An Approach for Mapping Ecologically Important Areas Off the Washington Coast

A project completed under Washington Department of Natural Resources Contract Number IAA 14-143 in support of Washington Marine Spatial Planning

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NOTE ON REVIEW STATUS OF THIS REPORT: Because of slower progress than anticipated over the course of the year, we were unable to make time for the iterative review process we had contemplated having with the Coastal Treaty Tribes, State Ocean Caucus, Washington Coastal Marine Advisory Council (WCMAC), and the Marine Spatial Planning Science Advisory Panel. As a consequence, we have requested that DNR not distribute this draft widely at this time or upload the maps to the MSP website until we have had time for more review and discussion with partners. We will continue seeking feedback from the partners listed above and anticipate updating the substance of this report and the maps in response.

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Overview

The purpose of this project was to use existing data to identify ecologically important areas off the Washington coast. There are many ways to approach the question of ecological importance. The one we take here focuses on animals, especially those of interest to fisheries and wildlife management, and where the existing data suggests they use the Marine Spatial Planning (MSP) Study Area most. Two of the layers, mapping kelp forests and rocky reefs, focus on habitat types instead of animals. Yet these habitat types are known to be important to several animal species and are not well surveyed.

To facilitate this analysis, we divided the Study Area into a hexagonal grid where each cell (“hexagon”) is one square mile in area. There are two basic steps in our approach. First, we converted the available data to maps (a.k.a. “layers”), overlaid them with the hexagon grid, and assign ecological importance scores to the relevant hexagons using a scale of 1 to 5. The highest ecological importance is indicated by a 1 and the lowest by a 5. The method of assigning the scores is described below for each layer. Where possible we also ranked the uncertainty associated with our scores on a scale of 1 to 3 with 3 being the highest uncertainty. The second step then involved overlaying the importance and uncertainty scores together and evaluating patterns across the Study Area.

A second focus of this project is on comparing the ecologically important area maps to those produced to show locations of potential alternative energy development. We have developed the proof of concept for doing so, and for comparing how the two may relate under different scenarios of energy development. Not having had time for sufficient review with MSP partners, for this report we only display some basic comparisons. We will continue pursuing this aspect of the project as we continue seeking review and feedback.

Areas and Species Covered

The MSP Study Area covers a large area and many habitat types. To help described these areas, we use terminology based on the Coastal and Marine Ecological Classification (CMEC) system and divide the Study Area into beach, nearshore, offshore, and oceanic zones or strata (Table 1 and Figure 1). The habitats beneath the tides can be further divided generally between those in the benthic zone of the seafloor and those in pelagic habitats of the ocean surface and water column.

Estuaries are a separate habitat type that can be further subdivided into different classes and types. However, we exclude all estuaries from our main analysis because mapping key areas within estuaries would require finer-scale resolution than current data can support. Existing data would allow us to map certain features within estuaries, like marine mammal haulouts, yet we could not identify which areas within an estuary would be most ecologically important to species like Green Sturgeon and Dungeness Crab. Years of research have nonetheless identified estuaries as being of key importance to many species. We consider the estuaries to be of the highest ecological importance, as high or higher than the any areas we identify as importance elsewhere in the Study Area.

Table 2 lists the 33 map layers we used in the project. Diverse types of data inform these layers, from scientific surveys, to statistical species distribution models, and logbooks from fishing vessels. We describe each layer and its supporting data individually and in more detail below. Figure 1 provides a view of how many layers apply to different parts of the Study Area. As shown, the outer continental shelf and break between the shelf and continental slope are covered by the most layers.

The focus was, again, on species for which data existed that was readily available for mapping. Some of these layers cover multiple species, yet there are many species we could not map because of a lack of data. Data for fish in the pelagic areas of the Study Area are particularly lacking. We are unable to map the distributions of highly important species like krill, Pacific Herring, Northern Anchovy, Pacific Sardine, and Albacore Tuna.

Another consideration for inclusion in the project was that the data had to provide contrast to the picture of ecological importance. For instance, available data may show that a species uses broad areas of the MSP Study Area and yet may not provide information on which areas may be more important than others. Leatherback Sea Turtles provide an example. The entire Study Area has been designated as critical habitat for the species under the Endangered Species Act. The Study Area has therefore be determined to be ecologically important to this species. Yet if we included the Leatherback critical habitat area in our maps, it would add no contrast to the results. The situation is similar for Green Sturgeon and large whales like Gray and Humpback Whales. The MSP Study Area is clearly important to these species and all areas are of some baseline ecological importance. The maps we provide should be viewed as providing contrast on top of that baseline.

Table 1. Coastal and Marine Ecological Classification (CMEC) subsystems used to stratify the planning area.

System	Subsystem	Depth	Tidal zone
Marine	Marine Nearshore	Shore to 30 m depth	Marine Nearshore Supratidal
			Marine Nearshore Intertidal
			Marine Nearshore Subtidal
	Marine Offshore	30 m depth contour to shelf break (100-200 m depth)	Marine Offshore Subtidal
	Marine Oceanic	Area seaward of the shelf break (> 100-200 m)	Marine Oceanic Subtidal

Table 2. List of data layers used in this analysis. For detail information about the data sources and how they were scored see Appendix I.

Title	Survey Methods/Dates	Season	Timespan of Data	Zone/ Strata
Bird and Mammal Data Layers				
Snowy plover	Transects and nest searches	April-Sept	2006-2013	Beach
Streaked horned lark	Transects and nest searches	April-Sept	2006-2013	Beach
Seabird Colonies	Colony counts	May – Aug	1970s - 2013	Beach, Nearshore

Title	Survey Methods/Dates	Season	Timespan of Data	Zone/ Strata
Seal/Sea Lion haulouts	Aerial	Year-round	1998-2013	Beach, Nearshore
Nearshore seabirds and marine mammals	Boat based line transect	May - July	2009-2013	Nearshore
Sea otter	Aerial	June	2012-2013	Nearshore
Winter bird and mammal encounter rates	Aerial	Feb - Mar	2011	Nearshore, Offshore
Seabird predicted abundance across 2 seasons – Black-footed Albatross – Northern Fulmar – Sooty Shearwater – Common Murre – Tufted Puffin – Marbled Murrelet	Modelled abundance surface using boat and aerial surveys results and environmental covariates.	1 season: Apr-Oct; 2nd season: Nov-Mar	1996-2013	Nearshore, Offshore, Oceanic
Fish, Shellfish, Crab, and Coral Data Layers				
Razor Claims	Beach survey locations	All	1997-2014	Beach, Nearshore
Dungeness Crab	Fishery logbooks	See layer description	2009/10 - 2012/13	Nearshore, Oceanic, Offshore
Groundfish: – Darkblotched Rockfish – Dover Sole – Greenspotted Rockfish – Longspine Thornyhead – Pacific Ocean Perch – Petrale Sole – Sablefish – Shortspine Thornyhead – Yelloweye Rockfish	Modeled abundance or probability of occurrence using bottom trawl survey information with covariates.	May – Oct	2003-2012	Offshore, Oceanic
Pacific Whiting	Fishery logbooks and observer records	See layer description	2001-2014	Oceanic, Offshore

Title	Survey Methods/Dates	Season	Timespan of Data	Zone/ Strata
Pink Shrimp	Fishery logbooks	See layer description	2003-2012	Oceanic, Offshore
Intertidal spawning forage fish spawning sites	Locations of beach spawning surveys		2003-2012	Oceanic, Offshore
Deep Sea Coral	Maxent species distribution model	All	several	Oceanic, Offshore
Important Habitat for Fish and Wildlife Data Layers				
Rocky Reefs/Hard benthic substrate types	Various	All	several	Nearshore, Oceanic, Offshore
Kelp	Polygons representing floating kelp beds derived from annual aerial photos.	Late summer	1989-2012	Nearshore

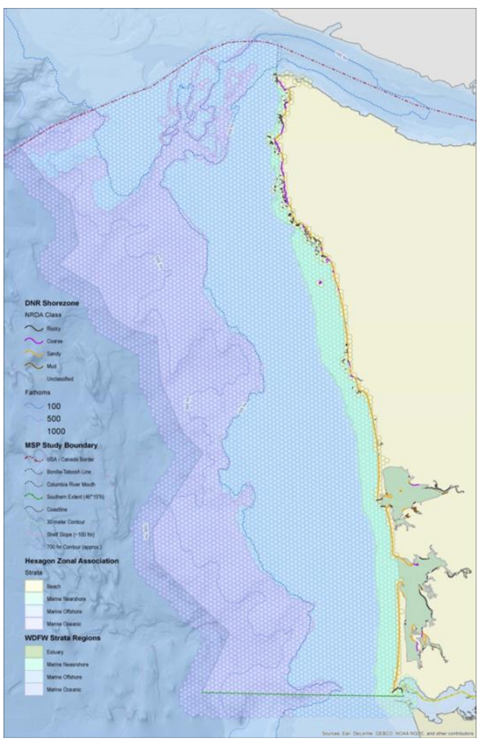


Figure 1. Map of the MSP Study Area and ecological strata for the Washington Coast.

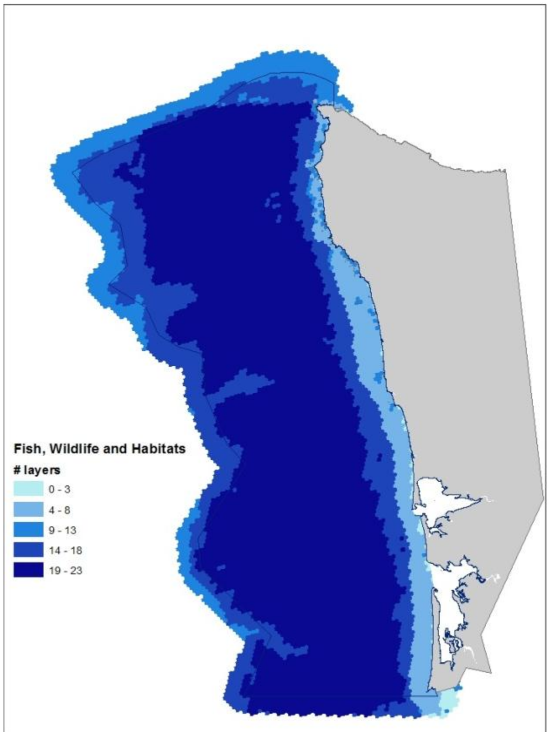


Figure 2. Count of layers applying across the MSP Study Area.

Views of Ecological Importance

Out of a desire for further review on this project, we keep the discussion of our results to a minimum for this report. We plan on elaborating on patterns and interpretations after we have more opportunity for review and discussion. To provide a broad overview of the information that we compiled, we present three types of maps, one provides the single highest importance score (minimum value) for each hexagonal cell. We refer to this as the minimum value map. In the second map, we provide counts of the number of high importance scores (1s and 2s) to provide information on areas important to many species – a "hot spot" map. The third type of map provides scores of low importance to many species (counts of low importance scores (4s and 5s) or a "cold spot" map. The latter two maps are influence by the number of layers applying to an area. As shown in Figure 2, the areas in the nearshore and outer offshore areas are covered by fewer layers.

Displaying information from multiple sources on a single map can be challenging and no one view can convey all perspectives. Figure 6 shows how we have been exploring making the individual layer scores available. We will work with our agency partners to ensure the information used to score maps like these are as transparent and publically available as feasible.

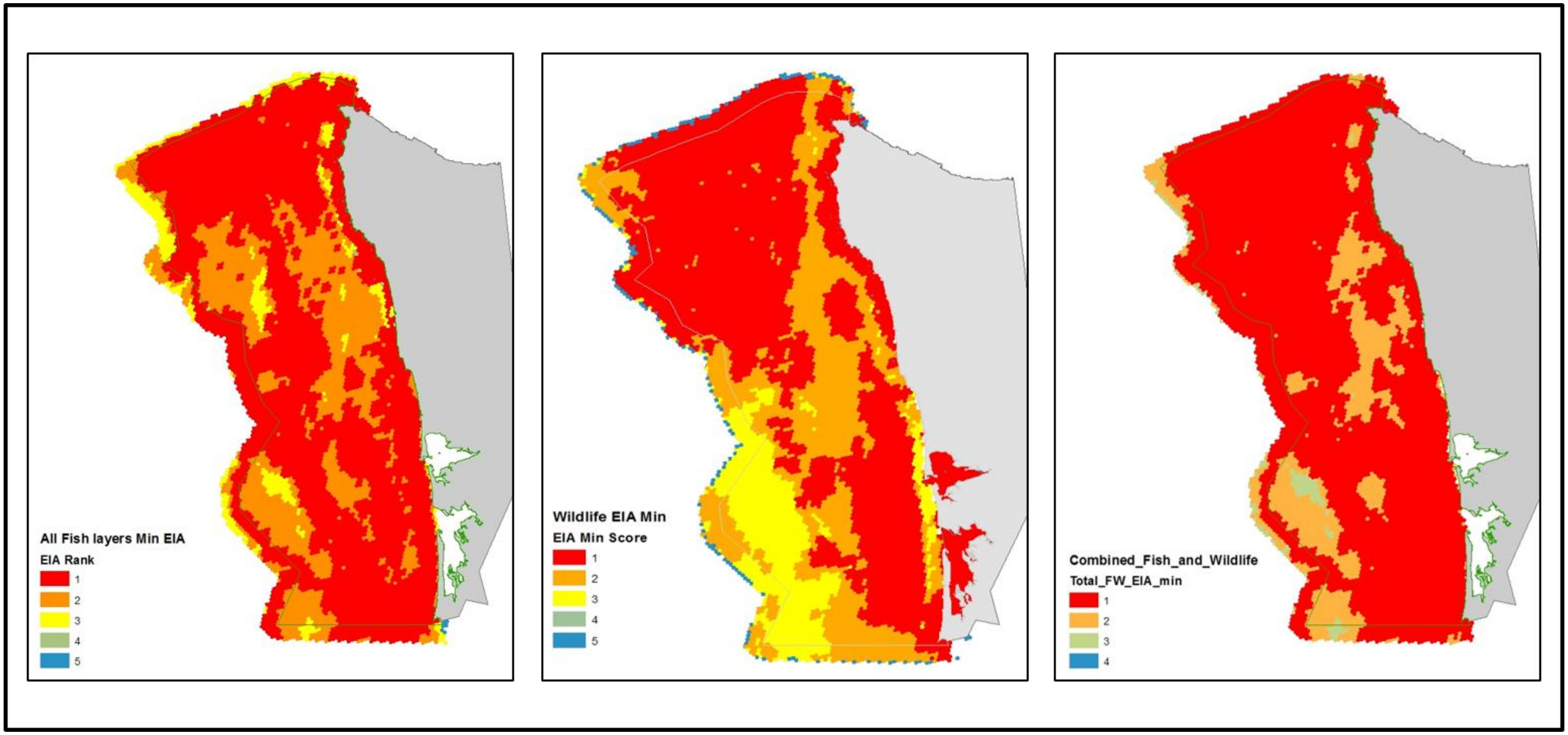


Figure 3. This set of maps shows the minimum importance score by hexagon for the fish and habitat layers (left), wildlife layers (center), and all layers combined (right). Note that when you combine layers, nearly every place within the planning area becomes important to at least on species/habitat layer.

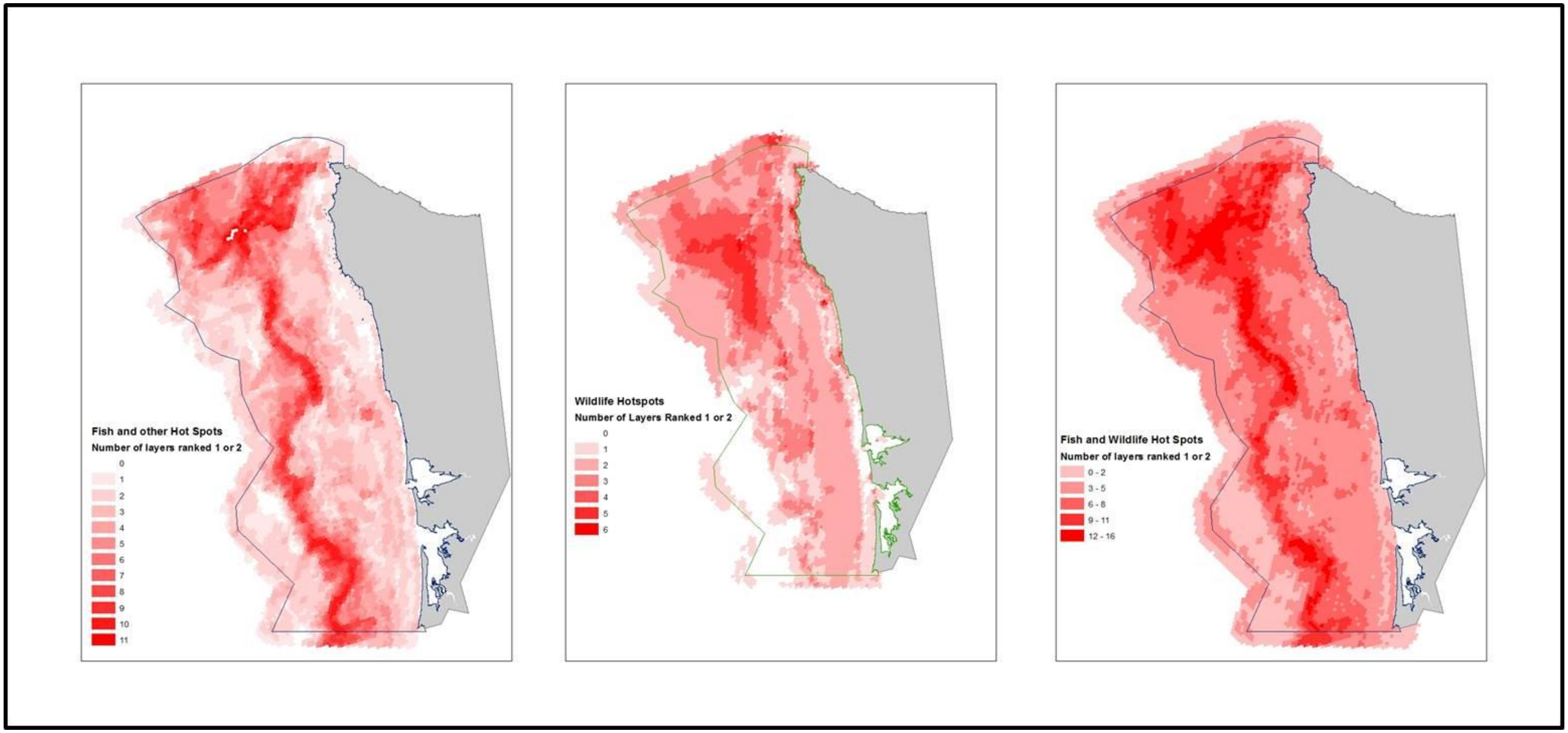


Figure 4. Counts of layers per hexagon with importance scores of 1 or 2 for the fish and habitat layers (left), wildlife layers (center), and all layers combined (right). Areas with darker colors have more layers with high importance.

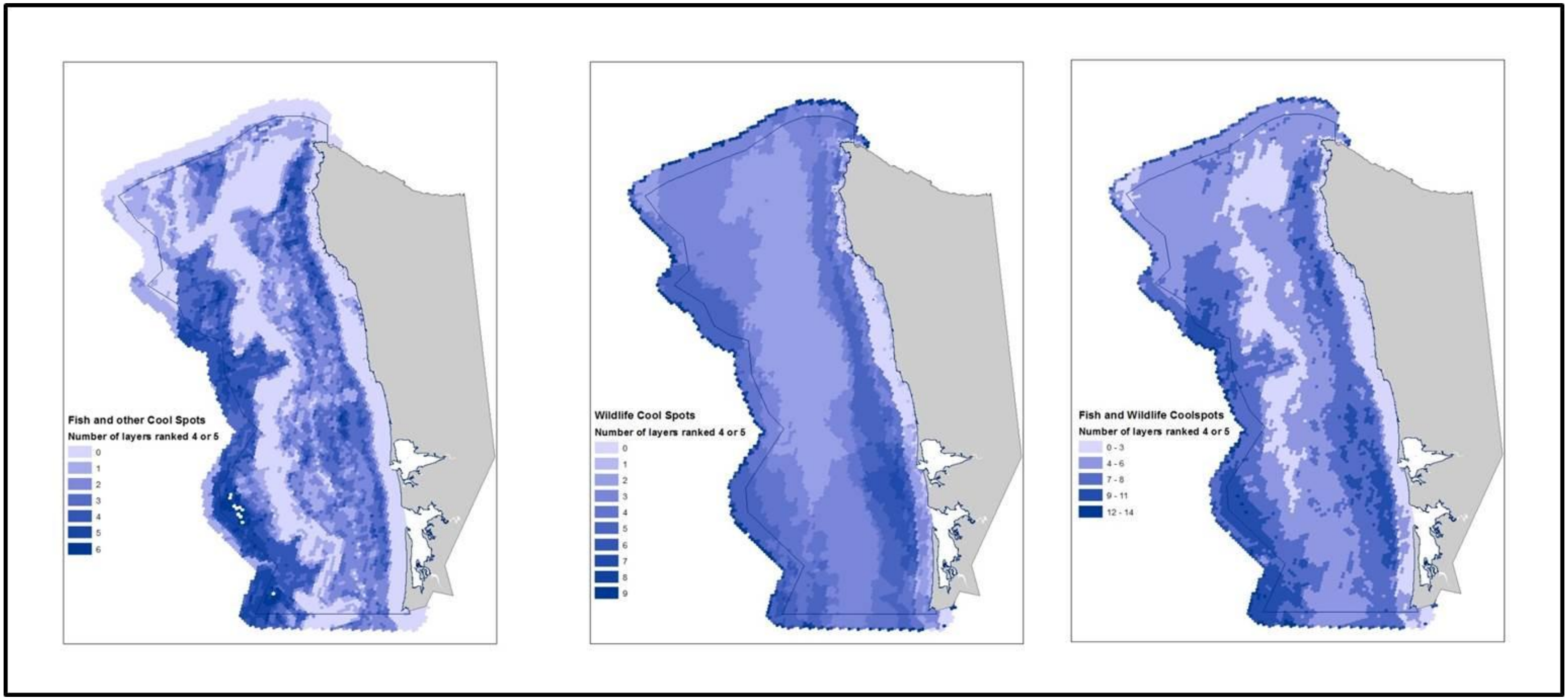


Figure 5. Counts of layers per hexagon with importance scores of 4 or5 for the fish and habitat layers (left), wildlife layers (center), and all layers combined (right). Areas with darker colors have more layers with high importance.

