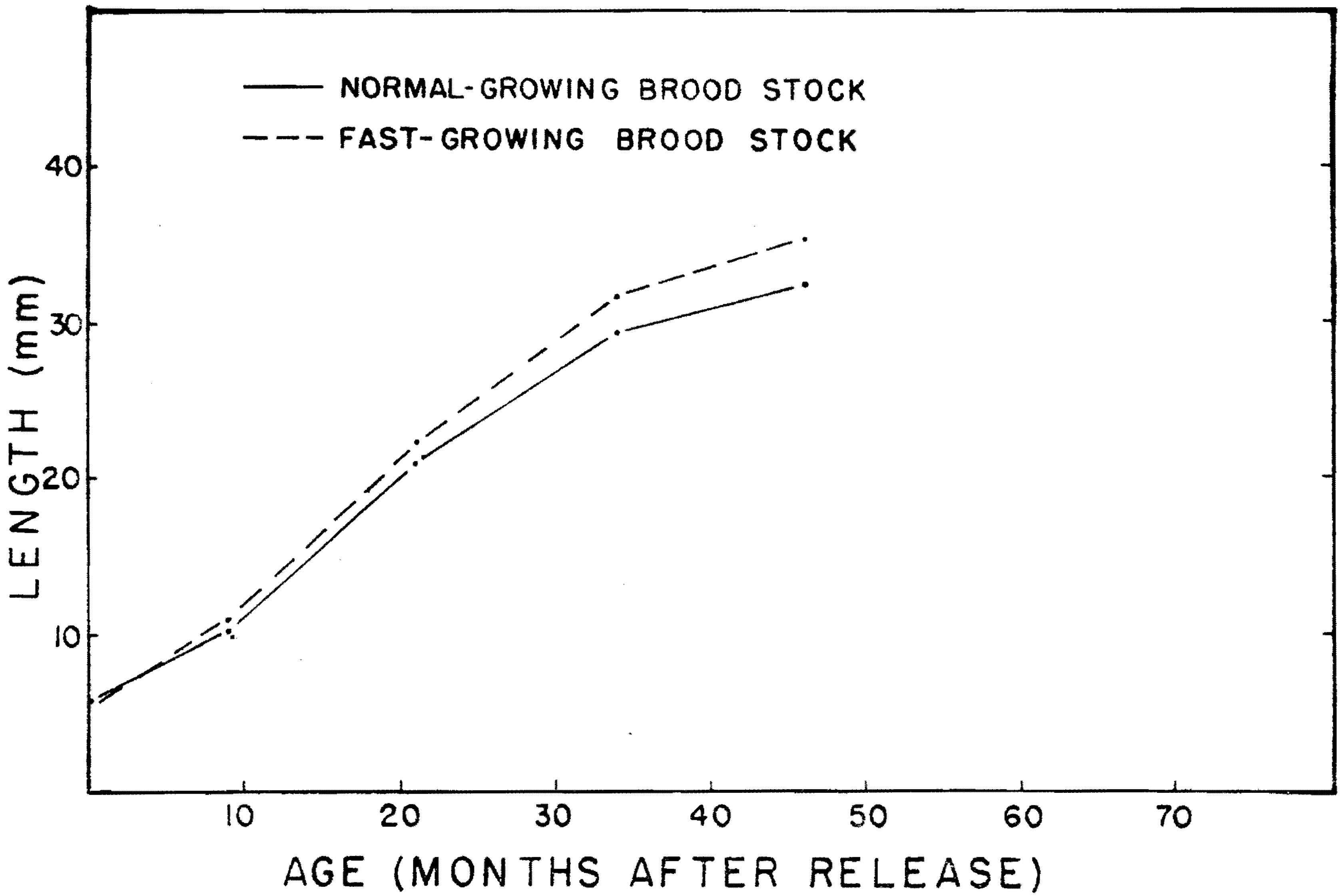

Figure 49. Growth Curve of Manila Littleneck Clams Spawned and Planted from Normal and Fast Growing Brood Stock in Netarts Bay, 1978.

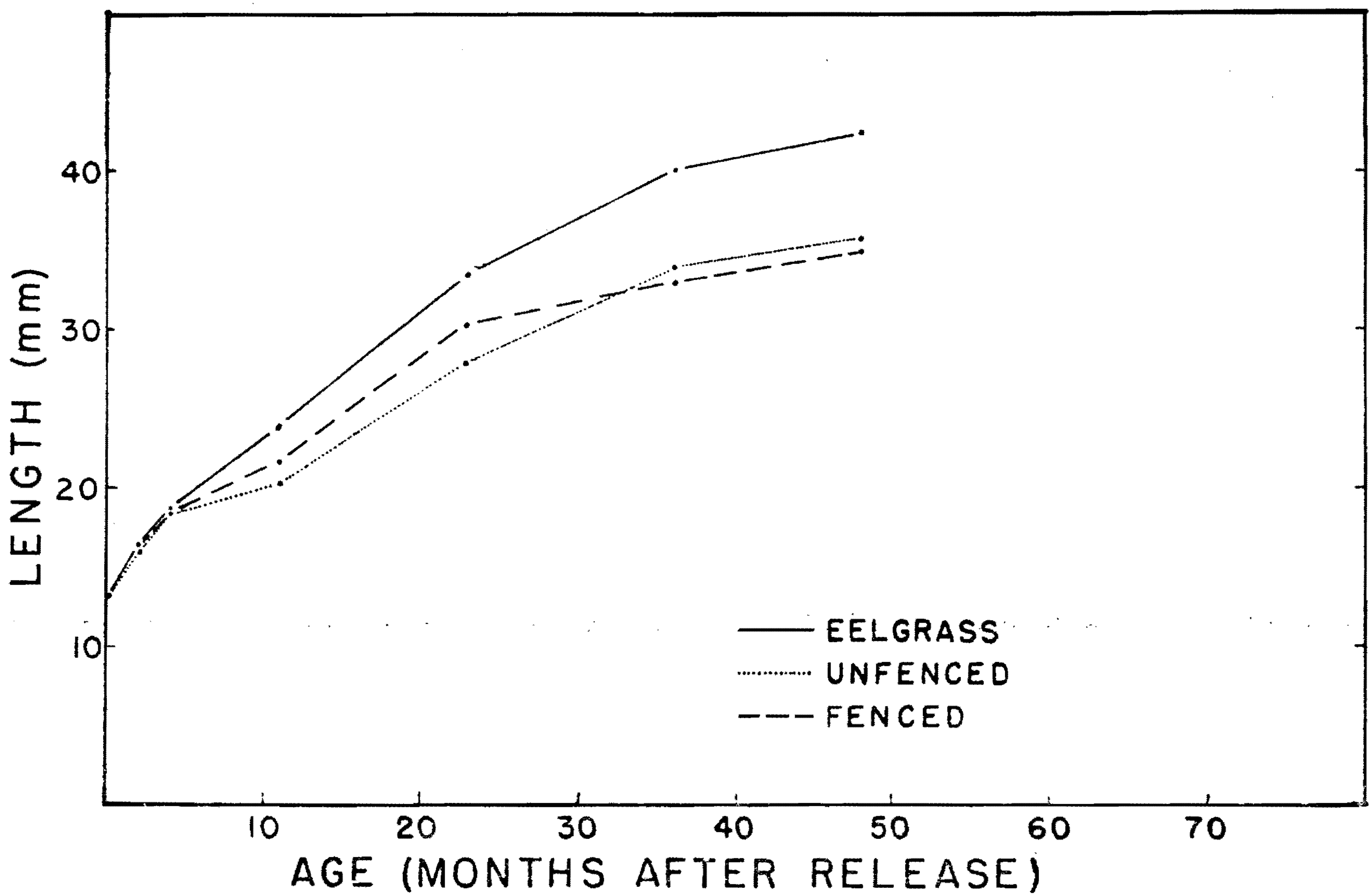

Figure 50. Growth Curve of Manila Littleneck Clams Planted in Fenced, Unfenced and Eelgrass Covered Areas of Netarts Bay, 1978.

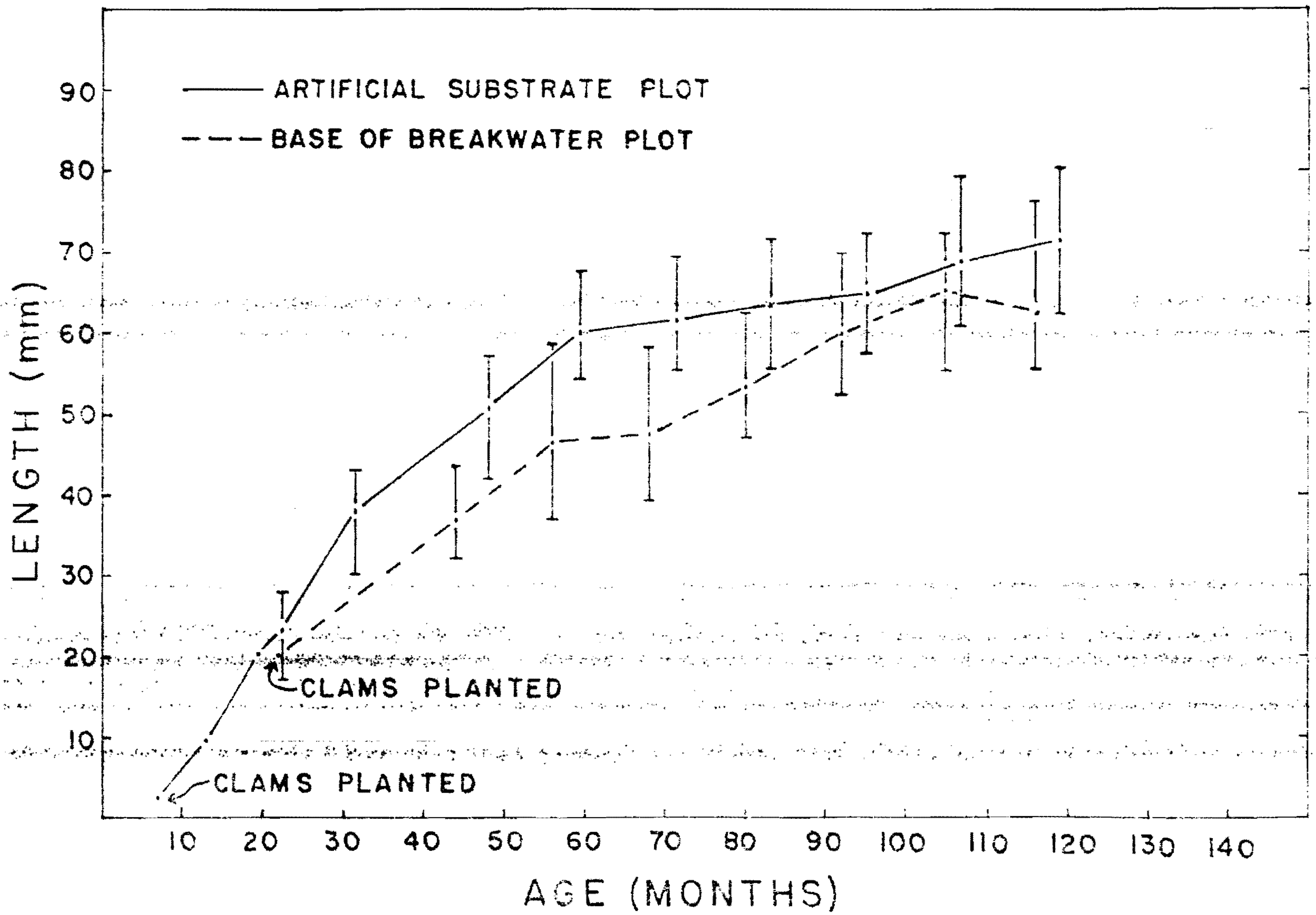

Figure 51. Growth Curve of Butter Clams Planted on the Yaquina Bay Breakwater (Vertical Lines Indicate Range in mm), 1978.

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Factors Influencing Spatial and Annual Variability in Eelgrass (*Zostera marina* L.) Meadows in Willapa Bay, Washington, and Coos Bay, Oregon, Estuaries

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ABSTRACT: Environmental factors that influence annual variability and spatial differences (within and between estuaries) in eelgrass meadows (*Zostera marina* L.) were examined within Willapa Bay, Washington, and Coos Bay, Oregon, over a period of 4 years (1998–2001). A suite of eelgrass metrics were recorded annually at field sites that spanned the estuarine gradient from the marine-dominated to mesohaline region of each estuary. Plant density (shoots m^{-2}) of eelgrass was positively correlated with summer estuarine salinity and inversely correlated with water temperature gradients in the estuaries. Eelgrass density, biomass, and the incidence of flowering plants all increased substantially in Willapa Bay, and less so in Coos Bay, over the duration of the study. Warmer winters and cooler summers associated with the transition from El Niño to La Niña ocean conditions during the study period corresponded with this increase in eelgrass abundance and flowering. Large-scale changes in climate and nearshore ocean conditions may exert a strong regional influence on eelgrass abundance that can vary annually by as much as 700% in Willapa Bay. Lower levels of annual variability observed in Coos Bay may be due to the stronger and more direct influence of the nearshore Pacific Ocean on the Coos Bay study sites. The results suggest profound effects of climate variation on the abundance and flowering of eelgrass in Pacific Northwest coastal estuaries.

Introduction

Estuaries are under tremendous stress from human development, commerce, resource exploitation, and waste discharges. Threats from harmful algal blooms (Boesch et al. 1996), eutrophication (Bricker et al. 1999), and climate change (Boesch et al. 2000; Scavia et al. 2002) have recently been the subject of reviews. A national assessment of threats from climate change on the United States cited added stresses to salmon among the four key issues for the Pacific Northwest (National Assessment Synthesis Team 2000). Although exploited since the mid 1800s, coastal estuaries in the Pacific Northwest may be among the least altered in the U.S. (Thom and Borde 1998; Emmett et al. 2000) and represent valuable systems to study to help understand factors driving natural variability in components of these systems. Pressure to develop and exploit them further will predictably grow and by understanding factors affecting natural spatial and temporal variability, we can better sort out the effects of potential human-induced stressors on important habitats as well as the ecosystem functions (Clements et al. 2001; Luoma et al. 2001; Thom et al. 2001a).

The purpose of this paper is to examine factors influencing the spatial and annual variability in eelgrass (*Zostera marina* L.) meadows in two of the three largest coastal estuaries in the Pacific Northwest. Eelgrass is a valuable indicator of estuarine health because it forms extensive meadows in most coastal estuaries in the region, harbors large numbers of fisheries species, is a nursery and feeding area for juvenile salmon (*Oncorhynchus* spp.) and Dungeness crab (*Cancer magister*), and responds to physical and chemical forcing factors through changes in its size, morphology, and distribution (Phillips 1984; Thom 1987; Simenstad 1994; Thom et al. 1998; Hovel 2003). Eelgrass distribution is the primary indicator of the effectiveness of nutrient abatement actions in improving water quality conditions in the Chesapeake Bay (Dennison et al. 1993). Short and Wyllie-Echeverria (1996) concluded that seagrasses have suffered losses because of human induced physical, chemical, and biological disturbances, and increasing anthropogenic inputs to the coastal ocean are primarily responsible for the worldwide decline in seagrasses. Clearly, research that increases the understanding of relevant forcing factors will assist the assessment and man-

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agement of anthropogenic impacts on seagrasses (Duarte 2002).

Although eelgrass is an important component of Pacific Northwest coastal estuaries, it has received little research (Phillips 1984; Thom 1984; Wyllie-Echeverria and Thom 1994). We present here the results of the Habitat/Bioindicator Study portion of the Pacific Northwest Coastal Ecosystem Regional Study (PNCERS). Our study was conducted to understand and document the factors responsible for spatial and interannual dynamics of eelgrass; one of a number of important aquatic habitats in these systems (Emmett et al. 2000).

Our study focuses specifically on temperature and salinity as significant factors affecting eelgrass dynamics. The list of factors assembled by Phillips (1984) for Pacific Northwest eelgrass systems included light, temperature, salinity, substrata, nutrients, waves, and current velocities. Information on many of these factors was not available for the region, and Phillips relied on published data from other systems. To date, variations in water properties, in particular temperature and light, have been shown to be important in seasonal and annual variations of estuarine macrophytes in the Pacific Northwest (Thom 1980; Thom and Albright 1990). Climate variability appears to have a substantial influence on processes in these systems (Thom 1995; Thom et al. 2001b, 2002).

Studies on seagrass spatial and temporal variation from other regions have focused largely on light, and less so on salinity, temperature, and other factors (Hemminga and Duarte 2000). Koch (2001) pointed out that light alone does not entirely explain seagrass distribution, and that other factors such as physical (e.g., waves, currents, tides) and geochemical (e.g., sulfide) conditions are also highly important. Better data on all factors can both help define requirements for understanding potential threats to these systems, and provide guidance for designing seagrass restoration programs (Dennison et al. 1993; Fonseca et al. 1998; Short et al. 2002).

Study Locations

Field studies were conducted in Willapa Bay and Coos Bay estuaries (Fig. 1). Willapa Bay is a larger estuary than Coos Bay and contains a greater proportion of eelgrass primarily distributed over very broad tidal flats (Table 1, Fig. 1). Willapa Bay has a low population density, little shipping activity, and is among the leading oyster producing regions in the U.S. (Dumbauld et al. 2000). Owing to a denser population, Coos Bay has greater potential disturbance from humans. Coos Bay has a larger shipping industry and more shoreline develop-

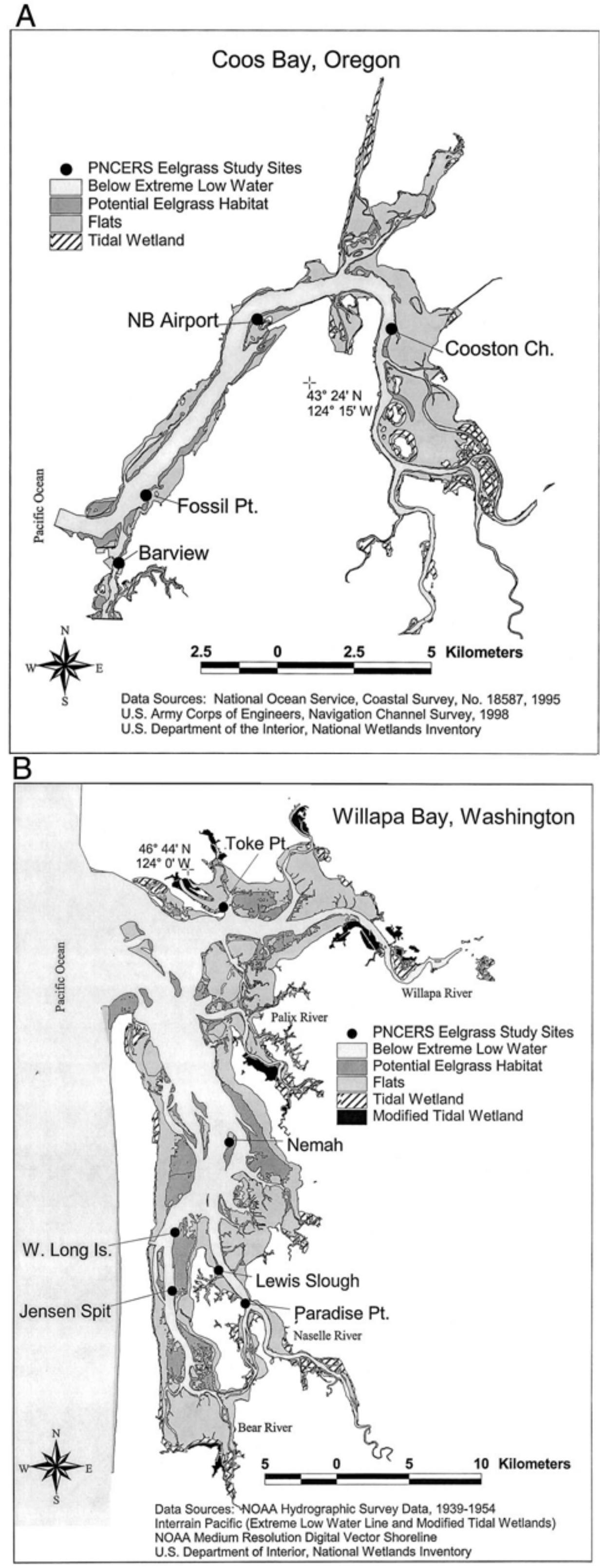

Fig. 1. Study sites in Coos Bay (A) and Willapa Bay (B).

TABLE 1. Characteristics of the Willapa Bay and Coos Bay estuaries (from NOAA 1990).

Characteristic	Willapa Bay	Coos Bay
Water surface area (km^2)	238	34
Mean daily freshwater inflow (m^3 s^{-1})	165	81
Mean depth (m)	4.9	4.3
Volume ($\times 10^6$ m^3)	1,200	146
Mean tidal range (m)	2.41	1.74
Mean spring tidal range (m)	3.05	2.29
Eelgrass area (km^2)	58.1	5.1
Eelgrass cover (% of water surface)	24	15
Population density (no. km^{-2})	44	132

ment (Rumrill In press). Oyster production largely occurs on flats in the mid and upper Coos Bay.

