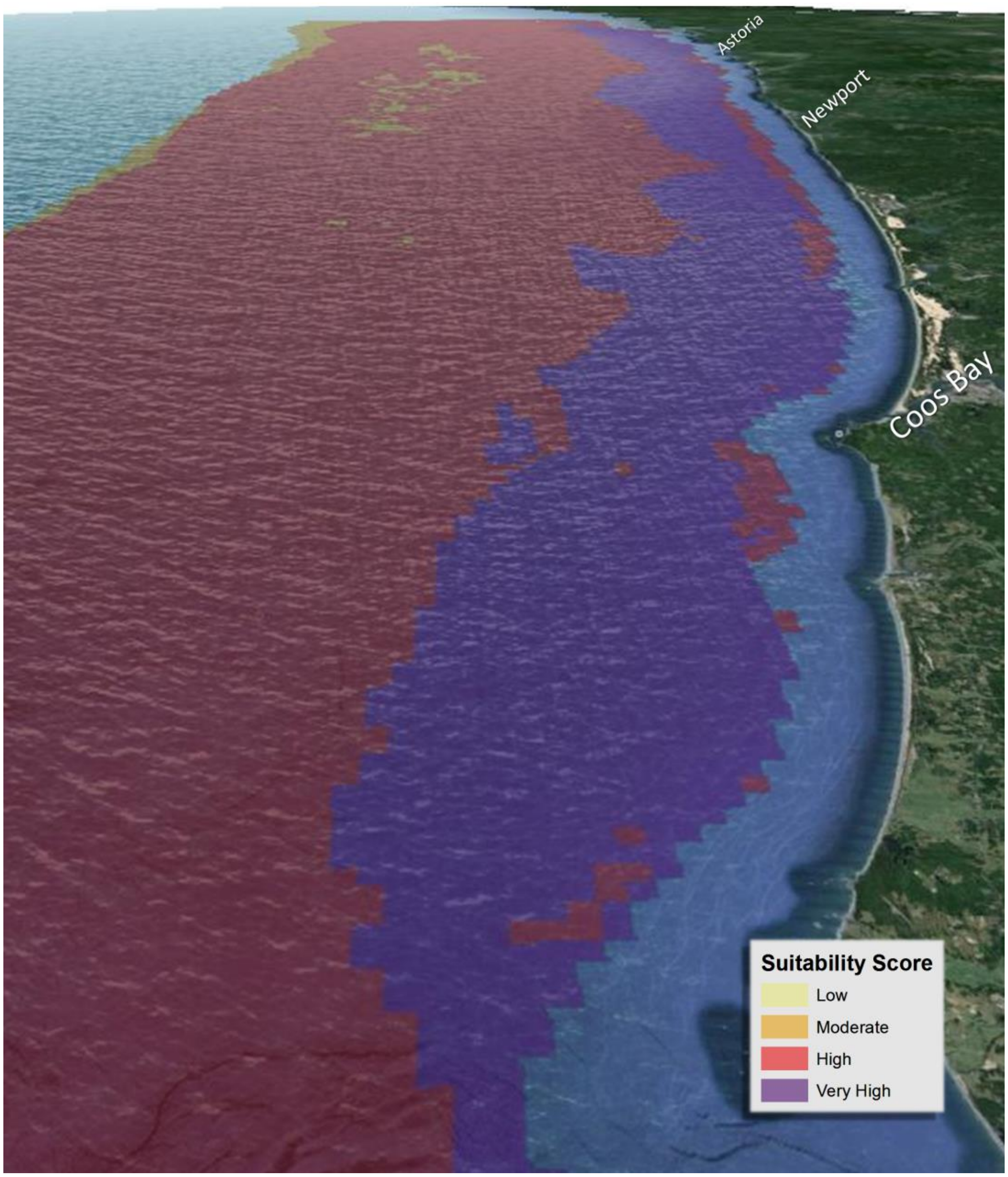
OCS Study
BOEM 2014-658

Offshore Wind and Wave Energy Feasibility Mapping for the Outer Continental Shelf off the State of Oregon



US Department of the Interior
Bureau of Ocean Energy Management
Pacific OCS Region
September 30, 2014

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Offshore Wind and Wave Energy Feasibility Mapping for the Outer Continental Shelf off the State of Oregon

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DISCLAIMER

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Abbreviations and Acronyms

BOEM	Bureau of Ocean Energy Management
CMSP	Coastal and Marine Spatial Planning
DOE	US Department of Energy
ft	foot (feet)
GIS	geographic information system
GW	gigawatt(s)
km	kilometer
km2	square kilometer(s)
kV	kilovolt(s)
kW	kilowatt(s)
MCDA	multi-criteria decision analysis
m	meter(s)
mi	mile(s)
m/s	meter(s) per second
NM	nautical mile(s)
MW	megawatt(s)
NOAA	National Oceanographic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
OCS	Outer Continental Shelf
OWET	Oregon Wave Energy Trust
PNNL	Pacific Northwest National Laboratory
TW	terawatt(s)
USACE	US Army Corps of Engineers
WEC	wave energy conversion

1. INTRODUCTION

Coastal and Marine Spatial Planning (CMSP) is a planning processes aimed at prioritizing and allocating current and future use of ocean space to improve the management and use of marine resources. In states that have completed or are engaged in CMSP, an initial step in the process involves coordinating among stakeholders to achieve a spatial and temporal understanding of ocean activities. Subsequent steps involve setting priorities, allocating space to compatible activities, and outlining a process for managing and granting permission to conduct activities. Contrary to the conception that the ocean is a vast frontier, little of the marine environment is “unused.” Activities include shipping and transportation, fishing, recreation, scientific research, oil and gas exploration, and marine conservation. In the United States, ocean renewable energy is a new and important addition to the national energy portfolio, mandated by the President’s “all of the above” energy strategy and joins a crowded seascape of existing uses. Siting of marine renewable energy must be purposefully incorporated in marine spatial planning to give fair consideration to the full suite of ocean activities with respect to stated local, regional, and national priorities.

The Bureau of Ocean Energy Management, (BOEM), an agency of the US Department of the Interior, manages the exploration and development of the nation’s offshore resources, including development of renewable energy in federal waters. BOEM is charged with the management and planning of renewable energy development on the US Outer Continental Shelf (OCS). As part of its CMSP process, BOEM identified a need for a series of mapping products to inform the development of renewable energy on the OCS off the coast of the state of Oregon. BOEM contracted with Pacific Northwest National Laboratory (PNNL) through an Interagency Agreement with the US Department of Energy to compile existing information on offshore wind and wave energy device types, to conduct interviews and surveys with device and potential domestic project developers, and to gather experiences from international developments. These inputs were used to inform existing device suitability parameters (Van Cleve et al. 2013) adapted for the purposes of this project and to develop and map spatially explicit device suitability areas. These areas represent a broad set of developer and technology perspectives and a range of device suitability.

The five primary objectives of this study are as follows:

- Identify and document areas preferred by industry for potential wind and wave renewable energy development in the Oregon OCS.
- Produce maps of the OCS with areas of potential development suitability based on a technical feasibility analysis.
- Rank areas of potential development from low to high in order to provide input on the BOEM planning process and base the outcomes on scenarios, varying either technology types, economic feasibility, or intensity of development.
- Develop a series of specifications based on each technology type’s design requirements.
- Acquire renewable energy device specifications to expand on previous similar studies carried out in the Oregon territorial sea, Washington State, and northern California, to the extent necessary, by consulting with individual developers, developer surveys, or by using larger facilitated workshops to bring developers together.

This study uses a multi-criteria decision analysis framework of weighted additive algorithms to evaluate site suitability. Attributes of suitability used in this analysis represent fundamental economic and technical feasibility considerations and include energy potential, water depth, proximity to shore, ports, and transmission infrastructure. Socioeconomic, legal, regulatory, national security, and environmental factors—key factors to consider when planning for renewable energy development—are beyond the scope of this study. The separation of fundamental suitability factors from other considerations influencing marine spatial planning is deliberate and intended to respect Oregon and BOEM's stakeholder-informed planning process. This study builds on methodology developed to assess site suitability for renewable energies off the Oregon and Washington coasts (OWET 2010 and Van Cleve et al. 2013). Because technical and economic factors affecting suitability are subject to change as offshore wind and wave technology and grid and port infrastructure are developed, the focus of this study was constrained to 5−10 years into the future.

1.1. Status of Marine Renewable Energy in the Oregon OCS

There are an estimated 930 gigawatts (GW) of wind energy within 50 nautical miles (NM) of the West Coast, 219 GW of which are adjacent to Oregon (Schwartz et al. 2010). The DOE estimates that there is 590 terawatt-hours per year of potential wave energy resource on the US West Coast, 322 of which are off the Oregon coast (25–49% of which is estimated to be recoverable) (EPRI 2011).[1] This substantial energy resource is attracting the attention of prospective developers and governmental entities.

BOEM and the state of Oregon are collaborating through a federal and state task force process to assess opportunities for marine renewable energy development. For wave energy projects, the Federal Energy Regulatory Commission plays a central role in licensing proposed projects. The state of Oregon recently completed a planning process in state territorial waters to assess interactions between marine renewable energy and other values and uses of the territorial sea. A set of maps depicting suitability for renewable energy development was produced during this process. The Oregon National Guard is scoping opportunities for development of marine renewables at the Camp Rilea Armed Forces Training Facility near the mouth of the Columbia River. Interest in both wind and wave development has also been shown near the coastal communities of Coos Bay, Reedsport, and Newport. As of the writing of this report, two projects in federal waters are applying for BOEM leases: 1) the DOE-funded Principle Power WindFloat demonstration project located approximately 18 NM from Coos Bay, Oregon, and 2) the Northwest National Marine Renewable Energy Center's Southern Energy Test Site located approximately 5 NM off the coast of Newport, Oregon

1.2. Overview of Wind and Wave Technology and Resources

Of the many factors affecting the siting of offshore wind and wave energy development, the characteristics of the energy resource, bathymetry, seabed, distance to shore, and competing uses are among the most important. Depth is a critical factor because it limits the type of technologies than can be deployed at a given location.

For offshore wind power development, fixed foundations are generally limited to shallower water. For example, monopile wind turbine foundations can be used in water depths <30 m, and jacket and tripod wind turbine foundations can be used in water depths <60 m. Floating wind platforms on mooring systems can be used in deeper water (>60 m). Unlike the Great Lakes and the East Coast of the United States, the bathymetry of the West Coast is characterized by a narrow continental shelf that drops rapidly offshore, such that the 60-m depth contour generally lies within a few hundred meters of the shoreline. Because only a small proportion of the West Coast offshore wind resource occurs in waters less than 60 m deep, floating wind turbine platforms will be a primary consideration for developers and regulators considering West Coast offshore wind resources (Schwartz et al. 2010).

Given the complexity and costs associated with project construction and permitting, optimal siting of offshore wind development areas will be crucial in making projects financially viable. States et al. (2012) note that this means offshore wind farms will need to be sited in areas that

- have a robust wind resource,
- have suitable bathymetry,
- have reasonable proximity to ports and onshore transmission connections,
- are outside of areas with special designations or high environmental sensitivity,
- that minimize conflicts with commercial and recreational fishing, shipping, and military uses.

For wave energy, similar suitability constraints apply. Wave energy conversion (WEC) devices are designed to take advantage of wave energy in a range of depths, including shore-based devices designed for breakwaters and beaches, nearshore devices that convert wave surge into energy, mid-depth devices that target depths from 10−50 m, and deep-water devices that can be deployed in depths greater than 125 m. This study considers nearshore, mid-depth, and deep-water devices because it focuses on the Oregon OCS, which provides limited opportunities for devices that function in shallow water.

2. METHODS

The study area for this assessment included OCS waters off the Oregon coast extending from the northern and southern Oregon State borders (i.e., ~46.2° to 42°N) and east-west from the western boundary of the territorial sea to the western extent of BOEM OCS lease blocks (~126°W). Each BOEM lease block is divided into sixteen 1.44 km^2 sections or aliquots, which were used as the minimum unit of analysis and are what is referred to as “sites” in this assessment. In total the study area encompasses more than 30,000 mi^2 and contains 54,793 aliquots.

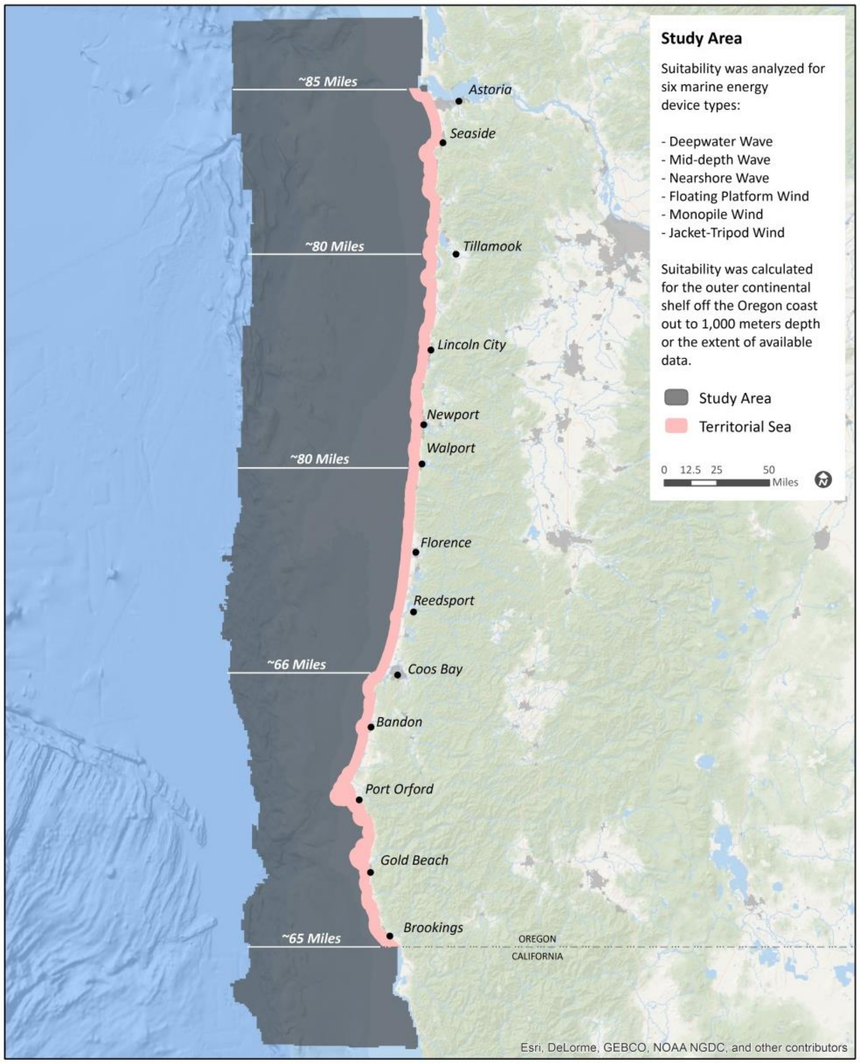

Figure 1. Study area for Oregon OCS wind and wave energy site suitability analysis.

2.1. Technology and Device Selection

The wave and wind technologies selected for this assessment are believed to represent the device types anticipated to be commercially viable on the West Coast. We considered full-scale devices technologically mature enough to be candidates for development in the OCS environment in the near future. While multiple devices are currently used to capture ocean energy, device requirements are often similar with respect to operating conditions. Because these similarities exist, we grouped devices into six categories based on the technology type (wave and wind), foundation type (floating and bottom-founded), and depth because it is a common constraining factor for most devices (Table 1). Because there are a wide variety of wave energy technologies and they are bottom-founded, they were categorized by the relative depth at which they are deployed (nearshore, mid-depth, deep-water). Conversely, wind devices were categorized by foundation type because it determines the relative depth at which they may be deployed.

Table 1. Six categories of renewable marine energy technologies evaluated in this study.

Energy Source	Foundation Type
Wind	Bottom-founded Monopile
	Bottom-founded Jacket/Tripod
	Floating platform
Wave	Bottom-founded Nearshore
	Bottom-founded Mid-depth
	Bottom-founded Deep-water

Nearshore wave energy devices considered in this study include coastline converter and nearshore surge device types such as Aquamarine Power's *Oyster*, Resolute Marine Energy's *SurgeWEC*™, and M3 Wave Energy System's *M3 Delos-Reyes Marrow*. Coastline converter devices are located on an existing natural or manmade coastline, or where a new coastline is artificially created in nearshore waters. Coastal surge devices harness the energy generated by a flap moving laterally in response to wave motion in shallow water.