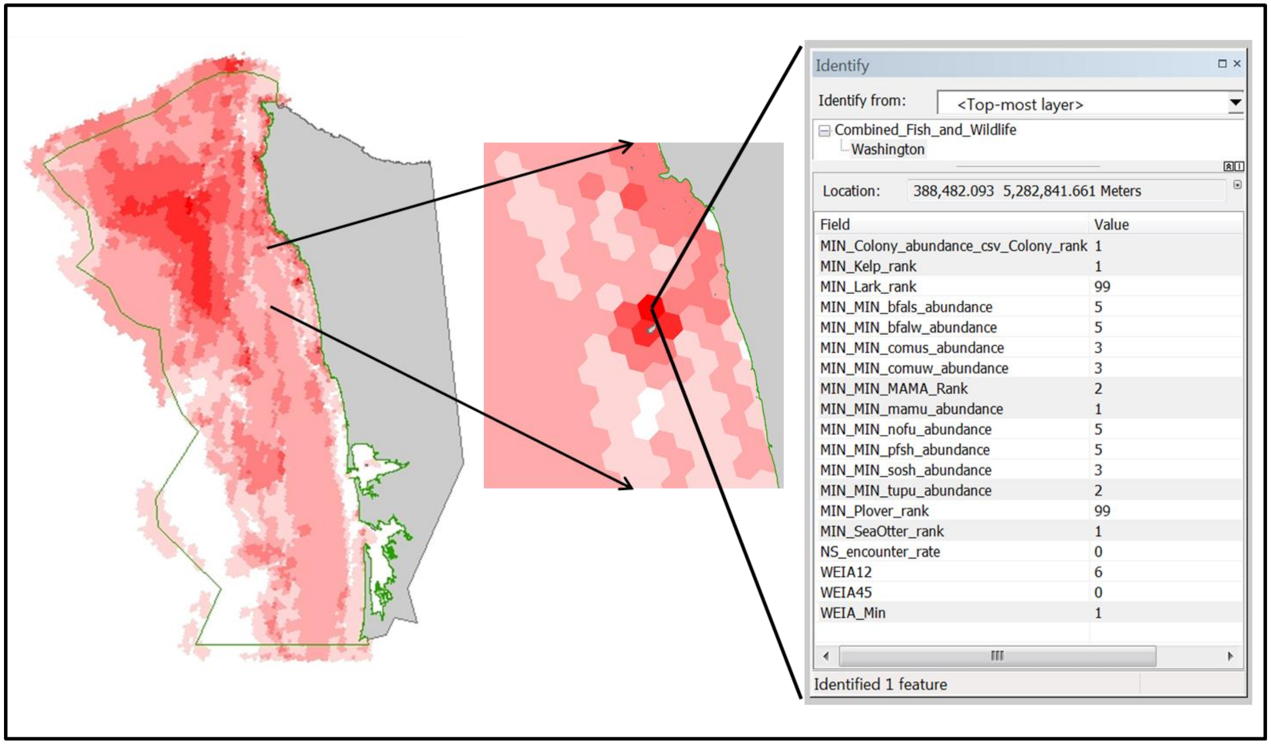


Figure 6. Demonstration of how we intend to make the underlying score information available in the ecological importance maps we upload to the MSP mapping portal.

Comparing Areas of Ecological Importance to Areas of Potential Energy Development

As described in the overview, a second aim of this project is to compare the ecological areas to scenarios of development. Our approach involves comparing our maps of ecological importance with scenarios derived from energy development produced by the Pacific Northwest National Laboratory and available on the state's MSP mapping tool. Figure 7 displays an example of such scenario involving wind and wave energy development. We will continue exploring methods of comparing the energy development and ecologically important areas as pursue further review and feedback of this approach with our MSP partners and tribal co-managers. We envision the approach as providing a coarse-level overview of how different types of energy development and ecology might interact off the Washington coast. The tool can be helpful for exploring trade-offs, yet the identification of optimal locations for energy development will require more than the tool can provide. We juxtapose the two maps in Figure 8 to highlight how the trade-offs involved can look quite different depending on which species are considered and the weight placed on them. More tools and analysis will be needed to more fully understand the trade-offs and impacts associated with development.

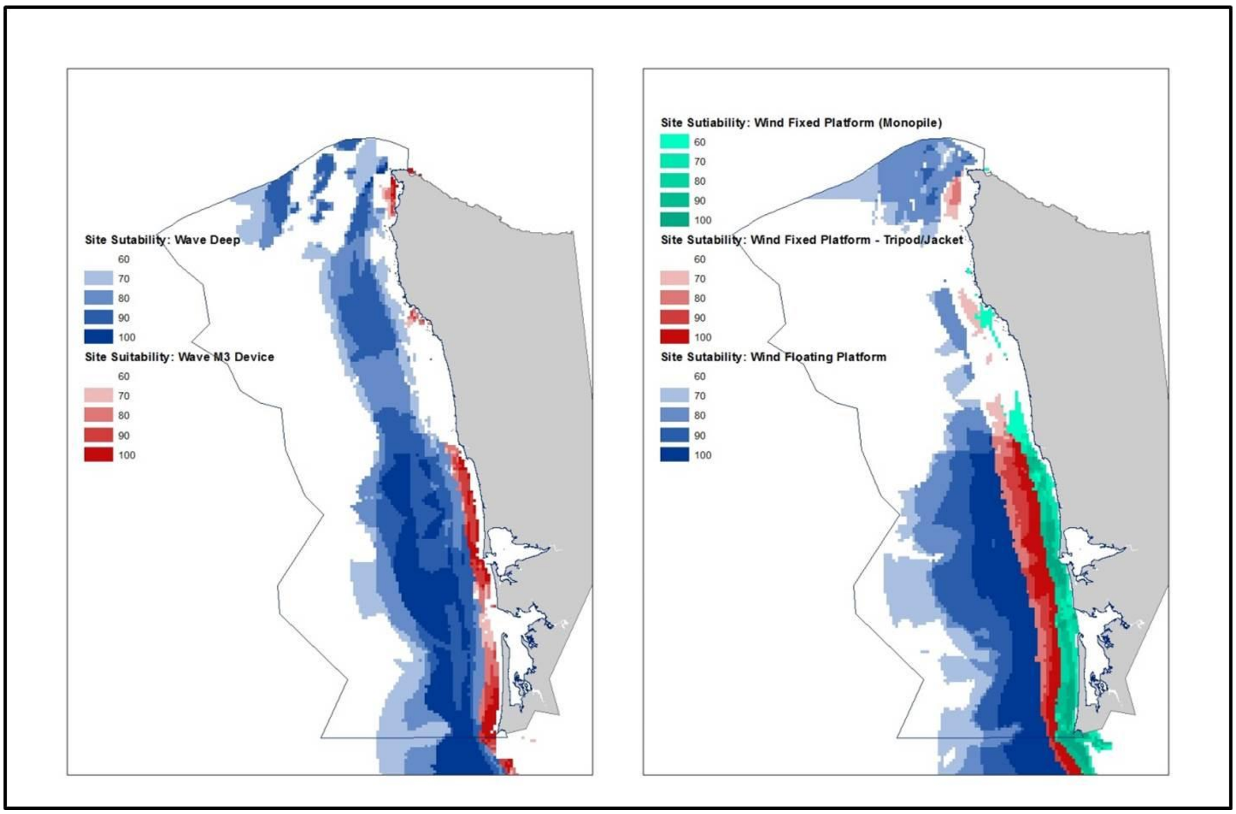


Figure 7. *These maps depict wave and wind energy development suitability. Overlaying these maps with fish and wildlife EIA maps such as in Figure 9 can be useful for identifying areas that are most suitable for energy development that also avoid areas of high importance to fish and wildlife.*

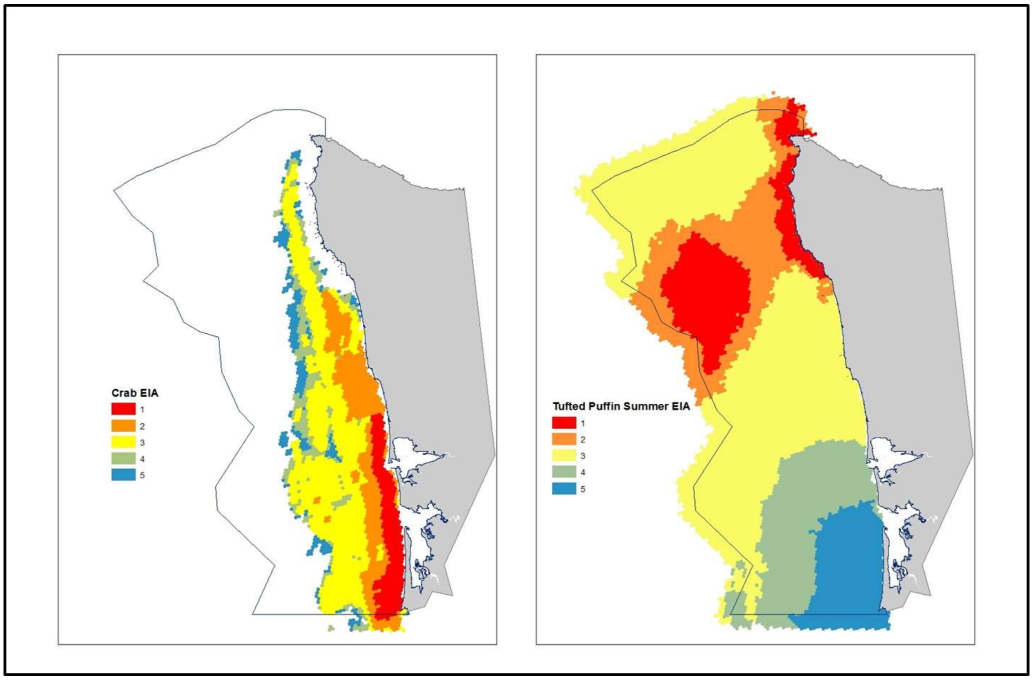


Figure 8. Which species are included or emphasized in a marine spatial planning context can have large influences on the resulting map. Here we show two species, Dungeness crab (left) and tufted puffin (right) that show large contrast in how they use different areas of the MSP Study Area.

Description of the Individual Map Layers

Wildlife

Nearshore seabirds and marine mammals at sea surveys

Source: Raphael et al. (2007) and Duff et al. (2014).

Goal of data gathering effort: intent of this annual survey effort is to estimate the population size and trend of the federally threatened marbled murrelet. However, all birds and mammals encountered during the survey are recorded.

Method: line transect or Distance sampling (Buckland 2001, 2004, Raphael et al. 2007) from boats

Area surveyed: entire outer coast out to 5 or 8 km depending on the Strata

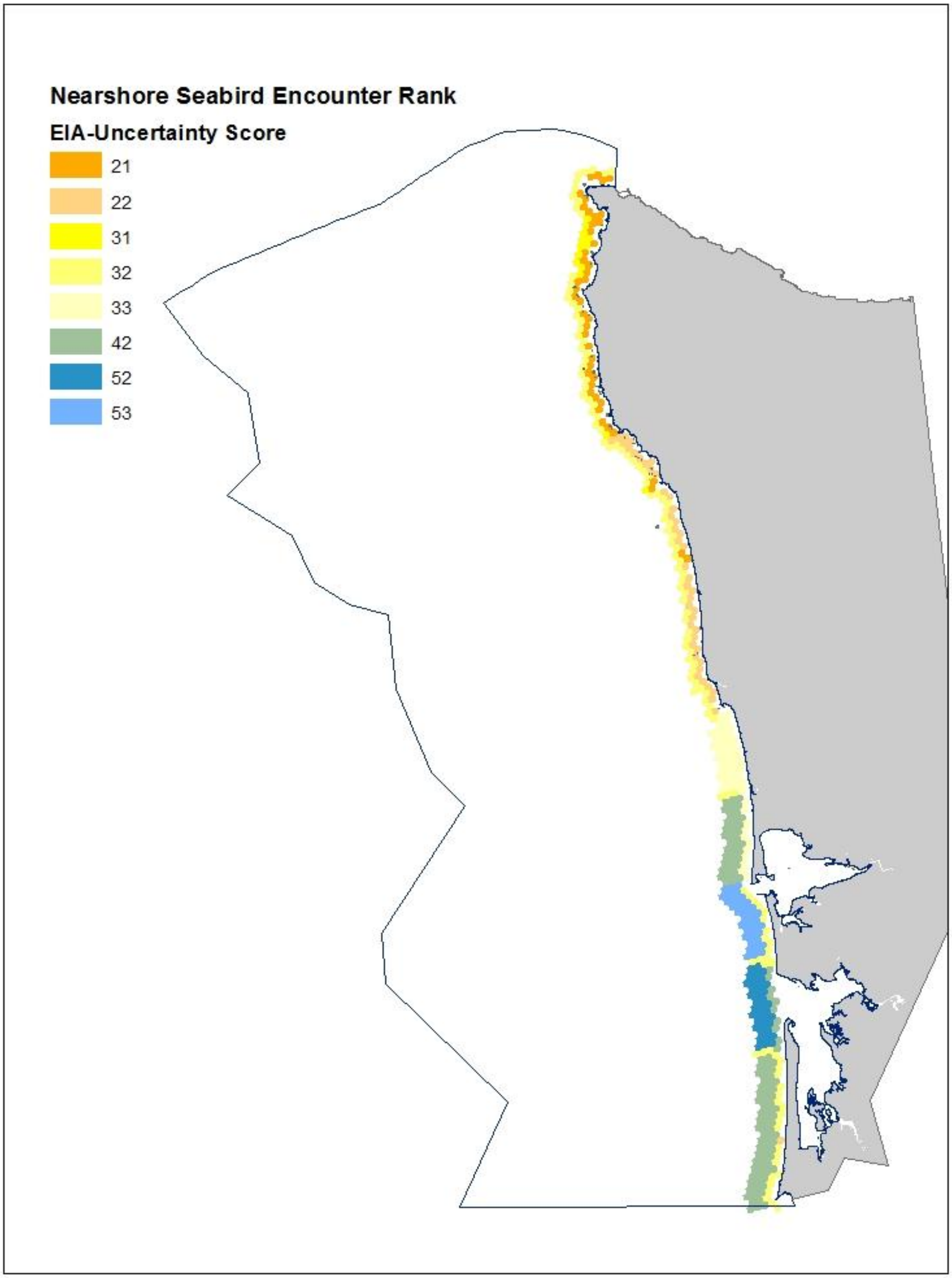
Years of data included: 2009-2013 (intended to provide the most recent distribution and abundance information)

Species included: We only included relatively abundant mammals and birds that breed locally and are more abundant in the nearshore (because this is a nearshore and spring/summer effort). The 9 species include: Cassin's auklet, ancient murrelet, rhinoceros auklet, Brandt's cormorant, double-crested cormorant, pelagic cormorant, pigeon guillemot, harbor seal, and harbor porpoise. Because of the duplication between the “predicted seabird abundance” layers and this effort, we dropped the marbled murrelet, tufted puffin, and common murre from this layer.

Data used: Annual average number of birds/mammals encountered by species per km traveled in both nearshore and offshore subunits of 20 km long (north-south) and 6-8 km wide primary sampling units.

Calculating the importance score: Each of the 9 species distributions of the yearly average encounter rates per nearshore and offshore subunits were binned in scores 1 – 5 based on quantiles (0-10%, 10-25%, 27-75%, 75-90%, 90-100%), respectively. In other words areas with average abundance in the top 10% for all areas along the outer coast received a score of “1”. Areas with average abundance in the bottom 10% along the outer coast received a score of “5”. We then combined all 9 layers and aggregated into each hexagon. If 5 or more (greater than 50% of all 9 species) species in a hexagon scored a “1”, the hexagon was given an overall importance score of “1”. If 5 or more (greater than 50% of all 9 species) species in a hexagon scored a “2” or a “1”, the hexagon was given an overall importance score of “2”. If 5 or more (greater than 50% of all 9 species) species in a hexagon scored a “3” or “2” or “1” the hexagon was given an overall importance score of “3”. If 5 or more (greater than 50% of all 9 species) species in a hexagon scored a “4” or “3” or “2” or “1” the hexagon was given an overall importance score of “4”. All other hexagons were scored a “5”.

Calculating the uncertainty score: We calculated each subunit’s (nearshore and offshore) coefficient of variation using the five yearly averages for each subunit for each species. We then divided the distribution of these coefficients of variation from all subunits for each species into the following relative groupings: high uncertainty (score “3”; upper 25% of CVs distribution), medium uncertainty (score = “2”; 25-75% of the CVs distribution), and low uncertainty (score = “1”; lowest 25% CVs distribution).


Nearshore Seabird Encounter Rank
EIA-Uncertainty Score
21
22
31
32
33
42
52
53

Sea Otter Concentration Areas

Source: Annual survey reports (e.g., Jameson and Jeffries 2014) and the geodatabase of Duff et al. (2014).

Goal of data gathering effort: Provide a population estimate and annual trend for an introduced population on Washington's coast. We used summer concentration areas (polygons) from summer aerial surveys conducted during 2012 and 2013 (Duff et al. 2014).

Method: Summer (July) aerial surveys. All otters enumerated by direct counts and by photographing larger groups and enumerating the group size by counting the individuals in the photograph.

Area surveyed: Coast-wide

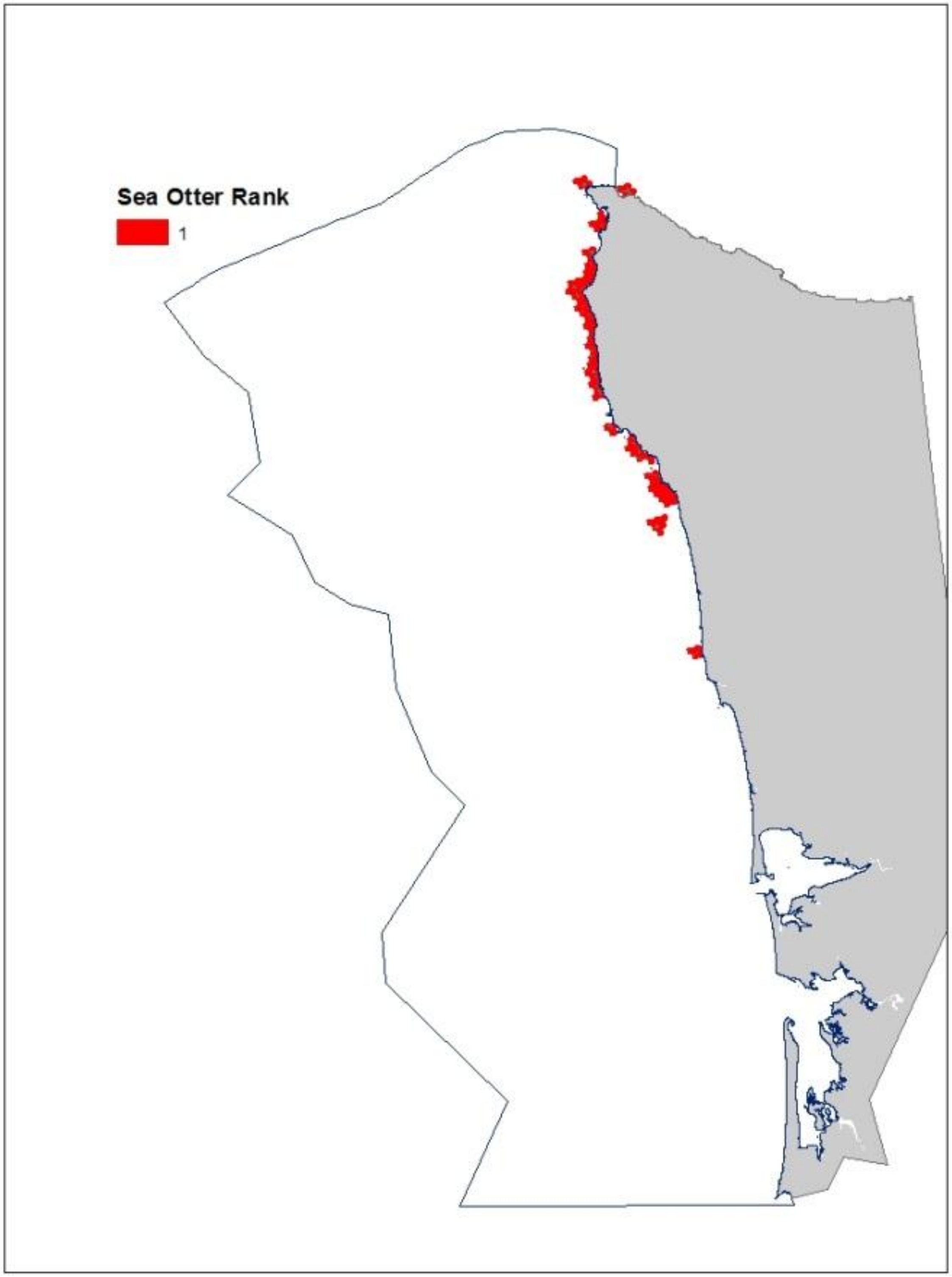
Years of data included: 2012-2013

Species included: Sea otter (*Enhydra lutris*)

Data used: Summer concentration areas (polygons) from Duff et al. (2014)

Calculating the importance score: Sea Otters are listed as an endangered species in Washington and all concentration area polygons were assigned an importance value of "1".

Calculating the uncertainty score: Sea Otter Concentration areas were identified from several years of surveys and were assigned an uncertainty score of "1".


Sea Otter Rank
1

Seabird Colonies

Source: Geodatabase and associated data. Speich and Wahl (1989), Jenkerson and Pearson (2012), Duff et al. (2014). As of 2012, the catalog included 808 unique colony sites located in 14 counties throughout coastal Washington. The updated catalog also includes 10,058 records (observations or counts) for 17 breeding species and those records are distributed across species as follows: Ancient Murrelet = 1, Arctic Tern = 10, Black Oystercatcher = 411, Caspian Tern = 80, Cassin's Auklet = 47, Common Murre = 183, Cormorants = 801, Gulls = 1086, Storm-petrels = 104, Pigeon Guillemot = 6611, Rhinoceros Auklet = 104, Tufted Puffin = 392. The database also includes 228 surveys where no species were observed.

Goal of data gathering effort: Single source of all seabird breeding colonies (n = 808) including counts by species for the State of Washington

Method: Various including total counts, estimates, aerial photograph interpretation, and boat based surveys.

Area surveyed: All of Washington's coastal seabird colonies

Years of data included: Late 1800s to 2013 included in the database. Only used data since 1970 in this project.