Study Sites

A total of 6 study sites were located within Willapa Bay and four study sites were located in Coos Bay. The sites spanned a salinity gradient from oceanic near the mouth to an up-estuary zone of variable salinity, which ranged from 13‰ to 32‰ driven by variations in river flows. Temperature and turbidity varied over this gradient also because of the dynamic nature of tidal-forced currents, winds, upwelling events, and river flows. The plots at each site consisted of 100 m-long transects that were permanently marked parallel to the water's edge following the method of Thom and Albright (1990). The elevations of the plots ranged between 0.0 and −1.0 m relative to mean lower low water (MLLW), which was generally in the middle of the eelgrass depth range within these systems (Phillips 1984; Thom 1987). By stratifying sampling at the elevation of greatest abundance, the data are biased toward the optimal, and most stable, conditions for eelgrass in these systems. We believe that detectable spatial variation between sites, and annual variation within sites, in eelgrass metrics would be a robust indication of the strength of controlling factors.

Materials and Methods

Annual Monitoring

We conducted sampling of the sites annually in mid-summer (July–August) in Willapa Bay and Coos Bay in 1998–2001. Eelgrass reaches its greatest density and biomass, as well as flowering shoot density, during this season (Phillips 1984; Thom 1990). At each site, we sampled eelgrass within twenty 1.0 m^2 quadrats along the transects during extreme low tides. The first quadrat was randomly positioned along the transect, and the remaining 19 quadrats were positioned at 5-m increments from the first quadrat. In the field, we recorded percent surface cover of vegetation, substrata, and animals using qualitative categories of 5% cover increments (e.g., eelgrass 80%, seaweed 5%, bare substrata 15%). We conducted an initial training to calibrate cover estimates among all observers. We recorded the number of eelgrass shoots within the quadrat. We also recorded the number of shrimp (ghost shrimp, *Neotrypaea californiensis* and mud shrimp, *Upogebia pugettensis*) burrows. Burrowing shrimp are major bioengineering species in these systems and can account for large amounts of surface sediment mixing (Dumbauld et al. 2000). We measured the depth of the deepest eelgrass shoot located immediately waterward from the transect during each site visit. Depth was recorded relative to the surface of the water and later corrected to MLLW by reference to actual tide level at the time of the measurement. Because we resampled these plots in four consecutive years, we implemented a protocol to minimize disturbance of the vegetation and sediments.

For aboveground biomass determination, we randomly collected 30 shoots immediately adjacent to the transects. To measure belowground biomass, we collected 10-cm diameter cores to a depth of 10 cm at five random points adjacent to the plots. We sieved these cores through a 2-mm mesh screen and placed the live roots and rhizome material retained on the screen into labeled plastic bags.

In the laboratory, we recorded if the shoot was flowering and removed visible epiphytes from the plants by gentle scraping. Epiphytes from all shoots were pooled, rinsed gently with water on a 2-mm mesh sieve, and weighed to the nearest milligram after drying. Rinsing was necessary to remove sediments and probably resulted in loss of microalgae. Tube-dwelling and large filamentous diatoms and macroalgae were retained on the sieve. The width of the second or third oldest (and healthy) leaf, on non-flowering shoots only, was measured in the approximate middle of the leaf. Eelgrass leaves have a constant width over the vast majority of their length, and leaf width is tightly correlated with leaf length and biomass (Phillips 1984). We dried each of the shoots to a constant weight and recorded their weights to the nearest milligram. Aboveground biomass was calculated by multiplying mean shoot density by mean shoot weight. The variance in aboveground biomass was calculated as the variance of a product of two independent random variables. All live root and rhizome material from the core samples were similarly dried and weighed.

To evaluate sedimentation and erosion at the plots, we recorded sediment flux by measuring the surface elevation of the sediment relative to a fixed point above the sediment surface. We drove two heavy PVC plastic pipes, spaced 1 m apart, as far

TABLE 2. Water properties and *Z. marina* lower depth limit at the sampling sites in Willapa Bay and Coos Bay. Ranges of values from all summer sampling trips (ND = not determined)

Sites	Salinity (ppt)	Temp. (°C)	Secchi (m)	Zostera Lower Depth (m, MLLW)	Other Notable Conditions
Willapa Bay					
Toke Point	21.8–29.2	16.0–17.8	1.00–1.15	−0.37 to −0.93	Flat, moderately soft, long-line oyster culture installed in 1999
Nemah	20.9–27.3	17.0–17.8	1.51–2.10	ND	Flat in pond behind sand berm, firm
Northwest Long Island	21.2–27.4	17.1–18.0	0.60–2.00	−0.91 to −1.23	Very broad flat; moderately soft
Jensen Point	20.7–27.1	17.0–18.0	1.52–2.20	−0.98 to −1.23	Very broad flat; moderately soft
Lewis Slough	17.9–24.1	16.5–18.7	0.77–1.36	−0.76 to −1.13	Steep, very narrow band, sandy
Paradise Point	13.3–17.2	17.1–19.1	0.80–1.16	−0.76 to −0.95	Steep, very narrow band, very soft sediment
Coos Bay					
Fossil Point	28.0–31.9	13.1–16.7	1.50–2.10	−1.00 to −1.54	Broad flat, firm substrata, oceanic, fog
Barview	29.0–32.1	10.0–16.7	1.36–2.70	−0.79 to −1.17	Moderate flat, somewhat soft, ulvoids abundant; clamming disturbance
North Bend Airport	24.5–30.7	15.4–18.6	1.00–1.75	−0.63 to −0.69	Steep, sandy, very narrow band
Cooston Channel	25.0–29.4	17.0–20.1	0.98–1.50	−0.24 to −0.68	Moderately steep, moderately firm, ulvoids abundant, wake disturbance

as possible into the sediment, and cut their tops approximately 30 cm from the surface of the sediment (Simenstad and Thom 1996). We suspended a heavy wooden meter stick between the tops of the two stakes, and measured the vertical distance between the meter stick and the sediment surface at five points along the meter stick. Two of these sedimentation stations were established within 1 m of each plot.

Temperature was recorded at 1-h intervals using a continuous temperature loggers (HOBO from Onset Computer Corporation) at each plot in Willapa Bay and Coos Bay. The sensors were firmly attached at the sediment surface to a stake located at one end of each transect. Sensors were downloaded annually during field trips. We also collected water temperature and salinity data within 0.5 m of the surface and at the bottom immediately offshore from each site using a multiprobe (YSI 600XLM) sensor. This latter sampling was conducted only during the annual field trips to the sites.

Eelgrass Depth Distribution

The depth distribution of eelgrass was recorded at six sites in Willapa Bay and four sites in Coos Bay in 1999. We recorded eelgrass density within 1.0 m^2 quadrats placed along transects, perpendicular to the water's edge, that spanned the depth gradient of eelgrass at the sites. We gathered 130 samples in Willapa Bay and 100 samples in Coos Bay in this manner. Depth was established by surveying (using a hand level and stadia rods) the elevation of the quadrat relative to the water's edge. The time of each sample was recorded and the depths were then calibrated to actual depths for the day of the survey using tide curves from National Oceanic and Atmospheric Administration tide recording stations nearest the site.

Analysis and Interpretation of Data

We drew conclusions based on trends in data. Statistics that assisted us in the interpretation of trends included significant correlation coefficients between two variables, or non-overlapping error bars (95% confidence limit) around means. This follows the recommendation by Yoccuz (1991) that simple graphs with error bars and measures of relationships normally are all that are required to interpret ecological data.

Results

Water and Site Properties

The lowest summer salinities were recorded at the four up-estuary sites in Willapa Bay, and the coldest water temperatures were recorded at the two down-estuary sites in Coos Bay (Table 2). Fog was often present in summer at Fossil Point and Barview sites in Coos Bay. These results are consistent with the observation that Coos Bay is somewhat more marine influenced (Roegner et al. 2003). The most up-estuary sites of Paradise Point, Lewis Slough, Cooston Channel, along with Toke Point had smaller Secchi depth readings indicating more turbid conditions compared with seaward sites; and these up-estuary sites also had the shallowest eelgrass depth limits (Table 2).

Eelgrass Spatial Variation

Vertical

The depth versus density distribution sampling in 1999 showed that eelgrass was largely distributed between 0.0 and −1.5 m MLLW in Willapa Bay,

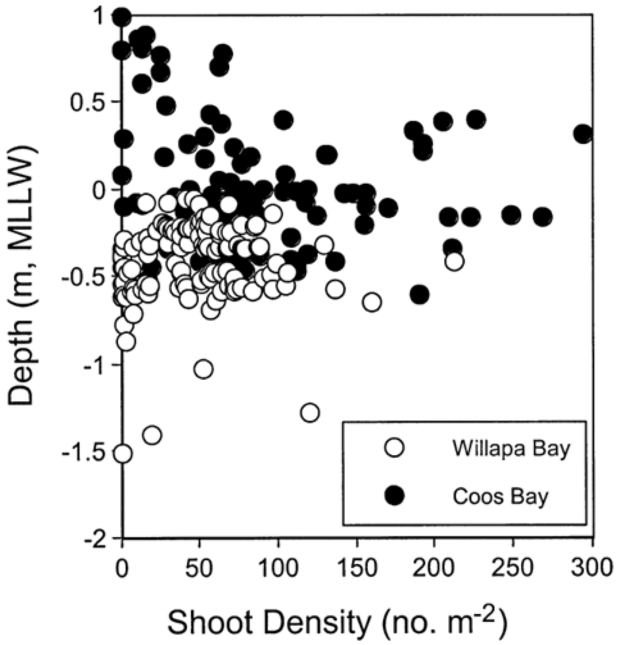

Fig. 2. Eelgrass shoot density versus depth in Coos Bay and Willapa Bay.

and between +1.0 and −0.6 m MLLW in Coos Bay (Fig. 2). Maximum densities were centered at about −0.5 and +0.1 m MLLW in Willapa Bay and Coos Bay, respectively. Depth distribution sampling done in conjunction with annual monitoring showed that eelgrass was recorded as deep as −1.54 m MLLW at Fossil Point in Coos Bay (Table 2).

Horizontal

Mean shoot density showed a significant ($p < 0.05$) positive correlation with salinity, with the greatest densities being recorded at the most saline sites (Fig. 3). Mean density showed a weak but significant ($p < 0.05$) negative correlation with temperature (Fig. 3), with a great deal of variation over a temperature range of about 15–18°C. Taken together, the data show that sites with the greatest salinity and lower temperatures in summer contained the densest eelgrass.

Eelgrass Annual Variation

Willapa Bay

There were strong between-year differences in shoot density and aboveground biomass with the general trend of increasing density and biomass between a low in 1998 and a high in 2000 (Fig. 4). All sites exhibited the annual variation in density, with the greatest proportional change (ca. 4.3 fold) between 1998 and 2000 recorded at Jensen Spit (Fig. 4e). Between 1998 and 2000, mean bio-

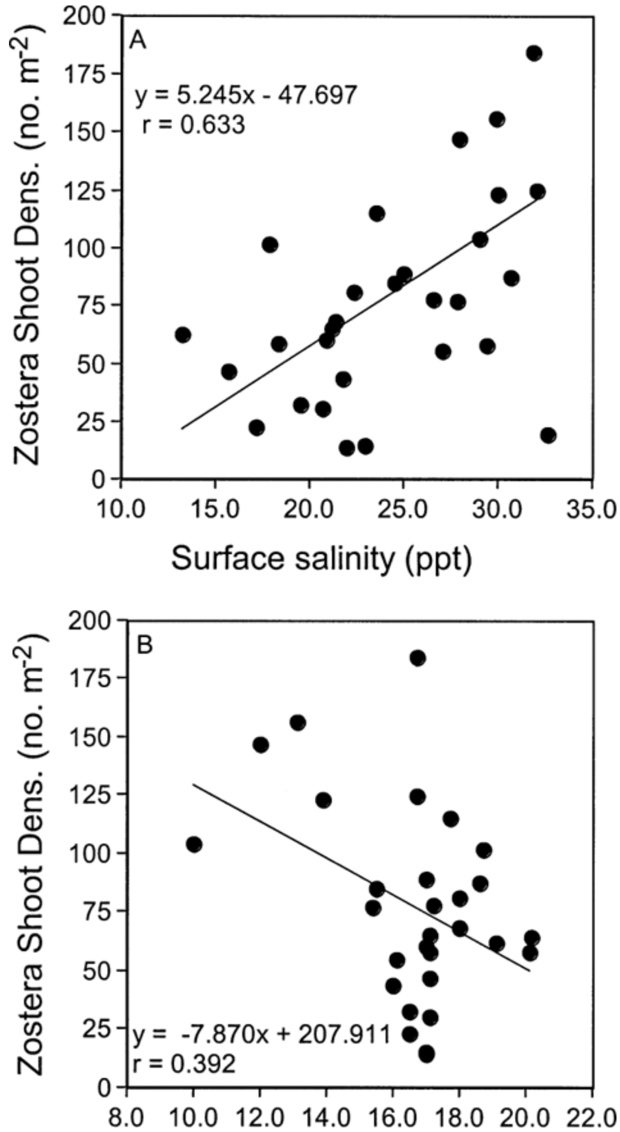

Fig. 3. Eelgrass shoot density versus surface water salinity (A) and temperature (B) from summer samplings.

mass over all sites increased approximately 5.0-fold, with the greatest increase (5.7-fold) at Jensen Spit and the least increase (1.4-fold) at North Long Island. Belowground biomass in Willapa Bay showed no discernable annual or spatial trends. The ratio of aboveground to belowground biomass averaged 2.5 (SD = 4.6) over all sites during the entire study period.

Epiphyte biomass was very low at all sites (mean = 0.025 g dry wt shoot^{-1}; SD = 0.044) and averaged 1.06 g dry wt m^{-2} (SD = 1.60), which was 1.3% of the average aboveground biomass over all

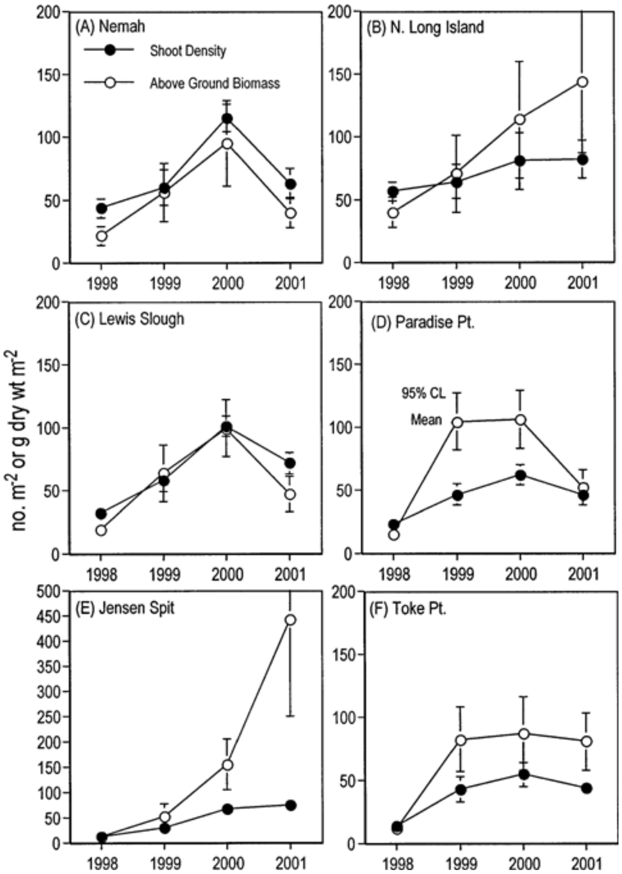

Fig. 4. Annual variations in eelgrass mean shoot density and aboveground biomass at the six sites in Willapa Bay estuary. Error bars are shown where they exceed the diameter of the points.

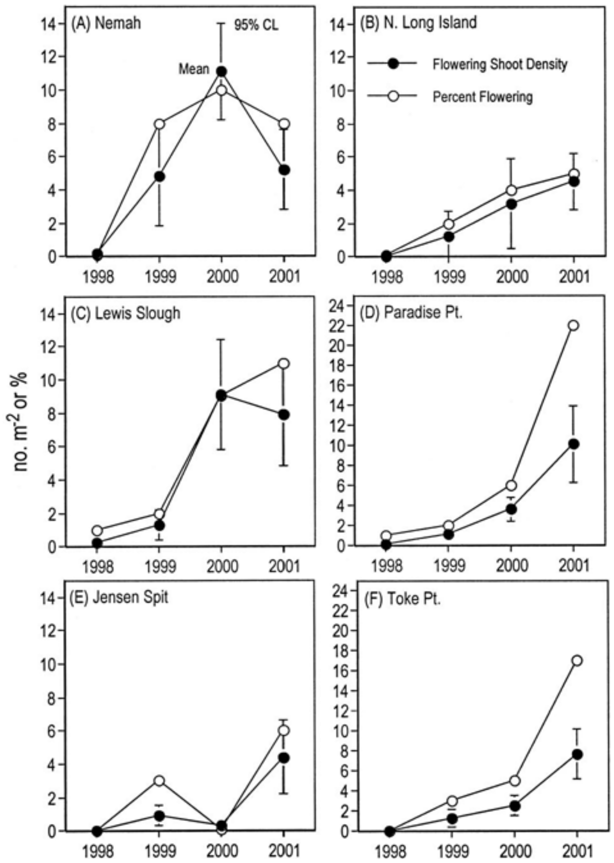

Fig. 5. Annual variation in flowering shoot density and percent of the population flowering at the six sites in Willapa Bay estuary.

sites. Ulvoids (not attached to eelgrass) were recorded only once and in low cover (0.1%) at Toke Point in 1998.

Substantial changes were recorded between 1998 and 2000 in flowering shoot density and percent of the total number of shoots flowering at Willapa Bay sites (Fig. 5). Flowering shoot density at the most marine-influenced site (Nemah) increased from near zero to ~11 shoots m^{-2} between 1998 and 2000, but declined in 2001. Flowering increased steadily at the most up-estuary site (Paradise Point) through 2001, with a substantial increase between 2000 and 2001.

Coos Bay

On average, eelgrass density and aboveground biomass showed less interannual variability at the Coos Bay sites (Fig. 6) as compared to Willapa Bay (Fig. 4). The down-estuary sites (Barview and Fossil Point) and the most up-estuary site (Cooston) differed in their trend, with the down-estuary sites showing an increase between 1998 and 2001, and

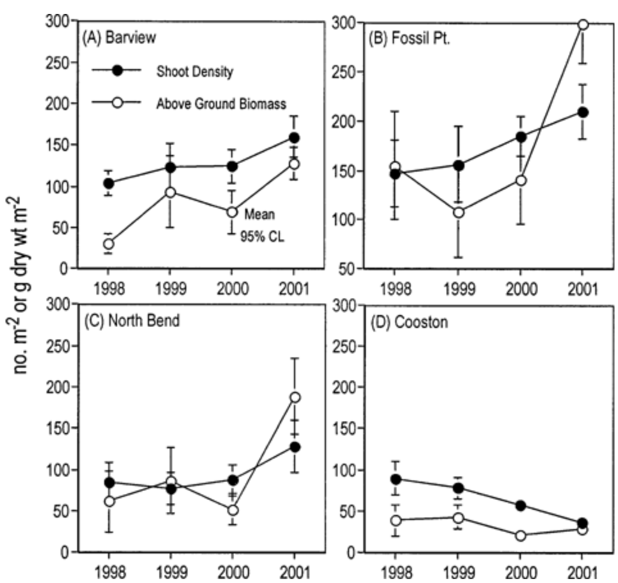

Fig. 6. Annual variations in eelgrass mean shoot density and aboveground biomass at the four sites in Coos Bay estuary. Error bars are shown where they exceed the diameter of the points.

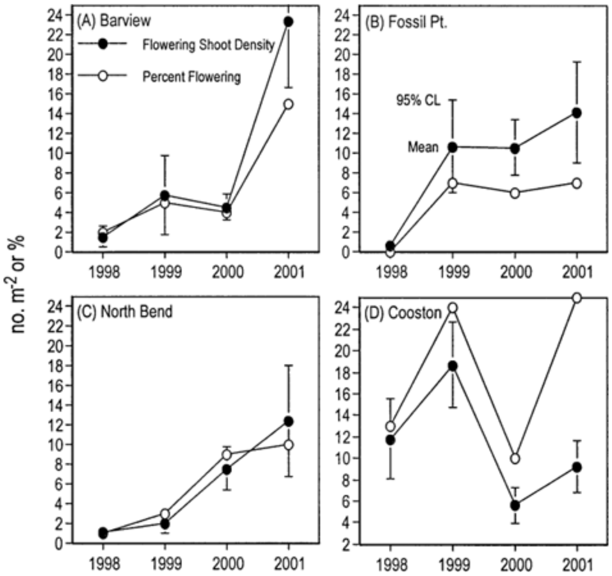

Fig. 7. Annual variation in flowering shoot density and percent of the population flowering at the four sites in Coos Bay estuary.