Mid-depth wave energy devices considered in this study include oscillating water columns, offshore pressure devices, and mid-depth surge devices such as Neptune Wave Power's rotating mass turbine WEC. These devices are designed to operate in depths ranging from 10 to 50 m (5.5 to 27.3 fathoms). Mid-depth oscillating water column devices generate energy via an above-surface turbine powered by the surge generated by waves within a below-surface chamber. Mid-depth offshore pressure devices generate energy via a seabed-based flexible reservoir that cyclically compresses and expands as waves pass over it. Mid-depth surge devices generate energy via the pressure differential created by two proximal arms moved by passing waves.

Deep-water wave energy devices considered in this study include point absorber, oscillating water column, offshore surge, and attenuator and pivot device types such as Columbia Power Technologies' *StingRay*, Ocean Power Technologies' *PowerBuoy*, and Northwest Energy Innovations/Pacific Energy Ventures' *WET-NZ*. These devices are typically designed to be anchored at depths of 50 to 125 m (27.3 to 68.4 fathoms). Point absorber wave energy devices contain floating structures that absorb energy in all directions through their movements at or near the water surface. Deep-water oscillating water column devices capture the surge generated by waves within a chamber that is used to drive air through an above-surface turbine. Deep-water surge devices generate energy via the pressure differential created by two proximal arms moved by passing waves. Attenuator or pivot devices capture the energy of passing waves via the resistance of an articulated joint that is moved around a pivot to generate electricity.

Monopile wind devices were included in this study even though only a small portion of the Oregon OCS near the mouth of the Columbia River has depths suitable for this technology. Typical offshore monopile wind turbines have a maximum depth of 40 m. For the purposes of this study, we used the same technical specifications in our model as those used by Van Cleve et al. (2013) for monopile wind technologies.

Siting needs for jacket and tripod devices were similar enough that we categorized them together in this assessment. These foundations are designed to be deployed at depths of up to 200 m, with an optimal range of 30−40 m. For the purposes of this study, we used the same technical specifications in our model as those used by Van Cleve et al. (2013) for jacket/tripod wind technologies.

Floating wind turbines are attached to a floating base or platform anchored to the sea floor, allowing for deployment in much greater depths than monopile or jacket/tripod foundations. Because much of the Oregon OCS exceeds depths that would be suitable for monopile or jacket/tripod foundations, greater emphasis was put on floating wind turbine technology for this study. In addition to data collected by Van Cleve et al. (2013) on two offshore wind technologies (Principle Power's Wind Float and HyWind by Statoil ASA), the project team obtained survey data from three other offshore wind developers: the University of Maine (VolturnUS), Nautica Wind Power, and Glosten Associates (PelaStat tension-leg system).

2.2. REVIEW BY INDUSTRY ADVISORS

Industry experts (e.g., device developers, project developers, industry coalitions, academic experts) were asked to participate in the selection and scoring of attributes in the suitability model to ensure the study results accurately reflect basic technical and economic siting decisions. This task was led by the Oregon Wave Energy Trust (OWET) and involved developing an industry contact list for representative technologies, vetting that list with project partners, establishing an advisory committee consisting of industry representatives from that list, developing an appropriate survey instrument and study design, hosting a webinar to introduce and explain the survey, administering an online survey, summarizing data, and following up with respondents to validate results.

PNNL, OWET, and Parametrix developed a comprehensive list of wind and wave companies that might have interest in developing marine renewable energy in the Oregon OCS in the next 5-10 years and invited them to participate in the study. In total, 65 respondents were selected to receive the survey. Industry members were selected based upon the following criteria:

- **Relevance of technology to the purpose of the survey.** Technology relevance was defined by whether or not a specific technology was applicable to the Oregon OCS. Because depth is a constraining factor for all technologies, we focused survey efforts on technologies for which there are suitable depths on the Oregon OCS. This included all three wave energy device types and floating wind turbines. Surveys were not solicited from developers of wind monopile and jacket/tripod device types because of the lack of suitable depths on the Oregon OCS. Instead, we used the model parameters that Van Cleve et al. (2013) used to assess site suitability for these device types.
- **Efforts to commercialize and knowledge of deployment requirements**. The survey was distributed to companies that have demonstrated recent progress in their efforts to commercialize their technologies and have a good understanding of the deployment requirements for their technology.
- **Relationship to OWET.** The OWET team has fostered many relationships throughout the industry, which facilitated obtaining responses from some of the most prominent offshore renewable energy companies in the world.

In addition to contacting developers, certain members of marine renewable energy research community were asked to serve as an advisory committee for the project. These members included Principle Power, Columbia Power Technologies, M3, the University of Washington, and Oregon State University. These members helped to inform data collection activities and reviewed the approach and results of data analysis.

A customized online survey was distributed to industry advisors to obtain technical feedback on deployment specifications for their respective technologies. The surveys were designed so that respondents could assign scores to model attributes and attribute ranges according to their preferred deployment conditions. These scores were later summarized by OWET to determine median values for model parameters. Respondents were also asked to assign weighting values to the three components of the suitability model (i.e., site quality, grid connection, shore-side support) based on their relative importance to the developer. Prior to the release of the survey, OWET and PNNL hosted an informational webinar to answer questions and give background for the purposes of the upcoming industry survey.

2.3. GEOSPATIAL SITE SUITABILITY MODEL

Available technologies drove the development and parameterization of the site suitability model used in this assessment. The Oregon OCS site suitability model is based closely on a model developed by Van Cleve et al. (2013) for assessing site suitability for offshore wind and wave energy off the Washington State coast. The model is organized around the following three factors that may affect siting:

- **Site Quality**. How good is the site in terms of the preferred levels of energy resource, depth, and substrate for a given technology?
- **Grid Connection**. What is the site's location relative to available electrical transmission and distribution infrastructure?
- **Shore-Side Support.** How close is the site to necessary port infrastructure for device installation, operation, maintenance, and decommissioning?

For each siting factor, two to three measurable attributes were identified and used to calculate an index value representing the relative suitability of that factor (Figure 2). A total of eight attributes were included in the model.

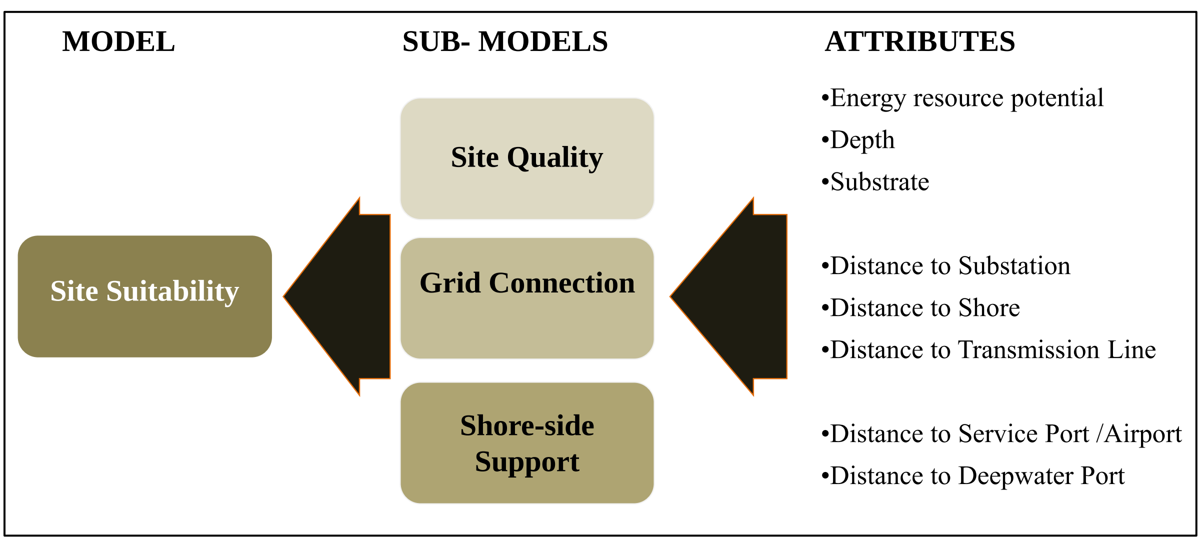

Figure 2. Framework of the Oregon OCS site suitability model.

Spatial data representing the eight attributes was acquired primarily from publicly available resources, with the exception of transmission infrastructure data (Table 2). Methods to spatially quantify model attributes in each aliquot were similar to those used by Van Cleve et al. (2013). Distances to shore, substations, transmission lines, and ports were based on Euclidean or straight line distance from each aliquot to the nearest feature. Although straight line distance is a simplification of assumed cable or navigation routes, it still provides a useful measure of proximity that can be used to assess site suitability.

In offshore wind development, ports serve three primary functions: component assembly, project construction and deployment, and operation and maintenance. While component assembly and project construction will likely require deep-water port access (i.e., ports with channel depths greater than 30 ft), operation and maintenance activities could be based out of either a deep-water port or a smaller port capable of accommodating shallow draft vessels (herein referred to as "service port"). The scale of offshore wind turbines and challenges associated with transporting and handling turbines up to 500 ft tall require greater specificity in defining deep-water ports with capacity to support offshore wind development. For this assessment, ports with >180-m clearance were considered acceptable deep-water ports for floating offshore wind turbines. In addition, service activities on floating platforms would likely be performed by helicopter because of their large size and expected distances from shore.[2] Therefore, coastal heliports and airports that have helicopter support were used as service ports for the evaluation of floating platform site suitability.

For this assessment, the following Oregon ports were considered potential service ports for wave and shallower wind devices (monopile, jacket/tripod): Alsea, Astoria, Bandon, Brookings, Charleston, Coos Bay, Crescent City (CA), Depoe Bay, Florence, Garibaldi, Gold Beach, Newport, Pacific City, Port Orford, Toledo, and Winchester Bay. Ports that were considered deep-water ports for this study included Coos Bay, Astoria, and Newport. However, Newport was not considered a suitable deep-water port for floating wind technologies because of the limited height clearance below the span of the Yaquina Bay bridge (133 ft).

Table 2. Attributes of siting factors, descriptions, and summary of corresponding geospatial data used to evaluate suitability.

Attribute	Description	Data Source
Wind Speed	Mean wind speed at 90 m	NREL 90-m offshore average wind speed[a]
Wave Power Density	Power in kilowatts per meter	NREL Wavewatch III model[b]
Depth	Depth from water surface to seabed	NOAA U.S. Coastal Relief Model – Central Pacific[c]
Substrate	Majority substrate type on the surface of the seabed.	Pacific Coast Ocean Observing System[d]
Distance to Shore	Euclidean distance from site to the coast	NOAA U.S. Coastal Relief Model – Central Pacific[c]
Distance to Substation	Euclidean distance from the site to the nearest substation.	Homeland Security Infrastructure Program[e]
Distance to Transmission Line	Euclidean distance from nearest shore access point to the nearest transmission line	Homeland Security Infrastructure Program[e]
Distance to Service Port/Airport	Euclidean distance from the site to nearest port or airport.[f]	USACE Navigation Data Center[g] National Transportation Atlas Database[h]
Distance to Deep-Water Port	Euclidean distance from the site to nearest deep-water port.	USACE Navigation Data Center[h]

(a) NREL 2014a
(b) NREL 2014b
(c) NOAA 2014
(d) PaCOOS 2014
(e) HSIP 2014
(f) In the offshore wind floating platform model only, distance to nearest airport is measured rather than distance to service port.
(g) USACE 2014
(h) USDOT 2014

2.4. SITE SUITABILITY CALCULATION

Weighted sum algorithms were used to describe the relative suitability of sites for each offshore energy type. The OWET industry survey provided input on the attributes, the model organization, and preferred ranges for each attribute (as described in Section 2.2). In the survey, attribute values were binned into ordinal ranges and respondents were asked to score each range from 0 to 10, with 0 representing no potential for development and 10 representing most favorable for development. Respondents were also asked to weight the relative importance of each siting factor. The median response was determined for each attribute range and siting factor weight and used to parameterize the model.

For each aliquot in the study area, the model performs an algorithm to calculate an index score for each siting factor and an overall suitability index score using the eight attributes described above. Index scores for site quality (*SQ*), grid connection (*GC*), and shore-side support (*SS*)] siting factors are calculated as follows:

$$Siting\ Factor\ Score = \frac{\sum_{k=0}^{n}(Attribute\ \ Score\ ) \times Weight}{Potential\ \ Maximum\ \ Submodel\ \ Score_{a}} \quad (1)$$

where *k* indicates the lower limit and *n* is the upper limit attribute score. The result yields an index of suitability between 0.0 and 1.0. Unless recommended by industry advisors, each attribute was considered to be of equal importance (i.e., weight = 1) for calculating siting factor scores. In addition to receiving input on suitability ranges for each attribute, industry advisors provided feedback indicating that some siting factors were more important than others. In response, weights were applied to each siting factor score (full conceptual models including weights are provided in the Appendix). The final site suitability algorithm considers all three siting factor scores, where, w is the weight for each factor (*SQ, GC, SS*) and device type ($_a$):

$$Site\ Suitability_a = \frac{[(w_{1a} \times SQ_a)\ + (w_{2a} \times GC_a) + (w_{3a} \times SS_a)]}{1} \tag{2}$$

The final site suitability score was scaled by a factor of 10 for ease of interpretation, which yielded values ranging from 0 to 10. Maps of site suitability were created by displaying planning aliquots by a graduated color scheme based on their suitability scores The color scheme was classified into five bins that best visualized breaks in the distribution of suitability scores. Areas that did not meet a minimum suitability threshold for wind speed, wave power density, and water depth were classified as unsuitable regardless of other attribute criteria. Areas that did not have complete coverage for all eight model attributes were classified as "incomplete" rather than unsuitable.

3. RESULTS

A total of 65 industry experts were asked to participate in a survey designed to inform the selection and scoring of attributes in the site suitability model. The model, developed by Van Cleve et al. (2013) for the Washington State coast, was adapted for assessing site suitability of six offshore wind and wave energy device types on the Oregon OCS. This section describes the results of the survey efforts and subsequent modeling results for each device type.

3.1. SURVEY RESULTS AND TRENDS

We received a 31% response rate (21 respondents) on the online survey from industry advisors. Responses were received from four floating offshore wind developers, including Principle Power, a leading West Coast company and the only company to receive DOE funding for the development of a demonstration project on the West Coast. Data were also gathered from the University of Maine, which is developing the only floating wind platform on the East Coast. Four responses were received from nearshore WEC developers, including industry leading companies such as Aquamarine (Scotland), AW Energy (Finland), and Resolute Marine Engineering (USA). Five responses were received from mid-depth WEC companies such as Oscilla Power (USA), Ocean Energy Ltd (Ireland), and Langlee Wave Power (Norway), and seven responses were received from deep-water WEC developers such as Pelamis (Scotland), Columbia Power Technologies (USA), and Wedge Global (Spain).

Table 3. List of Respondents to Online Survey from Industry Advisors

Company Affiliation
Aquamarine Power
Atargis Energy
Atmocean
AW Energy
Bourne Energy
Columbia Power Energy
GLWN
Langlee
M3 Wave
Maine Aqua Ventus
Nautica Wind Power
Northwest Energy Innovations (WET-NZ)
Ocean Electric
Ocean Energy
Oscilla Power
Pelamis Wave Energy
PelaStar
Principle Power
Resolute Marine Energy
Shift Power
Wedge Global

3.2. Offshore Wind Energy

The following maps (Figures 3, 4, and 5) depict the suitability score for monopile, jacket/tripod, and floating platform wind energy device types, respectively. Areas shown as unsuitable did not meet minimum suitability criteria for either site depth and/or energy resource. Data were available for all eight siting factor attributes in approximately 55 percent (31,728 aliquots) of the Oregon OCS study area, which stretches from the coastline seaward to approximately 30−50 NM offshore (i.e., the OCS) and includes depths to approximately 3000 m. The geographic area for evaluation was limited by the availability of data on substrate type, depth, and wind speed.

Of the portion of the study area with complete data coverage, approximately 0.8, 41.5, and 99.6 percent of the area for the respective monopile, jacket/tripod, and floating wind energy device types had a suitability score greater than 0 (0 being not suitable and 10 being most suitable). Within these potentially suitable areas, mean site suitability scores were 7.7, 6.9, and 8.1 for monopile, jacket/tripod, and floating platforms, respectively.