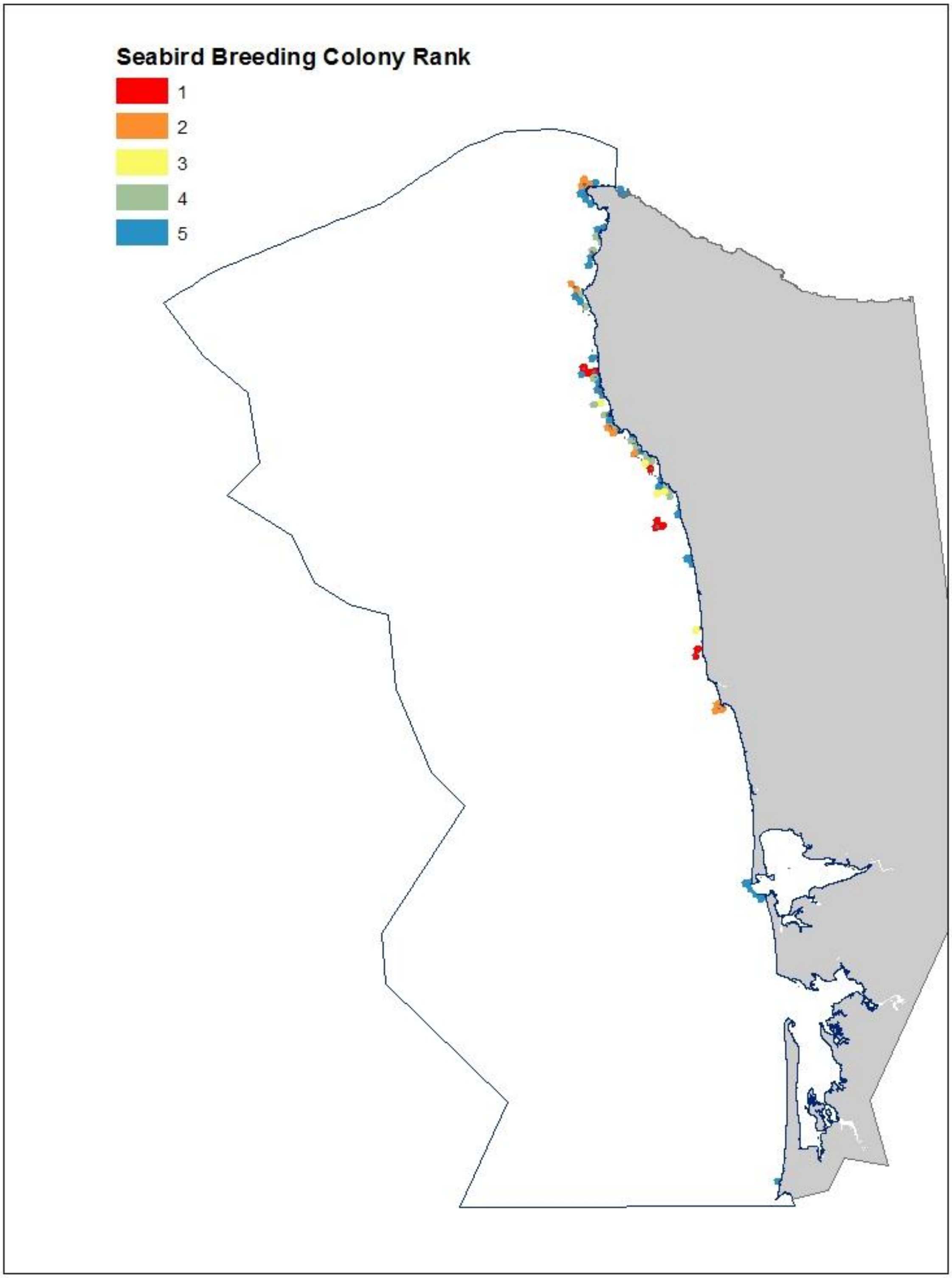
Species included: 14 species of birds including: black oystercatcher (Haematopus bachmani), Brandt's cormorant (*Phalacrocorax penicillatus*), Caspian tern (*Hydroprogne caspia*), Cassin's auklet (*Ptychoramphus aleuticus*), common murre (*Uria aalge*), double-crested cormorant (*Phalacrocorax auritus*), fork-tailed storm petrel (*Oceanodroma furcata*), glaucous-winged gull (*Larus glaucescens*), Leach's storm petrel (*Oceanodroma leucorhoa*), pelagic cormorant (*Phalacrocorax pelagicus*), pigeon guillemot (*Cepphus columba*), rhinoceros auklet (*Cerorhinca monocerata*), ring-billed gull (*Larus delawarensis*), and tufted puffin (*Fratercula cirrhata*).

Data used: most recent/most accurate counts since 1970.

Calculating the importance score: buffered all colonies with a 200 m "disturbance" buffer and then assigned the following importance scores based on number of breeding birds to the resulting polygon: 1 = > 25% of a species' coastal population; 2 = 10-25% of a species' coastal population; 3 = 5-10% (and total numbers > 50) of coastal population; 4 = 1-5% (or total numbers > 99 and not 1-3 above); 5 = < 1% (or total numbers less than 99 and not 1-4 above). Because the tufted puffin is listed as "endangered" by Washington State, we assigned all tufted puffin breeding colonies an importance score of "1" regardless of the number of breeding birds.

We buffered colonies by a disturbance buffer because human activities close to nesting colonies can have detrimental effects on reproductive success. In the literature, recommended disturbance buffers range from 50-600m depending on the species and geographic location (Rodgers and Smith 1995, 1997, Rodgers and Schwikert 2002, 2003, Carney and Sydeman 1999, Chatwin et al. 2013). We selected a ~200 meter buffer because that is the buffer used by the Washington Maritime National Wildlife Refuge Complex who manages nearly all of Washington's coastal seabird colonies and it is within the range of the buffers recommended by various research projects – especially for the species found within Washington's colonies.

Calculating the uncertainty score: The ranking of Seabird colonies were given a certainty score of 1. These colonies have been surveyed for several decades and we are confident in their location and relative importance for a species along the coast.



Location of all of Washington's seabird colonies. The number of species and their local population count or estimate can be queried for each colony. Note that only the coastal colonies between Cape Flattery and the Columbia River Estuary were included in this planning effort.

Seal and Sea Lion Haulouts

Source: geodatabase and associated data (Jeffries et al. 2000, Duff et al. 2014)

Goal of data gathering effort: identify the locations and approximate count of the number of animals using the haulouts by species for all of Washington's seal and sea lion haulouts. Daily counts per species are attributed to individual haulouts or assemblages of haulouts (e.g., sandy habitats in Grays Harbor). Source = polygonal geodatabase feature class and associated metadata (Duff et al. 2014).

Method: Summer and winter aerial surveys

Area surveyed: entire Washington coast

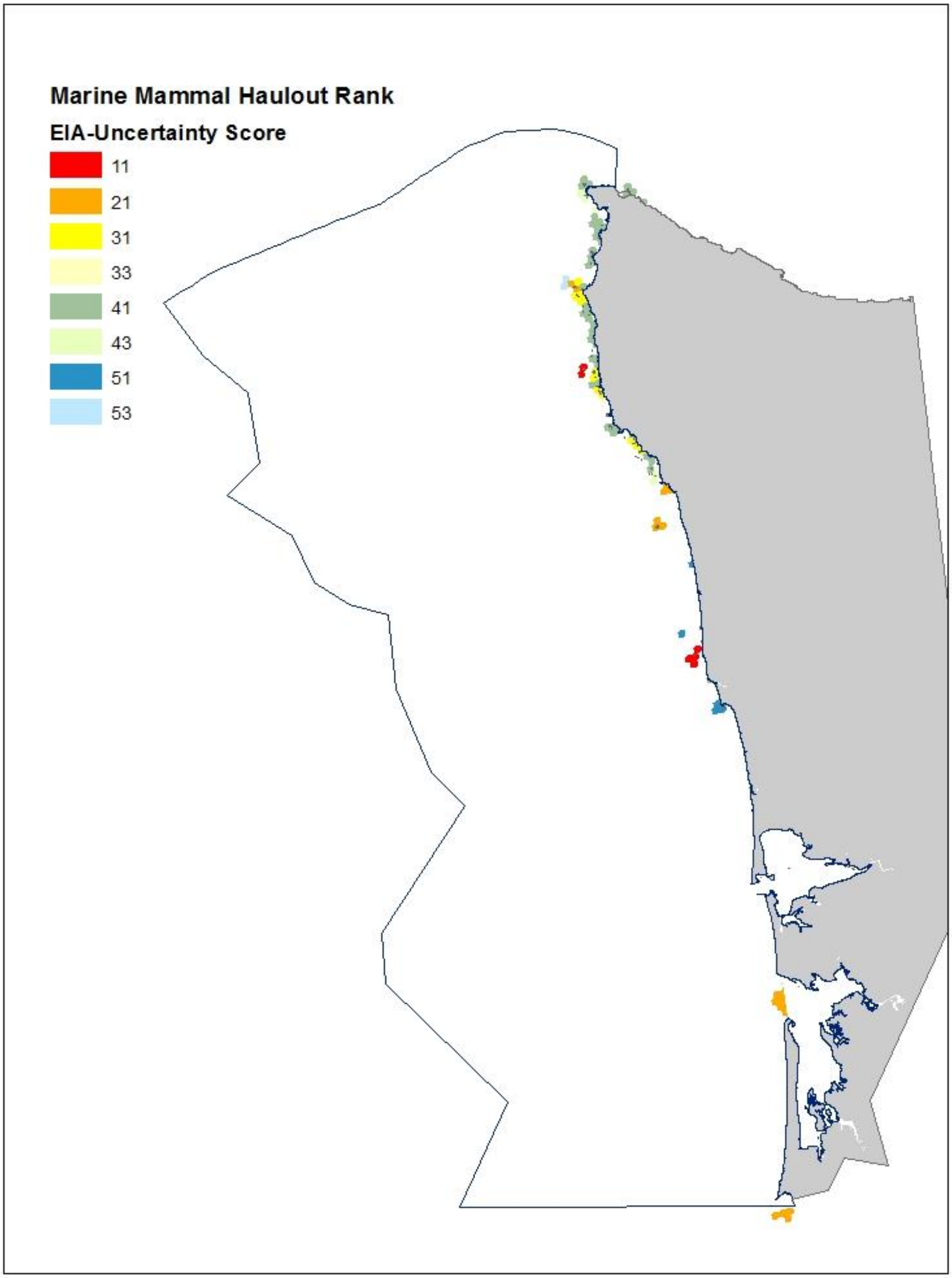
Years of data included:

Species included: Harbor seal (*Phoca vitulina*), California sea lion (*Zalophus californianus*), Steller sea lion (*Eumetopias jubatus*), and northern elephant seal (*Mirounga angustirostris*).

Data used: Daily counts per species from annual survey efforts applied to haulout polygons from our polygonal geodatabase feature class (Duff et al. 2014)

Calculating the importance score: We buffer all haulouts with the recommended 100 yard human approach buffer distance being implemented under the Marine Mammal Protection Act. Pupping season (1 May – 31 Aug) importance scores: 1 = >10 % total pup counts; 2 = 5-10% of total pup count; 3 = 1-5% of total pup count; 4 = all other pup sites; 5 = other summer haulouts with no pups. Winter season (1 Sept – 30 April) importance scores: 2 = >10 % total counts; 3 = 5-10% of total count; 4 = 1-5% of total count; 5 = all other sites.

Calculating the uncertainty score: Summer importance scores were given a certainty score of "1" because of repeated surveys within and among years and consistent occupancy and use for pupping. Winter haulout importance scores were given low uncertainty scores (i.e. "3") because the sites were visited very infrequently during the winter season.



Seal and sea lion haulout polygons for outer coast only. Known Grays Harbor, Willapa Bay and the Columbia River estuary haulout sites are not included.

Snowy Plover Nesting Areas

Source: Annual monitoring reports (e.g., Pearson et al. 2013, 2014, 2015)

Goal of data gathering effort: Estimate Washington's adult breeding population and reproductive success (hatching and fledging rates). Effort includes repeated adult surveys, locating and monitoring nests and following broods. Annually assess site occupancy at all suitable coastal nesting sites.

Method: Repeated transects surveys and intensive nest searching.

Area surveyed: All suitable nesting sites along Washington's coast

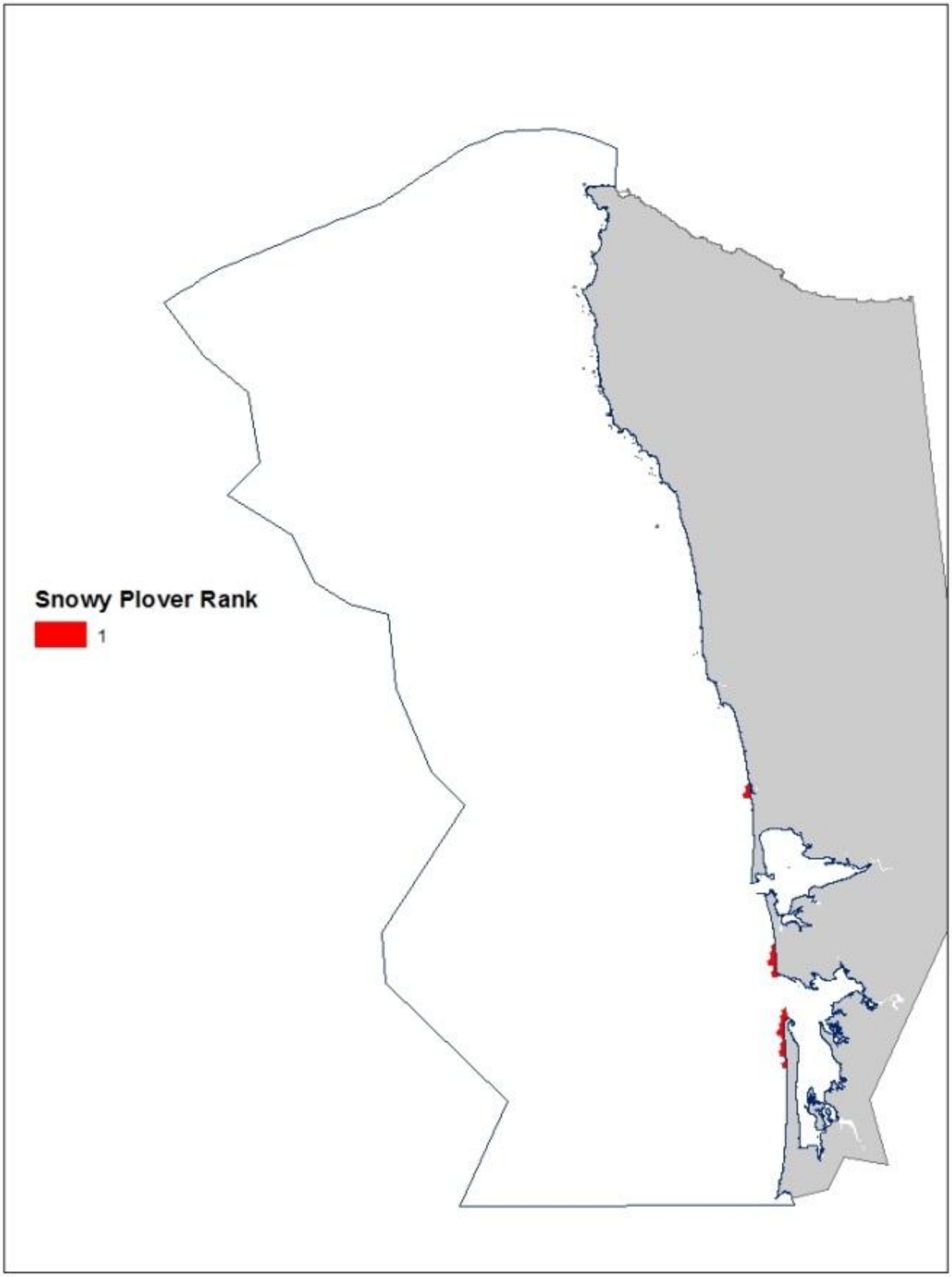
Years of data included: 2006-2014

Species included: Western Snowy Plover (*Charadrius nivosus nivosus*)

Data used: Survey polygons which were hand digitized based on suitable nesting habitat.

Calculating the importance score: Because the species is listed federally and by the State as "threatened", polygons received an importance score of "1".

Calculating the uncertainty score: Plover sites were given a certainty score of "1". These sites represent known breeding sites identified from several years of surveys, including suitable habitat in the vicinity. Surveys of potential suitable habitat have been conducted all along the outer coast and we have an 87% - 99% probability of correctly assessing a given site's occupancy status (Pearson et al. 2008).


Snowy Plover Rank
1

Predicted Seabird Abundance (n = 9 layers)

Source: Menza et al. 2015. Draft seabird distribution predictions off the Pacific Coast of Washington. National Centers for Coastal Ocean Science (NCCOS). Digital map format.

Goal of data gathering effort: create maps of predicted occurrence and abundance of 7 seabird species to support Washington State's marine spatial planning process. The goal of this effort was to focus on prediction, not determining the magnitude of ecological relationships.

Method: boosted generalize additive models were used to fit observed species abundance with various covariates. Used zero-inflated likelihoods and generalized additive models for location, scale and shape. Static variables included: bathymetric measures, 200 m isobaths, distance to breeding colony, etc. Seasonally variable covariates included: Chlorophyll a, eddy probability, frontal probability, salinity, and sea surface temperature.

Area surveyed: entire planning area – wall-to-wall predictive surfaces (raster) and associated errors.

Years of data included: 1996-2013

Species included:

Table 1. Species and seasons included in the modelling effort. Note that each species/season combination results in a predictive abundance layer used in our planning effort. Summer = April - October; Winter = November - March

Species	**Seasons**
Black-footed Albatross (*Phoebastria nigripes*)	Summer, winter
Common Murre (*Uria aalge*)	Summer, winter
Marbled Murrelet (*Brachyramphus marmoratus*)	Summer
Northern Fulmar (*Fulmarus glacialis*)	Summer
Pink-footed Shearwater (*Puffinus creatopus*)	Summer
Sooty Shearwater (*Puffinus griseus*)	Summer
Tufted Puffin (*Fratercula cirrhata*)	Summer

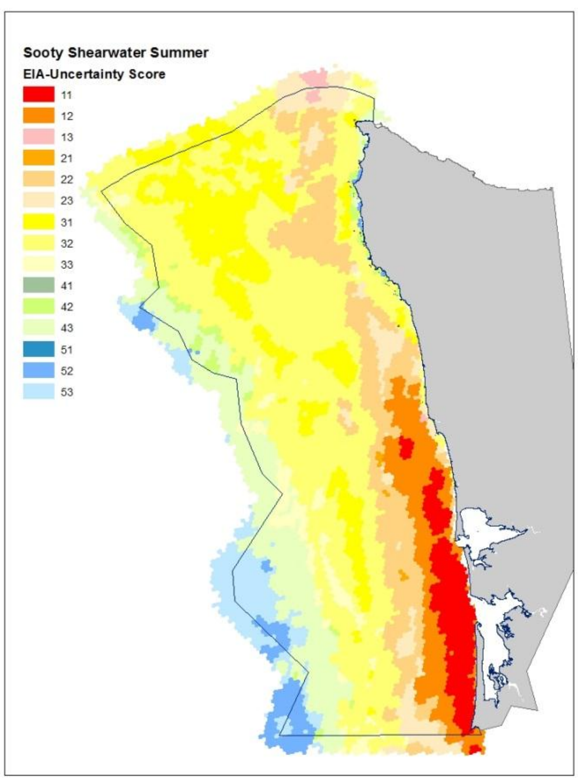
Data used: data from 8 federal and state survey efforts that occurred between 1996 and 2013. Summer surveys included ship based sightings only and winter surveys included aerial surveys only. Surveys were converted into strip transect counts that were 3 km long.

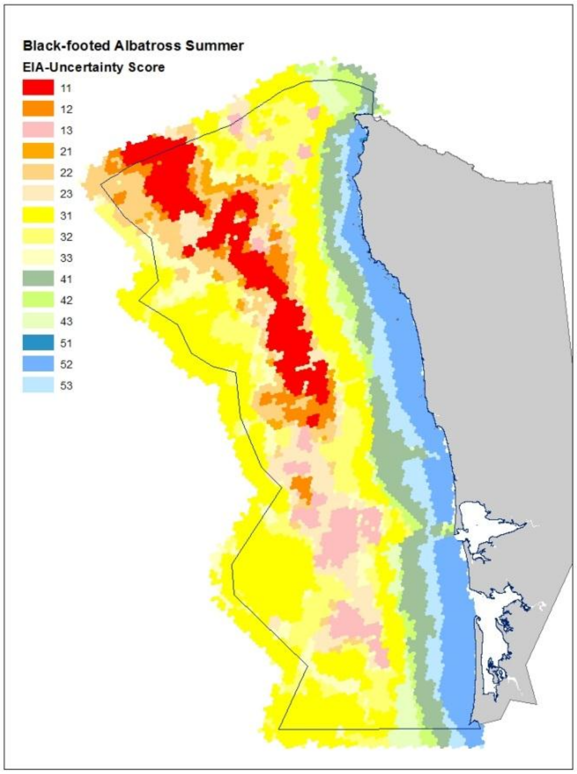
Calculating the importance score: for each species/season, we divided the distribution of predicted relative median abundance values for each cell (raster size = 3 km^2) across the entire planning area into quantiles (<10%, 10-25%, 25-75%, 75-90%, >90%). Each of these quantiles corresponds with our "importance" score for each cell. So, if the median value for a cell for a given species was in the upper 10% of abundance for the overall planning area, it received an importance score of "1". Conversely, if the median value was in the lower 10%, it received a score of "5". We then converted this new grid of importance scores to our hexagonal grid by overlaying our hexagon grid on the 3 km2 grid and then assigning each hexagon the minimum score (i.e. highest value) for the 3km^2 cells that it overlapped with. So, if a hexagon overlapped 2-3km^2 cells and one had a score of 1 and the other a 3, it received a score of “1”.

We then combined all of the species layers and their associated scores, so that each hexagon had an importance score for all 9 layers (Table 1 above). For the minimum score map, we displayed the minimum score for each hexagon. So, if a hexagon had the following importance values: 1,1,3,3,3,4,5,5,5 for all of the bird species layers, it received the minimum score of “1” indicating that the hexagon was “important” (predicted high abundance) for at least one species. We also developed a “hot spot” map by counting the number of layers in a hexagon that scored a “1” or a “2”, representing species with above average abundance. In the above example, this hexagon cell would get a “hot spot” count of 2 because there were two species that score a “1” and zero species that scored a “2”. Conversely we created a “cold spot” map by counting the number of layers in a hexagon that scored a “4” or a “5”, representing species with below average abundance. In the same above example, this hexagon cell would get a “cold spot” count of 4 because there is one species that scored a “4” and three species that scored a “5”.

<u>Calculating the uncertainty score</u>:

If the 90% confidence interval for the abundance estimate for each cell fell completely within its importance score bin (quantiles from the distribution of the median values across the planning area), it received low uncertainty score of “1”. If the confidence interval overlapped one additional bin, then it received a medium uncertainty score of “2”. And if it overlapped two or more bins, then it received a high uncertainty score of “3”. These uncertainty scores could then be combined with the importance scores to inform both the importance (abundance) estimate and its associated uncertainty. For example, a two-digit score of 12 for a given cell indicates an importance score of 1 with an uncertainty of 2.