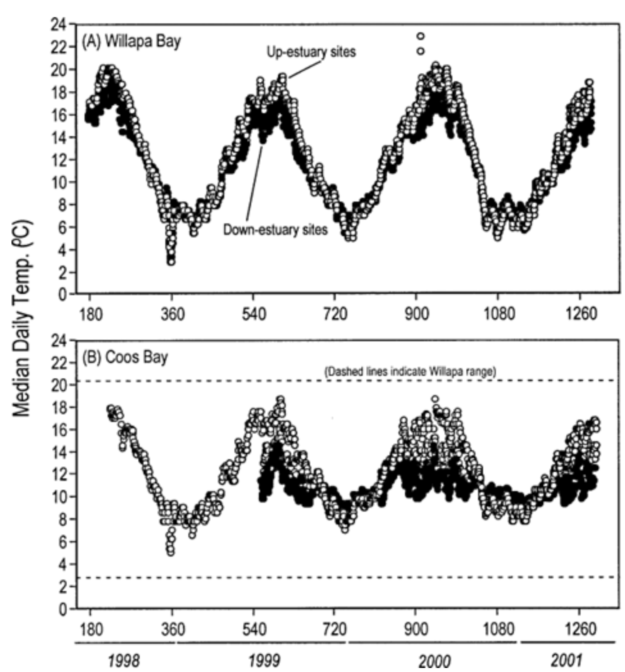

Fig. 8. Median daily temperature at Willapa Bay (A) sites and Coos Bay (B) sites. Willapa Bay up-estuary sites include North Long Island, Jensen Spit, Lewis Slough, and Paradise Point; and down-estuary sites include Toke Point and Nemah. Coos Bay up-estuary sites include North Bend Airport and Cooston Channel; and down-estuary sites include Barview and Fossil Point.

the up-estuary site showing a steady decrease over the same period.

Eelgrass density was on the order of two times greater in Coos Bay (Fig. 6) as compared to Willapa Bay (Fig. 4), although aboveground biomass was similar between the estuaries. This indicated that the individual shoots in Willapa Bay tended to be larger. Linear regression showed a significant ($p < 0.05$) negative relationship between shoot width (mm) and density (no. shoot m^{-2}) for all sites (density $= -18.97 \times$ width $+ 235.8$; $r = 0.65$), which verified this conclusion.

Similar to Willapa Bay, belowground biomass in Coos Bay was also variable in space and time, with no discernable trends. The ratio of aboveground to belowground biomass averaged 1.1 (SD = 0.7) over all sites during the entire study period. Epiphyte biomass was low (mean = 0.022 g dry wt $shoot^{-1}$; SD = 0.015) and averaged 2.50 g dry wt m^{-2} (SD = 1.98), which was 1.8% of the aboveground biomass. Ulvoids (not attached to eelgrass) were abundant at Barview and Fossil Point, with an average surface cover over all years of 39% and 18%, respectively. No other site showed an ulvoid cover greater than 1.5% on average.

Flowering shoot density was lowest in 1998 at three of the four sites in Coos Bay (Fig. 7). Flowering at the up-estuary Cooston Channel site showed the greatest variability between any two years among all sites. Percent flowering averaged over all sites was increased on the order of 3.5-fold between 1998 and 2001 in Coos Bay, as compared to 21-fold between 1998 and 2000 in Willapa Bay.

Water Temperature

Water temperature showed seasonal, between site, and interannual variation. Because of instrument loss, we did not acquire full data sets at all sites. The temperature monitoring showed the dynamic seasonal patterns at all sites (Fig. 8). Down-estuary sites (Nemah, Toke Point, Barview, and Fossil Point) showed a smaller range in temperature than up-estuary sites. The two most marine-influenced sites (Barview, Fossil Point) of all sites studied showed the least seasonal range in temperature (range = 9–15°C). Temperature range was greater in Willapa Bay than Coos Bay. There was an anomalous cold period in December 1998 that affected both estuaries. Compared to 1998, water temperatures were slightly, but detectably, cooler in summer and warmer in winter beginning in 1999.

Sedimentation, Burrowing Shrimp, and Other Observations

We recorded minimal (<1 cm) sediment flux at sites throughout the study period, which indicated no major burial or erosion within the plots. Burrows of burrowing shrimp reached densities as great as 35 m^{-2}. The greatest densities were recorded where eelgrass was in moderate density. Burrow density was low (<5 m^{-2}) where eelgrass shoot density exceeded 100 shoots m^{-2}.

We noted some human influences at the sites. Barview contained a relatively high cover of detached leafy green algae, which may indicate enhanced nutrients. The lower edge of the eelgrass meadow at Cooston Channel (outside the study plot) was scalloped with some exposed rhizomes indicating obvious erosion from boat wakes. A long line oyster operation initiated over the Toke Point site in 1999 showed very minor effects on the eelgrass. We only saw a loss of eelgrass within an approximately 0.25 m wide band directly underneath the suspended lines. Since lines were spaced approximately 3 m apart and were suspended approximately 0.5 m above the ground, eelgrass between the lines was not affected. Eelgrass leaves hung on the lines during low tide, which may enhance drying of the leaves and contribute to the loss of shoots especially during summer.

Discussion

There were several points evident from this study. There were variations in eelgrass related to salinity, temperature and, possibly, turbidity gradients in the systems. There were large interannual changes in shoot density, aboveground biomass, and flowering. The degree of ocean influence differed between the two systems, which may have affected eelgrass dynamics. As was known from past investigations (Hedgpeth and Obrebski 1981; Phillips 1984; Emmett et al. 2000; Rumrill In press), eelgrass is a major component of the intertidal-shallow subtidal portion of Coos Bay and Willapa Bay systems as well as other coastal estuaries in the region. Specific studies on eelgrass in these systems are rare. Eelgrass covers wide expanses of flats, and fringes steeper sloping portions of these estuaries. On the tidal flats, it occurs in areas that pond at low tide (Harrison 1982; Thom 1990) and flourishes at elevations centering in the lower intertidal-shallow subtidal zone (Thom et al. 1998). At these elevations, eelgrass is available for use by shallow water fish such as juvenile salmon (*Oncorhynchus* spp.), Dungeness crab (*Cancer magister*), Brant geese (*Branta bernicla*), and a wide variety of other fisheries resources (Phillips 1984; Thom 1987; Simenstad 1994). It is at this elevation range that eelgrass can also be vulnerable to stressors such as commerce, shoreline development, and climate change (Thom and Albright 1990; Thom 1995; Short and Wyllie-Echeverria 1996; Thom and Borde 1998; Thom et al. 1998, 2001b).

Vertical and Horizontal Within-Estuary Distribution

The combined effect of greater turbidity, as well as lower average water salinity, probably results in reduced eelgrass abundance at up-estuary sites. As has been shown for many other systems, light often limits the lower depth of eelgrass (reviewed in Hemminga and Duarte 2000), and desiccation stress controls the upper elevation limit (Phillips 1984; Boese personal communication). Secchi depth has been used as an indicator of the lower depth limit of eelgrass (e.g., Dennison et al. 1993; Carruthers et al. 2001). Our data suggest that the lower depth limit is at least approximated by our summer Secchi readings relative to annual mean sea level. Because these systems have large mixed semidiurnal tides, correlation of depth with Secchi depth is complicated. Relative to annual mean sea level, which is approximately +1.5 m MLLW, Secchi depths of 2 m suggest that eelgrass would be limited to a maximum depth of about −0.5 m MLLW. Mean sea level and tidal range varies among the sites, and the mean sea level during daylight hours in summer is much different than in winter. Up-estuary sites, where turbidity is typically greater, had shallower depth limits compared to outer estuary sites. Thermal expansion of the North Pacific Ocean during El Niño years can increase mean sea level on the order of 20–40 cm above average (Komar 1998), potentially further affecting the lower depth limit. Our data support the results of Koch and Beer (1996) showing that gradients in tidal factors and turbidity can strongly affect eelgrass vertical distribution and abundance, and must be considered when evaluating trends in eelgrass within and between systems. We add that interannual variation in climate-induced sea level variation may also be important.

The vertical depth limit was obviously affected by other factors also. In particular we noted erosion of the lower edge of the meadow at the Cooston site located very near the navigation channel near the Port of Coos Bay. Eelgrass can grow where tidal current velocities are in excess of 3 m s^{-1} (Phillips 1984), even though instantaneous current velocities (such as those generated by propellers) in excess of 75 cm s^{-1} can erode eelgrass (Thom et al. 1996). Propeller wash from small pleasure craft (Walker et al. 1989) as well as large ferryboats can both erode eelgrass as well as bury eelgrass from deposited sediment (Thom et al. 1996). We suspect that ship wakes are frequent and orbital wake velocities are great enough to erode eelgrass at the edges of navigation channels in active commercial ports such as Coos Bay, especially where the navigation channel is adjacent to the edges of eelgrass meadows.

Eelgrass density and biomass differed among the sites in both estuaries, with a trend for greater densities at sites with higher salinity. Several studies have shown that salinity affects seagrass production and growth, and that seagrasses can generally withstand large variations in salinity (Bayer 1979; Hellblom and Bjork 1999; Kamermans et al. 1999). Salinity is highly variable at all sites, but those sites furthest up-estuary (e.g., Paradise Point) had on average lower salinities than down-estuary sites.

Between-Estuary Comparisons

The two estuaries differed in eelgrass shoot density and temperature, as well as salinity may explain this difference. Eelgrass in Coos Bay (115 shoots m^{-2}; 95% confidence limits [CL] ± 25) was approximately twice as dense on average over all sites and years as compared with Willapa Bay (56 shoots m^{-2}; 95% CL ± 11), although this varied greatly by year with 2000 being the most similar between estuaries in terms of density. The densest eelgrass recorded occurred at the most marine-influenced sites of Fossil Point and Bayview in Coos Bay. The most up-estuary site in Coos Bay (Cooston) had densities similar to Willapa Bay sites in 2000 and 2001, but had much greater densities in 1998 and 1999. An obvious difference we recorded between the two estuaries was water temperature. Coos Bay had a smaller annual temperature range and had very cool summer temperatures, especially the most marine-influenced sites. Fog was often present in outer Coos Bay during summer. Although ocean influence is strong in Willapa Bay (Hickey and Banas 2003; Roegner et al. 2003), cooler temperatures, and fog indicate an even stronger ocean influence in Coos Bay. River flows (Table 1) are less important in Coos Bay as compared to Willapa Bay, which probably results in the broader temperature range in Willapa Bay, as well as lower average salinities in Willapa Bay. The site where temperature range was greatest and salinity was most variable and lowest in Coos Bay (i.e., Cooston) had shoot densities most similar to Willapa Bay sites. Average biomass over all sites and years was similar between the two estuaries (82.5 [±33] and 96.3 [±39] g m^{-2} for Willapa and Coos Bay, respectively) indicating that shoots were on average larger in Willapa Bay. Overall, the data suggest that cooler temperatures and high salinities in Coos Bay produced denser eelgrass but not necessarily greater standing stocks.

Interannual Variations

We suggest that temperature contributed to the interannual patterns we recorded in Coos Bay and Willapa Bay. There was a pronounced increase in average eelgrass density, biomass, and flowering in Willapa Bay between 1998 and 2000. Annual changes in eelgrass in Coos Bay were not as dramatic, and were more variable between sites. As also demonstrated by others (Kentula and McIntire 1986; Bulthuis 1987; Zimmerman et al. 1989; Thom 1990; Cabello-Pasini et al. 2003) temperature has a major control over seagrass productivity. Experimental data indicate that the optimal productivity occurs within a relatively narrow temperature range (Thom et al. 2001b). Although higher temperature can result in greater productivity up to a point, respiration rates increase with temperature (Zimmerman et al. 1989). Studies in Puget Sound indicated that eelgrass was healthiest within a very narrow temperature range (5–8°C), and that above about 15°C the eelgrass productivity to respiration ratio was very low, indicating stress to the plants (Thom et al. 2001b). Cabello-Pasini et al. (2003) concluded that temperature and light differences among bays in Baja California drove differences in shoot density, biomass, and flowering shoot density.

Flower production is normally low (less than 3% of the shoots flower) in Pacific Northwest systems (Phillips 1984), although pockets of very high flowering have been reported (Bayer 1979). It has long been recognized that flowering is controlled by light, temperature, and possibly salinity (Phillips at al. 1983). The increase in flowering shoot density and percent of the population flowering we recorded in Willapa Bay occurred following the strongest El Niño of the last century. We cannot sort out what particular change affected the flowering response, but the transition period had milder winter temperatures and cooler summers compared to 1998. Whether this, or the preceding more variable period, resulted in a flowering response is unknown. Low biomass and density recorded during 1998 may indicate that the population was stressed, and that the response of the plants was to produce flowers in subsequent years. We suspect that the lower range of flowering variability in Coos Bay compared to Willapa Bay may be related to the lower range in temperatures, which are regulated by a relatively stronger ocean-estuary coupling in Coos Bay.

The interannual changes we recorded correspond with regional and global changes in ecosystems. Weather patterns changed over our study period from a strong El Niño in 1997–1998 through a transition to a La Niña condition (Behrenfeld et al. 2001). Our temperature data collected at the sites indicate that, at least in 1999–2000, winters were warmer and summers were cooler than in 1998. On a regional scale, the data suggest that the period between 1998 and 2001 may represent a fundamental shift in weather patterns and climate in the Northwest (Swartzman and Hickey 2003). This shift, which is documented to occur approximately on 10–20 yr intervals, has been termed the Pacific Decadal Oscillation (PDO). Francis et al. (1998) have demonstrated the potential control of shifts in fisheries production and coastal zooplankton production that is likely linked to the PDO.

Behrenfeld et al. (2001) reported that net primary productivity increased 2–3 fold globally, particularly in the North Pacific during the El Niño-La Niña transition period. Our data suggest that eelgrass biomass in Willapa Bay, and to a lesser and more variable extent in Coos Bay, responded in a similar manner as did North Pacific phytoplankton. To roughly estimate annual changes in total biomass (concordant with methods used by Behrenfeld et al. for estimates of phytoplankton) we multiplied the mean biomass over all sites by the total eelgrass area estimate (Table 1). This estimate is highly biased because we used data only from our sites, and eelgrass abundance does vary with elevation (see Fig. 2). The estimate illustrates the magnitude of difference in total biomass among each year. Total aboveground biomass for Willapa Bay estuary was estimated to be 1.2×10^6 kg, 4.2×10^6 kg, 6.4×10^6 kg, and 7.8×10^6 kg for the years 1998–2001, respectively. Biomass in 2001 was 6.5 times that in 1998. Total aboveground biomass for the Coos Bay estuary was estimated at 0.36×10^6 kg, 0.42×10^6 kg, 0.36×10^6 kg, and 0.82×10^6 kg for the years 1998–2001, respectively. The 2001 biomass in Coos Bay was 2.3 times that in 1998, but did not show the same steady increase between the two years. Total system biomass averaged over 4 yr was 10 times greater in Willapa Bay (2.45×10^6 kg) than in Coos Bay (0.245×10^6 kg), which is proportional to the area of eelgrass in each system. The increases in biomass must be supported by favorable conditions of temperature, light, nutrients, carbon dioxide, and other factors.

Human Influence

Attempting to understand the role of natural variability in causing changes in eelgrass metrics is important to evaluating the impacts of human-induced stressors on this habitat (Short and Wyllie-Echeverria 1996; Duarte 2002). The present study provides information towards understanding natural as well as human-related effects on eelgrass in Pacific Northwest estuaries (Luoma et al. 2001). Retrospective studies showed that shoreline development, dredging, and disposal of dredged material resulted in loss of eelgrass in coastal systems. Our observations indicate that the eelgrass in Coos Bay and Willapa Bay are relatively undisturbed compared with more urbanized estuaries such as Puget Sound and San Francisco Bay (Emmett et al. 2000). We did find evidence of some stressors that may be affecting eelgrass. High abundances of green seaweeds like *Ulva* spp. and epiphytic microalgae can indicate eutrophication in estuaries and can result in loss of eelgrass (Dennison et al. 1993; Short et al. 1995; Short and Wyllie-Echeverria 1996). Relatively high abundances of ulvoids were recorded consistently at Barview in Coos Bay. Whether this site is influenced by increased nitrogen from local input is unknown. Eelgrass abundance is high at this site, and is on the order of that at another outer estuary site (Fossil Point), which indicates that ulvoids may not be having a significant negative effect on eelgrass as yet.

Physical erosion of the lower edge of eelgrass was evident at the site closest to the shipping channel and harbor in Coos Bay. The scalloped appearance of the edge along with our cursory observations of ship wakes impacting the edge of the bed indicated that ship wakes are a factor in controlling at least the quality and location of the lower edge of eelgrass in the vicinity of the Port. We have seen this type of eroded condition in Puget Sound (Thom unpublished data).

Shellfishing may damage eelgrass (Simenstad and Fresh 1995; Boese 2002). Clamming activity was apparent at Barview in Coos Bay but not at other sites probably because of their remoteness. We noted pits devoid of eelgrass throughout much of the Barview area caused by clamming activity. Our site was not noticeably affected, however. A suspended line oyster culture operation established over the Toke Point site in Willapa Bay afforded an opportunity to evaluate potential impacts. The lines were widely spaced (~3 m) and suspended well above the eelgrass. Care was taken to place the lines and minimize damage to eelgrass. The only evidence of effect we noted was a narrow (ca. 0.25 m wide) band of barren bottom created under the lines after 1–2 yr. Because the lines were high (~ 0.5 m) above the eelgrass and were widely spaced, shading under the lines was probably not a factor. We did see eelgrass leaves hung up on the lines during low tides. Especially in summer, drying of these leaves could be substantial, and may explain the small, denuded area under the lines.

Our data showed that burrowing shrimp co-exist with eelgrass, but do not indicate any negative interaction between eelgrass and the shrimp as shown by Harrison (1982) and Dumbauld et al. (1997). Willapa Bay receives periodic application of the pesticide carbaryl to control burrowing shrimp that threaten oyster-growing areas. There has been no direct study of the effects of pesticide spray on eelgrass.

In Willapa Bay, the invasion of smooth cordgrass is extensive and increasing and may threaten eelgrass (Mumford et al. 1990). To control the spread of the non-native smooth cordgrass (*Spartina alterniflora*), the herbicide glyphosate has been applied in the estuary. Only effects on the non-native invading seagrass *Zostera japonica* have been investigated because applications are made in the upper portion of the intertidal zone where cordgrass and *Z. japonica* overlap (Short and Wyllie-Echeverria 1996). The native *Z. marina* grows at lower elevations.

A recent review by Scavia et al. (2002) concluded that estuaries are vulnerable to climate change. The results of the present study suggest to us that the large annual variations in eelgrass biomass are indicative of changes in system-carrying capacity, which is regulated first by climatic factors, next by within-estuary factors, and finally by within-site factors; all of which can be influenced by human-activities at similar scales. Climate variability appeared to have a region-wide influence on eelgrass, but the response to these variations differed in degree between the two estuaries. We cannot predict precisely the response of eelgrass to global climate variation, but the combination of field data and the experimental studies provide evidence that climate variation could fundamentally change eelgrass abundance, flowering, and possibly vertical and horizontal distribution in Pacific Northwest estuaries.

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Literature Cited

Bayer, R. D. 1979. Intertidal zonation of *Zostera marina* in the Yaquina estuary, Oregon. *Syesis* 12:147–154.

Behrenfeld, M. J., J. T. Randerson, C. R. McClain, G. C. Feldman, S. O. Los, C. J. Tucker, P. G. Falkowski, C. B. Field, R. Frouin, W. E. Esaias, D. D. Kolber, and N. H. Pollack. 2001. Biospheric primary production during an ENSO transition. *Science* 291:2594–2597.

Boesch, D. F., D. M. Anderson, R. A. Horner, S. E. Shumway, P. A. Tester, and T. E. Whitledge. 1996. Harmful Algal Blooms in Coastal Waters: Options for Prevention, Control and Mitigation. NOAA Coastal Ocean Program Decision Analysis Series No. 10. NOAA Coastal Ocean Office, Silver Spring, Maryland.

Boesch, D. F., J. C. Field, and D. Scavia. 2000. The Potential Consequences of Climate Variability and Change on Coastal Areas and Marine Resources. Report of the Coastal Areas and Marine Resources Sector Team, U.S. National Assessment of the Potential Consequences of Climate Variability and Change, U.S. Global Change Research Program. NOAA Coastal Ocean Program Decision Analysis Series No. 21. NOAA Coastal Ocean Office, Silver Spring, Maryland.

Boese, B. L. 2002. Effects of recreational clam harvesting on eelgrass (*Zostera marina*) and associated infaunal invertebrates: In situ manipulative experiments. *Aquatic Botany* 73: 63–74.

Bricker, S. B., C. G. Clement, D. E. Pirhall, S. P. Orlando, and D. R. G. Farrow. 1999. National Estuarine Eutrophication Assessment: A Summary of Conditions, Historical Trends, and Future Outlook. National Oceanic and Atmospheric Administration, Silver Spring, Maryland.

Bulthuis, D. A. 1987. Effects of temperature on photosynthesis and growth of seagrasses. *Aquatic Botany* 27:27–40.

Cabello-Pasini, A., R. Muñiz-Salazar, and D. H. Ward. 2003. Annual variations of biomass and photosynthesis in *Zostera marina* at its southern end of distribution in the North Pacific. *Aquatic Botany* 76:31–47.

Carruthers, T. J., B. J. Longstaff, W. C. Dennison, E. G. Abal, and K. Aioi. 2001. Measurement of light penetration in relation to seagrass, p. 369–392. *In* F. T. Short and R. G. Coles (eds.), Global Seagrass Research Methods. Elsevier Science B.V., Amsterdam, The Netherlands.

Clements, W. H., S. N. Luoma, J. Gerritsen, A. Hatch, P. Jepson, T. Reynoldson, and R. M. Thom. 2001. Stressor interactions in ecological systems, p. 215–232. *In* D. J. Baird and G. A. Burton, Jr. (eds.), Ecological Variability: Separating Natural from Anthropogenic Causes of Ecosystem Impairment. Society of Environmental Toxicology and Chemistry (SETAC), Pensacola, Florida.