Depth significantly affects site suitability for monopile and jacket/tripod wind devices on the Oregon OCS. Almost all of the OCS, with the exception of a small area bordering state territorial seas near Astoria, exceeds a depth of 40 m, considered the maximum feasible depth for monopile wind devices in this study (Figure 3). Much of the OCS also exceeds optimal (30–60 m) and maximum (>200 m) feasible depths considered for jacket/tripod wind devices in this study. Thus, site suitability for jacket/tripod wind devices scored high (7.5–9) or very high (9–10) only in portions of the OCS bordering state territorial waters, particularly near Astoria, Seaside, Newport, and Waldport (Figure 4). More detailed maps of site suitability for each technology are available in Appendix A.

Conversely, approximately 44 percent of the Oregon OCS for which site suitability data were available scored high or very high (>7.5–10) for floating platform wind energy devices. Primary factors affecting the site suitability of floating wind included those related to grid connection (i.e., distances to nearest substation, kilovolt transmission line, shore). Thus, areas that scored high or very high were generally within 20 NM of the coast.

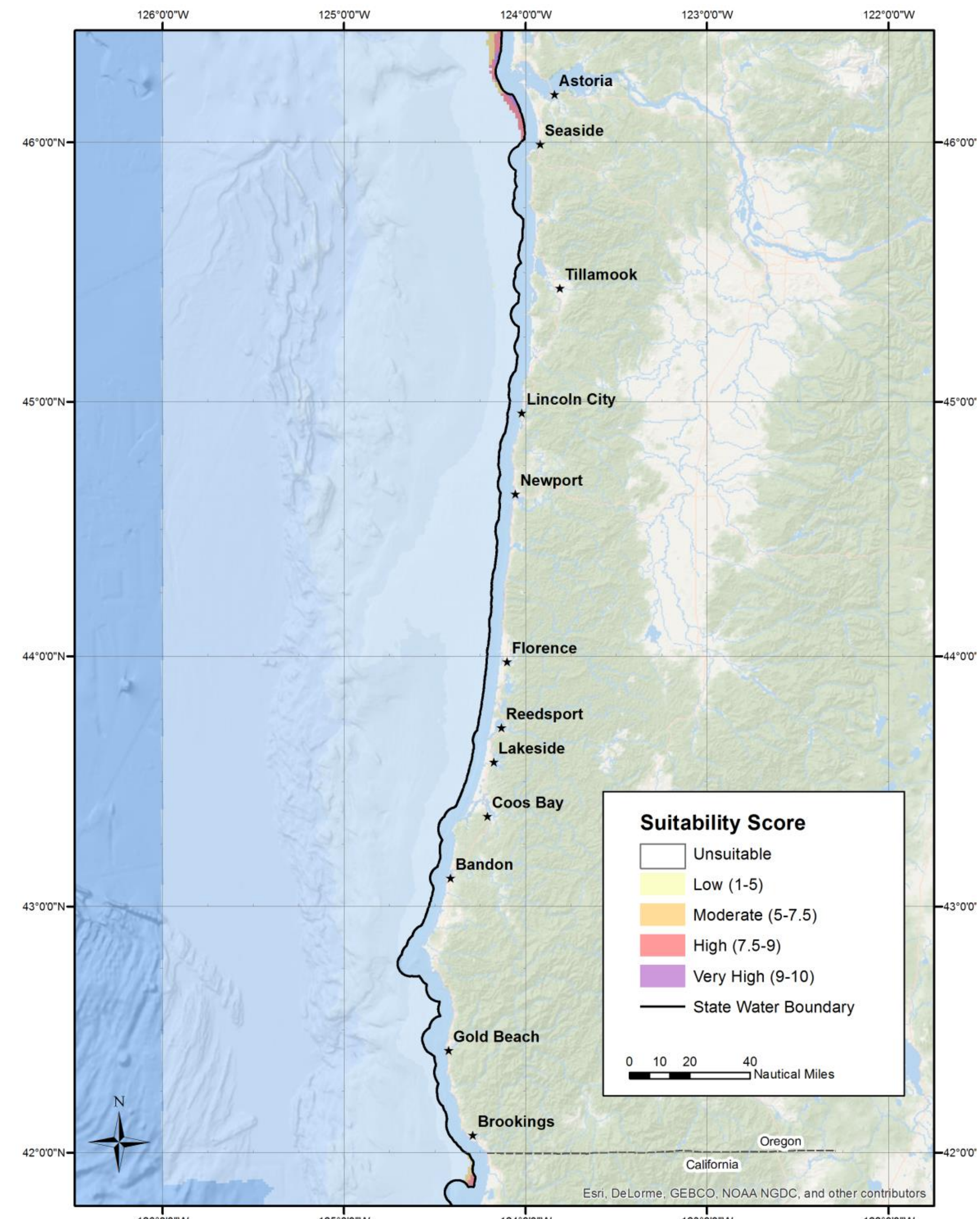

Figure 3. Site suitability for offshore monopile wind energy.

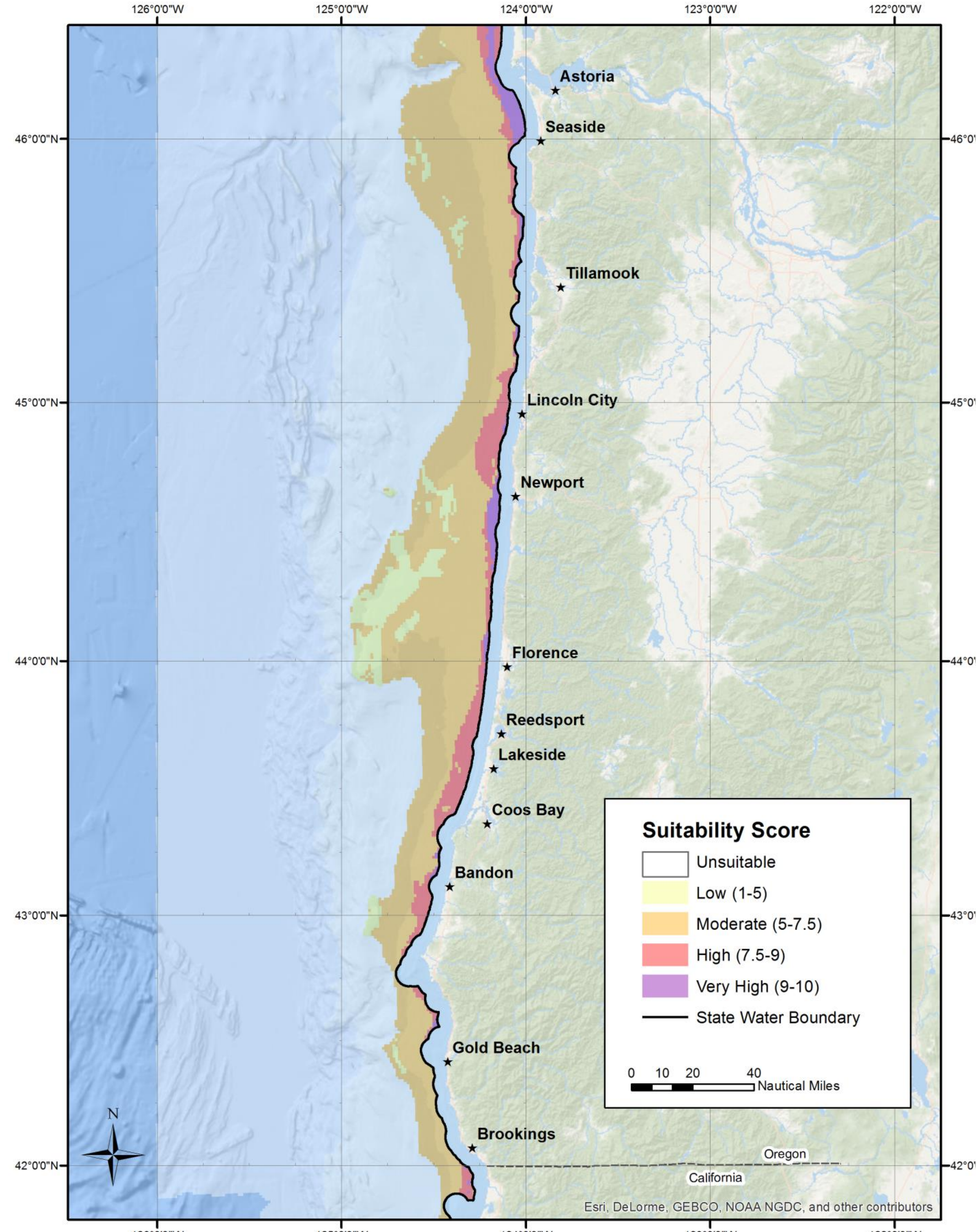

Figure 4. Site suitability for offshore jacket/tripod wind energy.

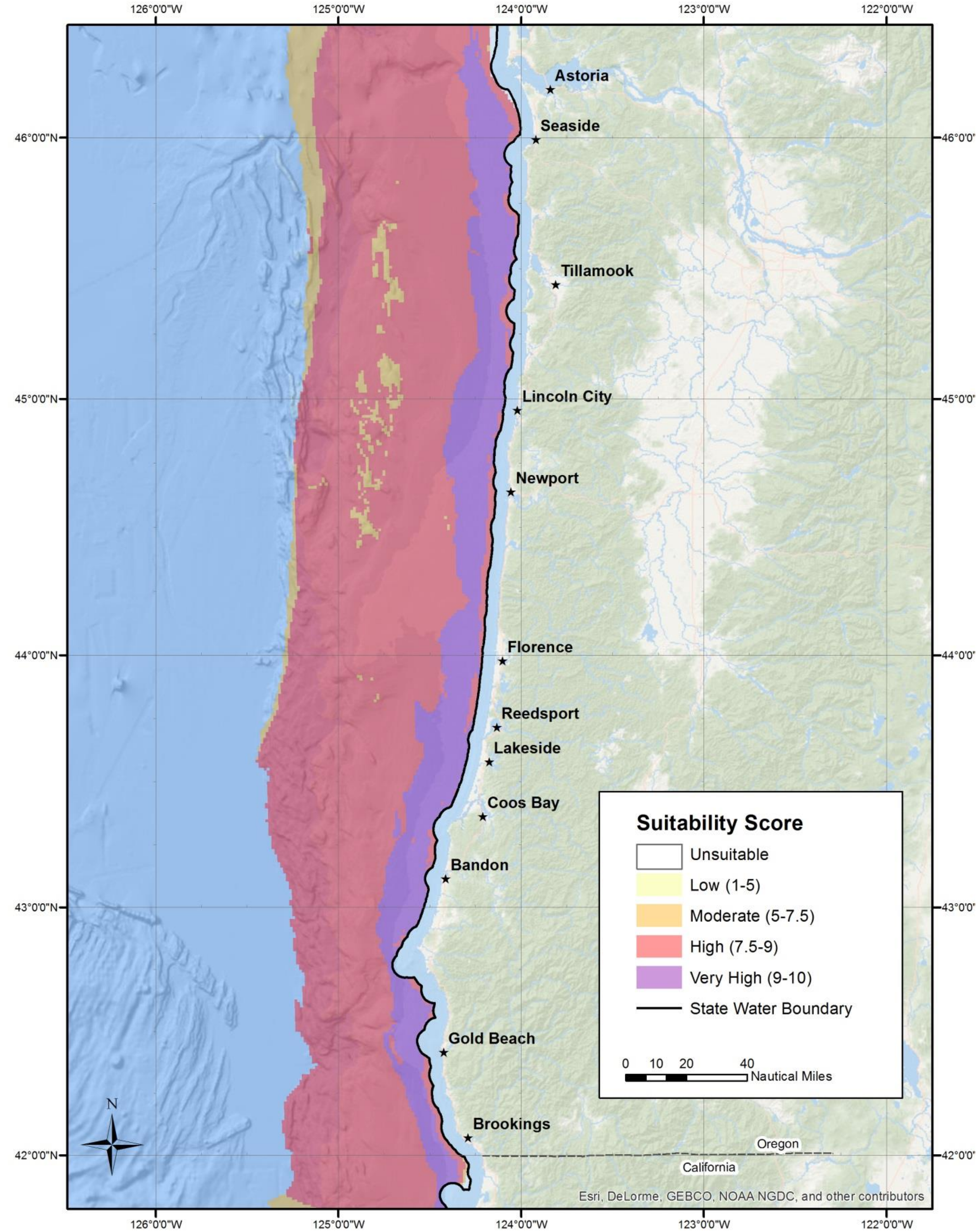

Figure 5. Site suitability for offshore floating platform wind energy.

3.3. Wave Energy

The following maps (Figures 6, 7, and 8) depict the site suitability score for nearshore, mid-depth, and deep-water wave energy device types. Areas shown in gray did not meet minimum suitability requirements for either site depth or energy resource or both. Data were available for all eight siting factors in approximately 60 percent (32,869 aliquots) of the Oregon OCS study area. This area of data availability includes the area from the coastline seaward to approximately 30−50 NM offshore and to depths of approximately 3000 m. The amount of area suitable for evaluation was limited by the availability of data on substrate type, depth, and wave power density.

Of the portions of the study area with complete data coverage, approximately 0.0001, 99.9, and 98.1 percent of the area, respective to nearshore, mid-depth, and deep-water wave energy device types, had a suitability score greater than 0 (0 being not suitable and 10 being most suitable). However, these values may overestimate the amount of potentially suitable area, particularly for mid-depth and deep-water technology types, because upper limits to feasible depths were not provided by industry advisors. Within these potentially suitable areas, mean site suitability scores ranged from 7.4, 5.7, and 6.4 for nearshore, mid-depth, and deep-water wave energy device types, respectively.

Depth significantly affects site suitability on the Oregon OCS for all wave energy devices considered in this study. Almost all of the OCS, with the exception of a small area bordering state territorial seas near Astoria, exceeds a depth of 40 m, which was considered the maximum feasible depth for nearshore wave energy devices in this study (Figure 6). Much of the OCS also exceeds depths that were considered optimal for mid-depth (30–85 m) and deep-water (50–150 m) wave energy devices in this study. Thus, site suitability for mid-depth devices scored high (7.5–9) or very high (9–10) only in portions of the OCS bordering state territorial seas, particularly between Astoria and Seaside, Lincoln City and Newport, Reedsport and Coos Bay, and Bandon and Port Orford (Figure 7). Site suitability for deep-water devices also scored high or very high in these areas, in addition to areas near Tillamook and Florence, Oregon (Figure 8).

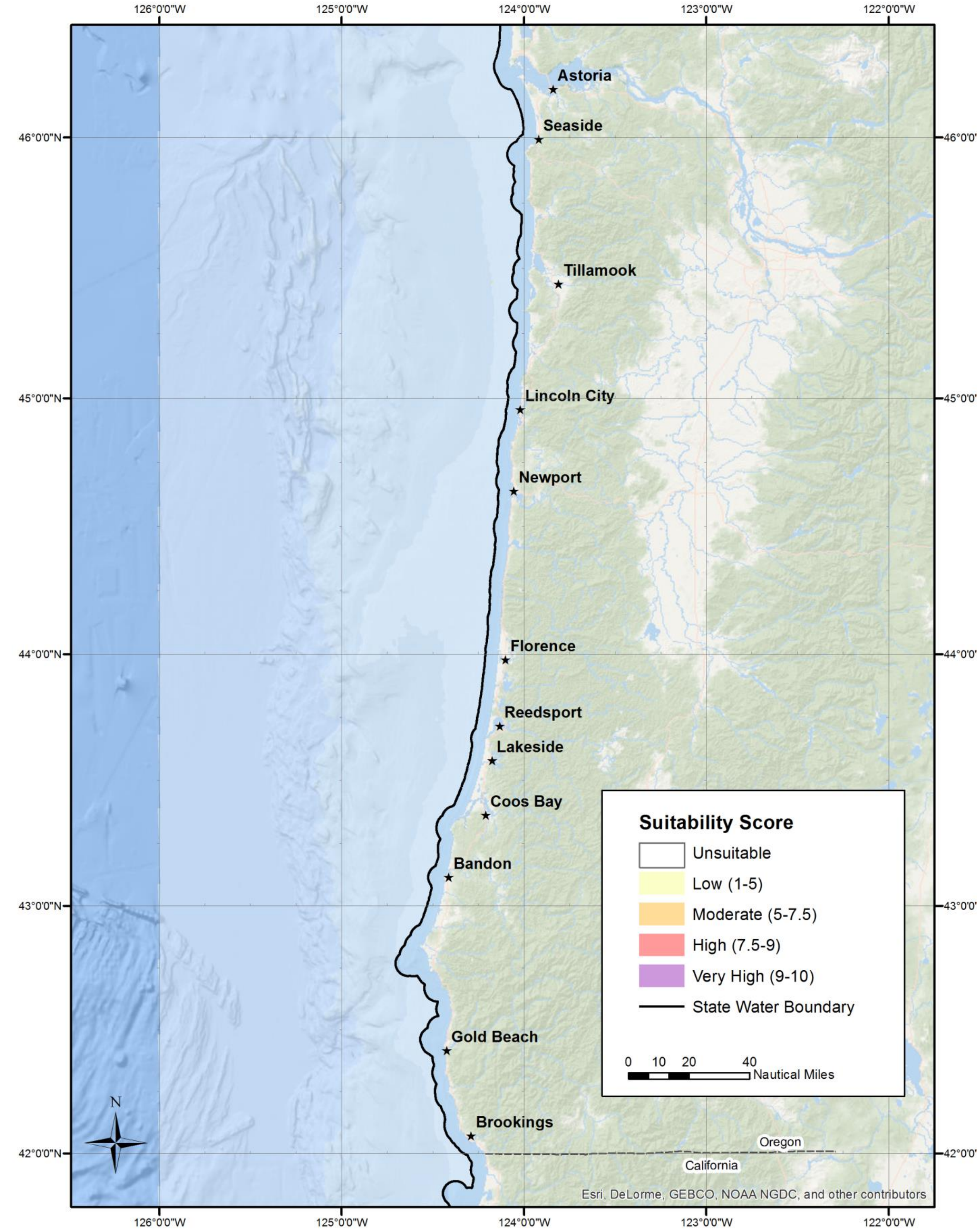

Figure 6. Site suitability for nearshore wave energy converter devices.