Black-footed Albatross Summer
EIA-Uncertainty Score
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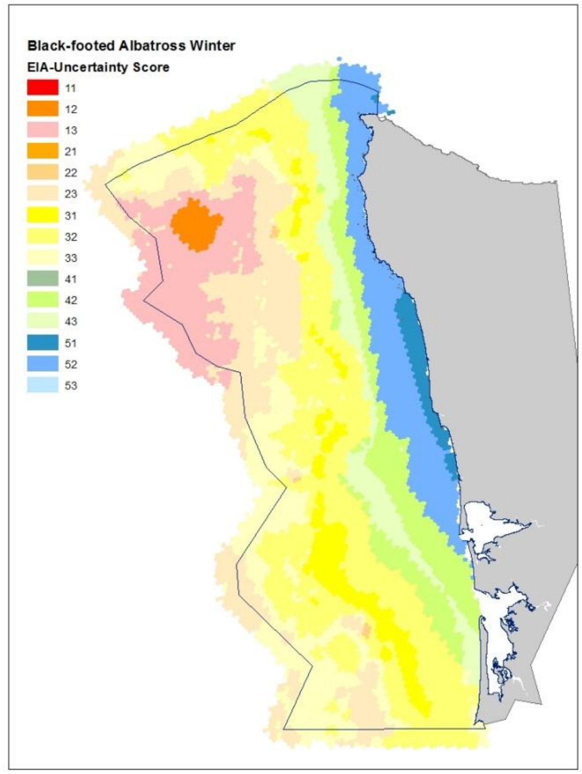
Black-footed Albatross Winter
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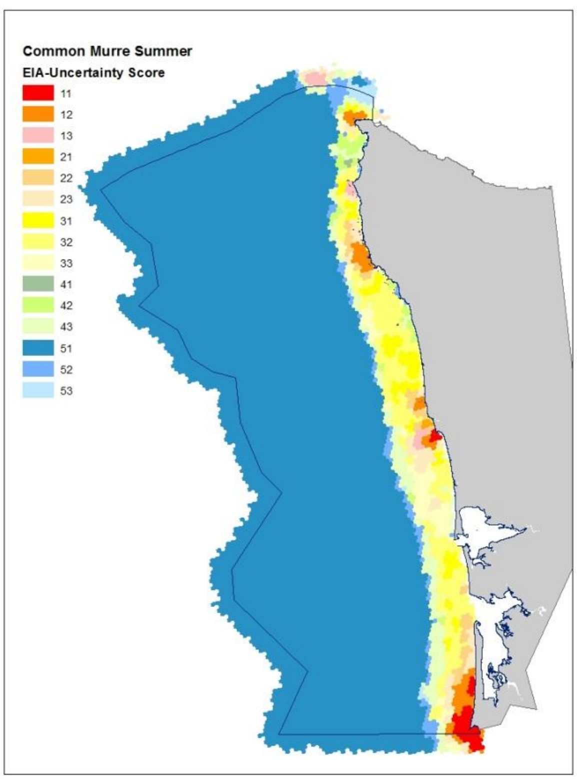
Common Murre Summer
EIA-Uncertainty Score
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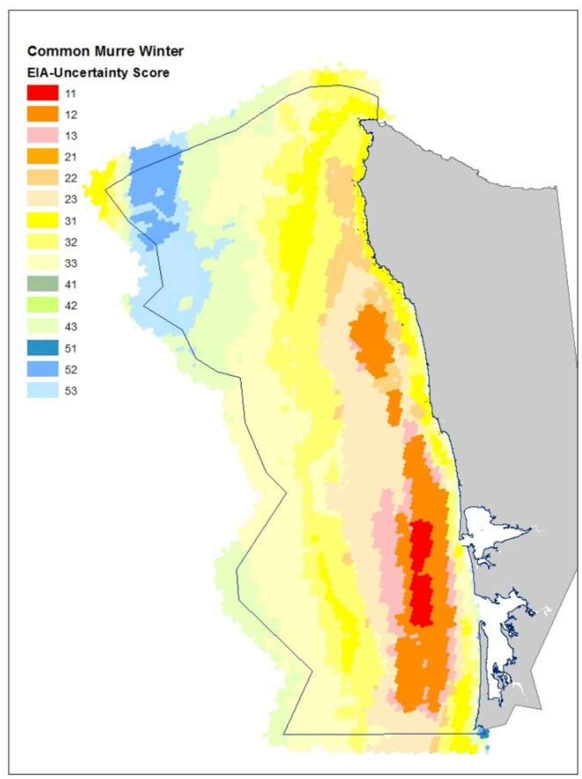
Common Murre Winter
EIA-Uncertainty Score
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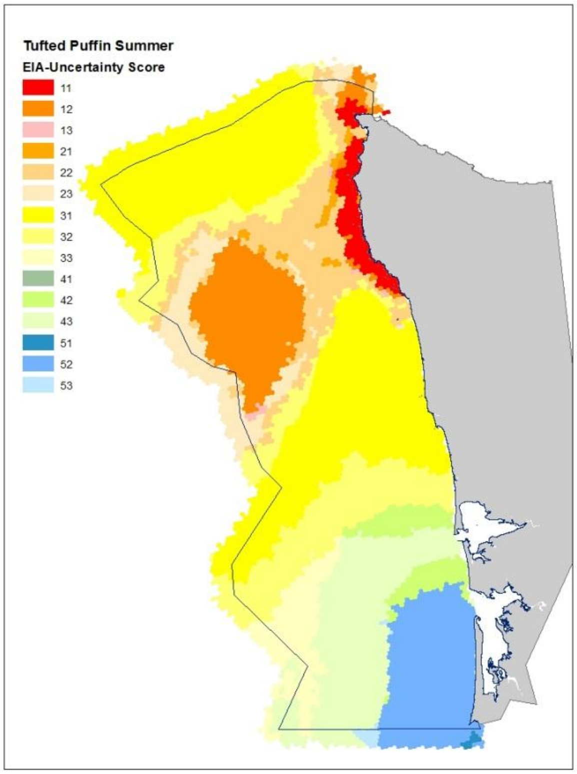
Tufted Puffin Summer
EIA-Uncertainty Score
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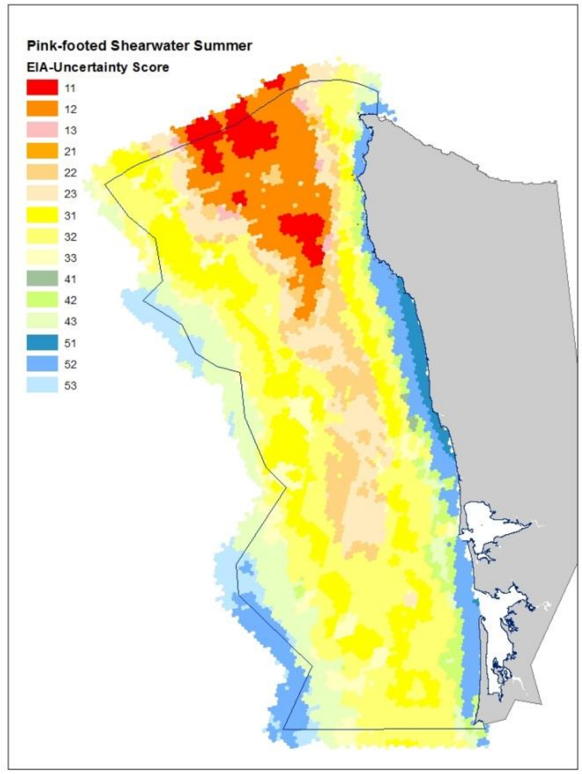
Pink-footed Shearwater Summer
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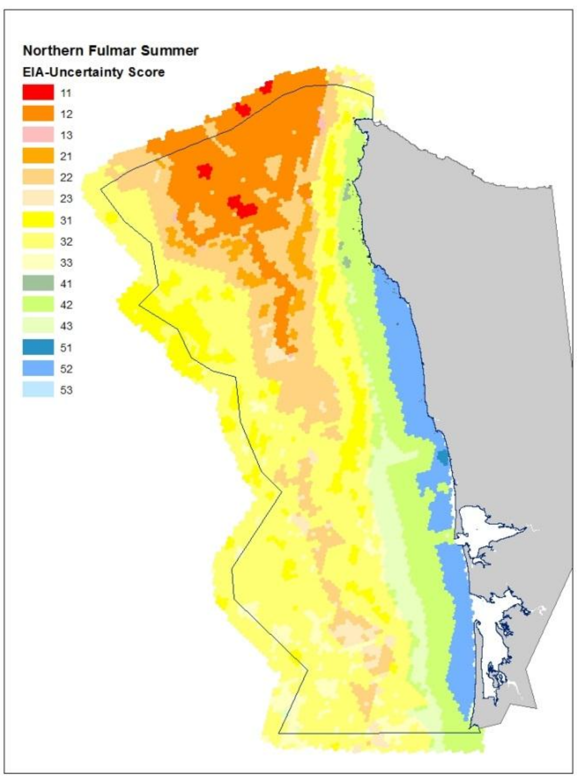
Northern Fulmar Summer
EIA-Uncertainty Score
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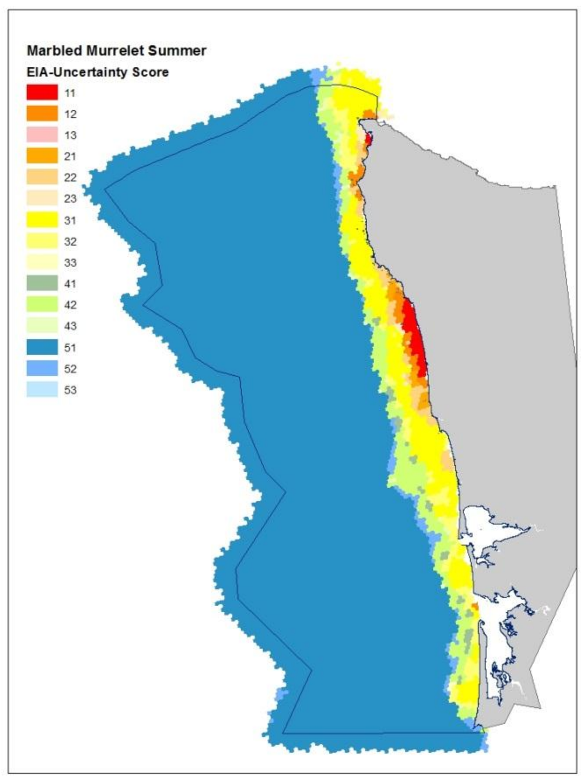
Marbled Murrelet Summer
EIA-Uncertainty Score
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Streaked Horned Lark Nesting Areas

Source: Annual monitoring effort. See Pearson et al. (2015) for the published protocol and Keren and Pearson (2015) for results and trends by site.

Goal of data gathering effort: Assess population trends by breeding site

Method: Line transect surveys through breeding habitat

Area surveyed: All occupied nesting sites in Washington

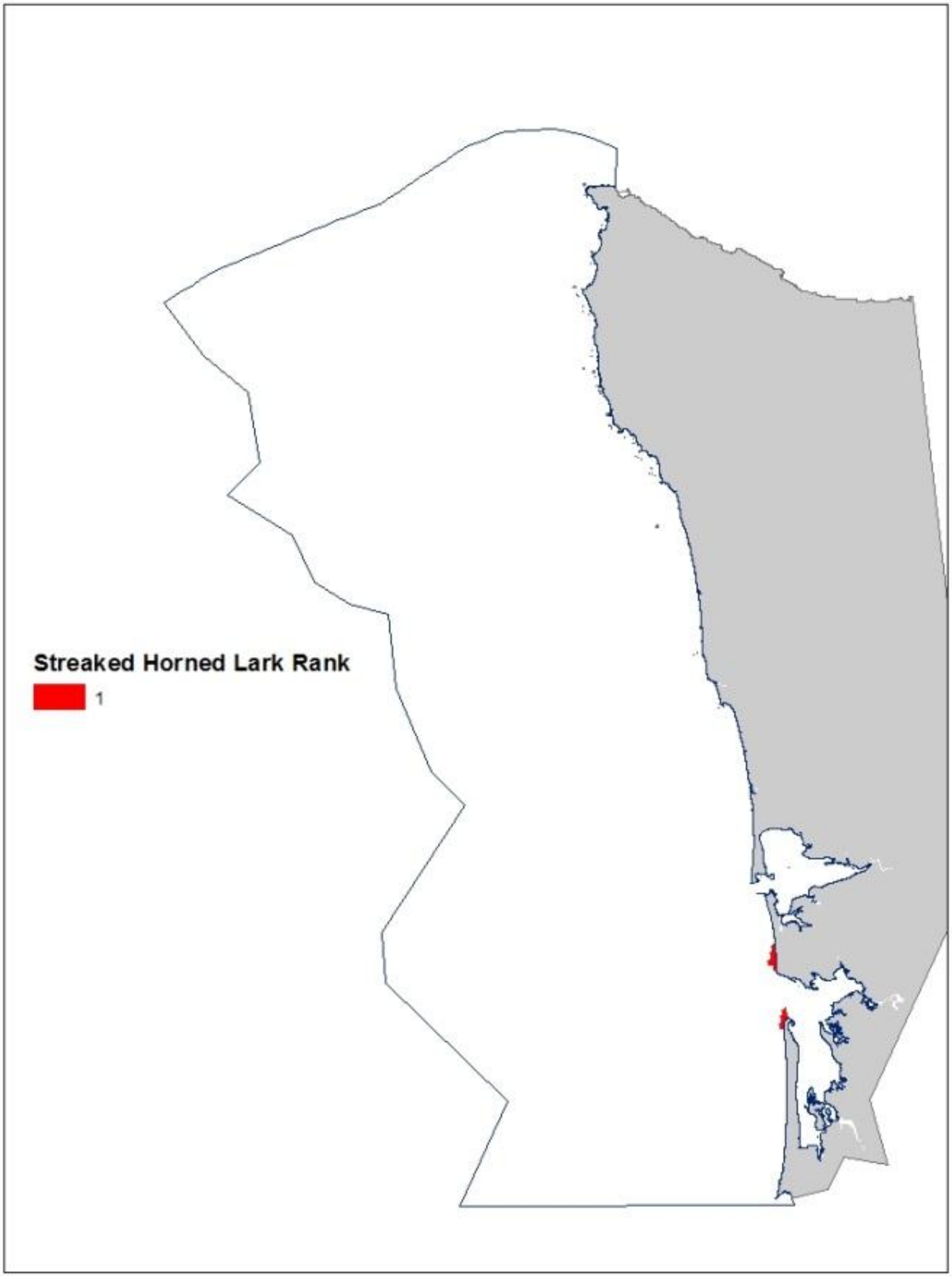
Years of data included: 2010-2015

Species included: Streaked horned lark (*Eremophila alpestris strigata*)

Data used: Survey polygons which were hand digitized based on suitable nesting habitat.

Calculating the importance score: Because the species is listed federally and by the State as "threatened", polygons received an importance score of "1".

Calculating the uncertainty score: Lark sites were given a certainty score of "1". The sites represents known breeding sites from several years of surveys, including suitable habitat in the vicinity. Surveys of non-occupied suitable habitat have been conducted all along the outer coast (Pearson et al. 2015).


Streaked Horned Lark Rank
1

Fisheries

Chinook Salmon Hotspots - Fishery Based Map

Source: Genetic Stock Identification (GSI) study of Chinook Salmon caught in Washington's ocean troll fishery (Moran et al. 2013).

Goal of data gathering effort: Many stocks of Chinook Salmon mix and are caught in the ocean, including at risk populations like the Endangered Species Act listed Puget Sound Chinook stocks. Stocks cannot be distinguished morphologically. GSI studies are intended to understand where and when different stocks are being caught to aid fisheries management in the goal of avoiding the most vulnerable populations.

Method: Tissues from fish caught by salmon troll vessels were collected opportunistically and the coordinates and time of the catch recorded. Sampling was not systematic or random.

Area surveyed: The study focused on the salmon troll fleet operation in ocean waters off north of Leadbetter Point, Washington.

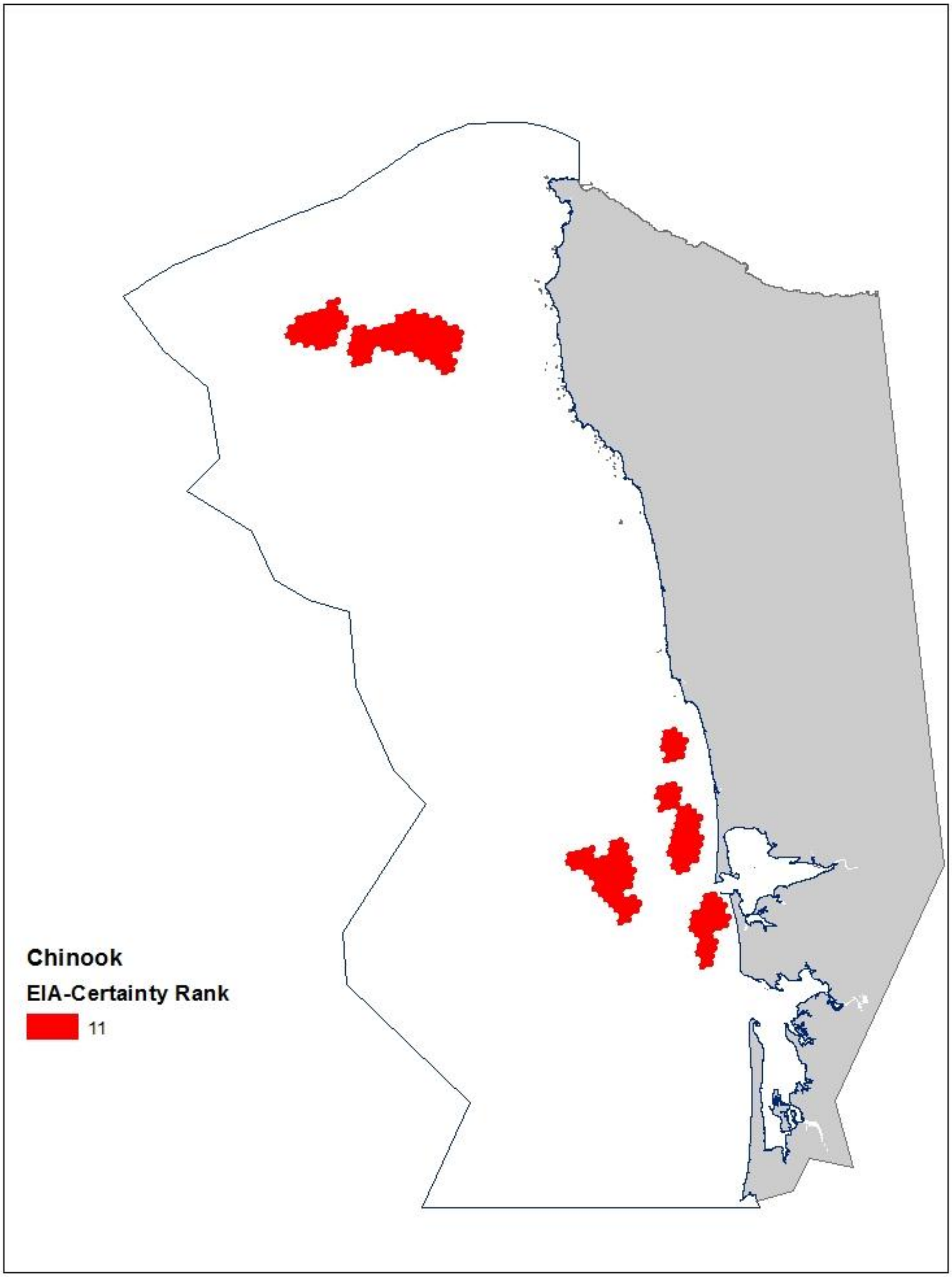
Years and seasonality: Samples were collected May through July in 2011 and May through September in 2012.

Species and life history stages included: Adult Chinook Salmon (*Oncorhynchus tshawytscha*).

Data used: We used the coordinates from 1,877 Chinook caught in the MSP Study Area.

Calculating the importance score: We counted the number of Chinook collected within each hexagon and used the ArcGIS Cluster-Outlier analysis to identify hotspots among the hexagons. We assigned all hexagons within the hotspots as 1.

Calculating the uncertainty score and interpreting the data: We assigned a certainty score of 1 to all hotspots. While there only two years of data in the data set, the areas identified as hotspots do match up to knowledge of important fishing grounds. However, the data supporting this map does not speak to the question of what areas are the most important to Chinook, nor is it able to identify all areas of importance to the species. Chinook are known to use and migrate through large portions of the MSP Study Area. Moran et al. (2013) advise that the fishing effort during the project "was substantially concentrated" and so "might not necessarily represent the true distribution of stocks in time and space." Lastly, for this map in particular, we strongly emphasize the caveat that the lack of evidence for ecological importance in this data set is not evidence that an area lacks ecological importance to the species.


Chinook
EIA-Certainty Rank
11

Coastal Intertidal Forage Fish Spawning Sites

Source: Coastal intertidal forage fish spawning surveys conducted by WDFW in collaboration with the Hoh, Makah, Quileute Indian Tribes, and Quinault Indian Nation (Langness et al. 2015).

Goal of data gathering effort: The survey project was conducted to identify intertidal forage fish spawning sites.

Method: The methods are detailed in Langness et al. (2015). In brief, "semi-exposed cobble-mixed coarse" and "exposed sandy" beaches were identified as possible spawning habitat and then sampled in 1000 foot segments following a stratified random design. Samplers used a variant of established WDFW intertidal forage fish spawning habitat survey protocols to detect the presence of eggs at each site. Over the course of the survey, 89 percent of the beaches identified as possible spawning habitat were sampled.

Area surveyed: Washington's outer coastline, from the Columbia River to Cape Flattery, excluding estuaries. Maps of sampling sites are available in Langness et al. (2015).

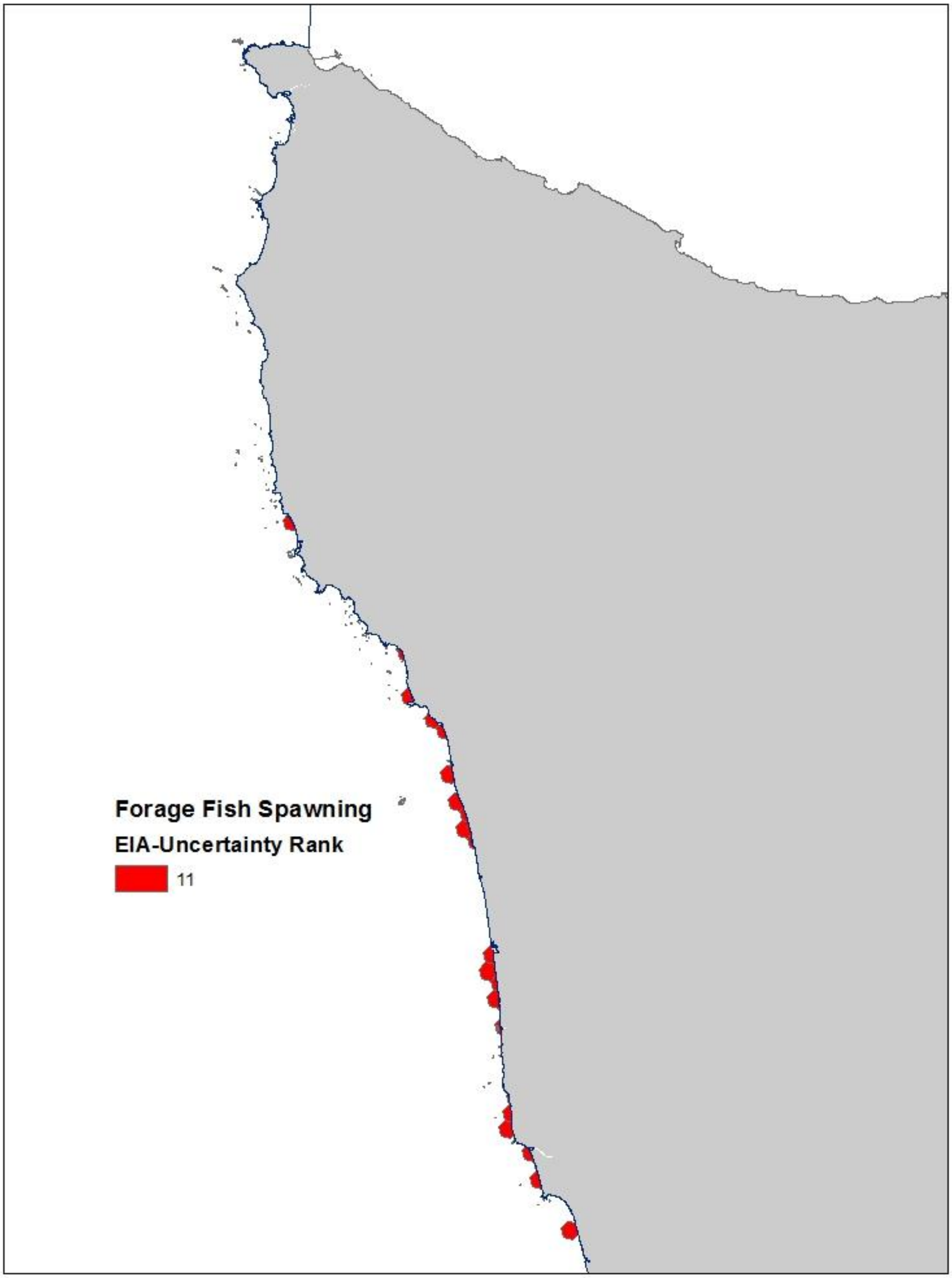
Years of data included: The survey was conducted monthly from October 2012 through October 2014.