Dennison, W. C., K. A. Orth, R. J. Moore, J. C. Stevenson, V. Carter, S. Kollar, and R. A. Batiuk. 1993. Assessing water quality with submersed aquatic vegetation. *BioScience* 43:86–94.

Duarte, C. M. 2002. The future of seagrass meadows. *Environmental Conservation* 29:192–206.

Dumbauld, B. R., D. A. Armstrong, and J. R. Skalski. 1997. Efficacy of the pesticide carbaryl for thalassinid shrimp control in Washington state oyster (*Crassostrea gigas,* Thunberg 1793) aquaculture. *Journal of Shellfish Research* 16:503–518.

Dumbauld, B. R., E. P. Visser, D. A. Armstrong, L. Cole-Warner, K. L. Feldman, and B. E. Kauffman. 2000. Use of oyster shell to create habitat for juvenile Dungeness crab in Washington coastal estuaries: Status and prospects. *Journal of Shellfish Research* 19:379–386.

Emmett, R., R. Llanso, J. Newton, R. Thom, M. Hornberger, C. Morgan, C. Levings, A. Copping, and P. Fishman. 2000. Geographic signatures of North American West Coast estuaries. *Estuaries* 23:765–792.

Fonseca, M. S., W. J. Kenworthy, and G. W. Thayer. 1998.

Guidelines for the Conservation and Restoration of Seagrasses in the United States and Adjacent Waters. NOAA Coastal Ocean Program Decision Analysis Series No. 12. NOAA Coastal Ocean Office, Silver Spring, Maryland.

FRANCIS, R. C., S. R. HARE, A. B. HOLLOWED, AND W. S. WOOSTER. 1998. Effects of interdecadal climate variability on the oceanic ecosystems of the Northeast Pacific. *Fisheries Oceanography* 7: 1–21.

HARRISON, P. G. 1982. Spatial and temporal patterns in abundance of two intertidal seagrasses, *Zostera americana* den Hartog and *Zostera marina* L. *Aquatic Botany* 12:305–320.

HEDGPETH, J. W. AND S. OBREBSKI. 1981. Willapa Bay: A Historical Perspective and a Rationale for Research. Office of Biological Services, U.S. Fish and Wildlife Service, Washington, D.C.

HELLBLOM, F. AND M. BJORK. 1999. Photosynthetic responses in *Zostera marina* to decreasing salinity, inorganic carbon content and osmolality. *Aquatic Botany* 65:97–104.

HEMMINGA, M. A. AND C. M. DUARTE. 2000. Seagrass Ecology. University Press, Cambridge, U.K.

HICKEY, B. AND N. BANAS. 2003. Oceanography of the U.S. Pacific Northwest coastal ocean and estuaries with application to coastal ecology. *Estuaries* 26:1010–1031.

HOVEL, K. A. 2003. Habitat fragmentation in marine landscapes: Relative effects of habitat cover and configuration on juvenile crab survival in California and North Carolina seagrass beds. *Biological Conservation* 110:401–412.

KAMERMANS, P., M. A. HEMMINGA, AND D. J. DE JONG. 1999. Significance of salinity and silicon levels for growth of a formerly estuarine eelgrass (*Zostera marina*) population (Lake Grevelingen, The Netherlands). *Marine Biology* 133:527–539.

KENTULA, M. E. AND C. D. MCINTIRE. 1986. The autoecology and production dynamics of eelgrass (*Zostera marina* L.) in Netarts Bay, Oregon. *Estuaries* 9:188–199.

KOCH, E. W. 2001. Beyond light: Physical, geological, and geochemical parameters as possible submersed aquatic vegetation habitat requirements. *Estuaries* 24:1–17.

KOCH, E. W. AND S. BEER. 1996. Tides, light and the distribution of *Zostera marina* in Long Island Sound, USA. *Aquatic Botany* 53:97–107.

KOMAR, P. D. 1998. Beach Processes and Sedmentation, 2nd edition. Prentice Hall, Upsaddle River, New Jersey.

LUOMA, S. N., W. H. CLEMENTS, T. DEWITT, J. GERRITSEN, A. HATCH, P. JEPSON, T. REYNOLDSON, AND R. M. THOM. 2001. Role of environmental variability in evaluating stressor effects, p. 141–177. *In* D. J. Baird and G. A. Burton, Jr. (eds.), Ecological Variability: Separating Natural from Anthropogenic Causes of Ecosystem Impairment. Society of Environmental Toxicology and Chemistry (SETAC), Pensacola, Florida.

MUMFORD, JR., T. F., P. PEYTON, J. R. SAYCE, AND S. HARBELL. 1990. *Spartina* Workshop Record. Washington Sea Grant Program. University of Washington, Seattle, Washington.

NATIONAL ASSESSMENT SYNTHESIS TEAM. 2000. Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change. U.S. Global Change Research Program, Washington, D.C.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA). 1990. Estuaries of the United States: Vital Statistics of a National Resource Base. Special NOAA 20th Anniversary Report. NOAA, Rockville, Maryland.

PHILLIPS, R. C. 1984. The Ecology of Eelgrass Meadows in the Pacific Northwest: A Community Profile. U.S. Fish and Wildlife Service FWS/OBS-84/24. Washington, D.C.

PHILLIPS, R. C., C. MCMILLAN, AND K. W. BRIDGES. 1983. Phenology of eelgrass, *Zostera marina* L., along latitudinal gradients in North America. *Aquatic Botany* 15:145–156.

ROEGNER, C., D. ARMSTRONG, B. HICKEY, AND A. SHANKS. 2003. Ocean distribution of Dungeness crab megalopae and recruitment patterns to estuaries in southern Washington State. *Estuaries* 26:1032–1043.

RUMRILL, S. S. In press. The Ecology of the South Slough Estuary: Site Profile of the South Slough National Estuarine Research Reserve. Technical Report. NOAA, Oregon Division of State Lands, Salem, Oregon.

SCAVIA, D., J. C. FIELD, D. F. BOESCH, R. W. BUDDEMEIER, V. BURKETT, D. R. CAYAN, M. FOGARTY, M. A. HARWELL, R. W. HOWARTH, C. MASON, D. J. REED, T. C. ROYER, A. H. SALLENGER, AND J. G. TITUS. 2002. Climate change impacts on U.S. coastal and marine ecosystems. *Estuaries* 25:149–164.

SHORT, F. T., D. M. BURDICK, AND J. E. KALDY, III. 1995. Mesocosm experiments quantify the effects of eutrophication on eelgrass, *Zostera marina*. *Limnology and Oceanography* 40:740–749.

SHORT, F. T., R. C. DAVIS, B. S. KOPP, C. A. SHORT, AND D. M. BURDICK. 2002. Site-selection model for optimal transplantation of eelgrass *Zostera marina* in the northeastern U.S. *Marine Ecology Progress Series* 227:253–267.

SHORT, F. T. AND S. WYLLIE-ECHEVERRIA. 1996. Natural and human-induced disturbance of seagrasses. *Environmental Conservation* 23:17–27.

SIMENSTAD, C. A. 1994. Faunal associations and ecological interactions in seagrass communities of the Pacific Northwest coast, p. 11–18. *In* S. Wyllie-Echeverria, A. M. Olson, and M. J. Hershman (eds.), Seagrass Science and Policy in the Pacific Northwest. EPA 910/R-94-004. Environmental Protection Agency, Seattle, Washington.

SIMENSTAD, C. A. AND K. L. FRESH. 1995. Influence of intertidal aquaculture on benthic communities in Pacific Northwest estuaries: Scales of disturbance. *Estuaries* 18:43–70.

SIMENSTAD, C. A. AND R. M. THOM. 1996. Functional equivalency trajectories of the restored Gog-Le-Hi-Te estuarine wetland. *Ecological Applications* 6:38–56.

SWARTZMAN, G. AND B. HICKEY. 2003. Evidence for a regime shift after the 1997–1998 El Niño, based on 1995, 1998, and 2001 acoustic surveys in the Pacific Eastern Boundary Current. *Estuaries* 26:1032–1043.

THOM, R. M. 1980. Seasonality in low intertidal benthic marine algal communities in central Puget Sound, Washington, USA. *Botanica Marina* 23:7–11.

THOM, R. M. 1984. Primary production in Grays Harbor estuary, Washington. *Bulletin Southern California Academy of Sciences* 83: 99–105.

THOM, R. M. 1987. The biological importance of Pacific Northwest estuaries. *The Northwest Environmental Journal* 3:21–42.

THOM, R. M. 1990. Spatial and temporal patterns in plant standing stock and primary production in a temperate seagrass system. *Botanica Marina* 33:497–510.

THOM, R. M. 1995. Implications for restoration: Light, temperature and enriched CO_2 effects on eelgrass (*Zostera marina* L.), p. 523–528. *In* Proceedings of Puget Sound Research 1995, Bellevue, Washington. Puget Sound Water Quality Action Team, Olympia, Washington.

THOM, R. M. AND R. G. ALBRIGHT. 1990. Dynamics of benthic vegetation standing-stock, irradiance, and water properties in central Puget Sound. *Marine Biology* 104:129–141.

THOM, R. M., L. D. ANTRIM, A. B. BORDE, W. W. GARDINER, D. K. SHREFFLER, P. G. FARLEY, J. G. NORRIS, S. WYLLIE ECHEVERRIA, AND T. P. MCKENZIE. 1998. Puget Sound's eelgrass meadows: Factors contributing to depth distribution and spatial patchiness, p. 363–370. *In* Proceedings of Puget Sound Research 1998, Seattle, Washington. Puget Sound Water Quality Action Team, Olympia, Washington.

THOM, R. M., S. L. BLANTON, A. B. BORDE, G. D. WILLIAMS, D. L. WOODRUFF, AND M. H. HUESEMANN. 2002. Investigations into wetland carbon sequestration as remediation for global warming, p. 311–320. *In* K. W. Nehring and S. E. Brauning (eds.), Wetland and Remediation II. Battelle Press, Columbus, Ohio.

THOM, R. M. AND A. B. BORDE. 1998. Human intervention in Pacific Northwest coastal ecosystems, p. 5–37. *In* G. R. McMurray and R. J. Bailey (eds.), Change in Pacific Northwest Coastal Ecosystems. Proceedings of the Pacific Northwest Coastal Ecosystems Regional Study Workshop, Troutdale, Oregon. NOAA Coastal Ocean Program Decision Analysis Series No. 11. NOAA Coastal Ocean Office, Silver Spring, Maryland.

THOM, R. M., A. B. BORDE, S. L. BLANTON, D. L. WOODRUFF, AND G. D. WILLIAMS. 2001b. The Influence of climate variation and change on structure and processes in nearshore vegetated communities of Puget Sound and other Northwest estuaries. *In* T. Droscher (ed.), Proceedings of the 2001 Puget Sound Research Conference. Puget Sound Water Quality Action Team, Olympia, Washington.

THOM, R. M., A. B. BORDE, P. J. FARLEY, M. C. HORN, AND A. OGSTON. 1996. Passenger-Only Ferry Propeller Wash Study: Threshold Velocity Determinations and Field Study, Vashon Terminal. Report No. PNWD-2376. Pacific Northwest National Laboratory, Richland, Washington.

THOM, R. M., A. B. BORDE, G. D. WILLIAMS, J. A. SOUTHARD, S. L. BLANTON, AND D. L. WOODRUFF. 2001a. Effects of multiple stressors on eelgrass restoration projects. *In* T. Droscher (ed.), Proceedings of the 2001 Puget Sound Research Conference. Puget Sound Water Quality Action Team, Olympia, Washington.

WALKER, D. I., R. J. LUKATELICH, G. BASTYAN, AND A. J. MCCOMB. 1989. Effect of boat moorings on seagrass beds near Perth, Western Australia. *Aquatic Botany* 36:69–77.

WYLLIE-ECHEVERRIA, S. AND R. M. THOM. 1994. Managing Seagrass Systems in Western North America: Research Gaps and Needs. Alaska Sea Grant College Program Report No. 94-01. University of Alaska Fairbanks, Fairbanks, Alaska.

YOCCUZ, N. G. 1991. Commentary: Use, overuse, and misuse of significance tests in evolutionary biology and ecology. *Bulletin of the Ecological Society of America* 72:106–111.

ZIMMERMAN, R. C., R. D. SMITH, AND R. S. ALBERTE. 1989. Thermal acclimation and whole plant carbon balance in *Zostera marina* L. (eelgrass). *Journal of Experimental Marine Biology and Ecology* 130:93–109.

SOURCE OF UNPUBLISHED MATERIALS

BOESE, B. personal observation. U.S. Environmental Protection Agency, Newport, Oregon.

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Effects of burial on the heart cockle *Clinocardium nuttallii* and the Dungeness crab *Cancer magister*

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Keywords: cockles; crabs; Cancer; wastes; sand particles; laboratory method

Burial experiments with dredge spoil sand were performed in the laboratory using the heart cockle *Clinocardium nuttallii* and the Dungeness crab *Cancer magister*. All cockles buried by 5 cm or less re-established siphon contact with water in less than 24 h. Under 10 cm of sand, less than 50% reached the surface in 24 h while none did so under 20 cm of sand. All crabs reached the surface in less than 24 h after burial by 10 cm or less of sand, while none did so under 20 cm.

Introduction

Burial of benthic organisms is one of the acute effects of ocean dumping of solid wastes. A number of studies have examined the effects of burial on benthic infauna, especially bivalves, but most have been oriented to paleoecology (Schafer, 1972; Kranz, 1974). The present laboratory study compared the effects of burial by different depths of dredged sand on two benthic animals, the relatively sedentary heart cockle *Clinocardium nuttallii* (Conrad) and the mobile Dungeness crab *Cancer magister* Dana. Such data may be useful as criteria when regulations concerning ocean disposal are formulated (IMCO etc., 1975).

C. nuttallii is normally burrowed in the substrate, with the tips of the two siphons exposed at the substrate surface. Because the siphons are short (less than 2 cm when extended), the shells of the cockles are usually less than 1 cm below the substrate surface. *C. magister* inhabits non-permanent burrows. Usually only the antennae, antennules, sometimes one or both eyes, the anterior edges of the third (outer) maxillipeds, and an opening to the mouth were visible at the sand surface. Burrowing behaviour has been described by McKay (1942). The respiratory currents in burrowed crabs have been described by Weymouth (1916): water is drawn in through the sand and through the narrow gap between the chelipeds and the anterior edge of the carapace; water then enters near the bases of the legs, passes over the gills, and leaves via the mouth opening.

Methods

General

All experiments were performed at the Pacific Environment Institute, West Vancouver, British Columbia, during April to June 1976. In all experiments seawater (10 °C, 26‰)

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Exhibit 9.3

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was constantly running through the experimental containers which were provided with sand deep enough for the animals to burrow in. At least one hour after burrowing was completed, dredged sand from the Fraser River (median grain size 400 μm) was added in less than 1 min, either by hand or with a shovel.

Clinocardium nuttallii

Specimens of *C. nuttallii*, 5–7 cm long, were collected near Vancouver, B.C. Cockles were buried with 5 different depths of sand (0·1–20 cm). Twelve cockles were used in each test, and a total of 20 cockles were used in the project.

For cockles buried by 5 cm or less of sand, a single cockle was placed in plastic 100 ml beakers containing 9 cm of sand. For all other tests, two cockles were used in plastic pails (25 cm diameter) containing 15 cm of sand. Experiments were usually ended after 24 h.

Cancer magister

Male crabs (carapace widths 12–29 cm) were collected from *ca* 10 m depth near Squamish, British Columbia. Burial depths ranged from 0·1 to 20 cm of sand. Twelve crabs were used in each test, employing a total of 25 animals. Crabs were placed in plastic pails (45 cm diameter) containing 10 cm of sand (one crab per pail) for burial by 20 cm of sand and for a few 10 cm tests. For all other experiments, oval fiberglass tanks were used (64×45 cm) containing 10 cm of sand (2 crabs per tank). Tests usually lasted 24 h.

Results

Clinocardium nuttallii

Immediately upon dumping of additional sand, the siphons were closed and withdrawn, and no escape behaviour was observed until after dumping was completed. The times from burial until appearance of the siphons at the new substrate surface are shown in Table 1. Cockles immobilized for 24 h under 10 cm or more of sand remained permanently buried. When 10 cm of sand was added, 5 cockles escaped burial 66–410 min after dumping while the other 7 were still buried after 24 h. The latter were still alive but showed no escape behaviour and had not moved from their positions at the time of burial. Two left for 2 days and one left for 3 days buried under 10 cm were still in their original positions when recovered dead. When 20 cm were dumped, no cockles escaped burial in 24 h and all were recovered alive in their original positions.

TABLE 1. Numbers of previously burrowed *Clinocardium nuttallii* opening both siphons at the substrate surface following covering by additional sand ('dumping')

Depth of dumped sand	Time from end of dumping						
	<1 min	1–10 min	10–60 min	1–6 h	6–24 h	Buried at 24 h	Total no. animals
1–3 mm[a]	1	10	1	0	0	0	12
1 cm[a]	0	2	10	0	0	0	12
5 cm[a]	0	1	6	5	0	0	12
5 cm	0	0	8	4	0	0	12
10 cm	0	0	0	4	1	7	12
20 cm	0	0	0	0	0	12	12

[a]Cockles allowed to burrow in 9 cm depth of sand before burial. In all other tests, cockles were allowed to burrow in 15 cm depth of sand.

Cancer magister

In order to maintain respiratory currents, sand covering the anterior carapace edge must not be excessive and an opening in the sand must be present above the mouth opening. The times from burial until re-establishment of such positions are shown in Table 2.

In the series of tests with 0·1–10 cm of sand, all crabs escaped in less than 6 h after burial. When 1–3 mm were dumped all crabs re-established clear openings to the buccal cavity in less than 10 s by expelling a burst of water. When 1 cm of sand was dumped all crabs re-established clear respiratory currents in less than 1 min to greater than 1 h (<6 h) after burial. Eight crabs were able to force the exhalent current through 1 cm of sand starting less than 1 min after burial. This was detected by the constant movement of sand grains above the buccal cavity, but it did not result in a permanently clear opening. This flow continued intermittently for from a few seconds to 38 min at which time all of these crabs raised their bodies, and allowed a clear buccal opening to be established by the exhalent current. When 5 cm were dumped, all crabs escaped in less than 1 min to greater than 6 h (<24 h) after burial. When 10 cm were dumped, all crabs escaped in less than 24 h, but none forced exhalent currents through the sand. Additional observations on escape behaviour were presented in an earlier preliminary report (Chang & Levings, 1976).

When covered with 20 cm of sand, no crabs escaped in less than 24 h and none showed any escape behaviour or respiratory currents. Crabs left for 24 and 72 h were recovered alive, but two crabs left for 120 h died. Crabs immobilized by burial for 24 h or more remained permanently buried.

TABLE 2. Numbers of previously burrowed *Cancer magister* re-establishing clear openings to the buccal cavity following covering by additional sand ('dumping')

Depth of dumped sand[a]	Time from end of dumping						
	<1 min	1–10 min	10–60 min	1–6 h	6–24 h	Buried at 24 h	Total no. animals
1–3 mm	12	0	0	0	0	0	12
1 cm	6	2	3	1	0	0	12
5 cm	4	4	1	1	2	0	12
10 cm	6[b]	5	0	1	0	0	12
20 cm	2[b]	0	0	0	0	10	12

[a]All crabs allowed to burrow in 10 cm depth of sand before burial.
[b]Includes 2 crabs at 10 cm and 2 crabs at 20 cm which were observed on the substrate surface before dumping was completed.

Discussion

The escape ability of *C. nuttallii* in this study was similar to that described by Ansell (1967) for other cardiid bivalves. The species is capable of rapid escape using its strong foot. Water jets which are used in burrowing cannot be used in escaping burial since an adequate water supply is not available while buried. The broad shell of *C. nuttallii* results in severe resistance to upward movement, especially in a stable substrate such as sand. Observations presented elsewhere (Chang & Levings, 1976) showed that cockles were able to escape more easily from unstable material such as wood chips. Other bivalve species may avoid burial effects by extension of their siphons. Pratt *et al.* (1973) found that *Pitar morrhuana* and *Mercenaria mercenaria* survived burial by a 5 cm layer of an unstable slurry of paper waste by extending their siphons through to the surface of the slurry. Goodwin (1975) found that the geoduck *Panope generosa* survived deposition of 15 cm of spoil (mud, clay, wood debris) by extending its long siphons, and there was some evidence this species could survive under as much as 50 cm of spoil in this way.

C. magister, a mobile epifaunal species, was better able to escape burial by sand compared to the cockle, even though the escape behaviour seemed less well adapted to upward movement through a substrate. Because of the large surface area of the carapace, much resistance must be overcome, especially in heavier materials such as sand. Nevertheless, forces directed through appendages enabled the crabs to move up through 10–20 cm of sand.

Our observations indicate that disposal of spoil from suction dredging in shallow, quiescent waters would be harmful to both the crab and the cockle, while clamshell dredging, which deposits spoil over longer time periods, would be more serious for *C. nuttallii* than *C. magister*. Exposed crabs should be able to avoid burial except during extremely rapid deposition, as *C. magister* was able to leave its burrows and move up as deposition occurred. The escape time for *C. magister* (excluding 1–3 mm burial) did not increase with burial depth as for *C. nuttallii*. It seems likely that *C. magister* could escape burial by greater than 10 cm burial if the disposal period was longer than in the present study (e.g. *ca* 1 h). *C. nuttallii* could escape this depth only if disposal took place over several hours.