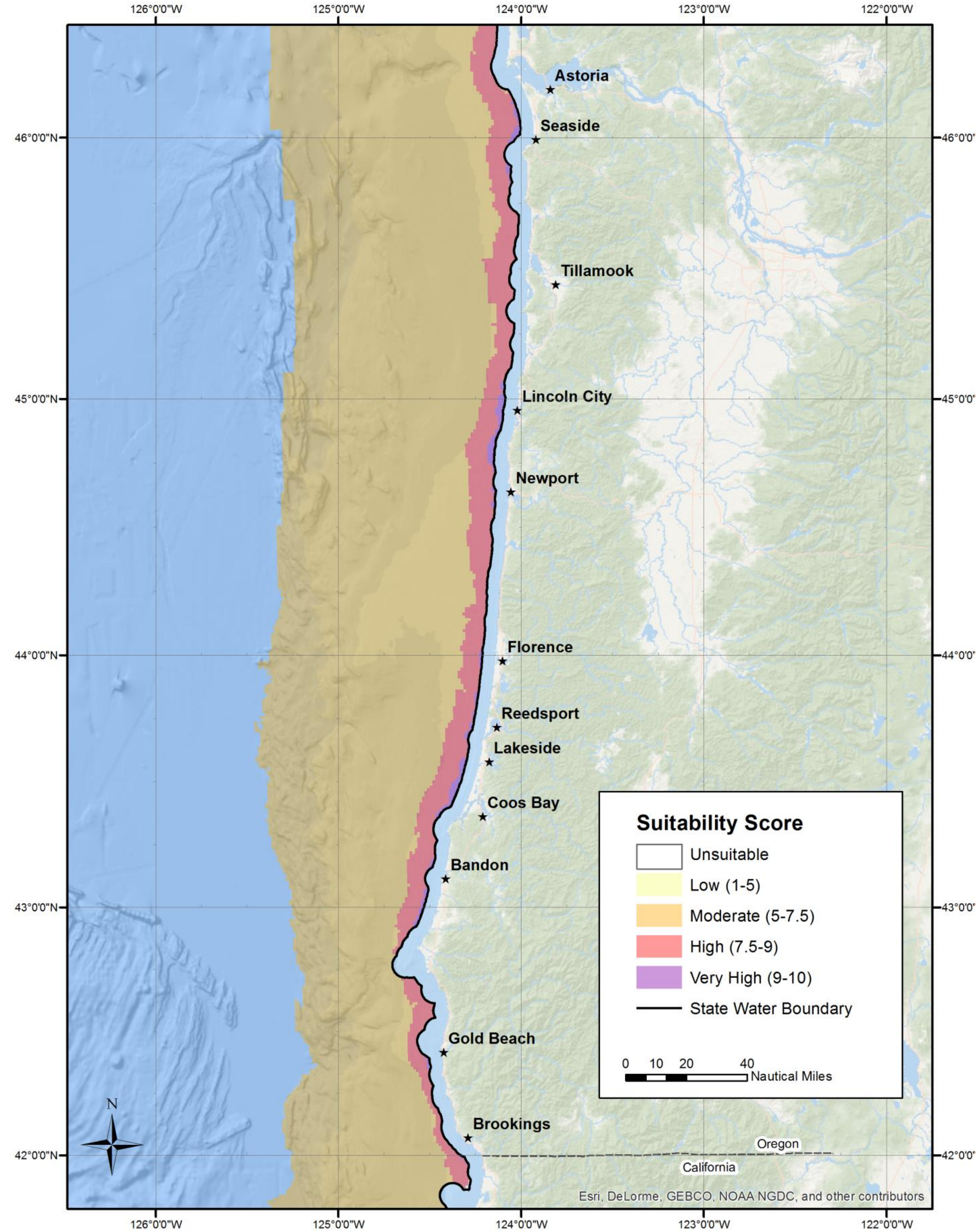

Figure 7. Site suitability for mid-depth wave energy converter devices.

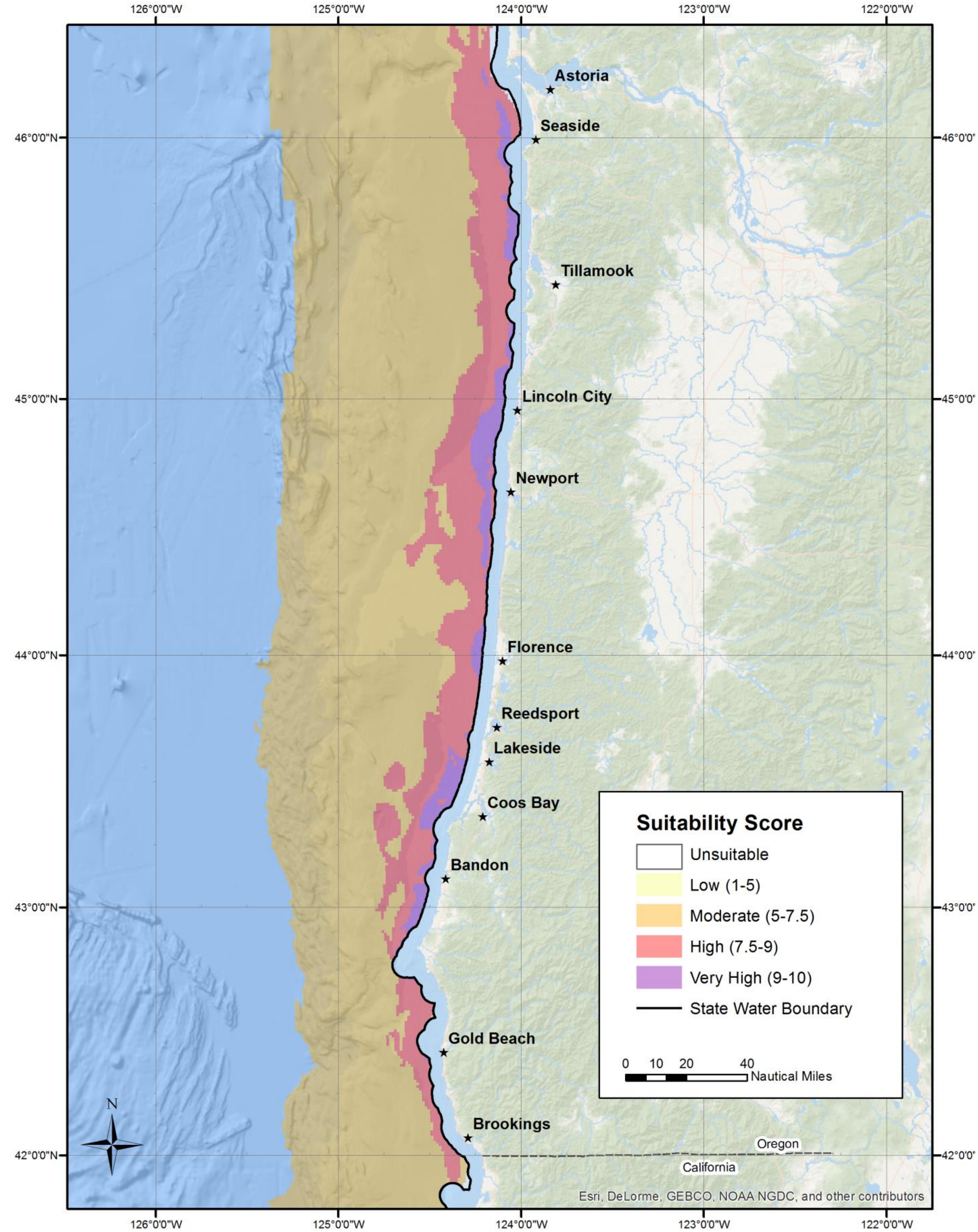

Figure 8. Site suitability for deep-water wave energy converter devices.

4. DISCUSSION

There are several important points to consider when interpreting the results presented herein. First, alternate scoring of the individual model inputs (depth, distance to port, etc.) may have an effect on the patterns of suitability. We used median response values from industry advisors and grouped results by like device types to capture general patterns of suitability at a large scale. However, this approach may not describe site suitability as well for certain device types that have more unique requirements. If desired, the approach and suitability model presented in this study can be modified to model site suitability for specific device types. Similarly, the model can be updated to reflect changes in available technologies, deployment constraints, and data availability.

Another important consideration is though our maps show different categories of suitability, the data underlying them are continuous (with the exception of substrate type) and thus the boundaries between one suitability class and the next should be considered "fuzzy". Similarly, the classes of suitability could be grouped differently based on a user's preferences. Although the underlying data are continuous, the scale at which most input datasets are developed does not support site-scale analysis. Thus, the products presented herein should be considered appropriate for identifying regions within the Oregon OCS that may be more appropriate for development or require additional site characterization.

The results of this study indicate the amount of potentially suitable area for floating wind and deep-water WEC is much more extensive on the Oregon OCS than shallower device types (nearshore and mid-depth WEC, monopile and jacket/tripod wind turbines). Although depth has less of an effect on site suitability for floating wind devices, factors related to grid connection (i.e., distances to nearest substation, kilovolt transmission line, and shore) reduced site suitability for floating wind applications. Conversely, site suitability of shallower device types on the Oregon OCS is more affected by depth than by factors related to grid connection. The majority of the study area scored high or very high (7.5–10) for offshore wind development on floating platforms with the best suitability determined to be approximately 10 to 20 NM of shore.

Industry advisors were supportive of these efforts and indicated the site suitability maps help address their needs for pre-application planning by providing a more consistent and quantitative measure of site suitability. Generally, industry advisors noted the analysis corroborates their expectation of suitability and confirms that the Oregon OCS has good ocean energy resources. However, some advisors noted that it may be important to include land ownership/jurisdiction and environmentally sensitive areas in the analysis or suitability maps. For example, Marine Protected Areas could be screened from the results or scored differently based on subsequent discussions with BOEM and industry advisors. Some advisors also commented on the apparent lack of opportunities for shallow-water technologies (e.g., nearshore and mid-depth WEC), which is the case for most of the OCS because of the steep slope of the Continental Shelf.

5. CONCLUSIONS

This case study demonstrates the application of available data pertaining to physical and logistical constraints to offshore wind and wave energy development; provides BOEM, industry, and state members with a common starting point for discussion of opportunities for OCS development; and highlights regions based on technical and economic feasibility for offshore wind and wave energy development in

Oregon. Though assembling survey data from industry experts is a time-intensive process, having industry insight into the study proved very valuable. Continuing engagement with industry will be important moving forward with CMSP because of their knowledge of rapidly-changing device designs, deployment constraints, and policy drivers.

Analyzing industry-advised site suitability requirements within a geospatial framework provides a repeatable and adaptable framework for assessing and visualizing the suitability for offshore renewable energy development. This framework can be updated periodically as new information becomes available, and it can be modified to model device-specific site requirements. Feedback from some industry advisors indicated that future assessments of site suitability should consider each technology's distinct needs and constraints.

The mapping products from this study provide an important tool for planning and potential development of offshore renewable energy in the Oregon OCS. Results confirmed that depth significantly affects site suitability within the Oregon OCS for all wave energy device types and shallower wind device types (monopile and jacket/tripod). The suitability for these devices generally ranked high only near state territorial waters where depths are shallower. Suitable depths for these device types exist within the Oregon territorial seas, which were evaluated in conjunction with the BOEM OCS but not presented in the results of this document. Areas of higher suitability for wave energy and shallower wind device types were generally between the cities of Astoria and Seaside, Lincoln City and Newport, Reedsport and Coos Bay, and Bandon and Port Orford, and north of Tillamook and adjacent to Florence.

Endnotes

1 The total recoverable wave energy resource, as constrained by an array capacity packing density of 15 MW/km of coastline, with a 100-fold operating range between threshold and maximum operating conditions in terms of input wave power density available to such arrays.

2 Banister, K. 2013. Personal communication. Principle Power, VP Business Development Americas and Asia, Portland, Oregon.

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APPENDIX I. REGIONAL MAPS OF SITE SUITABILITY FOR THE OREGON OCS

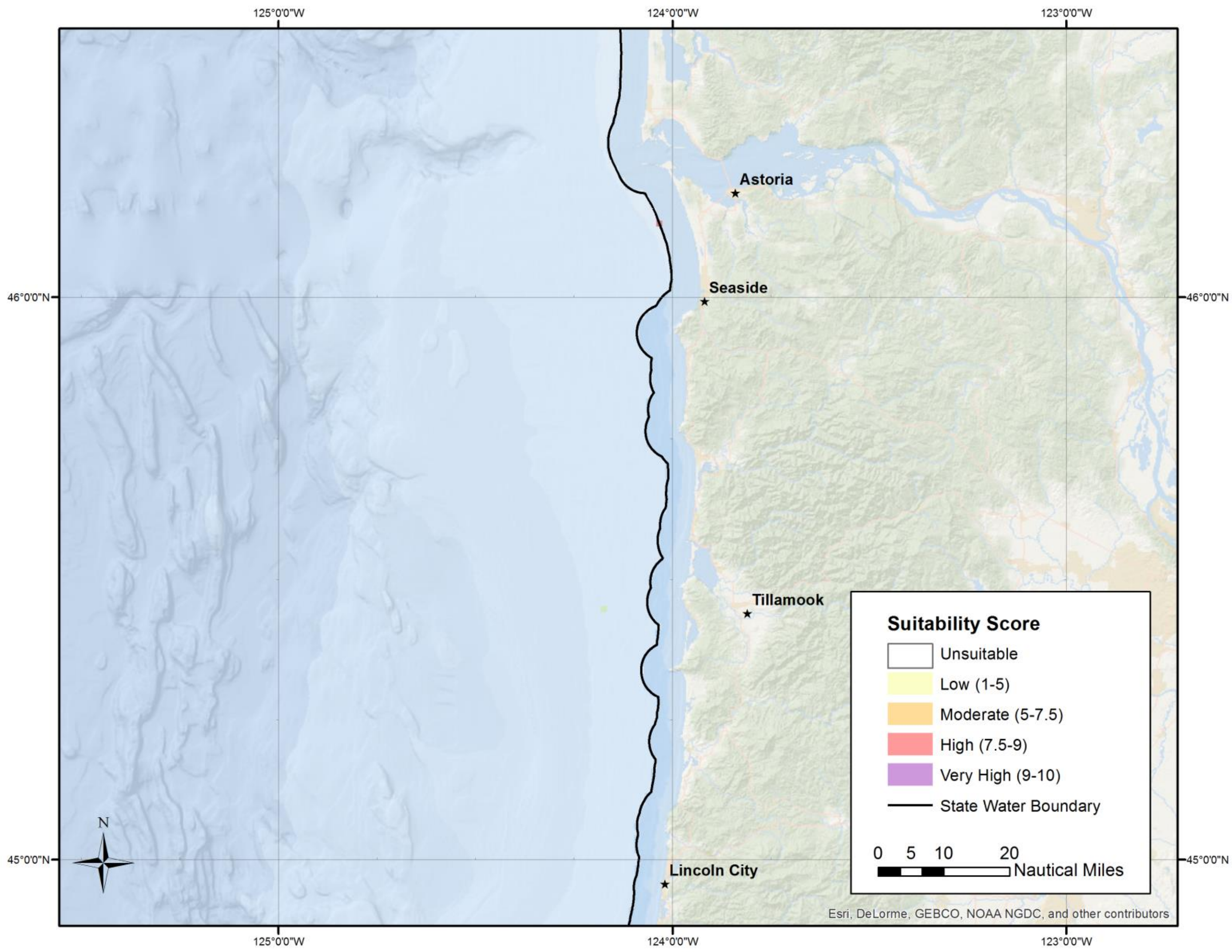

Figure I.1. Site suitability for nearshore wave energy converter devices along the north Oregon Coast.