Species included: Beaches were surveyed for three intertidal spawning species: Surf Smelt (*Hypomesus pretiosus*), Night Smelt (*Spirinchus starksi)*, and Pacific Sand Lance (*Ammodytes hexapterus*). The survey detected only smelt eggs (species undetermined).

Data used: Locations of all sites meeting the survey's minimum criteria of two or more eggs.

Calculating the importance score: We assigned an importance score of 1 to all spawning sites that were confirmed by the survey. There are 40 such sites contained within 24 hexagon cells.

Calculating the uncertainty score: All confirmed spawning locations were assigned an uncertainty score of 1 ("high" certainty). However, we would emphasize the greater uncertainty about the knowledge of intertidal spawning sites generally and advise that the survey was unlikely to have detected all spawning sites. Sites may have been missed because spawning activity varies between years and seasons and because the sampling protocols do not have a perfect probability of detecting eggs. WDFW will be exploring statistical modelling techniques to evaluate the factors that are associated with spawning sites. These techniques may be used to update this map layer in the future.


Forage Fish Spawning
EIA-Uncertainty Rank
11

Dungeness Crab Commercial Fishery-based Map

Source: Washington Coastal Commercial Dungeness Crab Logbooks.

Goal of data gathering effort: WDFW requires vessel operators to record the location and amount of catch for each fishing trip in logbooks. The logbook data is collected for a number of conservation and management purposes. Here, we use the information on catch locations as a proxy for Dungeness crab habitat.

Method: Fishing vessels capture crabs using baited traps ("pots"). The pots are set out in rows, called "strings" or "sets." A string of pots can stretch several miles in length. The average set in the logbook data used here consisted of ~58 pots and was 3.7 nautical miles long. WDFW's logbook requirements require vessel operators to record the starting and ending coordinates for each set, the number of pots deployed, the catch brought on board and kept, and a number of other attributes (*see* http://wdfw.wa.gov/fishing/commercial/crab/coastal/logbook.html).

Area surveyed: The logbooks cover all fishing activities and areas fished by commercial fishing vessels. Crab vessels cover the fishing grounds with more than 10,000 sets per year. In the absence of other factors, we would expect them to deploy their gear in areas where crabs can be found in the highest densities so as to maximize their catch per unit effort and their profits. However, other incentives and constraints do exist in the fishery and these influence the location of fishing. Co-management with the coastal treaty tribes is one such major factor. For example, a special management area used to co-manage the harvest with the Quinault Indian Nation (QIN) has been closed to the commercial fishery during all years for which we have logbook data. In addition, since 2006 the structure of the state commercial season opening has included a delayed season opening in the area north of Klipsan Beach, (46° 28' N. Latitude). This has likely shifted fishing effort south. Also, the fishery does take place inside estuaries. However, as with all the maps in this project, we excluded estuaries from the mapping and consider them of the highest importance for several species. Estuaries are highly important to Dungeness Crab.

Years and seasonality of data included: The Dungeness Crab commercial fishing season spans calendar years. It opens on various dates in December, depending on conditions, and closes on September 15 the following year. We used five seasons of logbook data for this analysis, covering the 2009/2010 through the 2013/2014 seasons. Of note, fishing effort and catch is not necessarily consistent throughout the season. Up to half of the season's catch can be harvested within the three months.

Species and life history stages included: The logbooks only record catch of Dungeness Crab (*Cancer magister* or *Metacarcinus magister*) that can be legally retained. The legal catch consists only of male crabs that are at least 6.25 inches in carapace width. At that minimum size, the males are thought to have reached 4 years of age. The fishery is thought to remove the grand bulk of these 4 year old males from the population each year and we expect the logbook data to provide good information on where these males have been found off the coast. On the other hand, we do not expect the logbooks to provide us with information on female or juvenile crab habitats as they differ from the legal-sized males.

Studies have shown that female adult crab use different habitats than males at certain times of the years and that the threats of cannibalism and predation have pushed juveniles to seek more protected habitats than adults. Moreover, the logbook data definitely lacks information on the habitats used by the earliest life history stages of this species. After hatching, Dungeness crab occupy pelagic habitats for several months.

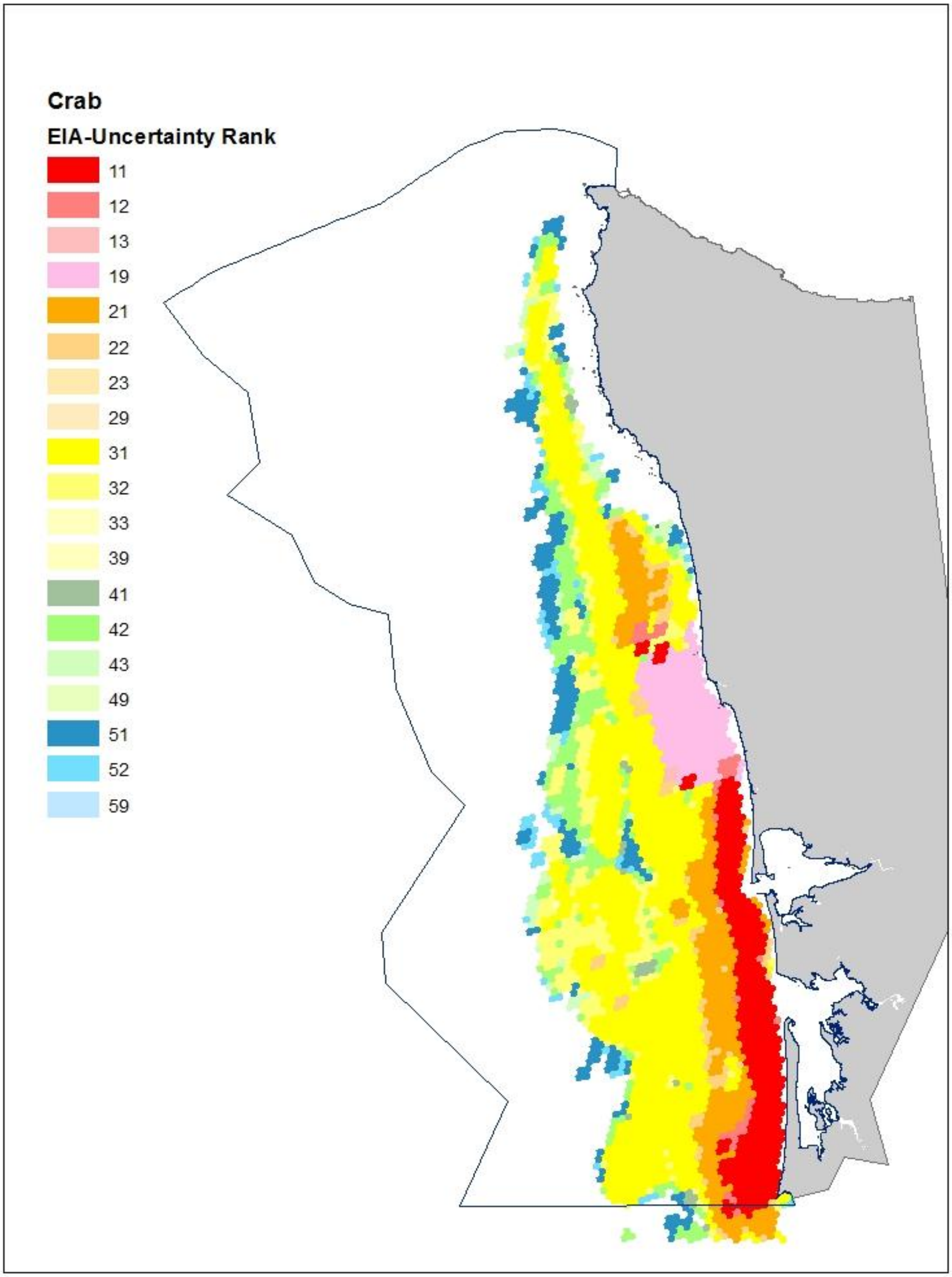
Data used: We used the start and end coordinates, date, and reported catch for each set. After filtering out likely and suspected erroneous records (~18 percent of the total records), we included a total of 63,394 records in the analysis. We plotted the sets as straight lines in ArcGIS and buffered them by 0.1 nautical miles to cover some of the error expected in logbook coordinates and the fact that a set is not likely to maintain an exact straight line in the ocean. For the unit of catch, we used the reported number of crab retained. We converted these catch recorded in weights to counts using an average weight of 1.6 pounds per crab.

Calculating the importance score: As with the other fishery-based maps, the assumption underlying the importance scores is that the total catch taken from an area provides some signal on its importance as habitat to the species. In following this approach, we ranked the hexagons proportionately to the amount of catch we could associate with each. We divided the sets into seasons, and within seasons, into an early (December and January) and later (February -September) period because catch in the fishery is heavily influenced by annual fluctuations in crab abundance and because of the regulatory and economic dynamics that drive a lot of the catch to occur at the start of each season and in areas south of Klipsan Beach. We represented catch for each set by the fraction it contributed to the total reported for the relevant season and period. For perspective, the average set contributed ~0.02 percent of the catch for a period with the highest set contributing ~ 0.4 percent. To rank the hexagons, we used the ArcGIS Spatial Join tool to overly all of the sets onto the hexagon grid and attributed the reported catch for a set to all intersecting hexagons. We then summed the catches from all sets intersecting with each hexagon and converted the totals to quantiles based on the empirical cumulative distribution. Consistent with our general approach, we converted the quantiles to the importance scores using the bins identified in the table below. Following conventions used to protect the confidentiality of logbook data, we excluded hexagons containing records from fewer than three vessels. These excluded hexagons would all have scored among the lowest 10 percent.

EIA score	1 *High*	2 *Med.-High*	3 *Medium*	4 *Med.-Low*	5 *Low*
Percentile range	> 0.90	0.90 ≤ & > 0.75	0.75 ≤ & > 0.25	0.25 ≤ & > 0.15	≤ 0.10

Lastly, we have temporarily assigned an importance score of 1 to the area that remains closed year-round to the commercial fishery in the QIN special management area. We assume this area is important to crab but did not have time to consult with QIN co-managers on the question.

Calculating the uncertainty score: We assigned the uncertainty scores by resampling the sets with replacement and re-calculating the importance score 5,000 times in the manner described above. The 5,000 iterations produced a distribution of quantile values for each hexagon. The importance score for a hexagon corresponds to the median value of its distribution. A hexagon's uncertainty score is then based on the difference between what its importance score would be at its 5th and 95th percentile values. If a hexagon's importance score changed 2 or more points between them, we assigned an uncertainty score of 3. If the score changed only 1 point, we assigned an uncertainty score of 2, and then a 1 if the importance scores did not change at all. This method of calculating the uncertainty scores focuses on the sensitivity to the subset of the data included in the analysis. There are greater sources of uncertainty related to the limitations of the data itself and the assumption that ecological importance to the species is proportional to catch. We cannot quantify these types of uncertainty. While areas identified as important in this map do provide habitat for crab, the uncertainty pertains to our understanding of their relative importance to the species. For example, areas that we score as a 5 could score higher if different survey data were available. Greater uncertainty also applies to our knowledge about areas not identified as important on the map. Lack of evidence of importance in the fishery data is not necessarily clear evidence that an area is ecologically unimportant. Lastly, we highlight the areas assumed to be of high importance within the QIN special management area with the unknown uncertainty score of 9.


Crab
EIA-Uncertainty Rank
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Groundfish Species-Habitat Associate Models

Source: The data used for this set of nine maps comes from two sets of species distribution models developed by analysts with the National Oceanic and Atmospheric Administration: (1) Northwest Fisheries Science Center (NWFSC) of the National Marine Fisheries Service (NMFS); and (2) the National Centers for Coastal Ocean Science of the National Ocean Service (NCCOS). The model outputs can be downloaded from the Consolidated GIS Data Catalog and Online Registry for the 5-Year Review of Pacific Coast Groundfish Essential Fish Habitat (EFH) (http://efh-catalog.coas.oregonstate.edu/synthesis).

Goal of data gathering effort: Both the NWFSC and NCCOS models were produced as part of an evaluation of the Pacific Fishery Management Council (PFMC)'s Groundfish EFH policies. The specific purpose of the models is to evaluate associations between the groundfish species and habitat and to relate those interactions to those policies. The primary data on which the models are based comes from the NWFSC West Coast Groundfish Bottom Trawl Survey, which is conducted annually to monitor groundfish stocks that are managed through the PFMC.

Method: The NWFSC and NCCOS models use different statistical methods, as explained in detail in NMFS (2013). However, both use methods to relate survey data on where the fish are caught to habitat characteristics like depth of the catch and sediment type. Both models produce estimates of the probability of occurrence of each species in a particular location, and for locations where that probability is greater than zero, estimates of relative abundance in the form of the expected long-term average catch per unit effort of each species at the location.

Area surveyed: The models cover much of the West Coast Exclusive Economic Zone (EEZ) and the MSP Planning Area. Input survey data covers depths from 55 to 1280 meters (30 to 700 fathoms) and runs from Cape Flattery to the U.S-Mexico border. The exact area over which the models produce estimates varies model by model and species by species.

Years of data included: The NWFSC West Coast Groundfish Bottom Trawl Survey has been run annually since 2003. The NWFSC and NCCOS models used data through 2011. Several of the species are known to have seasonal movements. However, because the survey is run from May to October, the models would not be expected to reflect seasonal changes in habitat use during the winter months. The Yelloweye Rockfish model includes additional observations from various submersible visual surveys that were conducted as far back as the 1980s.

Species included: The following table identifies the species and the models used in the EIA project. Individual maps are produced for each of the species listed (i.e. one map per species):

Species Modeled	NWFSC model	NCCOS model
Darkblotched Rockfish (*Sebastes crameri*)	Y	Y
Dover Sole (*Microstomus pacificus*)	N	Y
Greenspotted Rockfish (*Sebastes chlorostictus*)	Y	Y
Longspine Thornyhead (*Sebastolobus altivelis*)	Y	Y
Pacific Ocean Perch (*Sebastes alutus*)	N	Y

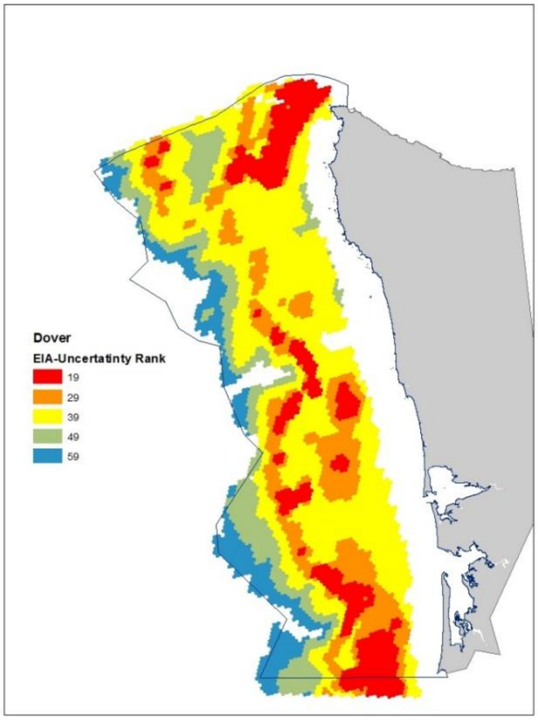
Petrale Sole (*Eopsetta jordani*)	Y	Y
Sablefish (*Anoplopoma fimbria*)	Y	Y
Shortspine Thornyhead (*Sebastolobus alascanus*)	N	Y
Yelloweye Rockfish (*Sebastes ruberrimus)*	Y	N

Data used: For all species but Yelloweye Rockfish, the EIA maps focus on the modeled estimates of relative abundance. For Yelloweye Rockfish, we used the modeled probability of occurrence because relative abundance estimates are not available for the version of the NWFSC Yelloweye Rockfish model version that includes the additional data from the visual based species.

Calculating the importance score: We calculated the importance scores by ranking the hexagons against one another for each species. Where a hexagon contained multiple values from a given model, we took the maximum value as representing the abundance or probability of occurrence. This was the case for many of the hexagons for species modeled by both the NWFSC and NCCOS because the models provide estimates at a finer-scale resolution than the 1 square nautical mile covered by each hexagon. The ranking scheme was based on quantiles (a.k.a. percentiles) calculated from the empirical cumulative distribution. We only ranked hexagons where the estimate of abundance or probability of occurrence was greater than zero. For those species and hexagons where estimates were available from the NWFSC and NCCOS models, the hexagon's value was calculated by taking the average of the two quantiles and all hexagons were re-ranked.

EIA score	1 *High*	2 *Med.-High*	3 *Medium*	4 *Med.-Low*	5 *Low*
Quantile range	> 0.90	0.90 ≤ & > 0.75	0.75 ≤ & > 0.25	0.25 ≤ & > 0.15	≤ 0.10

Calculating the uncertainty score: The uncertainty scores are based on Bayesian credible intervals that are available from the NWFSC models. Specially, those models produced 5th and 95th quantile credible intervals. Based on Bayesian statistical theory, the models predict that there is a 90 percent probability that the actual relative abundance or probability of occurrence for the species falls in between these intervals. To assign the uncertainty scores, we translated the 5th and 95th credibility intervals to EIA scores by converting the quantile range for each EIA score to the corresponding estimate of relative abundance or probability of occurrence for each species. If the 5th and 95th interval values were two EIA scores apart, the certainty score was designated as "low"; if one EIA score apart, "medium"; and if they corresponded to the same EIA score, it was designated as "high". Such intervals are not available for the NCCOS models. We are currently exploring how to characterize uncertainty for those models. In this draft, the uncertainty score comes from the NWFSC models for species that have one. For species only modeled by NCCOS, the uncertainty score is marked as unknown.