Acknowledgements

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References

Ansell, A. D. 1967 Leaping and other movements in cardiid bivalves. *Animal Behaviour* **15**, 421–426.

Chang, B. D. & Levings, C. D. 1976 Laboratory experiments on the effects of Ocean Dumping on benthic invertebrates. II. Effects of burial on the heart cockle (*Clinocardium nuttallii*) and the Dungeness crab (*Cancer magister*). Fisheries and Environment Canada. *Fisheries and Marine Service, Technical Report* No. 662. 20 pp.

Goodwin, L. 1975 Diver observations on effects of dredge spoil disposal on bottom substrates and associated macroscopic benthic organisms. pp. 98–117. In (Westley, R. E., Finn, E., Carr, M. I., Tarr, M. A., Scholz, A. J., Goodwin, L., Sternberg, R. W. & Collins, E. E., eds) Evaluation of effects of channel maintenance dredging and disposal on the marine environment in southern Puget Sound, Washington. *Washington Department of Fisheries, Technical Report* No. 15. Olympia, Washington. 142 pp.

IMCO/FAO/UNESCO/WMO/WHO/IAEA/UN Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) 1975 Scientific Criteria for the selection of sites for dumping of wastes into the sea. *Report Studies GESAMP* No. 3. FAO, Rome. 21 pp.

Kranz, P. M. 1974 The anastrophic burial of bivalves and its paleoecological significance. *Journal of Geology* **82**, 237–265.

MacKay, D. C. G. 1942 The Pacific edibile crab, *Cancer magister*. *Fisheries Research Board of Canada Bulletin* No. 62. 32 pp.

Pratt, S. D., Saila, S. B., Gaines, A. G., Jr., & Krout, J. E. 1973 Biological effects of ocean disposal of solid wastes. *Univ. of Rhode Island, Marine Technical Reports Series* **9**, 53 pp.

Schafer, W. 1972 *Ecology and Paleoecology of Marine Environments*. Oliver and Boyd, Edinburgh. 568 pp.

Weymouth, F. W. 1916 Contributions to the life history of the Pacific coast edible crab. *California Fish and Game* **2**, 22–27.

Oregon

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Date: February 6, 2018

To: Chris Kern, ODFW Salem; Caren Braby, David Fox, Steve Rumrill and Troy Buell, MRP Newport

From: Scott Groth and Katie Gregory, MRP Charleston

Subject: Summary of information regarding Oregon's red abalone recreational fishery.

This document summarizes the information which has been gathered and analyzed in recent months to consider management changes for Oregon's recreational abalone fishery.

Background:

Species:
Abalone are prized by fishermen, typically among the very highest per pound value of all seafood's. Seven species of abalones are found on the West Coast of North America. Oregon falls within the range of three species of abalone.

1. **Red abalone**, *Haliotis rufescens*, ranges from Baja to Coos Bay, Oregon. This is the largest abalone in the world and the subject a robust recreational fishery in California and a very small recreational fishery in Oregon. Red abalone are limited to a few small areas in Oregon.
2. **Flat abalone**, *Haliotis walallensis*, this is a small species (4-7") found in vegetated rock reefs throughout Oregon. Flat abalones were the target of a 2001-2008 commercial fishery in Oregon, closed amid conservation concerns.
3. **Pinto abalone**, *Haliotis kamtschatkana*, a small species which ranges from Baja to Alaska. This species is extremely rare in Oregon (only a few have been found).
4. **Black abalone**, *Haliotis cracherodii*, this species northern range extent is typically reported well south of Oregon (Point Arena, CA), however a few specimens have been found in Oregon, all in the 1950s and 1960s. They are unlikely to currently be found in Oregon.

Abalone fishery status:
Given their popularity, demand for abalone fisheries is high, though sustainability of those fisheries has been difficult to maintain. Abalones are marine snails that are sessile and herbivorous, their reproduction depends on high densities and recruitment is episodic. For these reasons they are: 1) accessible, 2) do not move, 3) important to persist in high densities. While data poor fisheries typically rely on inefficiency, the aforementioned biological factors of abalones are antithetical to fishery inefficiencies; as a result abalone fisheries are typically unsuccessful. While robust and valuable fisheries have occurred upon each of the seven species of abalone on the US West Coast, the result of most of these fisheries has been stock failure. Previously fished species White and Black abalone are ESA listed "Endangered", Pink, Green and Pinto abalone are listed "Species of concern". Red and flat abalone are currently the only two North American abalone with no ESA status.

In Oregon, red abalone were commercially fished for a few years in the 1950s soon after they were "discovered" to be in the area, in 1953. The red abalone commercial fishery was closed due to low numbers of abalone and opposition by recreational harvesters, about 250 abalone were estimated to be harvested in that effort.

Current fisheries:

Three abalone fisheries remain in North America 1) a subsistence fishery for pinto abalone in Alaska (5 a day), 2) a small trophy fishery for red abalone in Oregon, and 3) a robust, highly managed recreational fishery for red abalone in California. Despite highly active management which includes a robust fishery management plan, on December 7, 2017 California Fish and Game Commission (CFGC) unanimously decided to close the recreational red abalone fishery. The closure decision was mostly based on the fishery independent data (CDFW subtidal belt transects) showing densities fell below targets. The lowering of densities were largely attributed to ocean conditions, but also fishery pressure, HABs and competition from purple sea urchins.

History of red abalone fishery management:

Table 1. Relevant management changes to Oregon red abalone fisheries

Year	***Action***
1953	Red abalone "discovered" in Oregon.
1959	Personal use limits set at 3/day (or in any seven consecutive days), 8" minimum size.
1960-62	Commercial harvest began, then disallowed in Oregon
1965-1975	A major part of ODFWs Marine Region was the collection, spawning and out planting of red abalones. The purpose of this work was to enhance the sport fishery, however these efforts did not result in detectably larger populations or the attempting range extension to make a Newport/Depoe Bay area fishery.
1970-1972	An experimental harvest card was used for recreational red abalone harvesters
1994-2002	Collection and spawning program re-initiated, several OR abalones were collected (sea urchin divers were commissioned) then spawned (OSU's molluscan brood stock group). Some small number of young abalones were distributed haphazardly in Coos Bay and Brookings.
1995	ODFW takes red abalone to OFWC proposing full fishery closure given perceived recent reduction of population, poaching, lack of juveniles, etc. Result of OFWC was the reduction from 3/day (weekly limit) to a 1 daily/5 annual limit. It also introduced the free permit.
2006	Eight reporting zones added to the permit.
2013	Given increasing pressure for a commercial rock scallop fishery, reporting of these were added to the free abalone permit.

Table 2. Selected relevant management changes to California red abalone fisheries

Year	***Action***
1949	Commercial harvest disallowed north of Point Lobos, CA.
2000	Annual limit set at 100
2002	Daily limit reduced to 3, annual limit reduced to 24
2014	Annual limit reduced from 18 to 9 (some areas) harvest before to 8am disallowed
2016	Seasons changed to fewer months (May-June and August-October)
2017	Recreational red abalone fishery closed
2019	Sunset of fishery closure in April of 2019

Fishery Independent data:

Little fishery independent data exists for red abalone in Oregon. While staff has conducted many fishery independent projects related to red abalone, most of this work focused on enhancement. One potential source, sea urchin surveys, conducted from the 1980s to present would also enumerate red abalones however, due to the rarity of red abalones combined with their shallow depths, none were ever found in these surveys. Recently, staff has made efforts to produce quantitative measures of red abalone populations.

In 2011 staff conducted two days of pilot abalone surveys using contract divers. This survey helped understand appropriate methods to collect data and yielded size distribution data. On the first day of this two day study we found that red abalone densities were so low that statistically robust, randomized methods would likely not detect any abalones. During a second day, divers performed timed surveys, where contract divers searched for abalones without spatial restriction at sites known to have red abalones, this provided some abundance measure and size distribution data.

In 2015, using a State Wildlife Integrity Grant (SWIG), staff successfully collected relative abundance data on red and flat abalone at sites in Brookings and Port Orford. Using highly specialized knowledge, we were able to identify belt transects within red abalone habitats (19 in Port Orford, 24 in Brookings). Contract divers counted and measured flat and red abalone within each of these subtidal belt transects. At both sites, red abalones were found, but at very low densities (Table 3). At Brookings sites, where size distributions were collected in both surveys (2011 and 2015), the mean shell length was 225 mm, obviously, those differences weren't significant ($p=0.91$). Worth noting is that the densities of red abalones found on this survey ($0.025/m^2$ at Port Orford and $0.04/m^2$ at Brookings) are far lower than the level expected to be sustainable ($0.3/m^2$).

Table 3. Relative abundance survey data from 2015 surveys

Site	Survey Dates	# Transects	Area surveyed (m^2)	# flat abalone	# red abalone
Port Orford	Sep 24 & 25, 2015	19	1,140	21	28
Brookings	Sep 28 & 29, 2015	24	1,440	1	57
Totals:		43	2,580	22	85

In 2017, in the absence of a dive program or available funding for contract divers, staff revisited the idea of performing free dive surveys for abalones. Staff free dove to check in with Whale cove red abalone, the abalones which are there were placed there in the late 1980s, about four remain (the same ones we found 10 years ago!) We also scouted Charleston and Brookings areas. We found that a free dive survey may be possible (abalones were found and measured), but the best conditions would be needed to do this work.

Worth noting, is that many recreational divers have offered to help our survey work. While these offers are genuine and appreciated, the nature of index surveys relies on going back to specific sites; as such, there is concern that showing a harvesters where they can find large abalones will bias future surveys. We strive to find ways to incorporate harvesters into tracking the abalone population, however nothing has come up that may truly be "fishery independent".

Fishery Dependent Data:

Harvest permit background

Following the 1995 OFWC action, a free permit has been required to harvest abalone, starting in 2003, a shellfish license was also required. Throughout this time, key regulations include 1) 1 abalone daily limit, 2) 5 abalone annual limit, 3) 8 inch minimum size, and 4) possession limit of one daily limit. The permit "required" that last year's harvest record must be submitted prior to issuance of new permit; although this requirement had little binding, tendency was for good compliance. Each permit was mailed with instructions and a reporting map. In 2013, rock scallops (also collected by divers) was added to the free permit.

Number of permits:

Since 1996, 4,052 Oregon recreational abalone permits have been issued, averaging 184 permits per year. Permit issuance has risen over time, though these numbers are affected by 1) the introduction of the shellfish license (2004) and the addition of rock scallops to the permit (2013), Figure 1.

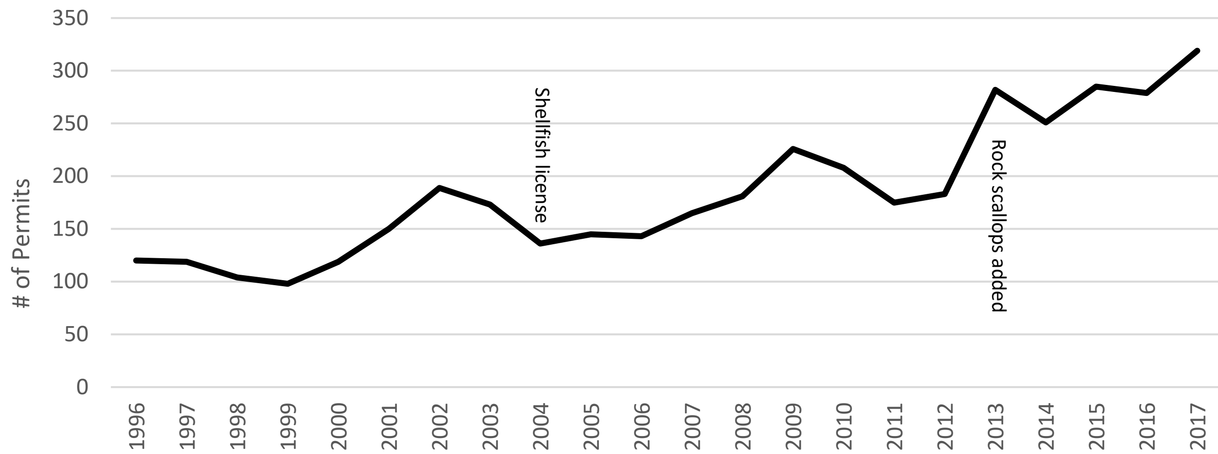

Figure 1. Issuance of Oregon abalone permits by year (1996-2017)

Number of permittees by state

Of the 3,456 abalone permits issued since 1996, for which we have addresses, only 62 have not gone to Oregon or California residents.

Issuance by office

Given the location of abalone habitats, most permits have been issued in South coast offices, Figure 2.

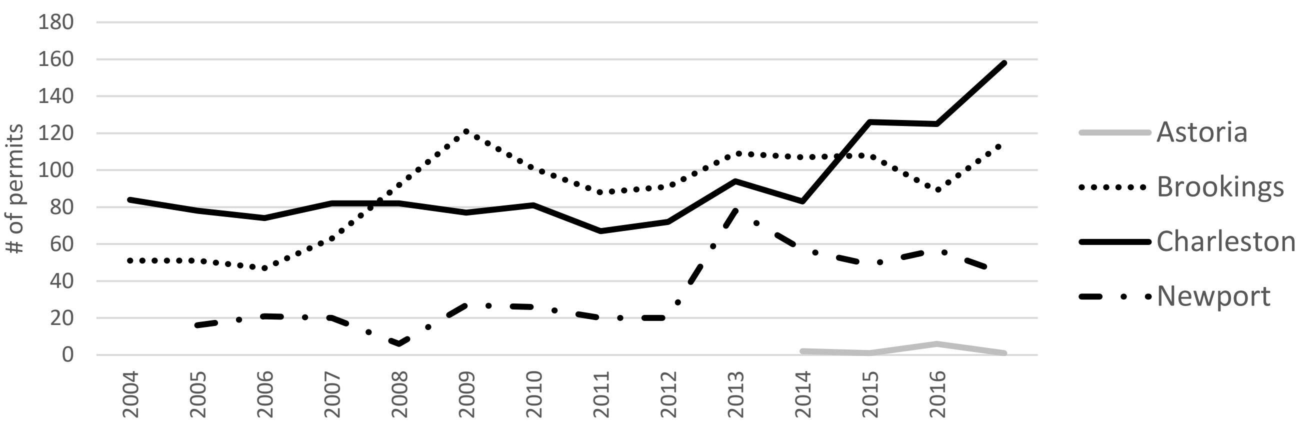

Figure 2. Issuance of Oregon red abalone permits by year, by ODFW office 2004-2017.

Permit compliance

Permit returns have been fairly high given the voluntary nature of this permit, the last 10 years has been about 65% permit return compliance, Figure 3.

Figure 3. Oregon red abalone permit compliance (i.e. returned permits) by year, 1996-2016.

Harvest data:

Number of abalone harvested by method

Most abalone are harvested via SCUBA, while free dive component is high, shore pick has reduced over time, Figure 4.

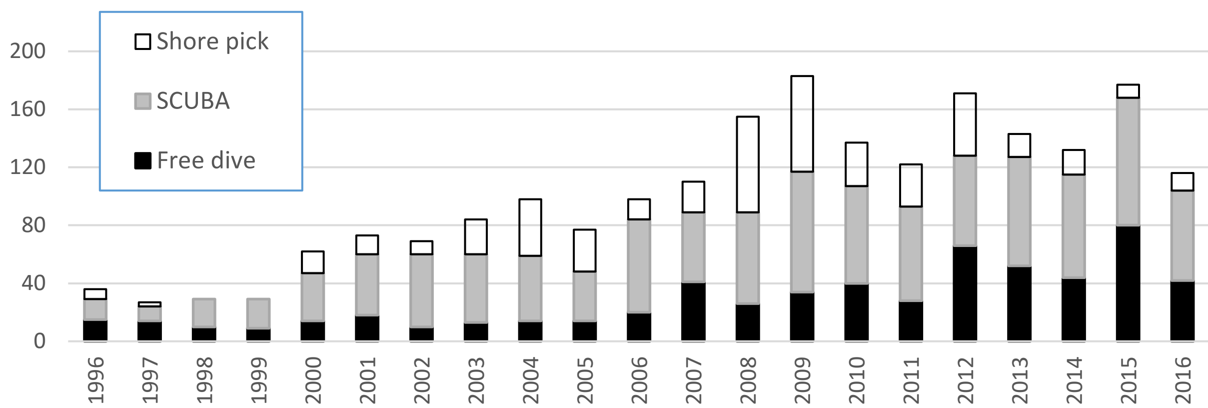

Figure 4. Reported Oregon red abalone harvest by year, by method, 1996-2016.

Harvest by permit holder residence

Most red abalone were harvested by permittees with Oregon addresses, however those from California are beginning to approach similar levels, Figure 5.

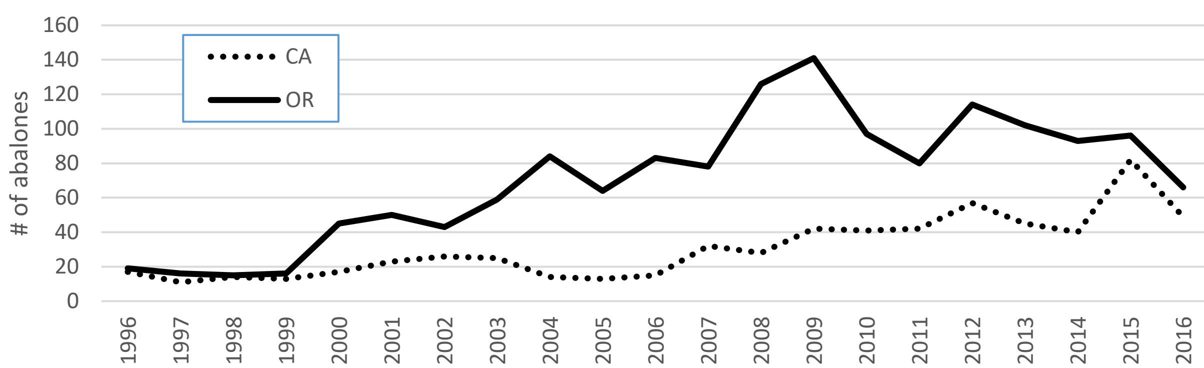

Figure 5. Reported harvest of red abalone by year, by state residence, 1996-2016.

Harvest location (by method)

Of the 1,710 red abalones harvested in Oregon with reported area, most were attributed to a few miles of shoreline in the southern part of the state, Figure 6.

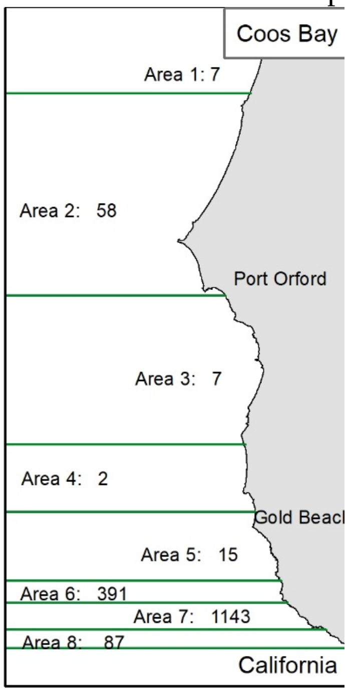

Figure 6. Self reported area of take for red abalone, 1996-2016

Harvest by month:

Harvest is principally in the summer, when marine weather is best, Figure 7.

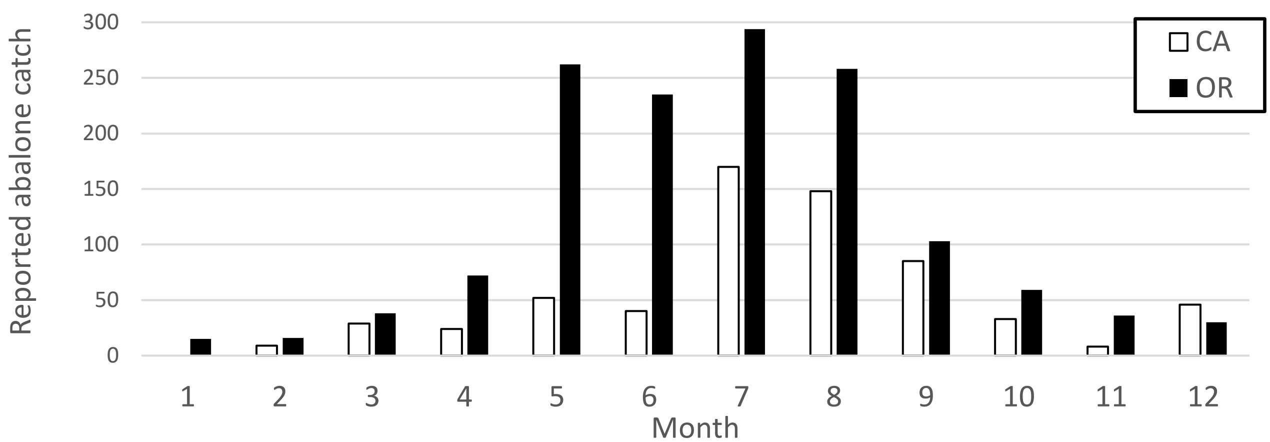

Figure 7. Red abalone catch by month and by state residence

Projections:

Projected effects of changing annual bag limit:

When considering the effects of changing the annual bag limit, we found that changing from 5/year to 3/year would have little effect, changing to 1/year has a more substantial effect, Figure 8. This projection does not account for changes in effort level.