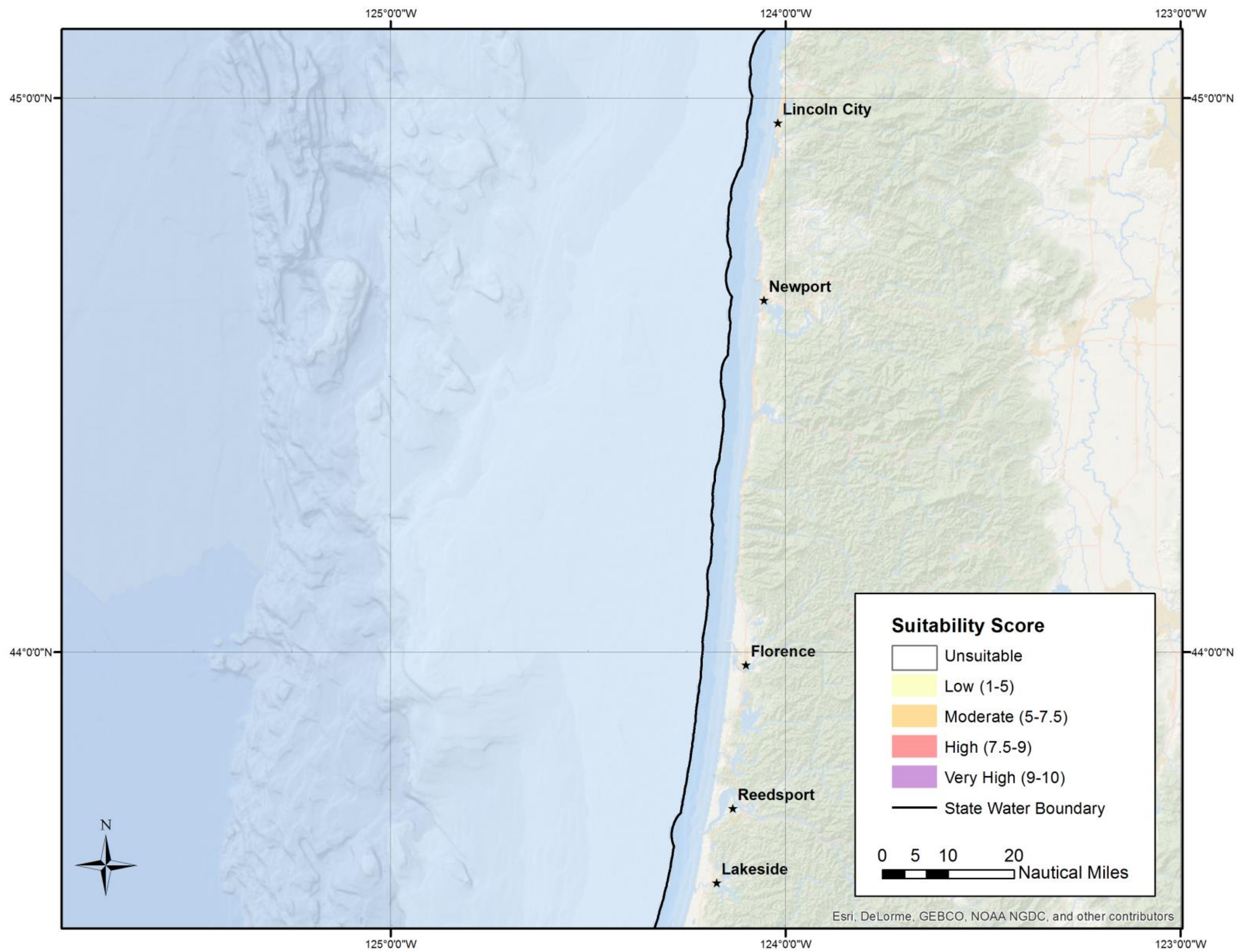

Figure I.2. Site suitability for nearshore wave energy converter devices along the central Oregon Coast.

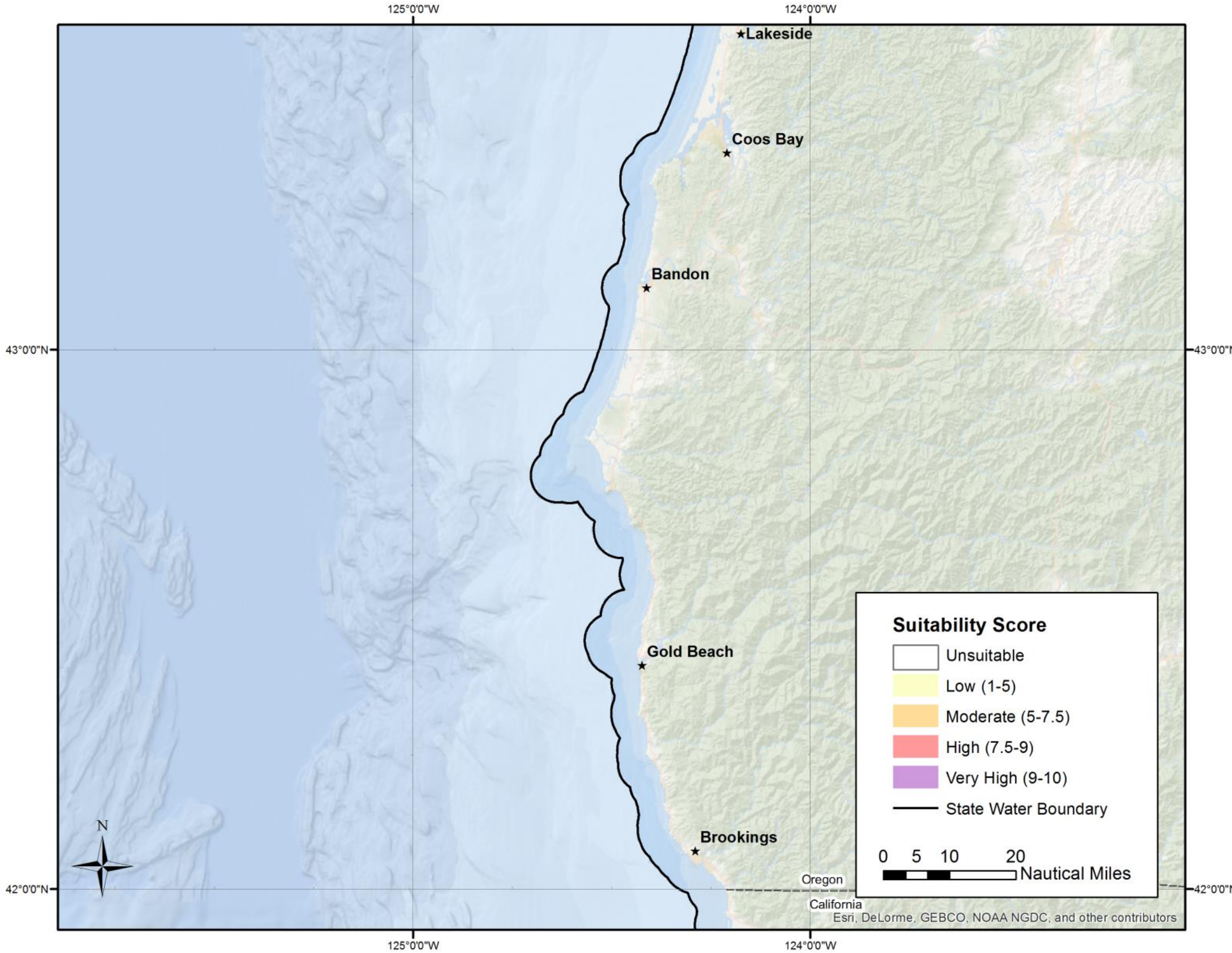

Figure I.3. Site suitability for nearshore wave energy converter devices along the southern Oregon Coast.

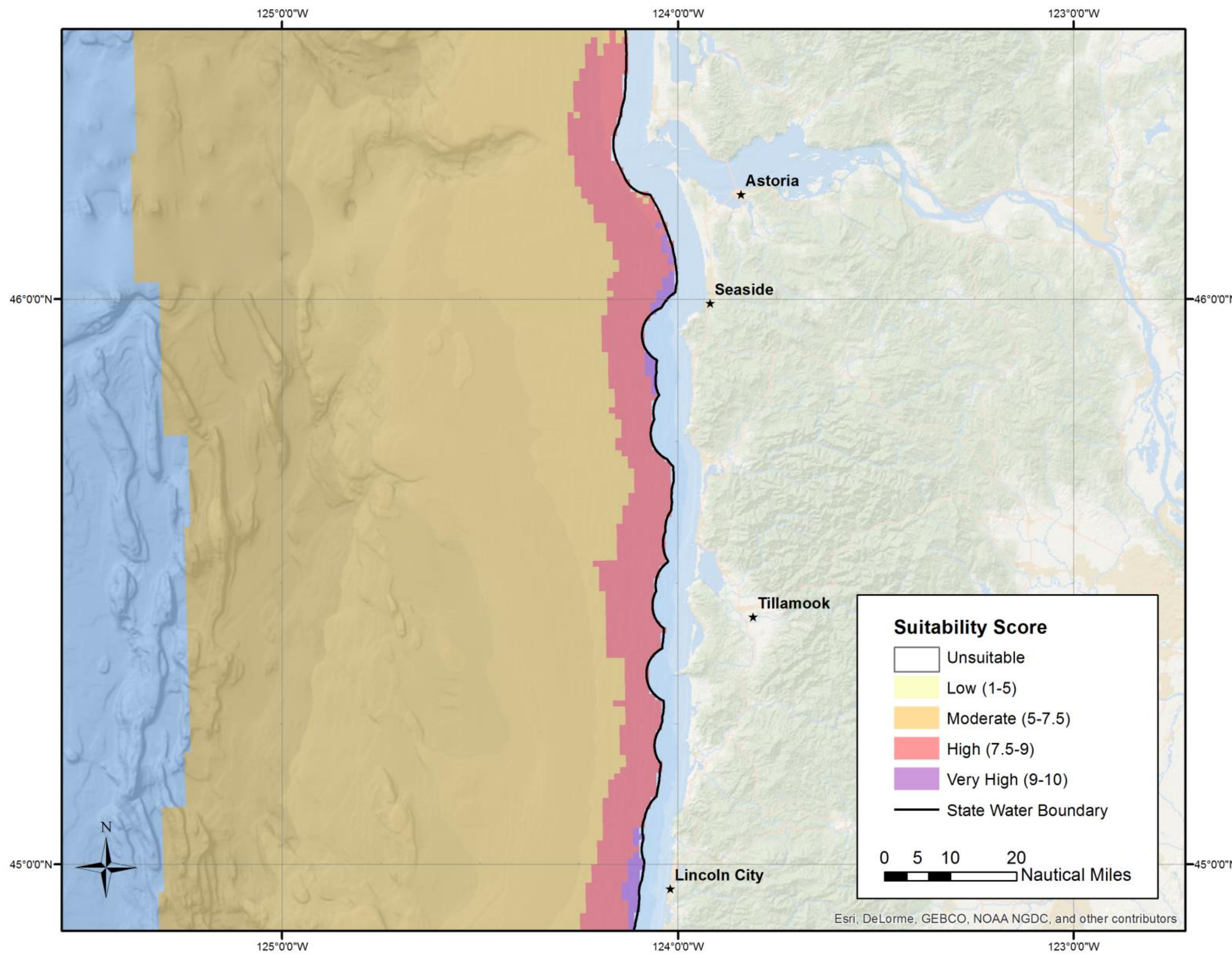

Figure I.4. Site suitability for mid-depth wave energy converter devices along the northern Oregon Coast.

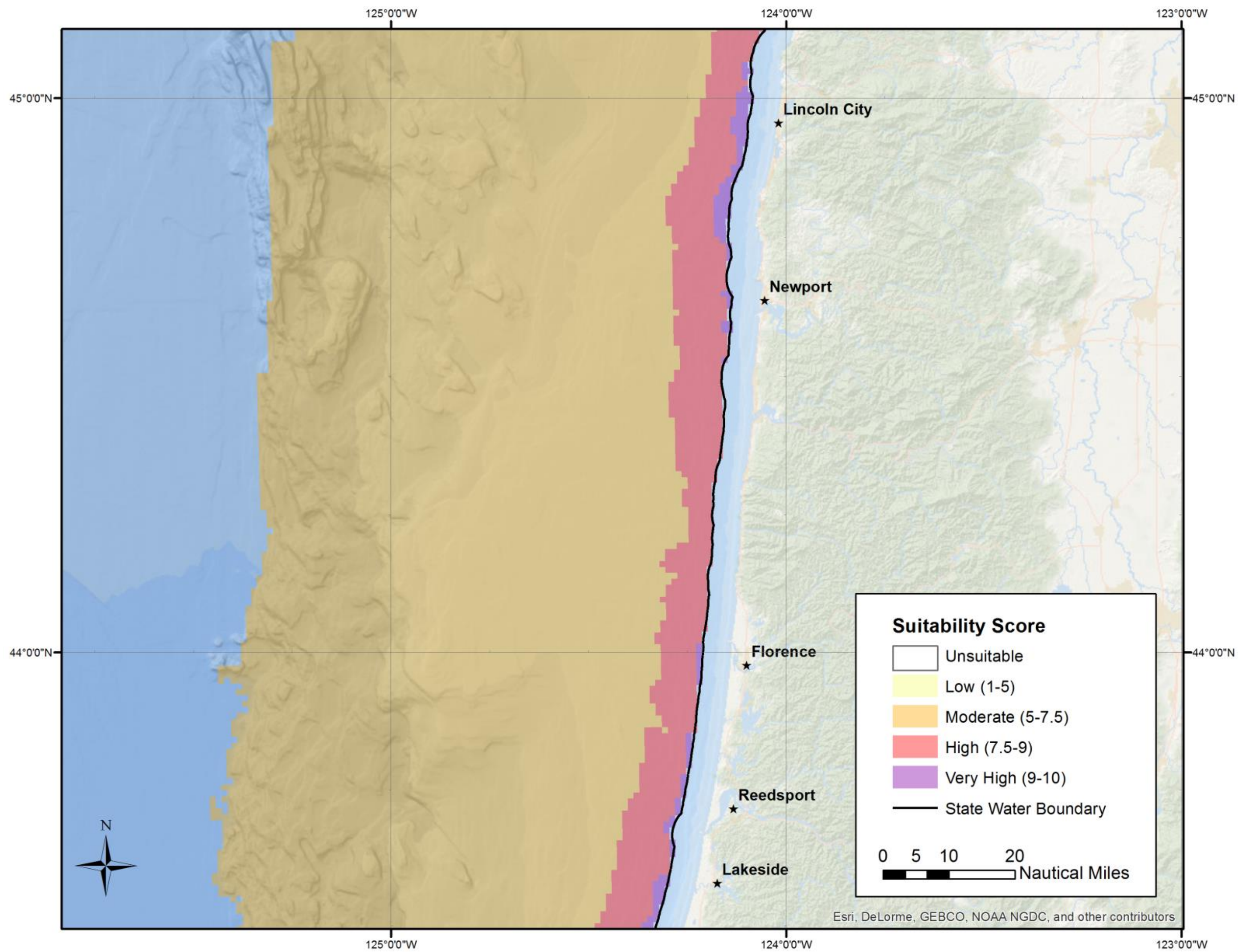

Figure I.5. Site suitability for mid-depth wave energy converter devices along the central Oregon Coast.