Dover
EIA-Uncertatinty Rank
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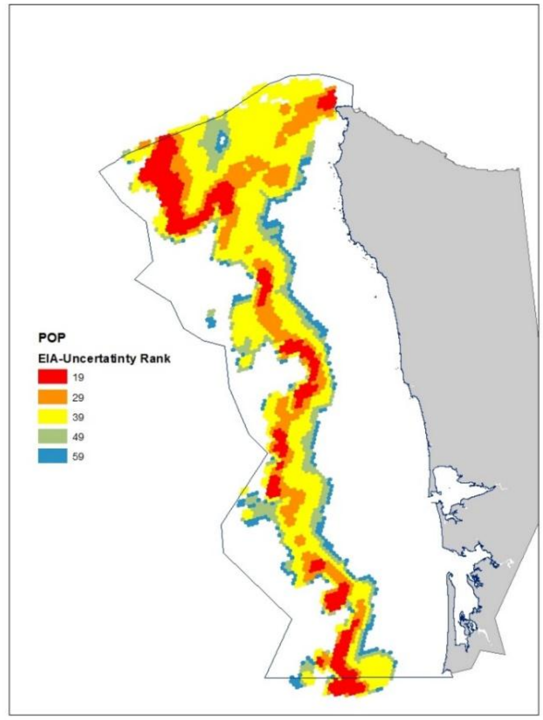
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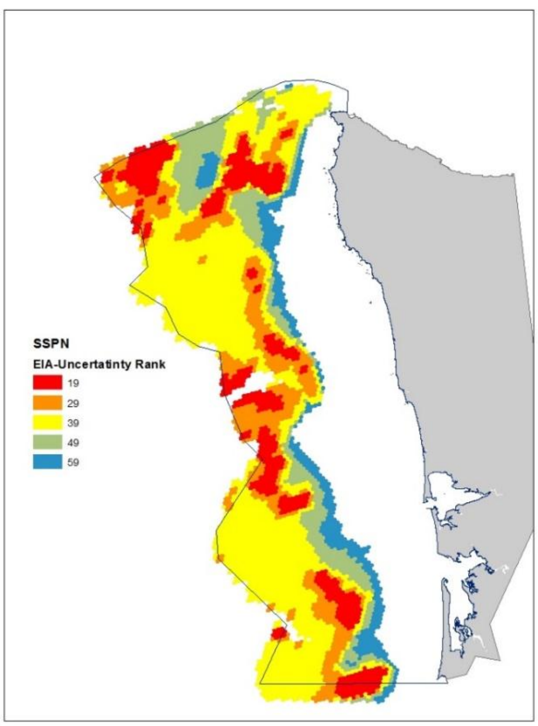
SSPN
EIA-Uncertatinty Rank
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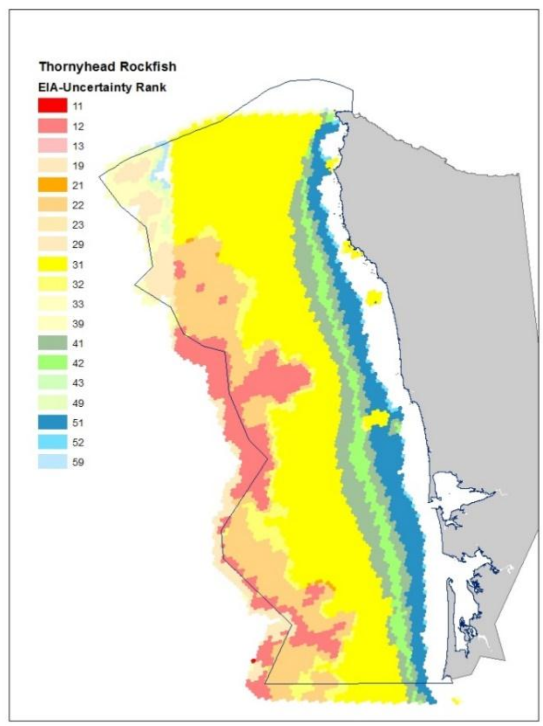
Thornyhead Rockfish
EIA-Uncertainty Rank
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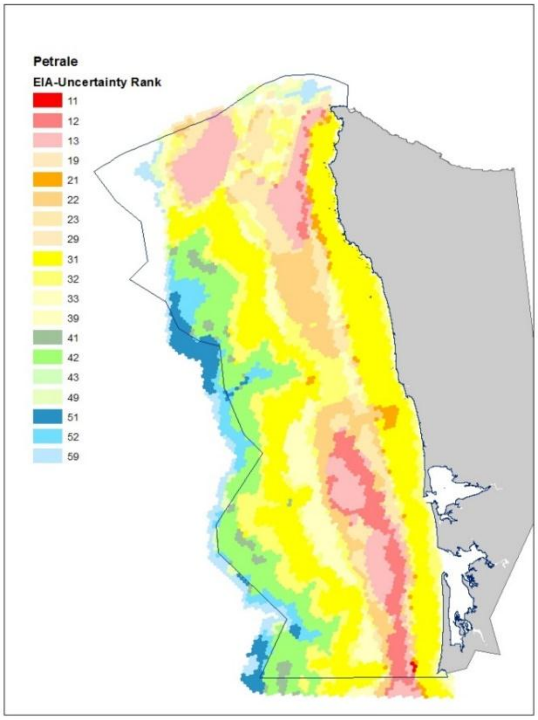
Petrale
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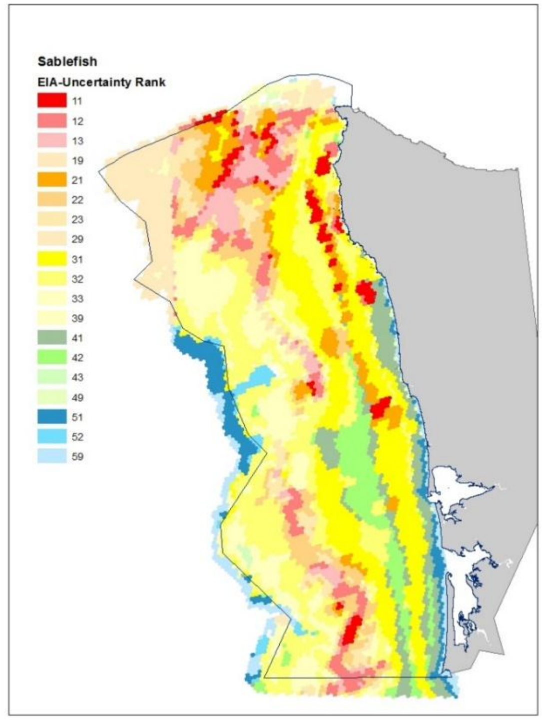
Sablefish
EIA-Uncertainty Rank
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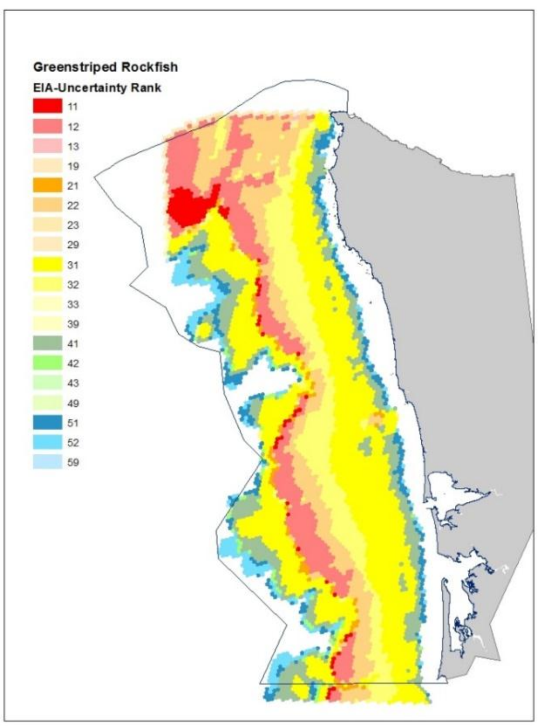
Greenstriped Rockfish
EIA-Uncertainty Rank
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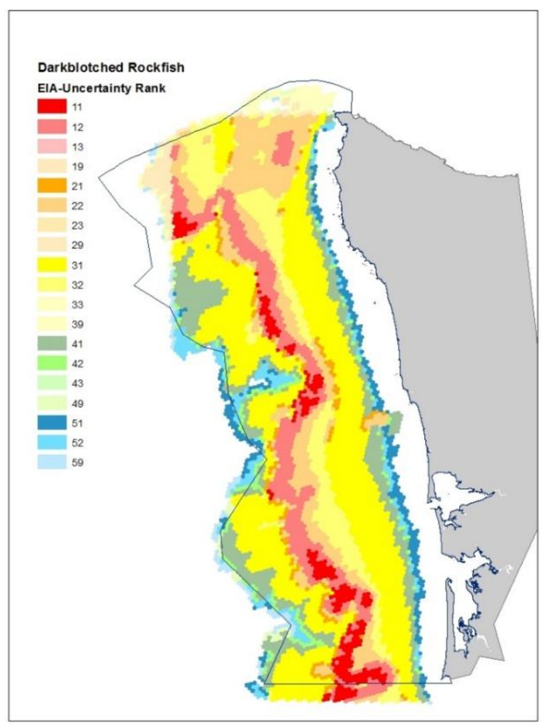
Darkblotched Rockfish
EIA-Uncertainty Rank
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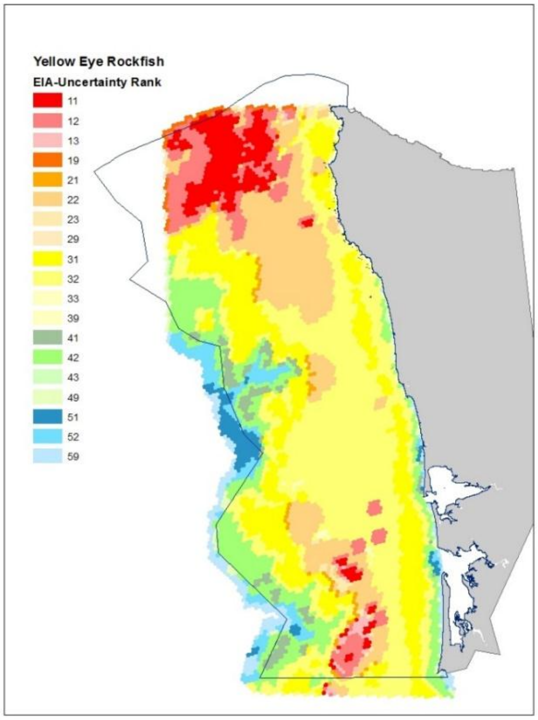
Yellow Eye Rockfish
EIA-Uncertainty Rank
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Razor Clam Beaches

Source: WDFW razor clam surveys and management of the five razor clam beaches (http://wdfw.wa.gov/fishing/shellfish/razorclams).

Goal of data gathering effort: Razor clams provide a very popular recreational harvest opportunity to the state as well as a limited commercial harvest. WDFW's survey and management are used to produce estimates of clam abundance that help the agency ensure that the harvest remains sustainable.

Method: WDFW uses random sampling and a pumped area method to produce density and abundance estimates by beach. For details see: http://wdfw.wa.gov/fishing/shellfish/razorclams/how_many.html.

Area surveyed: The five razor clam beaches surveyed by WDFW include: (1) Long Beach, from the Columbia River north to the mouth of the Willapa Bay; (2) Twin Harbors, from Willapa Bay north to the south jetty at the mouth of Grays Harbor; (3) Copalis Beach, from the north jetty at the mouth of Grays Harbor to the Copalis River; (4) Mocrocks, from the Copalis River to the south boundary of the Quinault Indian Reservation; and, (5) Kalaloch from the South Beach campground north to Beach Trail 3 inside Olympic National Park. The Quinault Indian Nation (QIN) survey and manage their razor clam beaches.

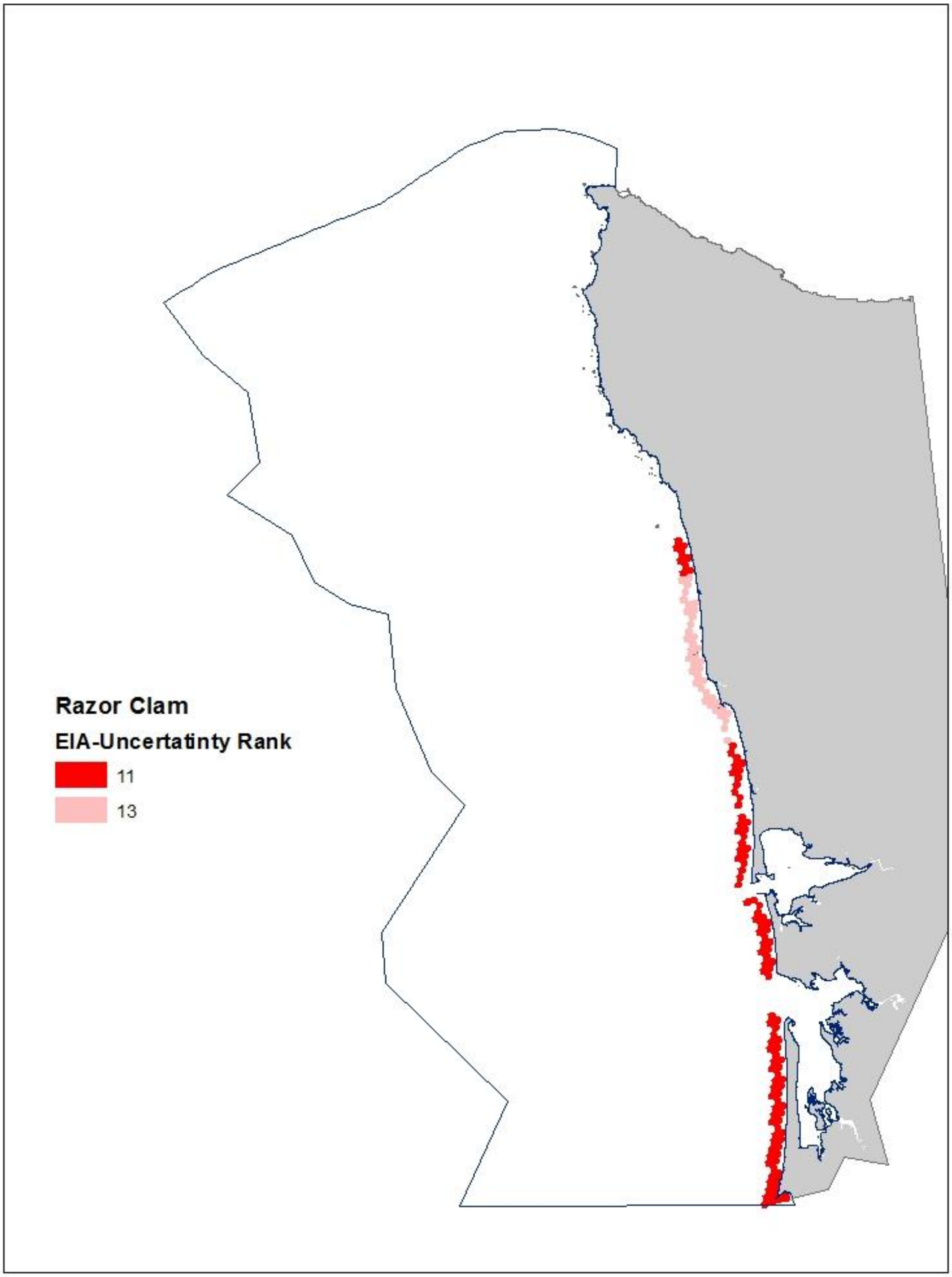
Years of data included: The survey time series we considered here runs from 1997 to 2014.

Species included: Pacific razor clam (*Siliqua patula*).

Data used: We considered the survey's estimated annual densities and locations of the five razor clam beaches.

Calculating the importance score: We assigned all razor clam beaches an importance score of 1. With annual density estimates available for each beach, we considered ranking the beaches relative to one another. However, given the large size of the beaches and the coarse-level purpose of the analysis, we chose to treat the beaches as equally important for now. Mocrocks would rank highest in terms of average density over the survey time series and Long Beach lowest. However, even Long Beach has ranked in the top 3 in terms of clam densities in some years. In future updates to this maps, we may consider looking at producing finer spatial scale using the survey transect locations.

Calculating the uncertainty score: All beaches receive the uncertainty score of 1 ("high" certainty) because they are known to provide important habitats for this species. There would be considerably more uncertainty if we took the step toward identifying which areas provide the most important habitat for razor clams. A long time source of uncertainty arises because razor clams are known to occupy areas beneath the tide that are inaccessible to the survey. The surveys also focus on clams that have settled on the beach. The ecological processes that lead the clams to settle on these beaches are not captured by this map. For this draft, we assigned the areas on the Quinault Reservation as having a "low" certainty of 3 temporarily until we have time to adequately coordinate with QIN staff. There are 23 miles of coastline within the Reservation, some of which provides razor clam habitat that are surveyed and managed by the QIN.


Razor Clam
EIA-Uncertatinty Rank
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Pacific Whiting/Hake Commercial Fishery-based Map

Source: Information reported by vessel operators delivering fish into Washington and Oregon or information collected by observers with the National Marine Fisheries Service's At-Sea Hake Observer programs.

Goal of data gathering effort: Logbooks and onboard observer data are collected to serve many fisheries conservation and management purposes.

Method: Commercial fishing vessels target Pacific whiting using midwater trawl gear. Observers and/or vessel operators record the start and end points of each trawl tow as well as several other attributes. Catch amounts are reconciled with actual weights as measured on scales on shore or aboard at sea processing vessels.

Area surveyed: Logbooks and observer records cover the full area of the fishery. Unlike a scientific survey, fishing vessels do not randomly or systematically sample areas. Nonetheless, we do expect catch from the fishery to provide some information on habitat use of Pacific Whiting. Fishing vessels will tend to set their gear in areas where the effort will produce the highest value of catches and therefore, they will focus on areas where the fish can be found at relatively high densities. Other factors influence fishing areas as well and cause the areas fished to vary from year to year. For instance, fishing vessels may avoid areas where Pacific Whiting can be caught at high rates because of the desire to avoid bycatch of species like Chinook salmon and several rebuilding rockfish species because too much bycatch can cause the fishery to shut down. In addition, areas fished by shoreside vessels may be influenced by incentives to fish close to port. The fishery is prohibited from operating in state waters (from shore to the 3 nautical mile line). We therefore applied the scores only to the marine offshore and oceanic zones in the MSP Study Area.

Years and seasonality: We included tows from the years 2000-2013 to explore the species' use of the MSP Study Area over a range of population sizes. The whiting stock goes through large swings in abundance when large cohorts enter the population. The 2000-2013 timespan covers two such cohorts, one born in 1999 and the other in 2010. In 2000, the best available science estimates that the stock was at just over 30 percent of its unfished size. The 1999 cohort pushed that number up to almost 63 percent in 2003. As the 1999 cohort was fished and consumed by predators, the stock dropped to a low of 22 percent in 2009. The 2010 cohort together with a relatively strong 2008 cohort have now increased the stock to over 70 percent of its estimated unfished size in 2014.

In terms of seasonality, the at sea fishery has opened on May 15th of each year with the shoreside sector opening a month later, or in some years, even later by choice. The fishery stays open until the end of the year or whenever the whiting quota or a bycatch limit is reached. The timing of the fishery has varied but in general, fishing is most active in summer and early fall. Whiting also shows seasonal and migratory movements. The species' movements are not known definitively, yet the general pattern has the stock moving into the MSP Study Area in spring and to the offshore and south in winter.

Species and life history stages included: The species of focus is Pacific whiting, also called Pacific hake (*Merluccius productus*). The commercial catch of whiting will be biased toward marketable fish that are age 2 and older. Spawning and larval habitats are not well known, yet are thought to occur in areas well south of the MSP Study Area. We included whiting in this analysis because the species occupies different habitats than the benthic-oriented groundfish and because it is one of the most abundant fish species in the ecosystem and a major consumer of krill. Just as the fishery provides some information on habitat use of whiting, the location of whiting may provide some information on the locations of this key prey species.

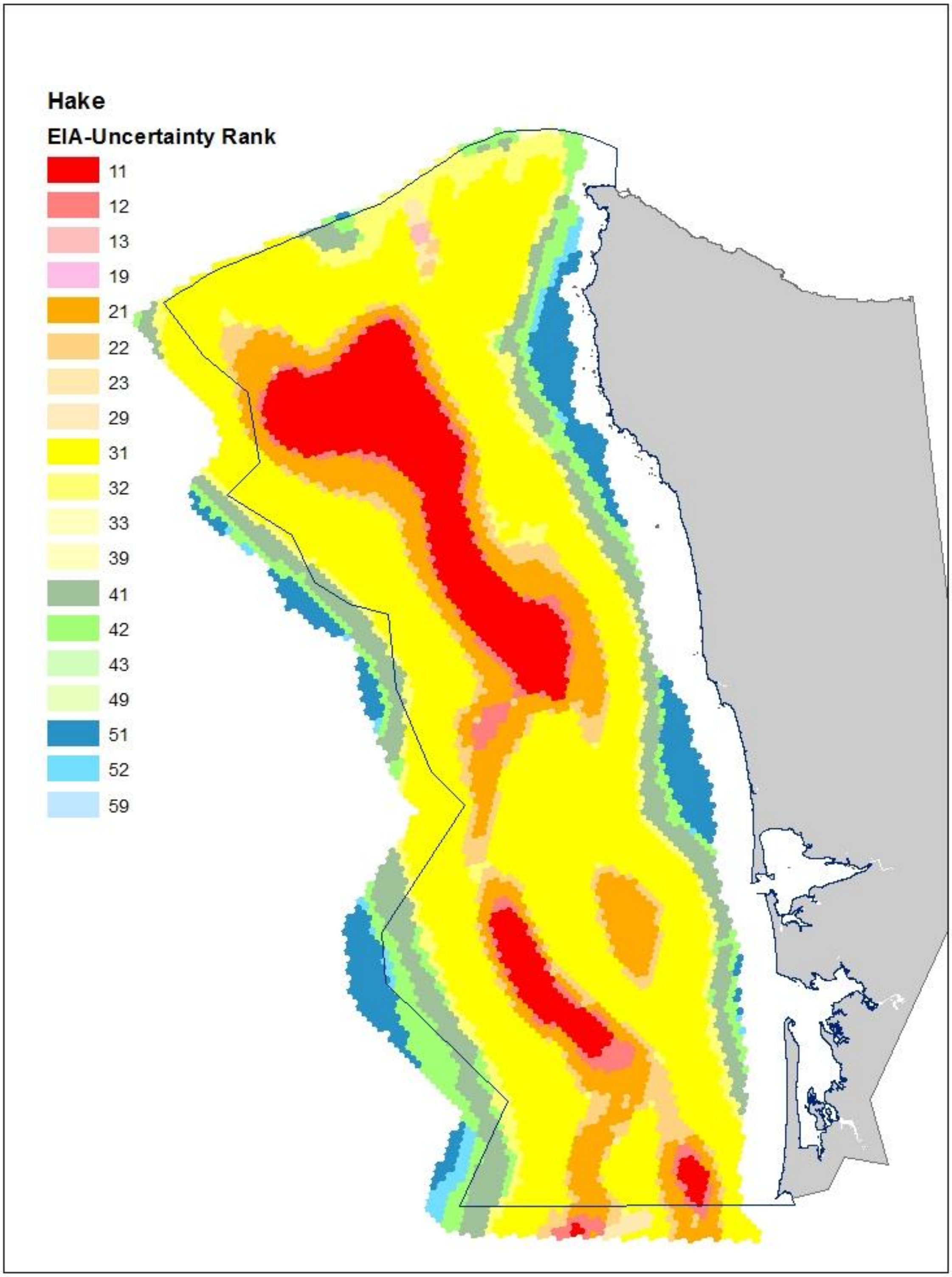
Data used: We used the location and catch of whiting from 31,349 combined tows made by shoreside and at-sea whiting vessels. We plotted each tow in ArcGIS using an ellipse based method meant to account for uncertainty in the path of the tow and recording of the start and end coordinates.

Calculating the importance score: As with the other fishery-based maps, the scoring approach we took for this map treats the relative ecological importance of an area as proportionate to the total catch the fishery removed from it. To evaluate the total catch that may have come from each hexagon, we overlaid the tows onto the hexagon grid, associating a tow's catch will all intersecting hexagons. While representing the tows as ellipses, we gave more weight to hexagons if they intersected the center of an ellipse than its outer edges. To account for variations between years and sectors, we represented the catch on each tow as a fraction of the total catch taken by year and by sector. We then summed the catch fractions within each hexagon and calculated the totals from each and equated to quantiles/percentiles using the empirical cumulative distribution. We then converted the quantiles to importance scores according to the following to table.

EIA score	**1** *High*	**2** *Med.-High*	**3** *Medium*	**4** *Med.-Low*	**5** *Low*
Percentile range	> 0.90	0.90 ≤ & > 0.75	0.75 ≤ & > 0.25	0.25 ≤ & > 0.15	≤ 0.10

Calculating the uncertainty score: We assigned the uncertainty scores by resampling the tows with replacement and recalculating the importance scores in the manner described above 5,000 times. These 5,000 iterations produced a distribution of quantile values for each hexagon. The importance score we assign to each hexagon corresponds to the median value of those distributions. A hexagon's uncertainty score, in contrast, is based on the difference between what its importance score would be at its 5th and 95th percentile values. If a hexagon's importance score changed 2 or more points between them, we assigned an uncertainty score of 3. If the score changed only 1 point, we assigned an uncertainty score of 2, and then a 1 if the importance scores did not change at all.

This method of calculating the uncertainty scores focuses on the sensitivity to the subset of the data included in the analysis. Scoring a 1 for both importance and uncertainty simply means that a hexagon comes out in the top 10 percent of hexagons no matter which subset of the data we include in the scoring. There are greater sources of uncertainty related to the limitations of the data itself and the assumption that ecological importance to the species is proportional to catch that we cannot quantify.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Ocean Pink Shrimp Commercial Fishery-based Map

Source: WDFW Coastal Commercial Pink Shrimp Fishery Logbooks.

Goal of data gathering effort: The information on the location of catch and fishing effort collected from logbooks is used for several conservation and management purposes.

Method: Fishing vessels in Washington target pink shrimp with single- or double- rigged, semi-pelagic, fine-meshed shrimp trawl nets. The great majority of vessels use double-rigged nets. Vessel operators are required to record information about the location, timing, and amount of catch in logbooks (*see* http://wdfw.wa.gov/fishing/commercial/shrimp/logbook.html).

Area surveyed: Logbooks cover the area of the fishery. Fishing vessels do not randomly or systematically sample areas as would a scientific survey, yet fishing vessels will tend to set their gear in areas that will produce the highest catches. Other economic and regulatory factors affect decisions on where to fish as well.

Years and seasonality: We included tows from the years 2011-2014. The commercial shrimp trawl fishery opens on April 1 and continues through October 31.