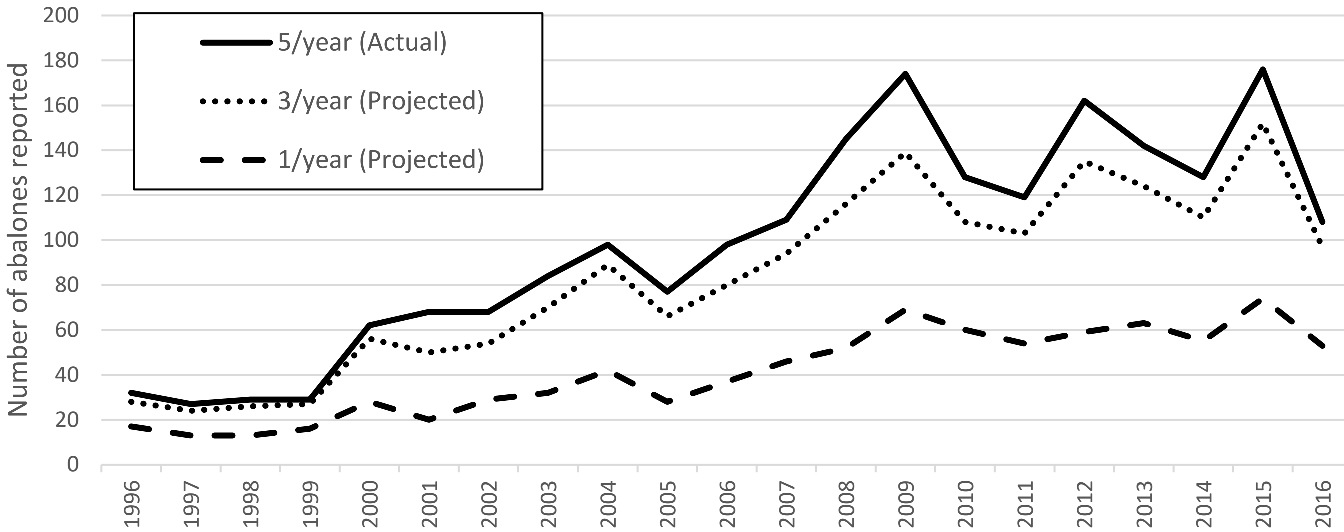

Figure 8. Number of abalone projected to be harvested given changes to annual limits.

Harvest expanded based on reporting compliance:

Analysis in this memo and other recently developed materials discuss harvest numbers, comparing them inter-annually, but do not account for differences in permit reporting, Figure 9.

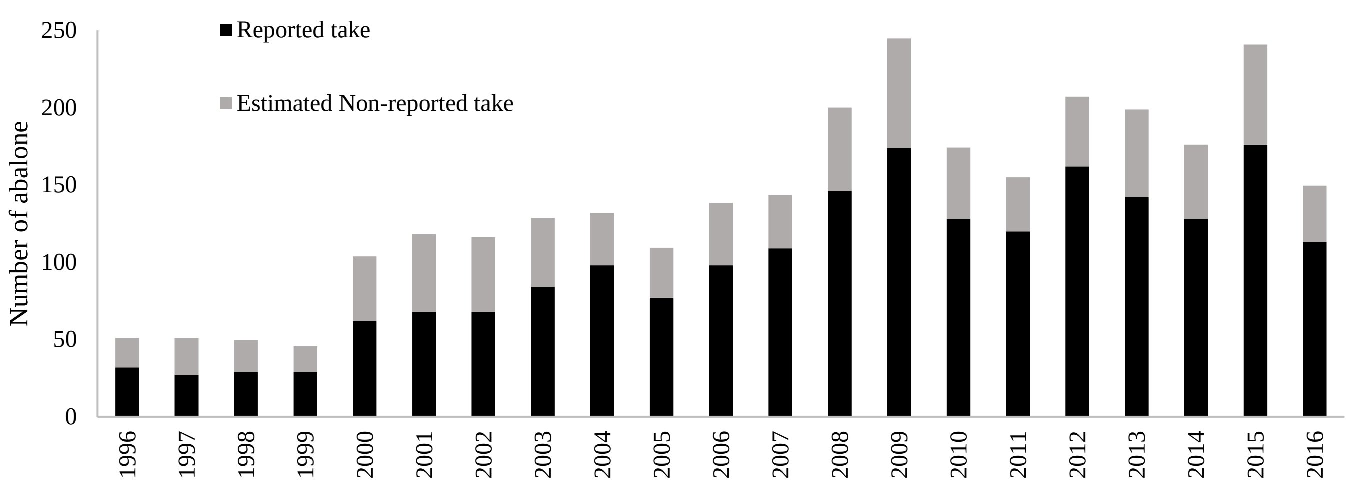

Figure 9. Abalone harvest by year divided into reported and expanded take

DEFINING AND ASSESSING BENTHIC RECOVERY FOLLOWING DREDGING AND DREDGED MATERIAL DISPOSAL

Dara H. Wilber[1] and Douglas G. Clarke[2]

ABSTRACT

Assessing the recovery of benthic habitats disturbed by dredging and dredged material disposal operations is an important and growing management issue throughout the world. Although many projects have been monitored and a substantial literature on the subject exists, few generalizations can be made about typical recovery rates because biological responses are influenced by numerous factors, including site-specific bathymetry, hydrodynamics, depth of deposited sediments, the spatial scale of the disturbance, sediment type, and the timing and frequency of the disturbance. Additionally, there is no accepted definition of what constitutes "recovery." In various studies, recovery has been defined as a return of benthic resources to a baseline (pre-impact) condition, a reference (neighboring unimpacted) condition and/or both. Infaunal macroinvertebrates are most commonly monitored to assess benthic recovery, usually by sampling the substrate, preserving organisms in formalin, and identifying and enumerating the organisms in the laboratory. Methods used to analyze these data vary and may influence study conclusions just as much as the aforementioned physical factors. Study results are generally presented through some combination of three methods of data analysis, i.e., univariate statistics (very common and used almost exclusively in early studies), multivariate statistics (increasingly common), and benthic indices. We review benthic recovery rates reported for approximately 50 dredging-related (disposal and dredging sites) projects and explore the relative influence of both physical and analytical factors in the determinations of recovery status. Although early impact assessments relied heavily upon univariate diversity indices that were derived from species level identifications of macroinvertebrates, it has become increasingly apparent that multivariate analyses of the same data sets provide more sensitive measures of ecological status.

Keywords: Meta-analysis, infauna, thin-layer, salt marsh, mud flat habitat

INTRODUCTION

Impact assessment of dredging activities has been conducted for many years and over a broad geographical range, although most study results are not published in the peer-reviewed literature (Bolam and Rees 2003). There have been several recent reviews of the environmental consequences of dredging impacts (Fredette and French 2004, Bolam et al. 2006a, Brooks et al. 2006), but no general consensus has emerged of an operational definition of recovered benthic habitat. Some studies define recovery as a return of the impacted area to pre-disturbance conditions, whereas others indicate recovery is attained once the impacted area is equal to or exceeds an undisturbed reference area in terms of biological metrics, however, locating suitable reference areas is often challenging (Quigley and Hall 1999, Sanchez-Moyano et al. 2004, Fraser et al. 2006). Estimates of benthic recovery rates are summarized as ranging from several months to several years (Qian et al. 2003), but associations with disturbance types (i.e., dredging vs. disposal sites) or details of the analytical approaches (univariate vs. multivariate statistical techniques) that were used to determine recovery status are generally not provided. Although there are several environmental conditions that are commonly identified as influencing benthic recovery rates, such as sediment type, depth of overburden, frequency and timing of deposition, and receiving habitat type, the relative importance of these factors in influencing benthic recovery is not known. In addition, benthic communities in estuaries can be highly dynamic, thus making it difficult to distinguish between natural variation and changes that occur as part of the recovery process (Wildish and Thomas 1985).

A general benthic successional paradigm (Pearson and Rosenberg 1978, Rhoads and Germano 1986) states that following initial decreases to benthic diversity, abundance, and biomass that immediately follow a disturbance, pioneering (Stage I) organisms, such as small, tube-dwelling polychaetes and small bivalves colonize the surficial sediments. These opportunistic taxa occur in relatively high abundances and low diversity and over time are

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replaced by larger, longer-lived and deeper-burrowing (Stage II) species. The Stage III assemblage is comprised of a more diverse but less abundant group of larger taxa such as maldanid polychaetes. Thus, the absence of deposit feeders and mid-depth burrowers is indicative of areas that are in a state of recovery. Reviews of dredging impacts on seagrass (Erftemeijer and Lewis 2006) and unvegetated benthic habitats (Bolam et al. 2006a) indicate that site-specific factors influence impacts, thus limiting the extrapolation of results across geographic regions. We summarize the ranges of observed recovery rates across broad habitat categories and disturbance conditions and examine potential associations between biological responses and characteristics of the dredging projects while noting the influence of different analytical approaches on determinations of recovery status. In addition, we review biological responses to the intertidal placement of dredged material in "beneficial use" projects, in which dredged material is used as a resource to enhance habitats.

PHYSICAL FACTORS AFFECTING BENTHIC RECOVERY

Depth of Overburden at Disposal Sites

Some benthic organisms such as burrowing polychaetes, amphipods and molluscs can colonize newly deposited sediments through vertical migration, therefore, if dredged material depths are limited to within the vertical migration capacity of these organisms (20-30 cm), recovery rates may be quicker than if colonization is dependent upon the lateral migration of juveniles and adults from adjacent areas and larval settlement. Successful vertical migration through 15 cm of sediments occurred for benthic infauna in Auckland, NZ (Roberts et al. 1998) and mud snails in Delaware Bay (Miller et al. 2002). Successful movements through up to 32 cm have been documented for polychaetes (Maurer et al. 1982) and bivalves (Maurer et al. 1981). The amount of the deposit and the frequency of deposition are interactive factors affecting vertical migration for nematodes (Schratzberger et al. 2000).

Habitat Type (disturbance history)

Shallow benthic habitats (< 20 m depth, Hall 1994) experience relatively frequent wave, wind, and current induced disturbances and thus are typically inhabited by low-diversity, r-selected benthic assemblages that can readily re-establish themselves under conditions of high frequency disturbances (Dauer 1984, Clarke and Miller-Way 1992, Ray and Clarke 1999). These communities are naturally held in early successional stages and therefore, are able to recover more rapidly than communities in deeper, more stable environments (Newell et al. 1998, Bolam and Rees 2003).

Sediment Type

Rapid recolonization of soft-bottom benthic habitats is frequently associated with either unconsolidated fine grain sediments (Cruz-Motta and Collins 2004) or the rapid dispersion of fine-grained dredged material by currents (Van Dolah et al. 1984). Newell et al. (1998) characterized typical recovery times at 6-8 months for mud habitats and 2-3 years for sand and gravel substrata.

Spatial Scale of Disturbance

The spatial scale of the dredged or disposal area may be proportional to recovery times (Zajac et al. 1998, Guerra-Garcia et al. 2003). For small-scale disturbances, the edge/surface area ratio of the disturbed area is larger than for larger disturbances, therefore colonization through adult immigration from surrounding undisturbed areas may facilitate recovery. With larger disturbed areas, the central portion of the disturbed areas is reliant upon settlement from the water column for colonization, which is very dependent on seasonal recruitment patterns and local hydrodynamics. Guerra-Garcia et al. (2003) demonstrate a log-linear relationship between recovery times and spatial scale using 14 studies of recovery at dredging and disposal sites. For instance, recovery in small patches (1000 m^2) took 7 months, whereas recovery was projected to require years at spatial scales of 10^5 m^2 and above.

Timing and Frequency of Disturbance

Avoiding dredging activities after seasonal larval recruitment periods is a common practice when possible. Deposition of sediments in several smaller units rather than one deep deposit also may be less detrimental to the benthos. In a microcosm study, sediment deposited in a single event caused more severe changes to nematode assemblages than the same amount of sediment deposited in smaller doses (Schratzberger et al. 2000).

METHODS THAT AFFECT RECOVERY ESTIMATES

Sampling

Sampling different components of the benthos may affect determinations of an area's recovery status, for example, nematodes are more sensitive to sediment structure than macrofauna and thus may exhibit changes in community structure more readily (Boyd et al. 2000). However, changes in meiofaunal community structure do not persist as long as changes to the macrofaunal community (Coull and Chandler 1992, Somerfield et al. 1995), therefore the faunal assemblage that is targeted for sampling may affect perceptions of impact severity and recovery rates. The accuracy of assessing habitat conditions can be increased by using remote survey methods, such as sidescan sonar and photography (both of which require ground-truthing). Habitat characterizations that are based solely on biological data may be a function of sampling methods (Rees et al. 1999, Brown et al. 2001). Macrofauna are most commonly monitored to assess benthic recovery, usually by sampling the seafloor, preserving organisms in formalin, and identifying and enumerating the organisms in the laboratory. Statistical techniques, however, vary among studies and may influence recovery estimates depending on the approach taken. In addition, the sampling methods used can influence the identity and abundance of benthic organisms that are captured. Two common methods of sampling soft benthic habitats are box cores and grab samplers.

Analytical

Study results are generally presented through some combination of three methods of data analysis, i.e., univariate statistics (very common and used almost exclusively in early studies), multivariate statistics (increasingly common), and benthic indices. Less common analytical approaches include examinations of functional groups (Niemi et al. 1990, Wilber and Stern 1992) and secondary production (Wilber and Clarke 1998). The thoroughness of data analyses may affect study conclusions, for example univariate measures such as total infaunal abundances (McCauley et al. 1977) may suggest more rapid recovery than multivariate (Bolam and Whomersley 2005) or functional group (Wilber and Stern 1992) analyses of the same datasets.

Univariate measures include commonly reported parameters such as, total abundance, taxa richness, and total biomass. There are a number of diversity indices that reduce multivariate data (e.g., abundances of multiple species) into a single index, which can then be treated statistically using univariate analyses. Common diversity indices include the Shannon-Weiner diversity index (H'), Margalef's index (d), Pielou's evenness index (J'), and the Simpson index (λ). Changes between sites or over time of univariate measures (including indices) are usually plotted as means and confidence intervals for each site and time (e.g., Fig. 1, taken from Burlas et al. 2001) and recovery is indicated when values for the impacted area (in this case, black circles) are no longer significantly lower than pre-disturbance levels or those of a reference location. Multivariate analyses of community structure have historically been conducted using cluster analysis, with resultant dendograms that group samples (for example, stations or sites) such that samples within a group are more similar to each other than samples from different groups. Segregation of stations from disturbed and reference areas may indicate impacts have affected community structure. Increasingly, non-parametric multi-dimensional scaling (MDS) ordination plots using the Bray-Curtis similarity measure are created to identify groups of samples having similar faunal assemblages (Clarke and Warwick 2001). Separation of impacted from reference sites is visually apparent and can be statistically tested with multivariate tests such as ANOSIM (Clarke and Warwick 2001). In addition, impacted sites frequently have greater variability in community composition than reference areas (Warwick and Clarke 1993), therefore the relative dispersion of samples from the two habitat types can be compared (e.g., Fig. 2, taken from Boyd et al. 2004). In Fig. 2, it is apparent that benthic community structure at the reference (blue) and low frequency (green) disturbance stations is both less variable and different from that of stations where dredging is more frequent (red). By using MDS ordinations, Jewett et al. (1999) demonstrate a similar pattern of higher variability among stations in sand and cobble substrate in the

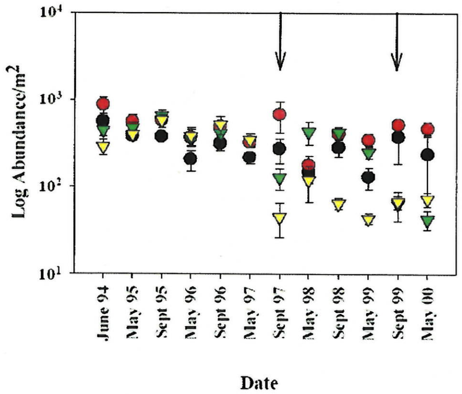

Figure 1. Example of univariate analyses that tracks a variable (total infaunal abundance) at an impacted site (black circles) before and after a disturbance (arrows) relative to reference areas (other symbols) from Burlas et al. 2001.

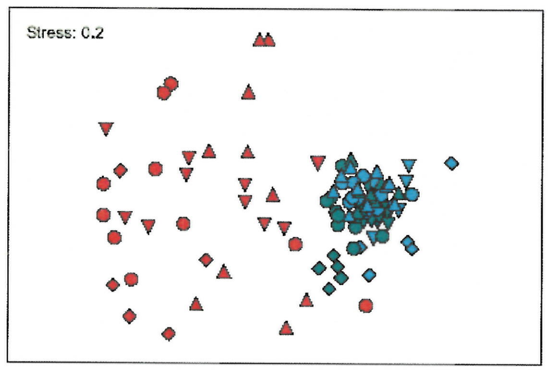

Figure 2. Example of multivariate analyses in which an MDS plot depicts variable community structure at high frequency disturbance sites (red symbols) relative to low frequency (green) and undisturbed (blue) sites over several years (denoted by different symbol shapes) from Boyd et al. 2004.

northeastern Bering Sea in a frequently mined area as compared to less variable community structure among stations in recovering habitat (2 – 7 years post-mining) and reference un-mined stations, which exhibited the smallest variation in community composition. Similar patterns of convergence in community variability are apparent as benthic gravel mining sites in the North Sea were sampled 2 weeks, one-year, and two-years after dredging and compared to reference stations (Kenny and Rees 1996).

Benthic indices have been developed to integrate macrobenthic community parameters into a single metric that can be used to distinguish between disturbed and undisturbed areas. In an effort to economize on labor, indicator species that are identified as either disturbance tolerant or intolerant are used to define areas as either disturbed or undisturbed, respectively. Relative abundances of these indicator species can be combined to provide an index of biological impact that is site- and impact-specific, thus simplifying subsequent monitoring efforts (Roberts et al. 1998). The major benefit of such an approach is the time and labor cost savings of not identifying the full macrofaunal assemblage. A potential problem with this approach is that reliance on single indicator species that may be patchily distributed can lead to erroneous interpretations. For example, the absence of a species cannot be reliably interpreted without extensive sampling. An index of biotic integrity developed for the Gulf of Mexico

(Engle et al. 1994) integrates both community structure and function. It is comprised of a benthic diversity measure (Shannon-Wiener index adjusted for salinity), proportion of tubificid oligochaetes (an indicator of organic pollution), and the proportion of bivalve molluscs (indicative of undegraded environmental conditions, Pearson and Rosenberg 1978).

RECOVERY ESTIMATES

Disposal Areas

Recovery of dredged material disposal sites has been studied throughout the world (Table 1). Longer recovery rates (up to several years) are observed at higher latitudes (Blanchard and Feder 2003, Harvey et al. 1998) where the associated stable physical environments and long-lived taxa take longer to recover from disturbances (Newell et al. 1998). Relatively rapid recovery of temperate and sub-tropical disposal areas (Table 1) is attributed to a greater community composition of opportunistic species at these latitudes (Clarke and Miller-Way 1992, Van Dolah 1984).

Theories as to the mechanisms of recovery at disposal sites, i.e., whether by adult migration or larval recruitment or some combination thereof, are usually circumstantially derived. One mode of colonization unique to disposal sites is the transfer of adult and/or juvenile organisms from the dredge site. Jones (1986) demonstrated that dredged material disposal buried the macrofaunal community at the disposal site, which was replaced by taxa common at the dredged site that had survived the dredging and dumping process. Vertical migration of juveniles and adults through the deposited sediments is also thought to contribute to relatively quick recovery rates in areas with shallow deposits or rapid dispersion of the dredged material due to currents or waves (e.g., McCauley et al. 1977, Newell et al. 1998, Ray and Clarke 1999).

Dredged Areas

Sand Mining

Recovery of dredged areas covers a broad spectrum of disturbance types, such as dredging of sand for beach replenishment projects (sometimes called borrow areas). Planning and operational aspects of the dredging practice can play an important role in influencing recovery rates. Dredging sand for beach nourishment typically results in either the creation of relatively shallow pits that are refilled by sand movement and are rapidly recolonized by opportunistic infauna or the creation of deeper pits that become depositional areas where fine sediments accumulate and sand-associated assemblages are replaced by soft-bottom fauna (Burlas et al. 2001). If borrow pits are deep enough that water circulation is restricted, hypoxic or anoxic conditions may result in a depauperate infaunal community. If possible, borrow areas can be located on bathymetric peaks so as not to create depressions on the seafloor (Burlas et al. 2001). Recovery of infaunal abundance, diversity and community composition in New Jersey occurred in one year, whereas the return of biomass to reference conditions took 1.5 to 2.5 years (Burlas et al. 2001). In Florida, relatively rapid recovery (~ 1 year) was reported for borrow areas when measured in terms of total abundance and taxonomic diversity, however, recovery times of up to three years were needed to restore functional groups, such as deposit feeders and mid-depth borrowers (Wilber and Stern 1992).