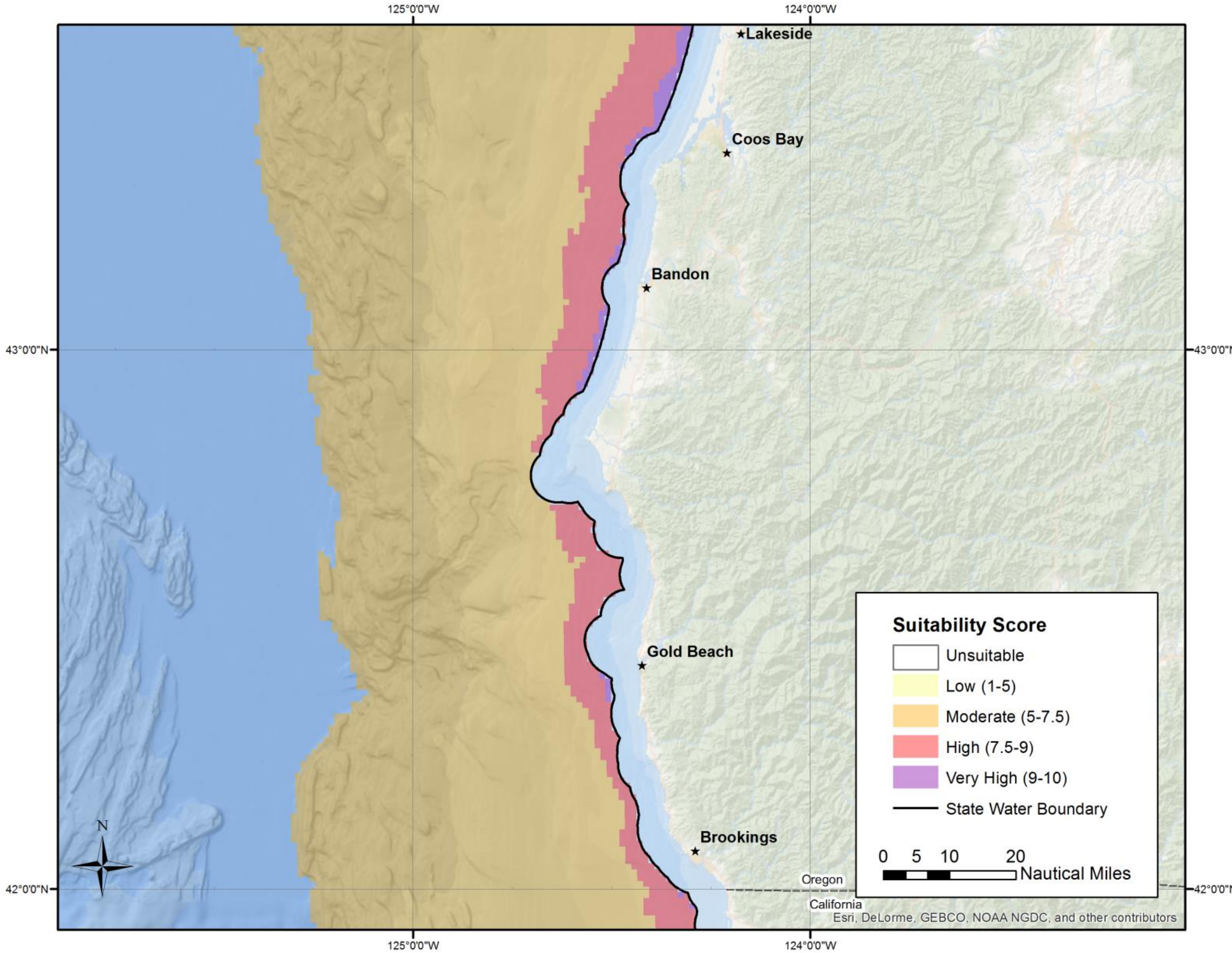

Figure I.6. Site suitability for mid-depth wave energy converter devices along the southern Oregon Coast.

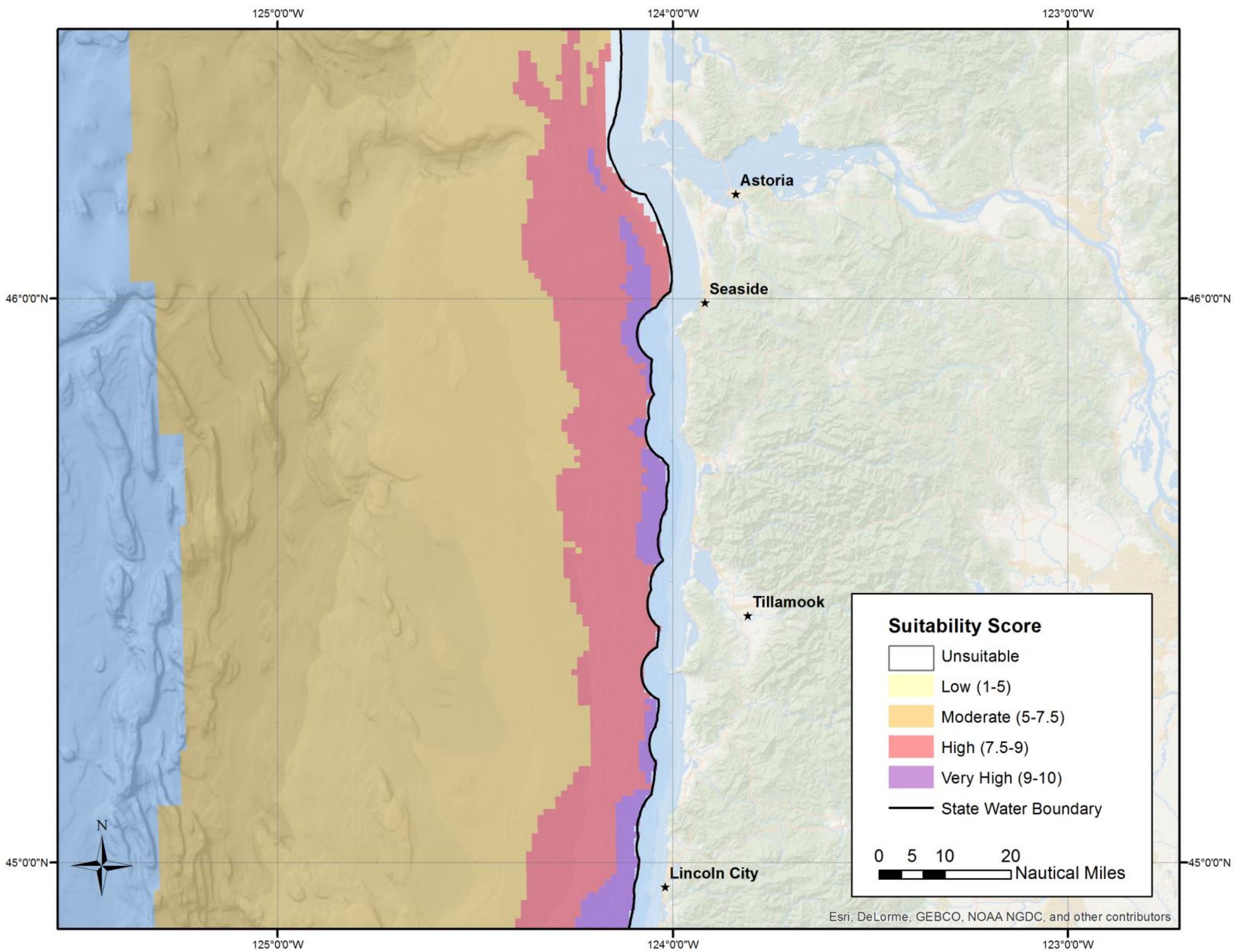

Figure I.7. Site suitability for deep-water wave energy converter devices along the northern Oregon Coast.

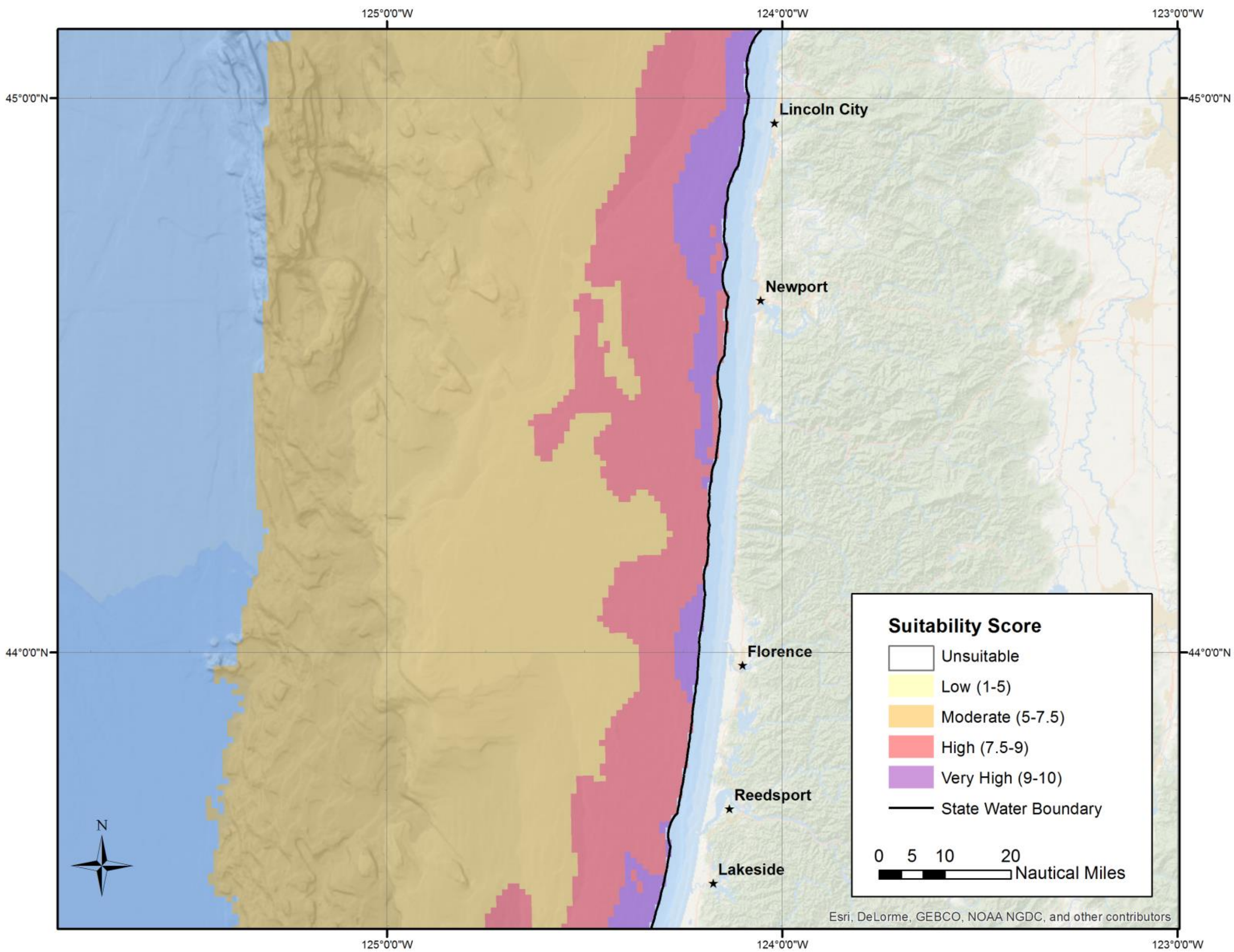

Figure I.8. Site suitability for deep-water wave energy converter devices along the central Oregon Coast.

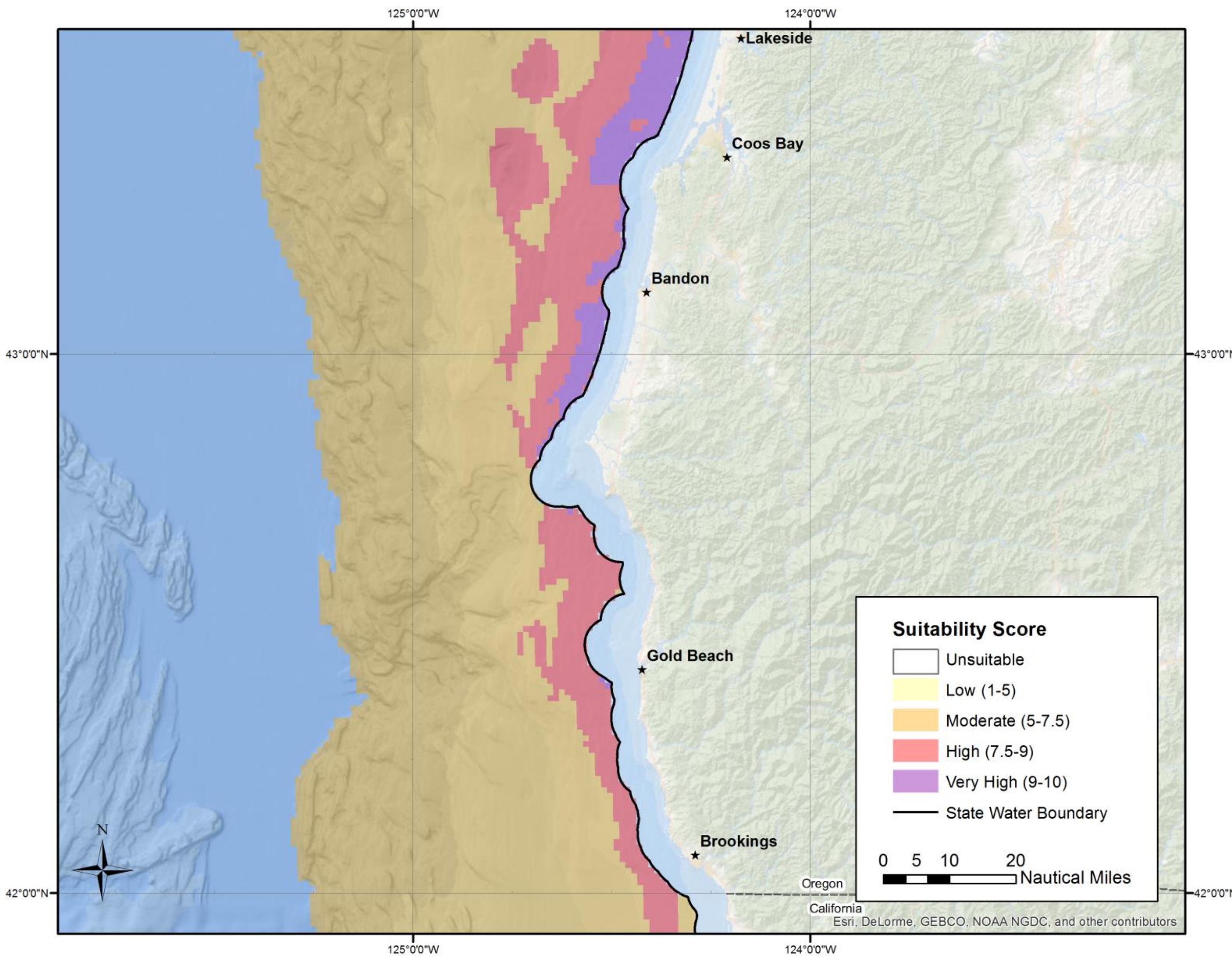

Figure I.9. Site suitability for deep-water wave energy converter devices along the southern Oregon Coast.