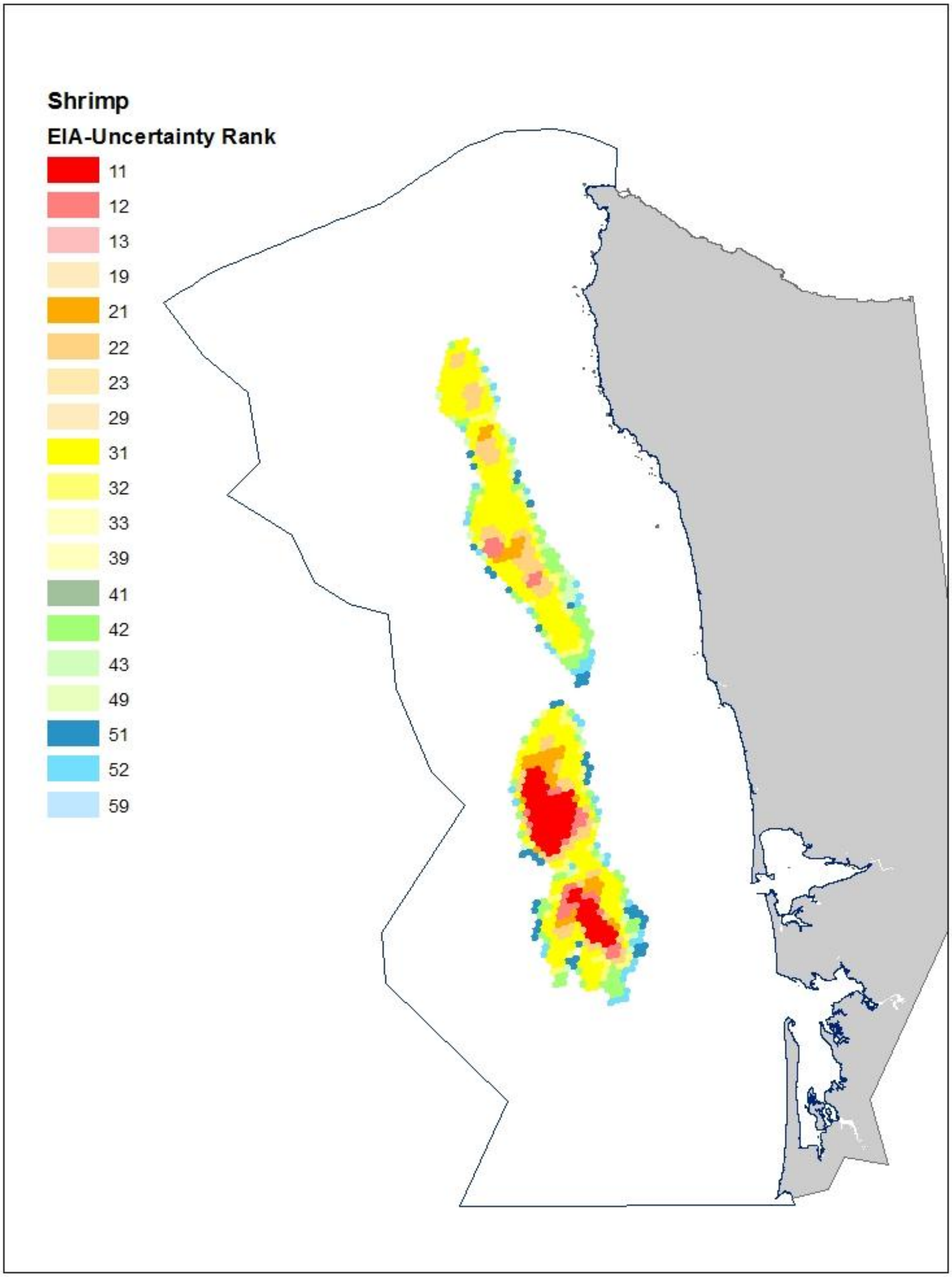
Species and life history stages included: Ocean Pink Shrimp (*Pandalus jordani).* The commercial catch recorded in logbooks is composed mainly of one and two year old shrimp. The species' maximum age is four years.

Data used: After filtering the data to remove clear and likely erroneous records (~15 percent of all records), we used the location and catch from 11,629 tows made by commercial shrimp vessels and plotted them in ArcGIS as lines.

Calculating the importance score: As with the other fishery-based maps, the scoring approach for this map treats the relative ecological importance of an area as proportionate to the total catch the fishery removed from it. To evaluate the total catch that may have come from each hexagon, we overlaid the tows onto the hexagon grid and associated a tow's catch with all intersecting hexagons. The catch for each tow was represented as a fraction of the total catch reported for that year. We then summed the catch fractions within each hexagon and calculated the associated quantiles/percentiles using the empirical cumulative distribution. Hexagons containing records from fewer than three vessels were excluded in following conventions on protecting the confidentiality of logbook data. Consistent with the approach taken for several other maps, we converted the percentiles to importance scores according to the following to table.

EIA score	**1** *High*	**2** *Med.-High*	**3** *Medium*	**4** *Med.-Low*	**5** *Low*
Percentile range	> 0.90	0.90 ≤ & > 0.75	0.75 ≤ & > 0.25	0.25 ≤ & > 0.15	≤ 0.10

Calculating the uncertainty score: We assigned the uncertainty scores by resampling the tows with replacement and recalculating the importance scores in the manner described above 5,000 times to produce a distribution of quantile values for each hexagon. The importance score we assign to each hexagon corresponds to the median value of those distributions. A hexagon's uncertainty score, in contrast, is based on the difference between what its importance score would be at its 5th and 95th percentile values. If a hexagon's importance score changed 2 or more points between them, we assigned an uncertainty score of 3. If the score changed only 1 point, we assigned an uncertainty score of 2, and then a 1 if the importance scores did not change at all. This method of calculating the uncertainty scores focuses on the sensitivity to the subset of the data included in the analysis. There are greater sources of uncertainty related to the limitations of the data itself and the assumption that ecological importance to the species is proportional to catch that we cannot quantify.


Shrimp
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Habitat

Floating Kelp

Source: Methods follow Van Wagenen (2015). Spatial data and meta data are available at: https://fortress.wa.gov/dnr/adminsa/DataWeb/dmmatrix.html

Goal of data gathering effort: Develop a state-wide, coastal kelp resource mapping and monitoring program that would accurately reflect the seasonal maximum kelp extent (August-October), by kelp species. Specifically, this program maps the canopy extent of *Nereocystis luetkeana* (bull kelp) and *Macrocystis integrifolia* (giant kelp) beween Port Townsend and the Columbia River.

Method: This is a multi-step process that involves:

1) Kelp canopy aerial photography and species composition estimations,
2) Qualitative kelp canopy mapping and species determination,
3) Quantitative kelp canopy/planimeter area and density analysis, and
4) Geographic Information System (GIS) electronic data-layer creation/file transfer.

Area surveyed: All nearshore habitat between Port Townsend and the Columbia River

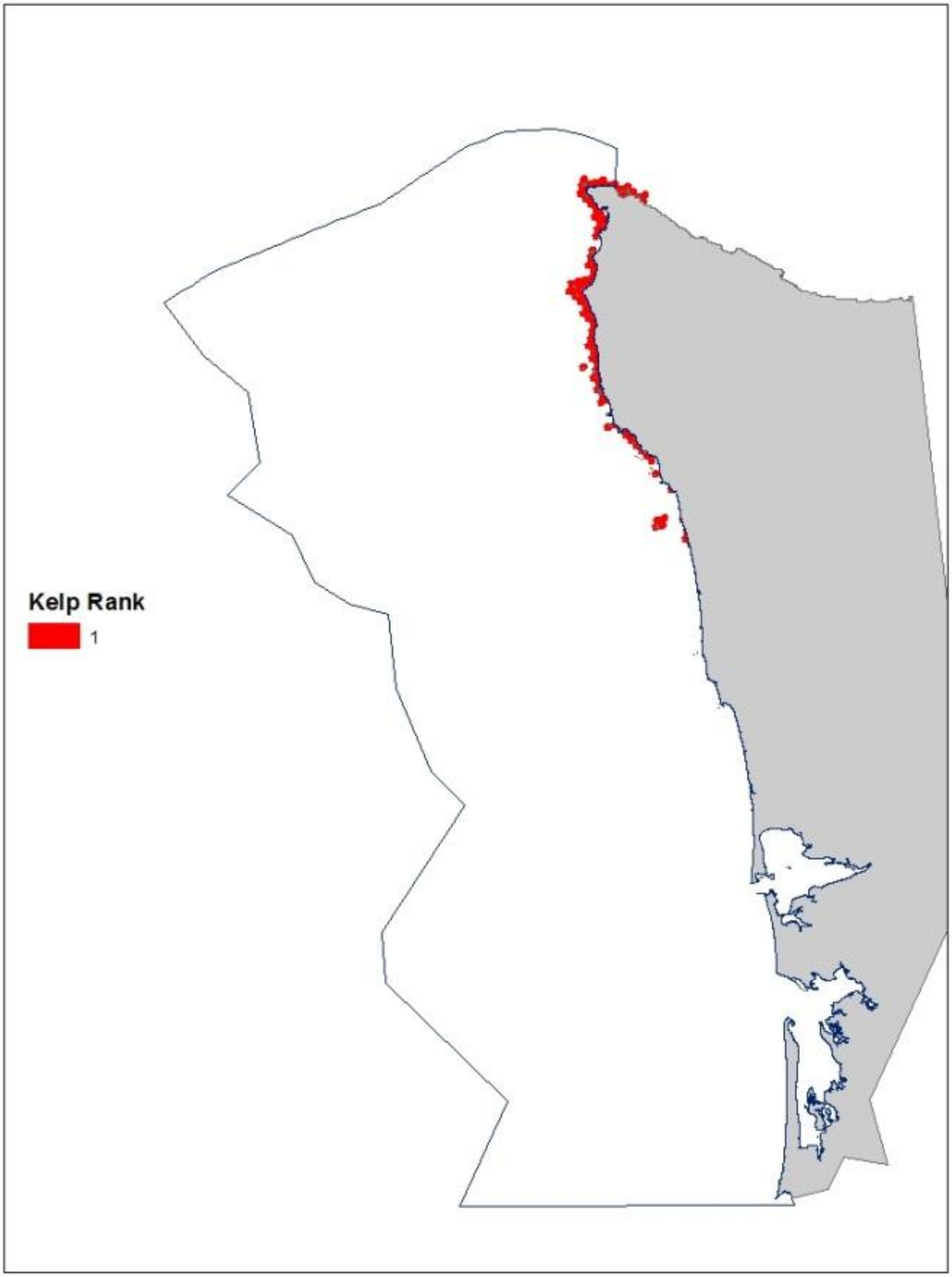
Years of data included: 1990-2014

Species included: *Nereocystis luetkeana* (bull kelp) and *Macrocystis integrifolia* (giant kelp)

Data used: Maximum extent from all years.

Calculating the importance score: Because of the critical biotic habitat that kelp provides, it was given an importance score of "1".

Calculating the uncertainty score: Annual surveys for 24 years with complete coastal coverage. Assigned a certainty of "1".



Kelp Rank
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Predicted Deep-Sea Coral Habitat Suitability

Source: The scores for this layer were derived from the predictive habitat suitability models of Guinotte and Davis (2014). The model outputs are available for download from and from the Supporting Information section Guinotte and Davis' article and the Consolidated GIS Data Catalog and Online Registry for the 5-Year Review of Pacific Coast Groundfish Essential Fish Habitat (see References).

Goal of data gathering effort: Deep-sea corals have been of conservation interest on the West Coast for two main reasons. First, some species are extraordinarily long-lived and slow growing and therefore show low resilience to and long recovery times from disturbance. Second, deep-sea corals are also hypothesized to provide structure that creates habitat for other animals, i.e. "biogenic habitats" (Hourigan et al. 2007). Much about the ecology of deep sea corals and the value of the biogenic habitat they provide is uncertain and the focus of research and debate.

Method: Guinotte and Davis used the maximum entropy statistical approach ("MaxEnt") for predicting habitat suitability. This modelling approach is commonly used where the species data is "presence only" (i.e. where surveys do not systematically cover areas or do not record zeros for areas where the species was not present). The technique uses associations between environmental variables like depth, substrate type, temperature, etc. and the observed corals to make predictions about habitat suitability in all areas.

Area surveyed: Guinotte and Davis' models apply to waters deeper than 50 meters within the U.S. West Coast Exclusive Economic Zone (EEZ). They assigned habitat suitability scores to a grid consisting of 500 meter by 500 meter cells. Our scores are based only on the grid cells located within the MSP Study Area.

Years of data included: Guinotte and Davis aggregated several years of coral observations and environmental variables from several sources. See their paper for details.

Species included: The term deep-sea, or cold-water, corals refers to diverse set of species commonly referred to as. Over 100 species of deep-sea coral, belonging to six different taxonomic orders, have been identified off the U.S. West Coast. These species can be broadly classified into "soft", "stony", and "black" types with all three known to occur off of Washington. To capture a broad look at coral habitats off of Washington, we focused on Guinotte and Davis' "all taxa" models. These predict whether a particular grid cell is suitable habitat for any species in the taxonomic orders Antipatharia or Scleractinia or the suborders Alcyoniina, Calcaxonia, Filifera, Holaxonia, Scleraxonia, Stolonifera. Guinotte and Davis also produced models that focus on six of these taxonomic groups individually. Mullineaux and Mills (2004) provide an introduction to the biology of deep-sea corals for the general reader. Whitmire and Clarke (2007) provide an overview specific to U.S. West Coast corals.

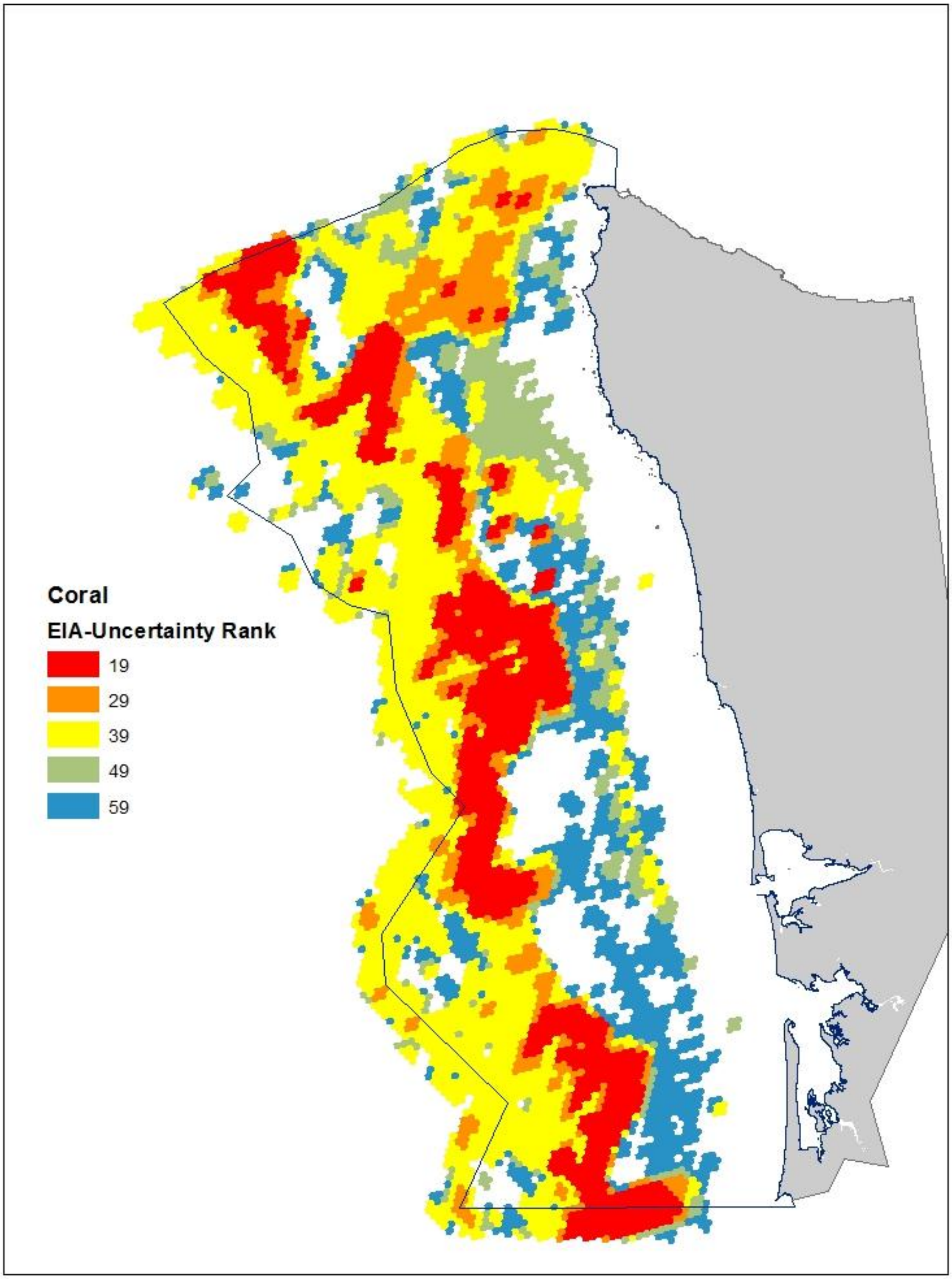
Data used: Guinotte and Davis' models incorporate 2,120 coral observations that were recorded across several studies. Their models relate these observations to seven environmental variables: temperature, salinity, particulate organic carbon, depth, dissolved oxygen, calcite saturation state, and slope of the seafloor (1 km resolution).

Calculating the importance score: The ecological importance scores for this layer are based on two sets of Guinotte and Davis' habitat suitability scores. The scores are provided on a scale of 0-4 with 4 being the highest predicted suitability. For both sets, we took the maximum suitability score per hexagon. One set of scores is based on standard model threshold of 0.50 and the other on a more stringent 0.75. The areas predicted to have the highest suitability would therefore score a 4 under the 0.75 threshold and those with the lowest suitability would score as a 1 under the standard threshold. See their paper for details. Table 3 identifies the full translation of Guinotte and Davis' model scores to the importance scores.

Table 4. Translation of Guinotte and Davis habitat suitability scores to ecological importance scores.

Thresholds		**0.75**				
	Suitability	***0***	***1***	***2***	***3***	***4***
0.50	***4***	3	3	2	2	1
	3	3	3	3	3	
	2	4	4	3		
	1	5				
	0	--				

Calculating the uncertainty score: Separate uncertainty scores were not assigned for this layer. Uncertainty, however, is incorporated to some degree in the importance scores. Guinotte and Davis used a cross-validation approach where they predicted suitability using four models, each differing in which coral observations were used as input data. A habitat suitability score of 2 means that only half of the models predicted the habitat as suitable, meaning that there is less certainty in the prediction relative to an area where all four models predicted it to be suitable.


Coral
EIA-Uncertainty Rank
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Rocky Reef and "Hard" Benthic Substrates

Source: The main sources for this map are two maps produced by Oregon State University's (OSU) Active Tectonics and Seafloor Mapping Lab and collaborators: the (1) Surficial Geologic Habitat Map, version 4.0; and (2) predicted rocky outcrop model. The source maps are available from http://bhc.coas.oregonstate.edu/boem_data/V4_0_SGH_WA_OR_NCA.zip; and http://bhc.coas.oregonstate.edu/boem_data/OutcropModel.zip). We supplemented these sources with the coordinates of known rockfish fish habitats from WDFW's hook and line rockfish surveys.

Goal of data gathering effort: The OSU maps synthesize data from many data gathering efforts undertaken for various purposes. The goal of WDFW's survey is to monitor trends in nearshore rockfish populations.

Method: The data underlying the OSU maps were produced from several surveys ranging from multibeam sonar, sidescan sonar, sediment grab samples, cores samples, seismic reflection profiles, and still or video images (see Goldfinger et al. (2014) for details). For WDFW nearshore sites, the agency uses recreational fishing gear to monitor trends in rockfish populations. Sampling sites were identified based on known fishing areas and exploratory efforts.

Area surveyed: The OSU led maps were produced for large areas off the Pacific Northwest down through northern California. The WDFW surveys have focused on nearshore areas of the state in depths ~30 fathoms and shallower.

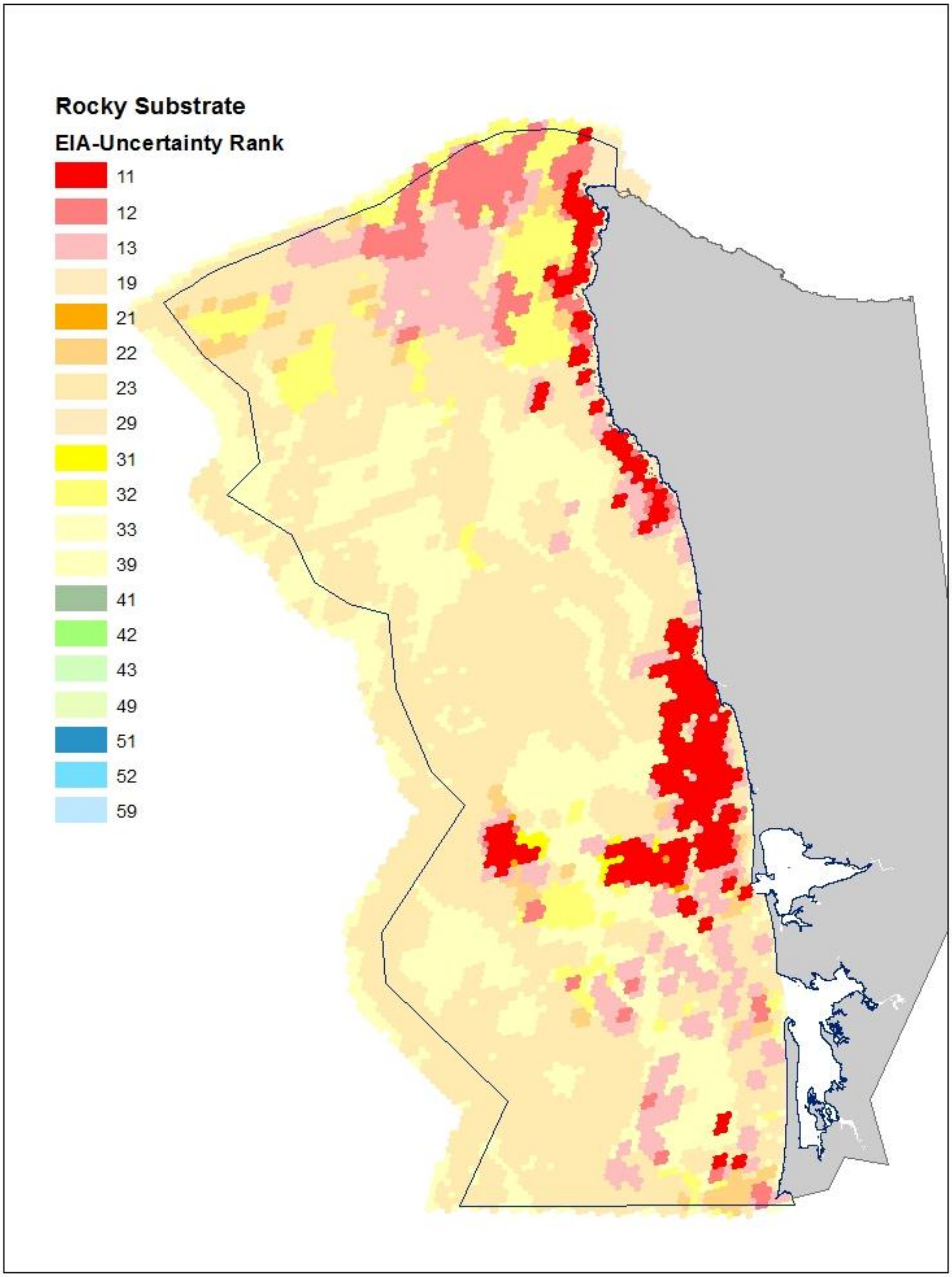
Years of data included: The many sources of input data used to produce the source layers for this map have been collected over several decades, even dating back to lead line surveys conducted during the first half of the 20th Century. WDFW has been surveying Black Rockfish since the late 1990s and in 2009 began scouting for survey stations suitable for other monitoring other species like China Rockfish, Cabezon, and Kelp Greenling.