Aggregate Mining

The effects of marine aggregate mining (sand and gravel extraction) on the environment and fisheries is a concern along the eastern and southern English coastlines where the practice has been common for decades, providing aggregate for both the construction industry and a source material for beach nourishment (Boyd et al. 2004). Benthic recovery in the resultant saucer-shaped depressions that are 8-10 m deep is dependent upon the scale of the dredging operation, frequency of dredging, degree to which sediments are changed, hydrodynamics and the general nature of the habitat (reviewed in Newell et al. 1998). Dredging can be expected to reduce macrobenthic population densities 40-90% and species diversity 30-70% (Newell et al. 1998), with restoration of benthic communities on the sandy, coarse gravel substrate occurring within approximately 2-4 years following the cessation of dredging (Table 1, Newell et al. 2004, Boyd et al. 2004). Typically, recovery of biomass takes longer than other community attributes, such as total infaunal abundance (Kenny and Rees 1996, Newell et al. 2004) and changes in community structure can last for many years, especially if there is a change in sediment type (Desprez 2000). Opportunistic

Table 1. Selected marine and estuarine studies in which benthic macrofaunal recovery rates were reported.

Site	Region	Depth (m)	Sediment Type	CH[1]	Mech[2]	Recovery Time[3]	Metric[4]	Reference
Open Water Disposal Sites								
New S. Wales, Australia	Temperate	6	Fine sand	N	A	3 months	U/M	Smith and Rule 2001
Gulfport, MS, US	Temperate	3	Silt and clay	Y	A	1 year	U/M	Wilber et al. in press
Corpus Christi, TX, US	Temperate	3	Silt and clay	N	L/A	< 1 year	U/M	Ray and Clarke 1999
South Carolina, US	Temperate	13	Fine sand	Y	Un	N/A	U/M	Zimmerman et al. 2003
Coastal Louisiana, US	Temperate	3	Silt and clay	N	Un	5 months	U/M	Flemer et al. 1997
Sewee Bay, SC, US	Temperate	3	Silt and clay	Y	A	6 months	U/M	Van Dolah et al. 1979
Dawho River, SC, US	Temperate	<5	Silt and clay	Y	A	3 months	U/M	Van Dolah et al. 1984
Delaware Bay, US	Temperate	Shallow	Silt and clay	N	Un	>5 months	U	Leathem et al. 1973
Queensland, Australia	Sub-Tropical	11	Silt and clay	Y	A	3 months	U/M	Cruz-Motta and Collins 2004
New S. Wales, Australia	Temperate	Shallow	Silt,clay,sand	N	A	1 month	U	Jones 1986
Mobile Bay, AL, US	Temperate	3	Mud	N	A	3 months	U	Clarke and Miller-Way 1992
Oregon, US	Temperate	8	Silt and clay	N	A	1 month	U	McCauley et al. 1977
Mirs Bay, Hong Kong	Sub-Tropical	19	Sand and gravel	Y	Un	< 2 years	U/M	Valente et al. 1999
Quebec, Canada	Cold	55	Fine sand	Y	L/A	> 2 years	U/M	Harvey et al. 1998
Port Valdez, Alaska	Cold	15-23	Mud	N	L	> 2.5 years	U/M	Blanchard and Feder 2003
Puget Sound, WA	Cold	60	Silt,clay,sand	N	A	> 9 months	U	Bingham 1978
Western Baltic Sea	Cold	19	Fine sand	N	A	< 2 years	U/M	Powilleit et al. 2006
Liverpool Bay, UK	Cold	10	Sand and mud	N	Un	N/A	U/M	Rees et al. 1992
Weser estuary, Germany	Cold	16	Silt and sand	Y	Un	> 8 months	U/M	Witt et al. 2004
James River, VA	Temperate	3	Fluid mud	N	L/A	3 months	U	Diaz and Boesch 1977, Diaz 1994
Columbia River, OR	Cold	Shallow	Fine sand, clay	N	L/A	>10 months	U	Richardson et al. 1977
Southern Brazil	Temperate	19	Silt,clay,fine sand	Y	A	< 9 months	U/M	Angonesi et al. 2006
Dredging Site – Borrow Area								
South Carolina, US	Temperate	Shallow	Sand	Y	A	3-6 months	U/M	Jutte et al. 2002
New Jersey, US	Temperate	17	Medium fine sand	Y	L/A	1 year	U/M	Burlas et al. 2001
Florida, US	Sub-Tropical	9-12	Sand	N	Un	2-3 years	FG	Wilber and Stern 1992
North Sea, Denmark	Cold	20	Sand	Y	L/A	2-4 years	U/M	van Dalfsen et al. 2000
Bay of Brest, France	Cold	7	Sandy mud	N	L/A	2 years	U/M	Hily 1983

Table 1 (continued)

Wadden Sea, Germany	Cold	10	Sand	N	A	2 years	U/M	Schuchardt et al. 2004
North Carolina, US	Temperate	12-15	Sand	N	L/A	< 9 months	U/M	Posey and Alphin 2002
Florida, US	Temperate	10	Medium sand	Y	Un	9-12 months	U	Johnson and Nelson 1985
NW Mediterranean	Temperate	15	Coarse/med sand	Y	Un	> 2 years	U	Sarda et al. 2000
Dredging Site - Channels								
Sewee Bay, SC, US	Temperate	4	Silt and clay	Y	A	6 months	U/M	Van Dolah et al. 1979
Dawho River, SC, US	Temperate	4	Silt and clay	N	A	3 months	U	Van Dolah et al. 1984
Georgia, US	Temperate	Shallow	Silt and clay	N	A	3 months	U	Stickney and Perlmutter 1975
Oregon, US	Temperate	11	Silt and clay	N	A	1 month	U	McCauley et al. 1977
Delaware Bay, US	Temperate	Shallow	Silt and clay	N	Un	>5 months	U	Leathem et al. 1973
Sardinia, Italy	Temperate	15-20	Silt and clay	N	A	~ 6 months	U	Pagliai et al. 1985
Ceuta, North Africa	Temperate	3	Silt and clay	Y	L/A	6 months	U/M	Guerra-Garcia et al. 2003
New South Wales, Australia	Temperate	Shallow	Silt,clay,sand	N	A	1 month	U	Jones 1986
Queensland, Australia	Temperate	17	Medium/fine sand	N	Un	N/A	U	Poiner and Kennedy 1984
Southwest Finland	Cold	9	Mud	N	L/A	2-5 years	U	Bonsdorff 1980, 1983
Long Island, NY	Temperate	2	Sand,silt,clay	Y	A	> 11 months	U	Kaplan et al. 1975
Algeciras Bay, Spain	Temperate	5,15,30	Fine sand	N	L/A	4 years	U/M	Sanchez-Moyano et al. 2004
Yaquina Bay, OR	Cold	6-11	Fine sand,silt	Y	L/A	1 year	U/M	Swartz et al. 1980
North Sea, UK	Cold	9	Silt and clay	N	A	> 3 months	U/M	Quigley and Hall 1999
Southern Brazil	Temperate	3-18	Silt,clay,sand	Y	Un	> 3 months	U/M	Bemvenuti et al. 2005
Dredging Site - Aggregate Mining								
Nome, AK	Cold	9-20	Sand, cobble	Y	Un	4 years	U/M	Jewett et al. 1999
Sotheast coast, England	Cold	27-35	Sand, gravel	Y	L	2-4 years	U/M	Boyd et al. 2004
South coast of U.K.	Cold	10-20	Sand,mud,gravel	N	Un	2-3 years	U/M	Newell et al. 2004
Eastern English Channel	Cold	15	Gravel	Y	Un	> 28 months	U	Desprez 2000
Southern Baltic Sea	Cold	10-14	Sand	Y	Un	> 10 years	U/M	Szymelfenig et al. 2006.
Southern North Sea	Cold	25	Sand, gravel	Y	L	> 2 years	U/M	Kenny and Rees 1996
Botany Bay, Australia	Temperate	14-18	Mud	Y	L	> 1 year	U/M	Fraser et al. 2006

Table 1 (continued)

Defaunation - Anoxia/Hypoxia								
Hong Kong, China	Sub-Tropical	1	Sand	N	L	< 15 mo	U/M	Lu and Wu 2000
Tampa Bay, FL, US	Sub-Tropical	intertidal	Silt,clay,sand	N	A	1 month	U	Dauer 1984
Tampa Bay, FL, US	Sub-Tropical	4-5	Silt, clay	N	L/A	8 months	U	Santos and Simon 1980
Gullmar Fjord, Sweden	Cold	115	Silt and clay	N	L	> 18 months	U	Josefson and Widbom 1988
Capping								
Hong Kong, China	Sub-Tropical	5-6	Mud	N	L	3 years	U/M	Qian et al. 2003

[1]Changes (CH) to the sediment type (granulometry) by the benthic disturbances are indicated by Y (yes) or N (no).
[2]The mechanism (Mech) of recovery (usually speculated) is given as A – adults, L – larval recruitment, or Un – unknown probably due to sampling protocol.
[3]Studies in which recovery times were not reported are noted as not applicable (N/A), for instance disposal areas may have been surveyed while they were in use or years after disposal stopped.
[4]Metrics used for data analyses and determinations of recovery rates are noted as either univariate (U), multivariate (M), or functional groups FG.

colonists of gravel substrates include barnacles, whereas polychaetes are more common colonists of sandy areas (Boyd et al. 2004). Impacts have also been observed outside the boundaries of the dredged areas, for example a local enhancement of the abundance of filter feeders that may reflect organic enrichment resulting from the dredging activity (Poiner and Kennedy 1984, Robinson et al. 2005). Excavation of deep pits (10-14 m) that are approximately 4-5 times deeper than the average bay depth in the southern Baltic Sea has created isolated depauperate microhabitats that differ from unimpacted reference areas over ten years after sand extraction (Szymelfenig et al. 2006).

Channels

Studies of benthic recovery in dredged channels are restricted to relatively shallow, less-stable habitat types and thus have relatively short recovery rates (Table 1). One mechanism of recovery in dredged areas is the colonization by infauna from adjacent areas undisturbed sediment, or from "hummocks" of unexcavated sediment that remain within the footprint of dredged bottom. Re-colonization of the defaunated dredged areas may occur from adults migrating from the relatively undisturbed hummocks (McCauley et al. 1977, Jutte et al. 2002). Rapid recolonization of unconsolidated sediments in dredged channels (Stickney and Perlmutter 1975, Van Dolah et al. 1984, Jones 1986) and a muddy-maerl habitat (DeGrave and Whitaker 1999) were attributed to slumping of non-dredged sediments into the dredged furrows, thus transporting benthic infauna.

BIOLOGICAL RESPONSES TO BENEFICIAL USES OF DREDGED MATERIAL

The intentional placement of dredged material to provide habitat functions is an alternative to open-water disposal that is commonly referred to as "beneficial use." Beneficial use projects in the marine environment are commonly conducted in intertidal habitats and include sediment enhancement of mudflats and tidal marshes through either habitat creation or restoration. Assessments of these restoration efforts typically rely on comparisons to reference habitats since the pre-discharge communities occur at lower tidal levels with associated differences in environmental conditions (Bolam et al. 2006b). Because salt marsh creation success for projects constructed on dredged material has recently been reviewed (Streever et al. 2000), we restrict our assessment of biological responses to thin layer dredged material placement in marsh restoration projects (sensu Cahoon and Cowan 1988). In this placement method, dredged material is hydraulically sprayed over the marsh habitat. The thickness of the sediments and the extent to which soil characteristics are changed influences the number of roots and rhizomes that survive to generate new shoots and establish a root and rhizome mat at the newly appropriate soil depth (Wilber 1993). This response mode typically requires two growing seasons. If altered soil conditions prevent substantial root and rhizome survival and shoot penetration into the dredged material, the marsh may be recolonized by seedlings, which requires longer to establish typical marsh vegetation.

Deltaic marsh habitats are being lost at high rates due to excessive inundation that occurs in many areas from a combination of subsidence and sea level rise. Deposition of sediments in river deltas has been altered by the construction of dams, levees, and berms, thus sediments have been artificially supplied (beneficial use projects) to raise marsh elevations and reverse habitat loss. In Louisiana, dredged sediments sprayed as a slurry over marsh habitat in thin layers (typically less than 15 cm) increased salt marsh grass, *Spartina alterniflora*, percent cover and stem density (Ford et al. 1999, Slocum et al. 2005).

Intertidal mudflats dissipate tidal and wave energy and provide important feeding areas for shorebirds and migratory waterfowl. Areas with inadequate sediment supply have lost mudflat habitat, which can exacerbate the erosion problems that occur at the base of seawalls (Widdows et al. 2006). In some areas, mudflat habitats have been lost through infilling and subsequent development and excavation for facilities such as ports (Evans et al. 1998). Because of limited knowledge concerning the movement of dredged material placed in the intertidal zone and the recovery rates of buried intertidal habitat, beneficial placement of dredged material in the UK has been limited to small-scale trials (Bolam and Whomersley 2005). Biological responses of created mudflat habitats (Table 2) include infaunal communities that were comparable to reference areas within two years of construction (Ray 2000), whereas at least three years were needed to create mudflat habitat with adequate abundances of benthic prey for shorebirds (Evans et al. 1998).

Table 2. Biological responses of intertidal mudflat and salt marsh habitats following dredged material placement as part of beneficial use projects.

Mudflat Habitat		
Source	Site	Summary of results
Bolam and Whomersley 2005	Southeastern UK	Low organic content/ silt/clay,high organic content/silt/clay, multivariate – 12 months, multivariate – >12 months
Bolam et al. 2006b	Southeastern UK	Diverse macro and meiofaunal communities were re-established within three months of sediment deposition. After 42 months, these communities remained significantly different from reference sites.
Widdows et al. 2006	Southeastern UK	Sediment erosion was measured with relation to abundances of key plant species that served as bio-stabilizers.
Schratzberger et al. 2006	Southeastern UK	Nematode colonization of the dredged material mudflat resulted from settling of suspended nematodes and their subsequent reproduction and differential survival.
Evans et al. 1999	Northeastern UK	Invertebrate colonization and bird foraging behavior suggest the functional attributes of the mudflat were achieved three years following sediment recharge.
Ray 2000	Maine, US	Infaunal taxa richness, abundance, and species diversity were similar between reference and constructed sites within two years of construction. Infaunal biomass at constructed sites remained lower than reference values at two constructed mudflats.
Salt Marsh Habitat		
Source	Site	Summary of results
Wilber et al. 1992	North Carolina, US	Healthy stands of marsh vegetation were present on thin-layer disposal areas ten years after deposition, however, species composition of the recharged habitat differed from that of reference areas.
Croft et al. 2006	North Carolina, US	Sediment (0-10 cm) placed on deteriorating marsh plots increased *Spartina* stem density by second growing season to reference levels.
Leonard et al. 2002	North Carolina, US	The addition of 2-10 cm of sediment on deteriorating marsh surfaces increased vascular plant stem densities and microalgal biomass. There were no longterm impacts to the infaunal community.
Ford et al. 1999	Louisiana, US	Spraying dredged material (approximately 23 cm depth) knocked down marsh plants, but they resprouted and recolonized the site within a year.
Slocum et al. 2005	Louisiana, US	Areas of the marsh that received moderate (2-12 cm) dredged material exhibited greater *Spartina alterniflora* % cover and canopy heights
Mendelssohn and Kuhn 2003	Louisiana, US	Sediment enrichment was associated with higher percent plant cover, biomass and height. Plant species composition did not change.
Schrift 2006	Louisiana, US	Two years after sediment recharge, marshes in the low elevation areas (11-16 cm above ambient marsh) were the most similar to reference marshes in plant cover and species richness.

Recovery Following Capping

Sediment caps are constructed by covering highly contaminated sediments with uncontaminated sediments to physically isolate the contaminants from fauna, flora, and other habitats. Most monitoring efforts of sediment caps, such as the Disposal Area Monitoring System (DAMOS) program established by the US Army Corps of Engineers, New England District have focused on documenting whether contaminants were contained by sediment caps (Fredette and French 2004) rather than rates of biological recovery. Comprehensive monitoring in Long Island Sound has demonstrated that caps can effectively isolate contaminants from the marine environment, with cap material clearly distinguishable from underlying mound material in sediment cores as much as 11 years after disposal (Fredette and French 2004). Bathymetric surveys conducted with sediment profile photography have proved to be effective methods of monitoring the physical stability of sediment caps (Nakayama et al. 1998, Fredette and French 2004). One study that documented recolonization of sediment caps on the subtropical coast of Hong Kong indicated recovery took several years (Qian et al. 2003), a finding that is consistent with other studies conducted in stable areas that are sheltered from storms and currents (Table 1).

FRESHWATER SYSTEMS

Open-water dredged material disposal in freshwater habitats is not as widely studied although maintaining adequate depths for commercial navigation in rivers and lakes has been a common practice for nearly a century. As with estuarine and marine benthos, freshwater benthic macroinvertebrates are an important energy source for higher trophic levels. Tidal freshwater habitats have low species diversity and are dominated by tubificid oligochaetes and chironomid insect larvae, along with molluscs and other insect and crustacean groups (Diaz 1994). Minimizing loss of benthic productivity is an important consideration for managing dredged material disposal projects in freshwater ecosystems. Corollaries with marine responses have been observed in freshwater studies in that disposal sites are initially colonized by taxa that have short life cycles, high turnover rates and can adapt to different substrate types (Koel and Stevenson 2002). For instance, the abundances of opportunistic oligochaete species as well as variability in community composition increase following disposal (Flint 1979). Tubificid oligochaetes are subsurface deposit feeders that can undergo subsurface migrations when environmental conditions deteriorate to more suitable habitat (Diaz 1994). Likewise, recovery times as measured by macroinvertebrate densities are lower than when either biomass or taxonomic richness is the metric being used (Flint 1979, Niemi et al. 1990). Dredged material placement along the main channel of the Illinois River reduced densities of dominant taxa, which included Chironomid midges and Ephemeropteran mayflies, and recovery was not observed within one year (Koel and Stevenson 2002). In contrast, recovery from disposal of fluid mud in a tidal freshwater portion of the James River, VA was achieved within three months (Diaz 1994). Avoiding dredged material placement in reaches with high macroinvertebrate densities, or near islands, may improve riverine productivity.

CONCLUSIONS

Although impacts of dredging and dredged material disposal on benthic habitats are varied and difficult to predict, several generalities emerge when studies are carefully reviewed. Suites of factors can be categorized as either being associated with recovery measured in months (such as, shallow, naturally disturbed habitats, unconsolidated, fine grain sediments, and univariate analytical approaches) or years (e.g., deep, stable habitats, sand and gravel sediments, and multivariate or functional group analytical techniques, Table 1). Perhaps the most consistent physical parameter influencing benthic recovery rates is the prior disturbance history of the habitat in question. Benthic recovery occurs more rapidly in shallow areas where the resident species assemblages are already adapted to shifting sediments. There are no obvious differences in the biological responses to beneficial use practices in intertidal habitats compared to recovery of subtidal benthos following traditional disposal methods (Bolam et al. 2006a). However, knowledge gained to date on how recovery proceeds has not led to a consensus on how to interpret rates of benthic recovery with respect to the need to manage dredging and dredged material disposal projects. Although identifying benthic assemblages at the species level and the use of univariate diversity indices to analyze the resultant data was the norm for early impact assessments, it has become increasingly accepted that multivariate analyses of the same data sets are more sensitive to detecting clear differences in assemblage composition (Warwick and Clarke 1991, Byrnes et al. 2004). Objective means to assess whether these sometimes subtle distinctions signify important differences in ecological functions of the benthic community remain elusive. Linking various spatial and temporal scales of benthic disturbance to appropriate triggers for management decisions will remain an arbitrary process until a unified definition of "recovery" is attained that can serve as a common endpoint for monitoring efforts.

REFERENCES

Angonesi, L.G., Bemvenuti, C.E. and Gandra, M.S. (2006). "Effects of dredged sediment disposal on the coastal marine macrobenthic assemblage in southern Brazil." *Brazilian Journal of Biology* 66,413-420.

Bemvenuti. C.E., Angonesi, L.G., and Gandra, M.S. (2005). "Effects of dredging operations on soft bottom macrofauna in a harbor in the Patos Lagoon estuarine region of southern Brazil." *Brazilian Journal of Biology* 65,573-581.

Bingham, C.R. (1978). "Aquatic disposal field investigations, Duwamish waterway disposal site, Puget Sound, Washington." Technical Report D-77-24, Vicksburg, MS: US Army Engineer Waterways Experiment Station.

Blanchard, A.L. and Feder, H.M. (2003). "Adjustment of benthic fauna following sediment disposal at a site with multiple stressors in Port Valdez, Alaska." *Marine Pollution Bulletin* 46, 1590-1599.

Bolam, S. G. and Rees, H.L. (2003). "Minimizing impacts of maintenance dredged material disposal in the coastal environment: A habitat approach." *Environmental Management* 32, 171-188.

Bolam, S.G. and Whomersley. P. (2005). "Development of macrofaunal communities on dredged material used for mudflat enhancement: a comparison of three beneficial use schemes after one year." *Marine Pollution Bulletin* 50, 40-47.

Bolam, S.G., Rees, H.L., Somerfield, P., Smith, R., Clarke, K.R., Warwick, R.M., Atkins, M., Garnacho, E. (2006a). "Ecological consequences of dredged material disposal in the marine environment: A holistic assessment of activities around the England and Wales coastline." *Marine Pollution Bulletin* 52, 415-426.

Bolam, S.G., Schratzberger, M., and Whomersley, P. (2006b). "Macro- and meiofaunal recolonisation of dredged material used for habitat enhancement: Temporal patterns in community development." *Marine Pollution Bulletin* 52, 1746-1755.