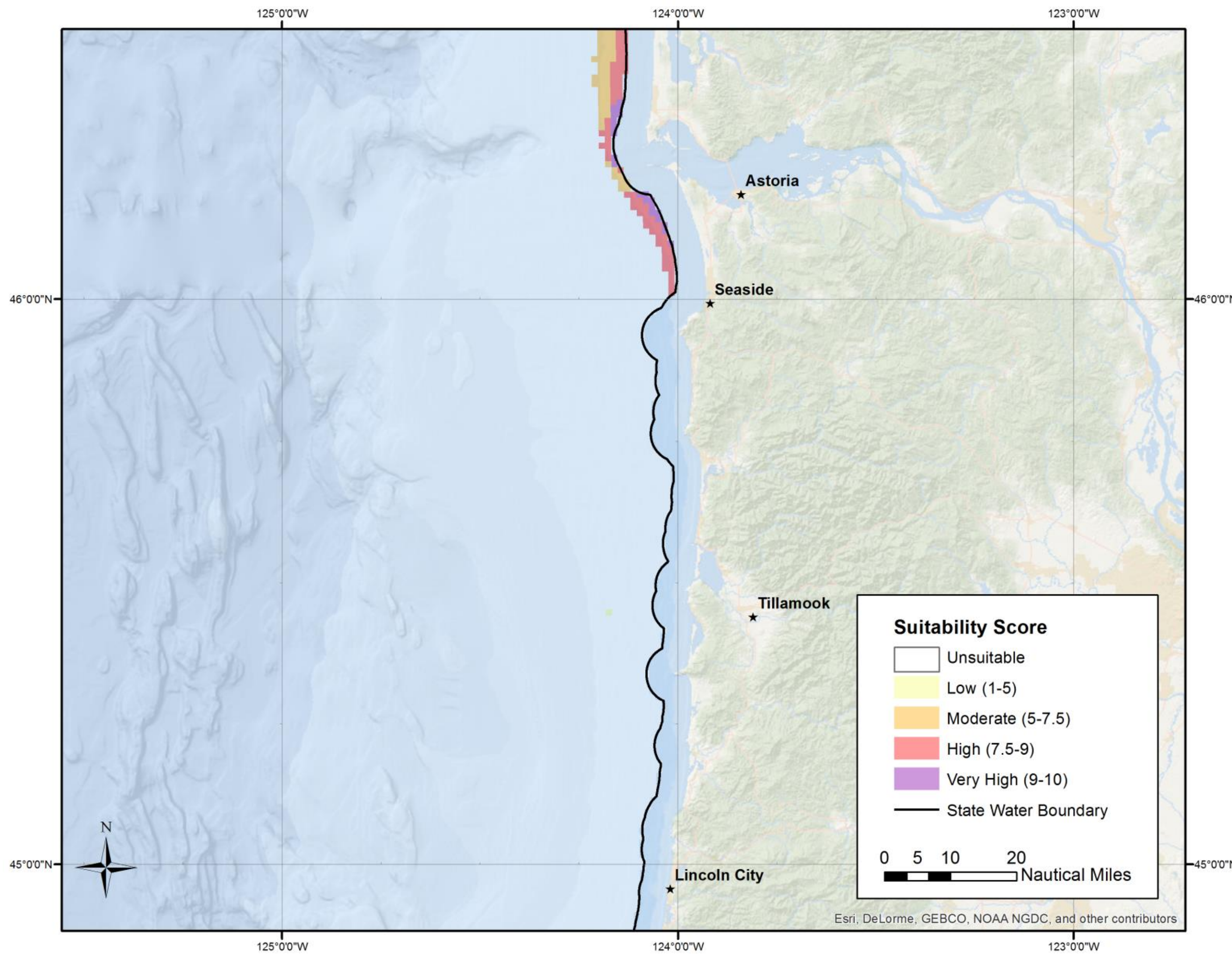

Figure I.10. Site suitability for monopile wind energy devices along the northern Oregon Coast.

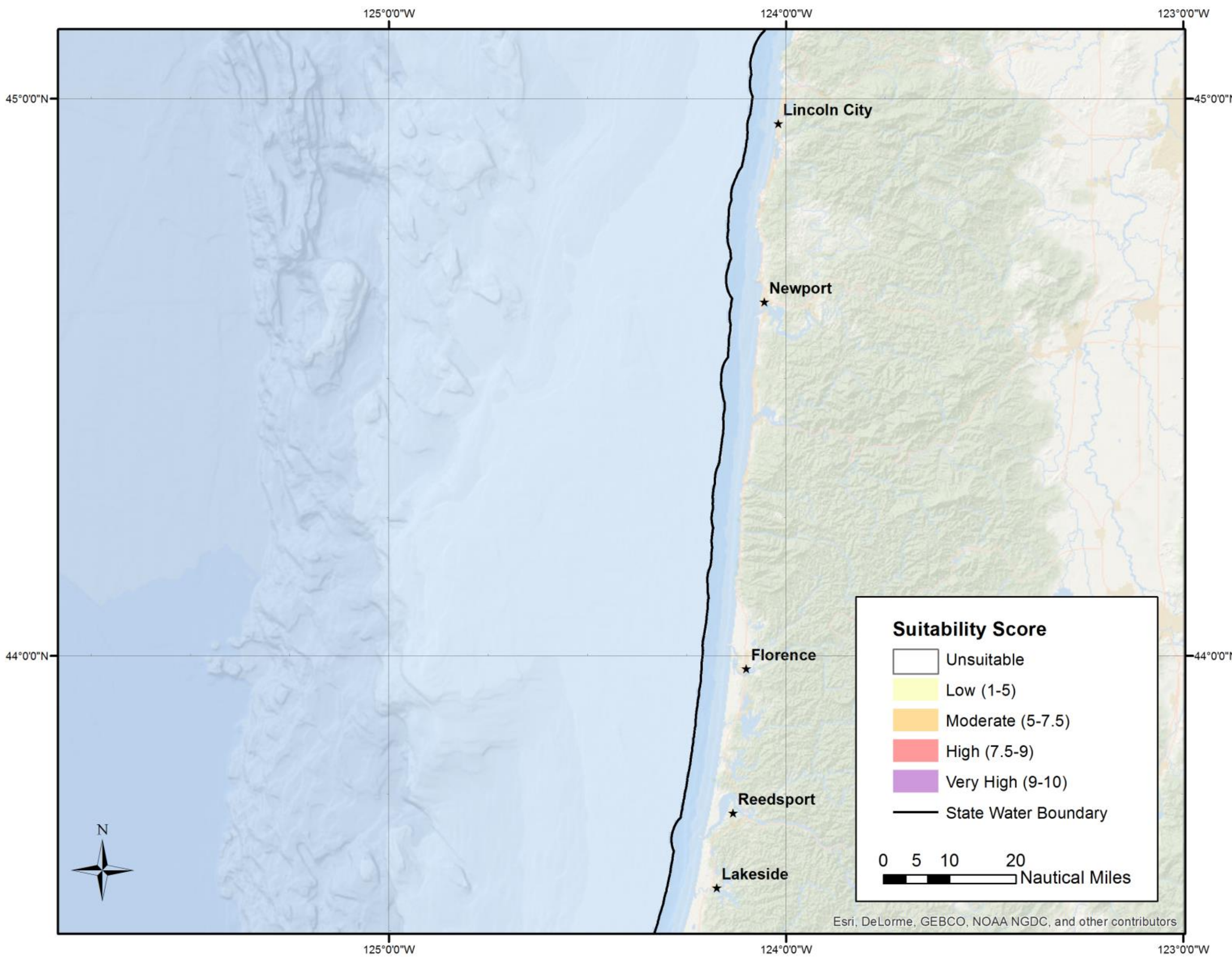

Figure I.11. Site suitability for monopile wind energy devices along the central Oregon Coast.

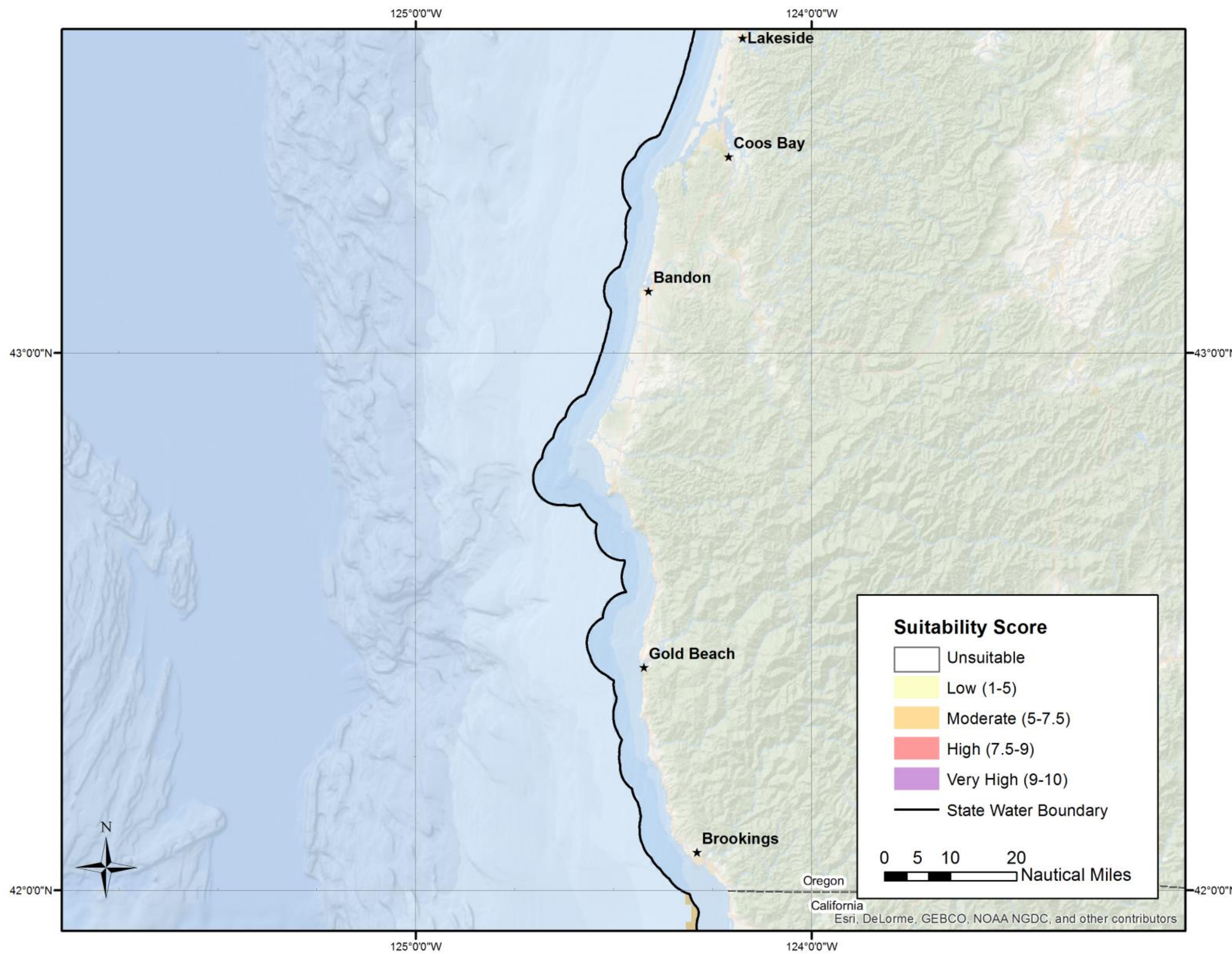

Figure I.12. Site suitability for monopile wind energy devices along the southern Oregon Coast.

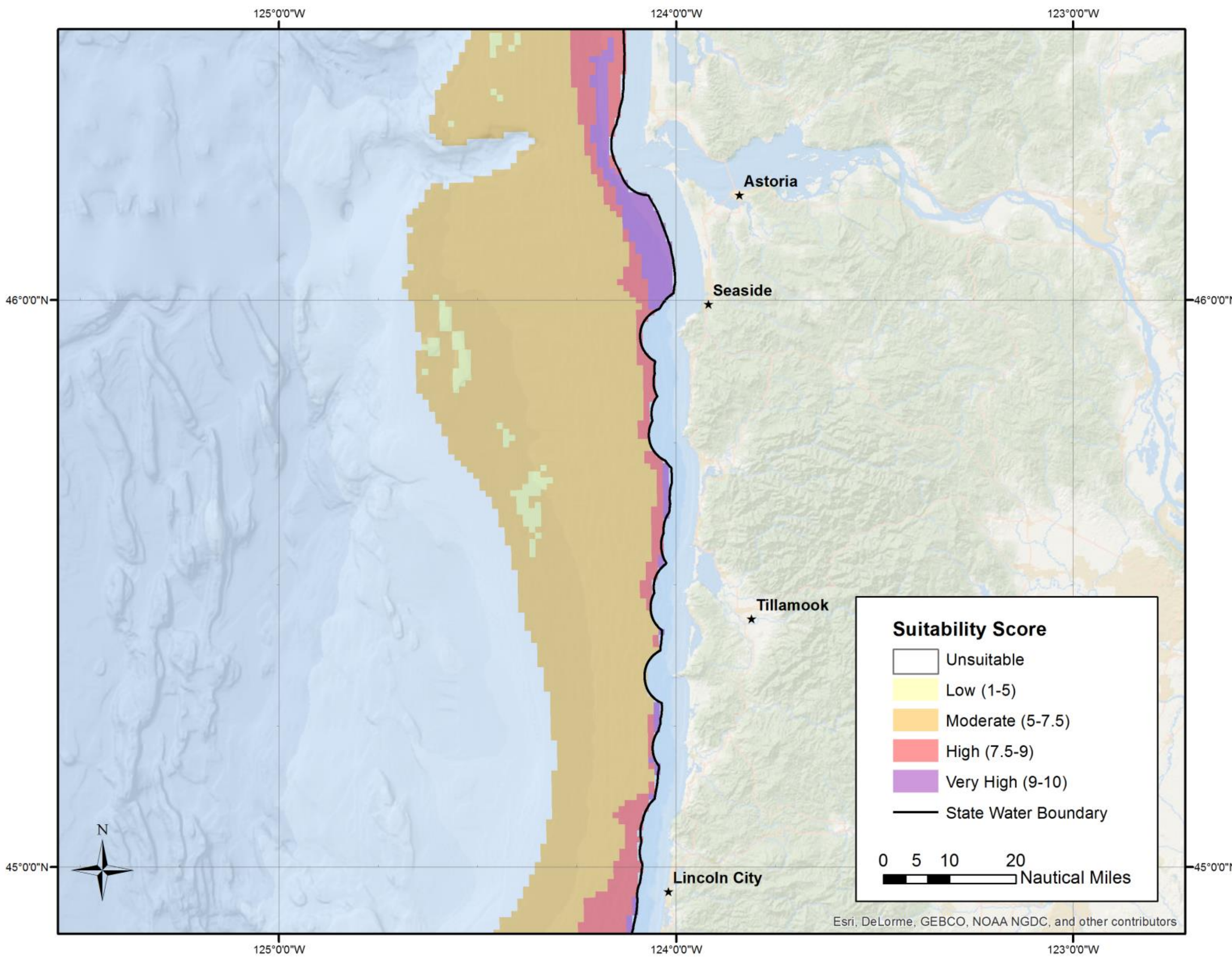

Figure I.13. Site suitability for jacket/tripod wind energy devices along the northern Oregon Coast.

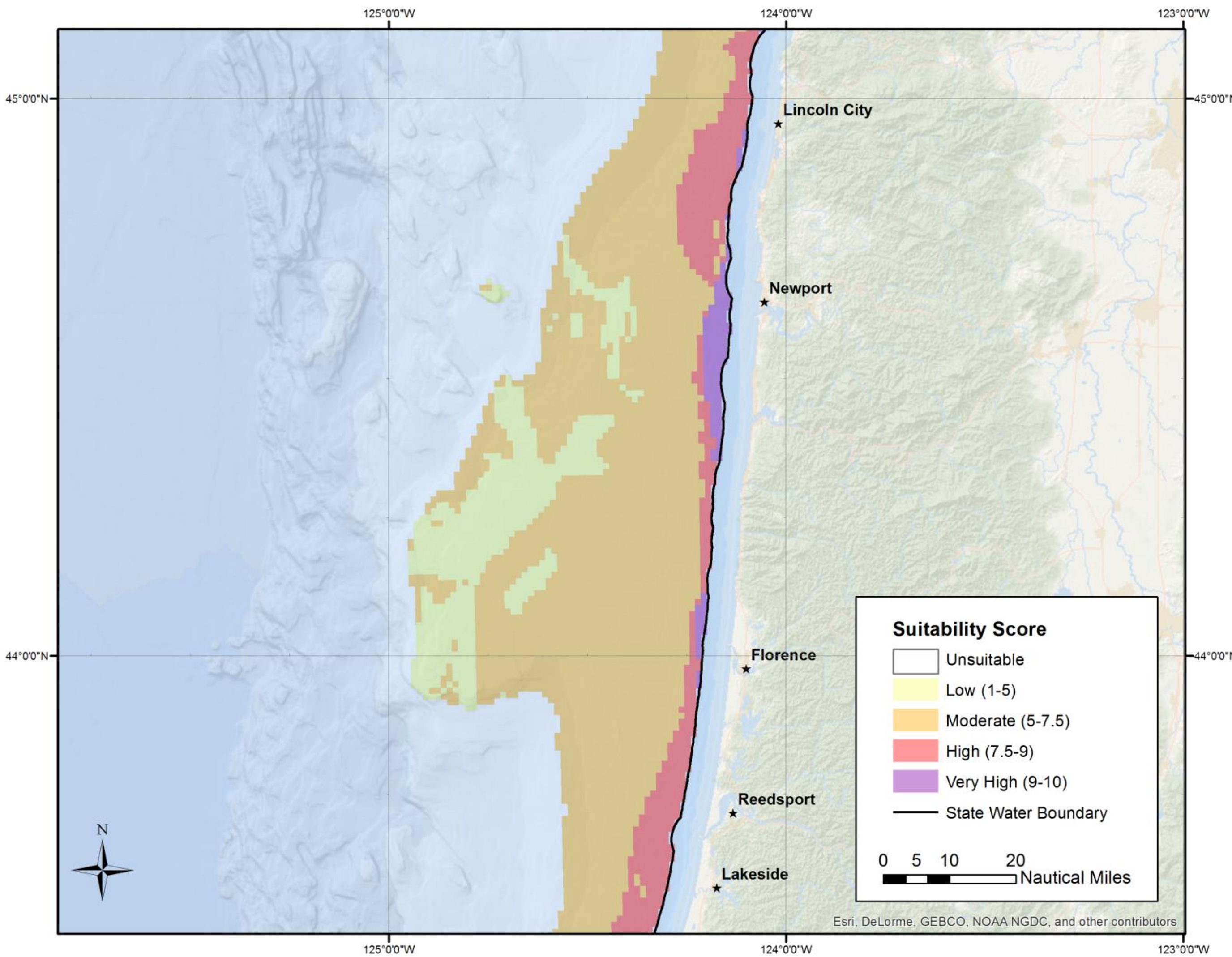

Figure I.14. Site suitability for jacket/tripod wind energy devices along the central Oregon Coast.