Bonsdorff, E. (1980). "Macrozoobenthic recolonization of dredged brackish water bay in SW Finland." *Ophelia, Suppl.* 1, 145-155.

Bonsdorff, E. (1983). "Recovery potential of macrozoobenthos from dredging in shallow brackish waters." *Oceanologica Acta*, Proceedings 17th European Marine Biology Symposium, Brest, France, pp. 27-32.

Boyd, S.E., Rees, H.L., and Richardson, C.A. (2000). "Nematodes as sensitive indicators of change at dredged material disposal sites." *Estuarine, Coastal and Shelf Science* 51, 805-819.

Boyd, S.E., Cooper, K.M., Limpenny, D.S., Kilbride, R., Rees, H.L., Dearnaley, M.P., Stevenson, J., Meadows, W.J., and Morris, C.D. (2004). "Assessment of the re-habilitation of the seabed following marine aggregate dredging." *Science Series Technical Report*, CEFAS Lowestoft, 121, 154 pp.

Brooks, R.A., Purdy, C. N., Bell, S.S., Sulak, K.J. (2006). "The benthic community of the eastern US continental shelf: A literature synopsis of benthic faunal resources." *Continental Shelf Research* 26, 804-818.

Brown, C.J., Hewer, A.J., Meadows, W.J., Limpenny, D.S., Cooper, K.M., Rees, H.L., and Vivian C.M.G. (2001). "Mapping of gravel biotopes and an examination of the factors controlling the distribution, type and diversity of their biological communities." *Science Series Technical Report*, CEFAS Lowestoft, 114, 43pp.

Burlas, M., Ray, G.L. and Clarke, D. (2001). "The New York District's Biological Monitoring Program for the Atlantic Coast of New Jersey, Asbury Park to Manasquan Section Beach Erosion Control Project. Final Report". U.S. Army Engineer District, New York and U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Byrnes, M.R., Hammer, R.M., Thibaut, T.D. and Snyder, D.B. (2004). "Physical and biological effects of sand mining offshore Alabama, U.S.A." *Journal of Coastal Research* 20, 6-24.

Cahoon, D.R. and Cowan, J.H. (1988). "Environmental impacts and regulatory policy implications of spray disposal of dredged material in Louisiana wetlands." *Coastal Management* 16, 341–362.

Clarke, D., Miller-Way, T. (1992). "An environmental assessment of the effects of open-water disposal of maintenance dredged material on benthic resources in Mobile Bay, Alabama." U.S. Army Engineer Waterways Experiment Station Environmental Laboratory. Miscellaneous Paper D-92-1, NTIS No. AD-A254 534, San Francisco.

Clarke, K.R. and Warwick, R.M. (2001). "Change in marine communitieis: an approach to statistical analysis and interpretation, 2nd edition." PRIMER-E: Plymouth.

Coull, B.C. and Chandler, G.T. (1992). "Pollution and meiofauna: field, laboratory, and mesocosm studies." *Oceanography and Marine Biology: An Annual Review* 30, 191-271.

Croft, A.L., Leonard, L.A., Alphin, T.D., Cahoon, L.B., and Posey, M.H. (2006). "The effects of thin layer sand renourishment on tidal marsh processes: Masonboro Island, North Carolina." *Estuaries and Coasts* 29, 737-750.

Cruz-Motta, J.J. and Collins, J. (2004). "Impacts of dredged material disposal on a tropical soft-bottom benthic assemblage." *Marine Pollution Bulletin* 48, 270-280.

Dauer, D.M. (1984). "High resilience to disturbance of an estuarine polychaete community." *Bulletin of Marine Science* 34:170-174.

De Grave, S. and Whitaker, A. (1999). "Benthic community re-adjustment following dredging of a muddy-maerl matrix." *Marine Pollution Bulletin*, 38, 102-108.

Desprez, M. (2000). "Physical and biological impact of marine aggregate extraction along the French coast of the eastern English Channel: short- and long-term post-dredging restoration." *ICES Journal of Marine Science*, 57, 1428-1438.

Diaz, R.J. and Boesch D.F. (1977). "Impact of fluid mud dredged material on benthic communities of the tidal James River, Virginia." Technical Report D-77-45. Vicksburg, MS: US Army Engineer Waterways Experiment Station.

Diaz, R.J. (1994). "Response of tidal freshwater macrobenthos to sediment disturbance." *Hydrobiologia* 278, 201-212.

Engle, V.D., Summers, J.K., Gaston, G.R. (1994). "A benthic index of environmental condition of Gulf of Mexico estuaries." *Estuaries* 17, 372-384.

Erftemeijer, P.L.A. and Lewis III, R.R. (2006). "Environmental impacts of dredging on seagrasses: A review." *Marine Pollution Bulletin* 52, 1553-1572.

Evans, P.R., Ward, R.M., Bone, M., Leakey, M. (1998). "Creation of temperate-climate intertidal mudflats: factors affecting colonization and use by benthic invertebrates and their bird predators." *Marine Pollution Bulletin* 37, 535–545.

Flemer, D.A., Ruth, B.F., Bundrick, C.M., and Gaston, G.R. (1997). "Macrobenthic community colonization and community development in dredged material disposal habitats off coastal Louisiana." *Environmental Pollution* 96, 141-154.

Flint, R.W. (1979). "Responses of freshwater benthos to open-lake dredged spoils disposal in Lake Erie." *Journal of Great Lakes Research* 5, 264-275.

Ford, M.A., Cahoon, D.R., and Lynch, J.C. (1999). "Restoring marsh elevation in a rapidly subsiding salt marsh by thin-layer deposition of dredged material." *Ecological Engineering* 12, 189-205.

Fraser, C., Hutchings, P., and Williamson, J. (2006). "Long-term changes in polychaete assemblages of Botany Bay (NSW, Australia) following a dredging event." *Marine Pollution Bulletin* 52, 997-1010.

Fredette, T.J. and French, G.T. (2004). "Understanding the physical and environmental consequences of dredged material disposal: history in New England and current perspectives." *Marine Pollution Bulletin* 49, 93-102.

Guerra-Garcia, J.M., Corzo, J., and Garcia-Gomez, J.C. (2003). "Short-term benthic recolonization after dredging in the harbour of Ceuta, North Africa." *Marine Ecology* 24, 217-229.

Hall, S.J. (1994). "Physical disturbance and marine benthic communities: life in unconsolidated sediments." *Oceanography and Marine Biology: An Annual Review* 32, 179-239.

Harvey, M., Gauthier, D., and Munro, J. (1998). "Temporal changes in the composition and abundance of the macro-benthic invertebrate communities at dredged material disposal sites in the Anse a Beaufils, Baie Des Chaleurs, Eastern Canada." *Marine Pollution Bulletin* 36, 41-55.

Hily, C. (1983). "Macrobenthic recolonization after dredging in a sandy mud area of the Bay of Brest enriched by organic matter." *Oceanologica Acta, Proceedings 17th European Marine Biology Symposium, Brest, France*, pp. 113-120.

Jewett, S.C., Feder, H.M., and Blanchard A. (1999). "Assessment of benthic environment following offshore placer gold mining in the northeastern Bering Sea." *Marine Environmental Research* 48, 91-122.

Johnson, R.O. and Nelson, W.G. (1985). "Biological effects of dredging in an offshore borrow area." *Florida Scientist* 48, 166-188.

Jones, A.R. (1986). "The effects of dredging and spoil disposal on macrobenthos, Hawkesbury Estuary, N.S.W." *Marine Pollution Bulletin* 17, 17-20.

Josefson, A.B. and Widbom, B. (1988). "Differential response of benthic macrofauna and meiofauna to hypoxia in the Gullmar Fjord basin." *Marine Biology* 100, 31-40.

Jutte, P.C., Van Dolah, R.F., and Gayes, P.T., (2002). "Recovery of benthic communities following offshore dredging, Myrtle Beach, South Carolina." *Shore and Beach* 70, 25-30.

Kaplan, E.H., Welker, J.R., Kraus, M.G., and McCourt, S. 1975. "Some factors affecting the colonization of a dredged channel." *Marine Biology* 32, 193-204.

Kenny, A.J. and Rees, H.L. (1996). "The effects of marine gravel extraction on the macrobenthos: Results 2 years post-dredging." *Marine Pollution Bulletin*, 32, 615-622.

Koel, T.M. and Stevenson, K.E. (2002). "Effects of dredge material placement on benthic macroinvertebrates of the Illinois River." *Hydrobiologia* 474, 229-238.

Leathem, W., Kinner, P., Maurer, D., Biggs, R., and Treasure, W. (1973). "Effect of spoil disposal on benthic invertebrates." *Marine Pollution Bulletin* 4, 122-125.

Leonard, L., Posey, M. Cahoon, L., Laws, R., and Alphin, T. (2002). "Sediment Recyling: Marsh renourishment through dredged material disposal." A Final Report submitted to the NOAA/UNH Cooperative Institute for Coastal and Estuarine Environmental Technology. 38 pp.

Lu, L. and Wu, R.S.S. (2000). "An experimental study on recolonization and succession of marine macrobenthos in defaunated sediment." *Marine Biology* 136, 291-302.

Maurer, D., Keck, R.T., Tinsman, J.C., and Leathem, W.A. (1981). "Vertical migration and mortality of benthos in dredged material: Part I: Mollusca." *Marine_Environmental Research* 4, 299-319.

Maurer, D., Keck, R.T., Tinsman, J.C., and Leathem, W.A. (1982). "Vertical migration and mortality of benthos in dredged material: Part III: Polychaeta." *Marine_Environmental Research* 6, 49-68.

McCauley, J.E., Parr, R.A. and Hancock, D.R. (1977). "Benthic infauna and maintenance dredging: A case study." *Water Research* 11, 233-242.

Mendelssohn, I. A. and Kuhn, N.L. (2003). "Sediment subsidy: effects on soil-plant responses in a rapidly submerging coastal salt marsh." *Ecological Engineering* 21, 115-128.

Miller, D.C., Muir, C.L., and Hauser, O.A. (2002). "Detrimental effects of sedimentation on marine benthos: what can be learned from natural processes and rates?" *Ecological Engineering* 19, 211-232.

Nakayama, J.S., Lunz, J.D., LeProwse, M.K., and Wakeman, J.S. (1998). "Assessing long-term physical stability and benthic infuanal conlonization of a sediment cap placed over chemically contaminated bottom sediments in the Wyckoff/Eagle Harbor Superfund Site, Bainbridge Island, Washington." Puget Sound '98.

Newell, R.C., Seiderer, L.J. and Hitchcock, D.R. (1998). "The impact of dredging works in coastal waters: A review of the sensitivity to disturbance and subsequent recovery of biological resources on the sea bed." *Oceanography and Marine Biology: An Annual Review* 36, 127-178.

Newell, R.C., Seiderer, L.J., Simpson, N.M., and Robinson, J.E. (2004). "Impacts of marine aggregate dredging on benthic macrofauna off the south coast of the United Kingdom." *Journal of Coastal Research* 20, 115-125.

Niemi, G.J., DeVore, P., Detenbeck, N., Taylor, D., Lima, A., Pastor, J., Yount, J.D., and Naiman, R.J. (1990). "Overview of case studies on recovery of aquatic systems from disturbance." *Environmental Management* 14, 571-587.

Pagliai, A.M., Cognetti Varriale, A.M., Crema, R., Curini Galletti, M., and Vandini Zunarelli, R. (1985). "Environmental impact of extensive dredging in a coastal marine area." *Marine Pollution Bulletin* 16, 483-488.

Pearson, T.H. and Rosenberg, R. (1978). "Macrobenthic succession in relation to organic enrichment and pollution of the marine environment." *Oceanography and Marine Biology: An Annual Review* 16, 229-311.

Poiner, I.R. and Kennedy, R. (1984). "Complex patterns of change in the macrobenthos of a large sandbank following dredging." *Marine Biology*, 78, 335–352.

Posey, M. and Alphin, T. (2002). "Resilience and stability in an offshore benthic community: Responses to sediment borrow activities and hurricane disturbance." *Journal of Coastal Research* 18, 685-697.

Powilleit, M., Kleine, J., and Leuchs, H. (2006). "Impacts of experimental dredged material disposal on a shallow sublittoral macrofauna community in Mecklenburg Bay (western Baltic Sea)." *Marine Pollution Bulletin* 52, 386-396.

Qian, P., Qiu, J., Kennish, R., and Reid, C.A. (2003). "Recolonization of benthic infauna subsequent to capping of contaminated dredged material in East Sha Chau, Hong Kong." *Estuarine, Coastal and Shelf Science* 56, 819-831.

Quigley, M.P. and Hall, J.A. (1999). "Recovery of macrobenthic communities after maintenance dredging in the Blyth Estuary, north-east England." Aquatic Conservation: *Marine and Freshwater Ecosytems* 9, 63-73.

Ray G.L. (2000). "Infaunal assemblages on constructed intertidal mudflats at Jonesport, Maine (USA)." *Marine Pollution Bulletin* 40, 1186–1200.

Ray, G.L. and Clarke, D.G. (1999). "Environmental assessment of open-water placement of maintenance dredged material in Corpus Christi Bay, Texas." Final report. Waterways Experiment Station, Vicksburg,

Mississippi, pp. 1-203.
Rees, H.L., Rowlatt, S.M., Limpenny, D.S., Rees, E.I.S. and Rolfe, M.S. (1992). "Benthic studies at dredged material disposal sites in Liverpool Bay." *Aquatic Environment Monitoring Report No. 28. ISSN* 0141-2499.
Rees, H.L., Pendle, M.A., Wladock, R., Limpenny, D.S. and Boyd, S.E. (1999). "A comparison of benthic biodiversity in the North Sea, English Channel and Celtic Seas." *ICES Journal of Marine Science.* 56:228-246.
Rhoads, D.C. and Germano, J.D. (1986). "Interpreting long-term changes in benthic community structure: a new protocol." *Hydrobiologia* 142, 291-308.
Richardson, M.D., Carey, Jr., A.G., and Colgate, W.A. (1977). "Aquatic disposal field investigations, Columbia River disposal site, Oregon; Appendix C: The effects of dredged material disposal on benthic assemblages." Technical Report D-77-30. US Army Engineer Waterways Experiment Station, Vicksburg, MS.
Roberts, R.D., Gregory, M.R., and Foster, B.A. (1998). "Developing an efficient macrofauna monitoring index from an impact study – a dredge spoil example." *Marine Pollution Bulletin* 36, 231-235.
Robinson, J.E., Newell, R.C., Seiderer, L.J., and Simpson, N.M. (2005). "Impacts of aggregate dredging on sediment composition and associated benthic fauna at an offshore dredge site in the southern North Sea." *Marine Environmental Research* 60, 51-68.
Sanchez-Moyano, J.E., Estacio, F.J., Garcia-Adiego, E.M., and Garcia-Gomez, J.C. (2004). "Dredging impact on the benthic community of an unaltered inlet in southern Spain." *Helgol. Mar. Res.* 58, 32-39.
Santos, S. L. and Simon, J. L. (1980). "Response of soft-bottom benthos to annual catastrophic disturbance in a South Florida estuary." *Marine Ecology Progress Series* 3, 347-355.
Sarda´, R., Pinedo, S., Gremare, A., and Taboada, S. (2000). "Changes in the dynamics of shallow sandy-bottom assemblages due to sand extraction in the Catalan Western Mediterranean Sea." *ICES Journal of Marine Science* 57, 1446–1453.
Schratzberger, M., Rees, H.L. and Boyd, S.E. (2000) "Effects of simulated deposition of dredged material on structure of nematode assemblages – the role of burial." *Marine Biology* 136, 519-530.
Schratzberger, M., Bolam, S., Whomersley, P., Warr, K. (2006). "Differential response of nematode colonist communities to the intertidal placement of dredged material." *Journal of Experimental Marine Biology and Ecology* 334, 244–255.
Schrift, A.M. (2006). "Salt marsh restoration with sediment-slurry amendments following a drought induced, large-scale disturbance." MS. Thesis, Louisiana State University. 63 pp.
Schuchardt, B., Scholle, J., Dau, K., and Brandt, T. (2004). "Sand extraction in a Wadden Sea National Park (Northern Germany): environmental impact and recovery." *Proceedings of the 17th World Dredging Congress*, CEDA, Hamburg, Germany.
Slocum, M.G., Mendelssohn, I.A., and Kuhn N.L. (2005). "Effect of sediment slurry enrichment on salt marsh rehabilitation: Plant and soil responses over seven years." *Estuaries* 28, 519–528.
Smith, S.D.A, and Rule, M.J. (2001). "The effects of dredge-spoil dumping on a shallow water soft-sediment community in the Solitary Islands Marine Park, NSW, Australia." *Marine Pollution Bulletin* 42,1040-1048.
Somerfield, P.J., Rees, H.L., and Warwick, R.M. (1995). "Interrelationships in community structure between shallow-water marine meiofauna and macrofauna in relation to dredgings disposal." *Marine Ecology Progress Series* 127, 103-112.
Stickney, R.R. and Perlmutter, D. (1975). "Impact of intracoastal waterway maintenance dredging on a mud bottom benthos community." *Biological Conservation* 7, 211-226.
Streever, W.J. (2000). "*Spartina alterniflora* marshes on dredged material: a critical review of the ongoing debate over success." *Wetlands Ecology and Management* 8, 295-316.
Swartz, R.C., DeBen, W.A., Cole, F.A. and Bentsen. L.C. (1980). "Recovery of the macrobenthos at a dredge site in Yaquina Bay, Oregon." *In* Contaminants and Sediments. Volume 2. Analysis, Chemistry, Biology (ed. R. A. Baker). Pp. 391-408.
Szymelfenig, M. Kotwicki, L., Graca, B. (2006). "Benthic re-colonization in post-dredging pits in the Puck Bay (Southern Baltic Sea)." *Estuarine, Coastal and Shelf Science* 68, 489-498.
Valente, R.M., McChesney, S.M., and Hodgson, G. (1999). "Benthic recolonization following cessation of dredged material disposal in Mirs Bay, Hong Kong." *Journal of Marine Environmental Engineering* 5, 257-288.

van Dalfsen, J.A., Essink, K., Toxvig Madsen, H., Birklund, J., Romero, J., and Manzanera, M. (2000). "Differential response of macrozoobenthos to marine sand extraction in the North Sea and theWestern Mediterranean." *ICES Journal of Marine Science*, 57, 1439–1445.

Van Dolah, R.F., Calder, D. R., Knott, D.M., and Maclin, M.S.. (1979). "Effects of dredging and unconfined disposal of dredged material on macrobenthic communities in Sewee Bay, South Carolina." *South Carolina Marine Research Center* Tech. Rep. No. 39, 54pp.

Van Dolah, R.F., Calder, D.R. and Knott D. (1984). "Effects of dredging and open-water disposal on benthic macroinvertebrates in a South Carolina estuary." *Estuaries* 7, 28-37.

Warwick, R.M. and Clarke, K.R. (1993). "Increased variability as a symptom of stress in marine communities." *Journal of Experimental Marine Biology and Ecology*, 172, 215-226.

Widdows, J., Brinsley, M.D., Pope, N.D., Staff, F.J., Bolam, S.G., Somerfield P.J. (2006). "Changes in biota and sediment erodability following the placement of fine dredged material on upper intertidal shores of estuaries." *Marine Ecology Progress Series* 319, 27-41.

Wilber, D.H. and Clarke, D.G. (1998). "Estimating secondary production and benthic consumption in monitoring studies: a case study of the impact of dredged material disposal in Galveston Bay, Texas." *Estuaries* 21:230-245.

Wilber, D.H., Clarke, D.G., and Rees, S.I. (2007). "Responses of benthic macroinvertebrates to thin-layer disposal of dredged material in Mississippi Sound, USA." *Marine Pollution Bulletin* 54, 42-52.

Wilber, T.P. (1993). "Managing dredged material via thin-layer disposal in coastal marshes." *Environmental Effects of Dredging Technical Notes.* EEDP-01-32. Waterways Experiment Station, Vicksburg, MS.

Wilber, P., Luczkovich, J., and Knowles, D. (1992). "The Long-Term Environmental Effects of Thin-Layer Disposal on a Salt Marsh, Lake Landing Canal, North Carolina," *Proceedings of the 13th Meeting of the Western Dredging Association,* WEDA, pp. 170-185.

Wilber, P. and Stern, M. (1992). "A re-examination of infaunal studies that accompany beach nourishment projects." Proceedings of the 5th Annual National Conference on Beach Preservation Technology, New Directions in Beach Management, Florida Shore and Beach Preservation Association, Tallahassee, FL, pp. 242-257.

Wildish, D.J. and Thomas, M.L.H. (1985). "Effects of dredging and dumping on benthos of Saint John Harbour, Canada." *Marine Environmental Research* 15, 45-57.

Witt, J., Schroeder, A., Knust, R., Arntz, W.E. (2004). "The impact of harbour sludge disposal on benthic macrofauna communities in the Weser estuary." *Helgol Mar Res* 58, 117-128.

Zajac, R.N., Whitlatch, R.B., and Thrush, S.F. (1998) "Recolonization and succession in soft-sediment infaunal communities: the spatial scale of controlling factors." *Hydrobiologia*, 375/376, 227–240.

Zimmerman, L.E., Jutte, P.C., Van Dolah, R.F. (2003). "An environmental assessment of the Charleston Ocean Dredged Material Disposal Site and surrounding areas after partial completion of the Charleston Harbor Deepening Project." *Marine Pollution Bulletin* 46, 1408-1419.