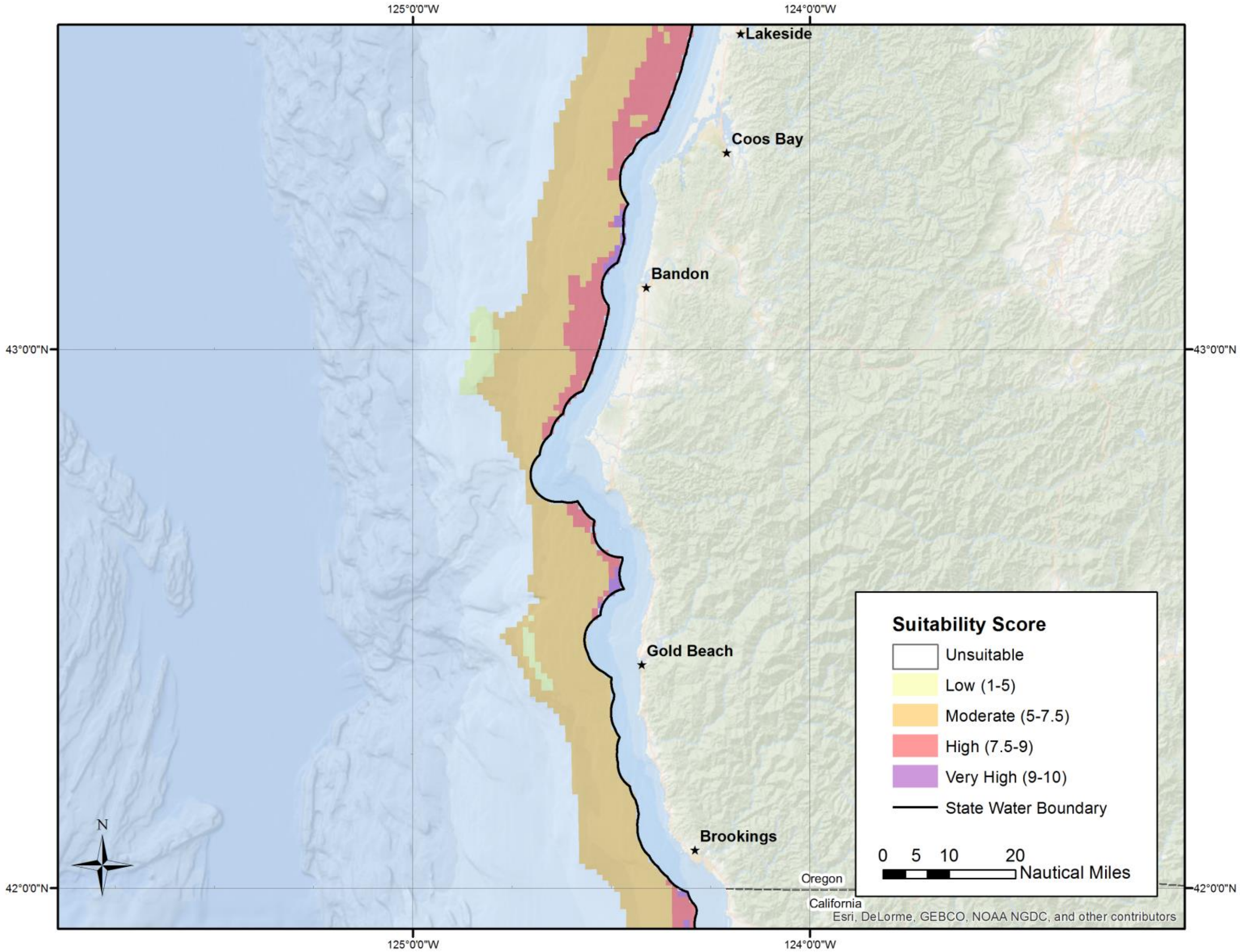

Figure I.15. Site suitability for jacket/tripod wind energy devices along the southern Oregon Coast.

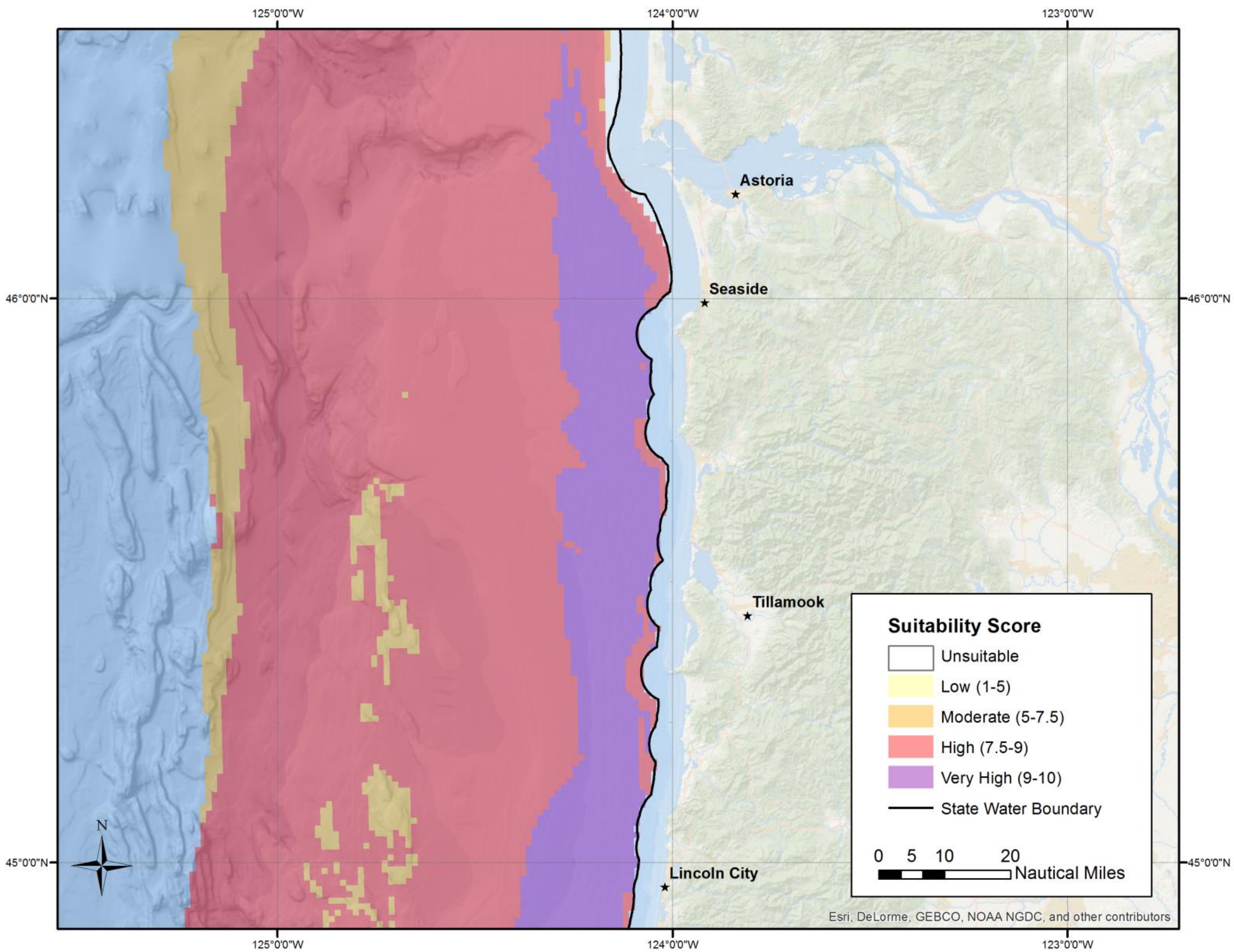

Figure I.16. Site suitability for floating platform wind energy devices along the northern Oregon Coast.

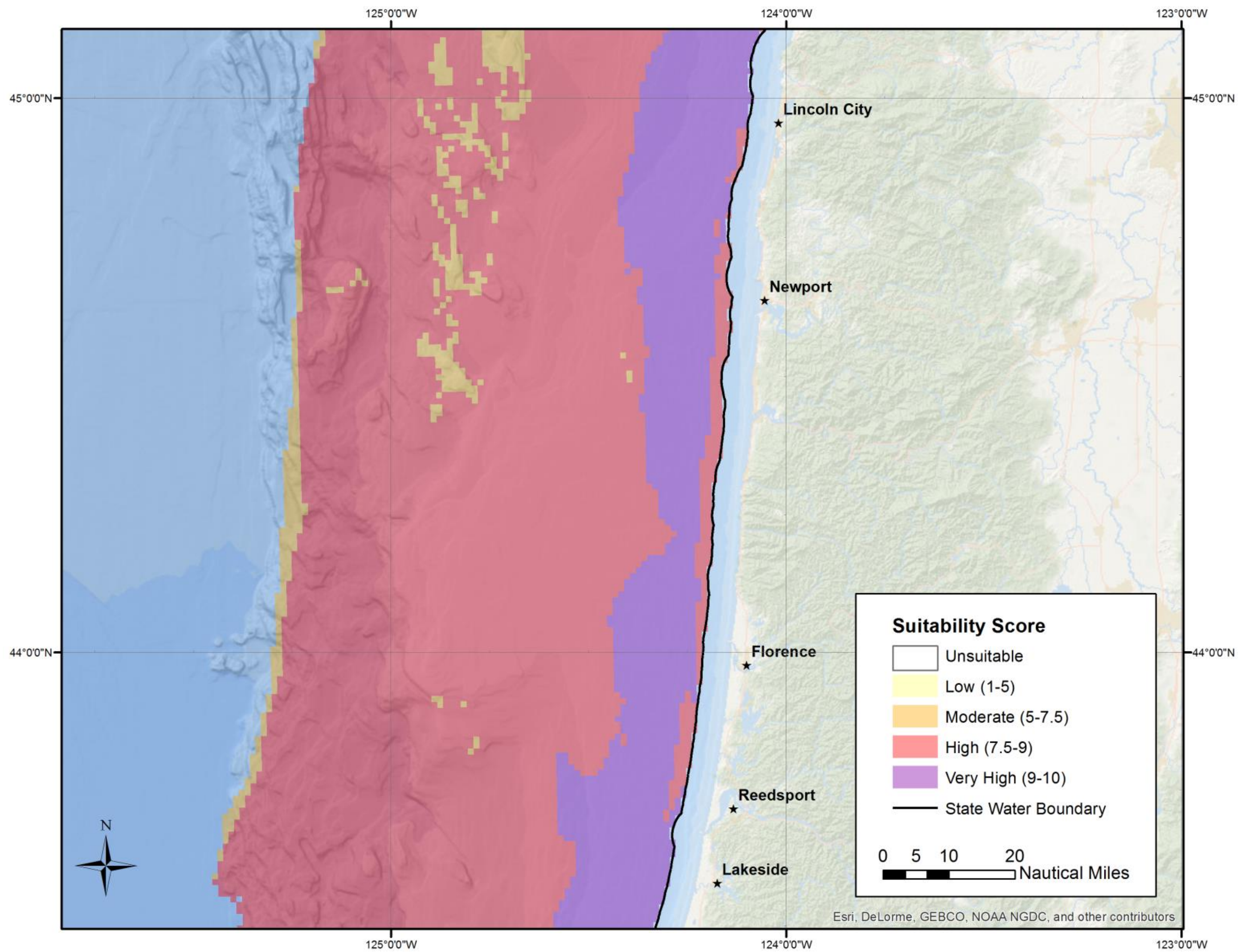

Figure I.17. Site suitability for floating platform wind energy devices along the central Oregon Coast.

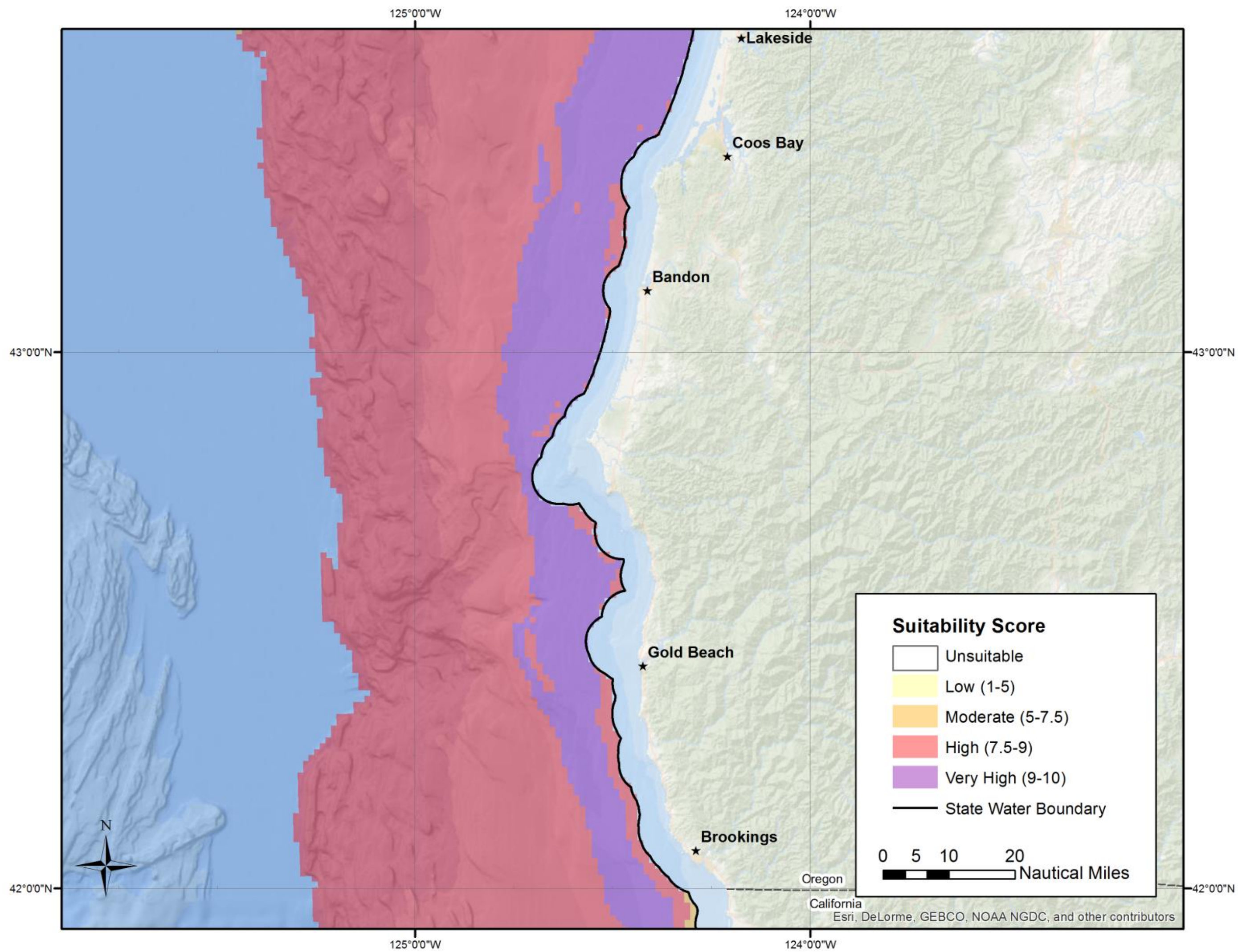

Figure I.18. Site suitability for floating platform wind energy devices along the southern Oregon Coast

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under US administration.

The Bureau of Ocean Energy Management

As a bureau of the Department of the Interior, the Bureau of Ocean Energy Management (BOEM) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS) in an environmentally sound and safe manner.