Species included: Unlike most of the other maps in this project, this map focuses directly on habitat instead of animals. The reason is that rocky habitats are known to provide key habitats to several fish and invertebrate species and yet to not have not been surveyed adequately. Surveying in such habitat types is logistically challenging and expensive. Hard substrates are also of interest because of their relative rarity and because they could be destroyed or permanently disrupted to a much larger degree than sandy or muddy habitats. Considering the West Coast as a whole, estimates show that roughly 90 percent of the benthic habitats in the U.S. West Coast Exclusive Economic Zone are sandy or muddy (NMFS 2008).

Data used: We used the surficial substrate ("lithology") classifications and predicted probabilities of rocky outcrops from the OSU-led source maps. From the WDFW survey, we used the coordinates from the catch of rocky reef oriented species.

Calculating the importance score: We assigned 1s to WDFW nearshore surveys sites and to the OSU rocky (a.k.a. "hard") surficial substrate categories, 2s to the mixed substrate types, and 3s to the sandy and muddy substrate types. For the sandy and muddy substrate types, we then considered the probability of rocky outcrop values. We adjusted hexagons from a 3 to a 2 if the predicted outcrop probability was 0.60 or greater, and then to a 1 if the probability was 0.75 or greater.

Calculating the uncertainty score: We assigned the uncertainty scores based on the data quality measures that accompany the OSU-led maps. These data quality scores range from 0 to 10 and derive from the number of data sources available for each area (see Goldfinger et al. 2014). For areas on the continental slope (a.k.a. "marine oceanic"), we assigned an uncertainty score of 3 to hexagons with data quality scores of 5 and lower, and assigned an uncertainty score of 1 to hexagons with data quality scores of 6 and greater as 1s (i.e. "low" uncertainty). For areas on the continental shelf (a.k.a. "marine offshore"), we translated the OSU data quality scores of 7 or higher to 1s, between 2 and 6 as 2s, and 0 and 1s to 3s. We chose to use to use differential scoring between the shelf and slope habitats after consulting with OSU analysts. In general, the continental slope areas are better mapped and less variable than those on the continental shelf. The continental shelf off Washington is one of the least well mapped areas on the West Coast and smaller scale rocky habitats are those that will tend to be missed where survey data are sparse. The WDFW rockfish survey sites are assigned a high certainty score of 1 because WDFW has confirmed the existence of the habitat. We chose to include these survey sites because they indicate rocky structures where the OSU-led maps do not. On the other hand, WDFW survey efforts have not found fish present in habitat that the OSU-led maps predict as containing rocky habitats.



Rocky Substrate
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References Cited and Literature Considered

Agresti, A. 2010. Analysis of Ordinal Categorical Data. Wiley Series in Probability and Statistics.Wiley.

Ainley, D.G and R.J. Boekelheide (eds). 1990. Seabirds of the Farallon Islands: ecology, dynamics, and structure of an upwelling system community. Stanford University press, Stanford, Calif.

Ainley, D.G., L.B. Spear and S.G. Allen. 1966. Variation in the diet of Cassin's auklet reveals spatial, seasonal, and decadal occurrence patterns of euphausiids off California, USA. Marine Ecology Progress Series 137: 1-10.

Ainley, D. G., L.B. Spear, C.T. Tynan, J. A. Barth, S.D. Pierce, R. G. Ford, and T.J. Cowles. 2005. Physical and biological variables affecting seabird distributions during the upwelling season of the northern California Current. Deep-sea Research II 52: 123-143.

Ainley, D.G., K.D. Dugger, R.G. Ford, S.D. Pierce, D.C. Reese, R.D. Brodeur, C.T. Tynan, and J.A. Barth. 2009. Association of predators and prey at frontal features in the California Current: competition, facilitation, and co-occurrence. Marine Ecology Progress Series 389:271–294.

Barth J.A., Pierce S.D., Cowles T.J. 2005. Mesoscale structure and its seasonal evolution in the northern California Current System. Deep-Sea Research II 52: 5−28

Birch, C.P.D., S.P Oom, and J.A. Beecham. 2007. Rectangular and hexagonal grids used for observation, experiment and simulation in ecology. Ecological Modelling 206:347-359.

Bowlby, C. E., B. L. Troutman and S. J. Jeffries. 1988. Sea otters in Washington: distribution, abundance, and activity patterns. Washington State Department of Wildlife, Olympia, WA. Final Report to National Coastal Resources Research and Development Institute, Newport, Oregon.

Buchanan, J.B. and J.R. Evenson. 1997. Abundance of shorebirds at Willapa Bay, Washington. Western Birds 28:158-168.

Buchanan, J.B., J.E. Lyons, L.J. Salzer, R. Carmona, N. Arce, G.J. Wiles, K. Brady, G.E. Hayes, S.M. Desimone, G. Schirato, and W. Michaelis. 2012. Among-year site fidelity of Red Knots during migration in Washington. Journal of Field Ornithology 83:282–289.

Buckland, S.T.; D.R. Anderson; K.P. Burnham; J.L. Laake; D.L. Borchers; L. Thomas. 2001. Introduction to distance sampling: Estimating abundance of biological populations. Oxford University Press, New York.

Buckland, S.T.; D.R. Anderson; K.P. Burnham; J.L. Laake; D.L. Borchers; L. Thomas. 2004. Advanced distance sampling: Estimating abundance of biological populations. Oxford University Press, New York.

Calambokidis, J., G. H. Steiger, B. L. Troutman, and C. E. Bowlby. 2004. Distribution and abundance of humpback whales (*Megaptera novaeangliae*). Fishery Bulletin 102:563- 580.

Carney, K.M., and W.J. Sydeman. 1999. A Review of Human Disturbance Effects on Nesting Colonial Waterbirds. Waterbirds 22: 68-79.

Carr, D.B., Olsen, A.R., White, D., 1992. Hexagon mosaic maps for display of univariate and bivariate geographical data. Cartography and Geographic Information Systems 19, 228–236.

Chatwin, T.A., R. Joy, and A.E. Burger. 2013. Set-back distances to protect nesting and roosting seabirds off Vancouver Island from boat disturbance. Waterbirds 36:43-52

Consolidated GIS Data Catalog and Online Registry for the 5-Year Review of Pacific Coast Groundfish Essential Fish Habitat. http://efh-catalog.coas.oregonstate.edu/synthesis/

Croll, D.A., Tershy, B., Hewitt, R., Demer, D., Fiedler, P., Smith, S., Armstrong, W., Popp, J., Kieckhefer, T., Lopez, V., and Urban, Ramirez, J. 1998. An integrated approach to the foraging ecology of marine birds and mammals. Deep-Sea Research II:1353-1371.

Dethier, M.N. 1991. The Effects of an Oil Spill and Freeze Event on Intertidal Community Structure in Washington, Final Report. OCS Study MMS 91-0002.

De Robertis, A., C.A. Morgan, R.A. Schabetsberger, R.W. Zabel, R.D. Brodeur, R.L. Emmett, C.M. Knight, G.K. Krutzikowsky, E. Casillas. 2005. Columbia River plume fronts II. Distribution, abundance, and feeding ecology of juvenile salmon. Marine Ecology Progress Series 299:33–44.

Druehl, L. D. 1969. The northeast Pacific rim distribution of the Laminariales. Proceedings of the International Seaweed Symposium 6: 161-170

Duff, A., J. Jenkerson, L. Salzer, S. Jeffries, and S. Pearson. 2014. Coastal Washington marine mammal and bird geodatabases. Washington Department of Fish and Wildlife, Wildlife Science Division, Olympia, Washington.

Estes, J. A., and J. F. Palmisano. 1974. Sea otters: their role in structuring nearshore communities. Science 185: 1058- 1060.

Evenson, J., T. Cyra, B. Murphie, and D. Kraege. 2011. Summary of the Winter 2011 Sea Duck Aerial Surveys of the Pacific Coast of Oregon and Washington. Washington Department of Fish and Wildlife.

FGDC (Federal Geographic Data Committee). 2012. FGDC-STD-018-2012. Coastal and Marine Ecological Classification Standard. Reston, VA. Federal Geographic Data Committee. http://csc.noaa.gov/digitalcoast/sites/default/files/files/publications/14052013/CMECS_Version%20_4_Final_for_FGDC.pdf

Fiedler, P.C., S.B. Reilly, R.P. Hewitt, D. Demer, V.A. Philbrick, S. Smith, W. Armstrong, D.A. Croll, B.R. Tershy, and B.R. Mate. 1998. Blue whale habitat and prey in the California Channel Islands. Deep-Sea Research Part II 45, 1781-1801.

Field, J.C. and R. C. Francis. 2006. Considering ecosystem-based fisheries management in the California Current. Marine Policy 30:552-569.

Goldfinger, C., Henkel, S.K., Romsos, C., Havron, A., and B. Black. 2014. *Benthic Habitat Characterization Offshore the Pacific Northwest Volume 1: Evaluation of Continental Shelf Geology*. US Dept. of the Interior, Bureau of Ocean Energy Management, Pacific OCS Region.OCS Study BOEM 2014-662 (http://www.boem.gov/2014-662-v1)

Guinotte, J. M. and A.J. Davies. 2014. Predicted Deep-Sea Coral Habitat Suitability for the U.S. West Coast. PLoS ONE 9(4): e93918. doi:10.1371/journal.pone.0093918.

Hickey, B.M. and N.S. Banas. 2003. Oceanography of the U.S. Pacific Northwest Coastal Ocean and Estuaries with Applications to Coastal Ecology. Estuaries 26(4B):1010-1031.

Hickey, B.M. and N.S. Banas. 2008. Why is the northern end of the California Current System so productive? Oceanography 21(4):90-107.

Hickey, B., S. Geier, N. Kachel, and A. MacFayden. 2005. A bi-directional river plume: The Columbia in summer. Continental Shelf Research 25:1631-1656.

Hourigan, T. F., Lumsden, S. E., Dorr, G., Bruckner, A. W., Brooke, S., & Stone, R. P. 2007 State of deep coral ecosystems of the United States: Introduction and national overview. In: SE Lumsden, Hourigan TF, Bruckner AW and Dorr G (eds.) The State of Deep Coral Ecosystems of the United States. NOAA Technical Memorandum CRCP-3. Silver Spring MD 365 pp. (http://www.coris.noaa.gov/activities/deepcoral_rpt/).

Jameson, R.J., and S. Jeffries. 2014. Results of the 2013 Survey of the Reintroduced Sea Otter Population in Washington State. Washington Department of Fish and Wildlife Science Program, Lakewood, Washington.

Jeffries, S.J., P.J. Gearin, H.R. Huber, D.L. Saul, and D.A. Pruett. 2000. Atlas of Seal and Sea Lion Haulout Sites in Washington. Washington Department of Fish and Wildlife, Wildlife Science Division, 600 Capitol Way North, Olympia Washington.

Jenkerson, J., and S.F. Pearson. 2012. Catalog of Washington Seabird Colonies: Converting the Catalog to a Geodatabase and Adding New Survey Data. Research Progress Report, Washington Department of Fish and Wildlife Science Division, Olympia, WA.

Keren, I., and S.F. Pearson. 2015. Streaked horned lark abundance and trends for the Puget lowlands and the lower Columbia River-Washington Coast, 2010-2014: Research Progress Report, Wildlife Science Division, Washington Department of Fish and Wildlife, Olympia

Langness, M., P. Dionne, D. Masello, and D. Lowry. Summary of Coastal Intertidal Forage Fish Spawning Surveys: October 2012 – October 2014. Washington Department of Fish and Wildlife, Fish Program Report Number FPA 15-01. http://wdfw.wa.gov/publications/01701/

Lassuy, D.R., and D. Simons. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest) -- Pacific razor clam. U.S. Fish and Wildlife Service Biological Report 82(11.89). U.S. Army Corps of Engineers, TR-EL-82-4 .

Lewin, J., C.T. Schaefer and D.F. Winter. 1989. Surf-zone ecology and dynamics. In M.R. Landry and B.M. Hickey (Eds.), Coastal Oceanography of Washington and Oregon. Elsevier, Amsterdam.

Leirness, J and C. Menza. 2015. Draft seabird distribution predictions off the Pacific Coast of Washington. National Centers for Coastal Ocean Science (NCCOS). Digital map format.

Litz, M.N.C., S.S. Heppell, R.L. Emmett, and R.D. Brodeur. 2008. Ecology and distribution of the northern subpopulation of Northern Anchovy (*Engraulis mordax*) off the US West Coast. California Cooperative Oceanic Fisheries Investigations Report 49:167–182.

MacFadyen, A., B.M Hickey, and W.P. Cochlan. 2008. Influences of the Juan de Fuca Eddy on circulation, nutrients, and phytoplankton production in the northern California Current System. Journal of Geophysical Research C: Oceans 113 (C8) DOI: 10.1029/2007JC004412

Marchetti, A., V.L. Trainer, and P.J. Harrison. 2004. Environmental conditions and phytoplankton dynamics associated with Pseudo-nitzschia abundance and domoic acid in the Juan de Fuca eddy. Marine Ecology Progress Series 281: 1-12.

McFarlane, G.A., D.M. Ware, R.E. Thomson, D.L. Mackas, and C.L.K. Robinson. 1997. Physical, biological and fisheries oceanography of a large ecosystem (west coast of Vancouver Island) and implications for management. Oceanologica Acta 20:191-200.

Mclean, J.H. 1962. Sublittoral ecology of kelp beds of the open coast area near Carmel, California. Biological Bulletin 122: 95-114.

Menza, C., J. Leirness, T. White, A. Winship, B. Kinlan, J. Zamon, L. Ballance, E. Becker, K. Forney, J. Adams, D. Pereksta, S. Pearson, J. Pierce, L. Antrim, N. Wright, and E. Bowlby. 2015. Modeling seabird distributions off the Pacific coast of Washington. NOAA, National Centers for Coastal Ocean Science, Silver Spring, MD

Miller, D. J. and J.J. Geibel. 1973. Summary of blue rockfish and lingcod life histories; a reef ecology study; and giant kelp, Macrocystis pyrifera, experiments in Monterey Bay, California. California Fish and Game Fish Bulletin 158: 1-137.

Moran, P., Dazey, J., and S. Young. 2013. Comparing genetic stock identification and coded-wire-tag stock composition estimates for the 2012 Chinook salmon commercial troll fishery Areas 2-4 U.S. West Coast.Morejohn, G.V. 1977. Marine Mammals. Pages 1-74 in: A summary of knowledge of the central and northern California coastal zone and offshore areas. Vol. II, Book 2 of 3: Biological Conditions. U.S. Dept. of Commerce PB-274-213. National Technical Information Service, Springfield, VA.

Morgan, C.A., A. DeRobertis, and R.W. Zabel. 2005. Columbia River plume fronts I. Hydrography, zooplankton distribution, and community composition. Marine Ecology Progress Series 299:19–31.

Mullineaux, Lauren S., and Susan W. Mills. 2004. "Coral Gardens in the Dark Depths." Oceanus Magazine 43:2. http://www.whoi.edu/oceanus/feature/coral-gardens-in-the-dark-depths.

National Marine Fisheries Service (NMFS). 2013. Groundfish Essential Fish Habitat Synthesis Report and Appendix to Groundfish Essential Fish Habitat Synthesis: A Report to the Pacific Fishery Management Council. NOAA NMFS Northwest Fisheries Science Center, Seattle, WA, April 2013. ; http://www.pcouncil.org/wp-content/uploads/Groundfish_EFH_Synthesis_Report_to_PFMC_FINAL.pdf; http://www.pcouncil.org/wp-content/uploads/Appendix_to_Groundfish_EFH_Synthesis_Report_to_PFMC_FINAL.pdf

Parnel, M.M., R.L. Emmett, and R.D. Brodeur. 2008. Ichthyoplankton community in the Columbia River plume off Oregon: effects of fluctuating oceanographic conditions. Fisheries Bulletin 106:161–173.

Pearson, S.F., K. Brennan, C. Sundstrom, and K. Gunther. 2008. Snowy Plover Population Monitoring, Research, and Management Actions: 2007 Nesting Season Research Progress Report. Washington Department of Fish and Wildlife, Wildlife Science Division, Olympia.

Pearson, S.F., C. Sundstrom, W. Ritchie, and S. Peterson. 2013. Washington State Snowy Plover Population Monitoring, Research, and Management: 2012 Nesting Season Research Progress Report. Washington Department of Fish and Wildlife, Wildlife Science Division, Olympia.

Pearson, S.F., C. Sundstrom, B. Hoenes, and W. Ritchie. 2014. Washington State Snowy Plover Population Monitoring, Research, and Management: 2013 Nesting Season Research Progress Report.

Pearson, S.F., C. Sundstrom, and W. Ritchie. 2015. Washington State Snowy Plover Population Monitoring, Research, and Management: 2014 Nesting Season Research Progress Report. Washington Department of Fish and Wildlife, Wildlife Science Division, Olympia.

Pearson, S.F., M. Linders, I. Keren, H. Anderson, R. Moore, G. Slater, and A. Kreager. 2015. Streaked horned lark occupancy and abundance survey protocols and Strategies. Washington Department of Fish and Wildlife, Wildlife Science Division, Olympia.

Peterson, S.H., M.M. Lance, S.J. Jeffries, A. Acevedo-Gutierrez. 2012. Long distance movements and disjunct spatial use of harbor seals (Phoca vitulina) in the inland waters of the Pacific Northwest. PLoS ONE 7(6): e39046. doi:10.1371/journal.pone.0039046

Quast, J.C. 1968. Fish fauna of the rocky inshore zone. P. 35-55 In W.J. North and C.L. Hubbs (eds.), Utilization of kelpbed resources in southern California. Cali. Dept. Fish Game, Fish Bull. 139.

Raphael, M.G., J. Baldwin, G.A. Falxa, M.H. Huff, M. Lance, S.L. Miller, S.F. Pearson, C.J. Ralph, C. Strong, and C. Thompson. 2007. Regional population monitoring of the marbled murrelet: field and analytical methods. Gen. Tech. Rep. PNW-GTR-716. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Rodgers, J. A., Jr., and H. T. Smith. 1995. Set-back distances to protect nesting bird colonies from human disturbance in Florida. Conservation Biology 9:89-99.

Rodgers, J. A., Jr., and H. T. Smith. 1997. Buffer zone distances to protect foraging and loafing waterbirds from human disturbance in Florida. Wildlife Society Bulletin 25:139-145.

Rodgers, J. A., Jr., and S. T. Schwikert. 2002. Buffer-zone distances to protect foraging and loafing waterbirds from disturbance by personal watercraft and outboard-powered boats. Conservation Biology 16:216-224.

Rodgers, J. A., Jr., and S. T. Schwikert. 2003. Buffer zone distances to protect foraging and loafing waterbirds from disturbance by airboats in Florida. Waterbirds 26:437-443.

Santora J.A., S. Ralston, and W.J. Sydeman. 2011. Spatial organization of krill and seabirds in the central California Current. ICES Journal of Marine Science 68:1391−1402.

Scheffer, V.B. 1940. The sea otter on the Washington coast. Pacific Northwest Quarterly 10:370-388.

Sherman K. 1995. Achieving regional cooperation in the management of marine ecosystems: The use of the large marine ecosystem approach. Ocean and Coastal Management 29:165-185.

Simenstad, C., L.F. Small, C.D. McIntire, D.A. Jay and C. Sherwood. 1990. Columbia River estuarine studies: an introduction to the estuary, a brief history, and prior studies. Progress in Oceanography 25:1-14.

Skewgar, E. and S.F. Pearson (Eds.). 2011. State of the Washington Coast: Ecology, Management, and Research Priorities. Washington Department of Fish and Wildlife, Olympia, Washington.

Speich, S.M., and T.R. Wahl. 1989. Catalog of Washington seabird colonies. U.S. Fish and Wildlife Service Biological Report. 88(6).

Stephens, John S., Jr., Ralph Larson and Daniel J. Pondella, II. 2006. Rocky Reefs and Kelp Beds. Chapter 9 In The Ecology of Marine Fishes: California and Adjacent Waters (L. G. Allen, D. J. Pondella, II, and M. Horn, editors) pp. 227-252. University of California Press, Los Angeles.

Strickland, R. and D.J. Chasan. 1989. Coastal Washington: A synthesis of information. Washington State & Offshore Oil and Gas. Washington Sea Grant Program, University of Washington, Seattle, WA.

Suryan, R.M., J.A. Santora, and W.J. Sydeman. 2012. New approach for using remotely-sensed chlorophyll-a to identify seabird “hotspots”. Marine Ecology Progress Series 451:213-225.

Swanson, T., D. Canning, S. O’Shea, B. Shorin, and T. Trihimovich (Eds.). 2001. Managing Washington’s Coast – Washington State’s Coastal Zone Management Program. Publication 00-06-029. Washington Department of Ecology, Olympia, WA.

Sydeman, W.J., R.W. Bradley, P. Warzybok, C.L. Abraham, J. Jahncke, K.D. Hyrenbach, V. Kousky, J.M. Hipfner, and M.D. Ohman. 2006. Planktivorous auklet *Ptychoramphus aleuticus* responses to ocean climate, 2005: Unusual atmospheric blocking? Geophysical Research Letters 33:1-5.

Thorn, R M., and L. Hallum. 1990. Long-term changes in the areal extent of tidal marshes, eelgrass meadows and kelp forests of Puget Sound. Wetland Ecosystem Team, Fisheries Research Institute, University of Washington. NTIS, FRI-UW-9008 to the U.S. Environmental Protection Agency, Region 10.

Trainer, V. L., B. M. Hickey, and R. A. Horner. 2002. Biological and physical dynamics of domoic acid production off the Washington coast. Limnology and Oceangraphy 47(5):1438-1446.

Van Wagenen, R.F. 2015. Washington Coastal Kelp Resources Port Townsend to the Columbia River Summer 2014. Prepared by Ecoscan Resource Data, Watsonville, CA for Washington Department of Natural Resources, Nearshore Habitat Program, Olympia, Washington.

Washington Department of Fish and Wildlife. 2002. “How many Razor clams are there?” Razor clam population sampling. URL: http://wdfw.wa.gov/fishing/shellfish/razorclams/how_many.html (September 17, 2010).

Washington State Ocean Policy Work Group. 2006. Washington’s Ocean Action Plan: Enhancing Management of Washington State’s Ocean and Outer Coasts. Olympia, WA.

Wheeler, W. N., and L. D. Druehl. 1986. Seasonal growth and production of Macrocystis integrifolia on British Columbia, Canada. Marine Biology 90: 181-186.

Whitmire, Curt E. and M. Elizabeth Clarke. 2007. State of the U.S. Deep Coral Ecosystems in the United States Pacific Coast: California to Washington. In: SE Lumsden, Hourigan TF, Bruckner AW and Dorr G (eds.) The State of Deep Coral Ecosystems of the United States. NOAA Technical Memorandum CRCP-3. Silver Spring MD 365 pp. (http://www.coris.noaa.gov/activities/deepcoral_rpt/).

Zamon, J.E., E.M. Phillips, and T.J. Guy. 2014. Marine bird aggregations associated with the tidally-driven plume and plume fronts of the Columbia River. Deep Sea Research Part II: Topical Studies in Oceanography, 107:85-95. doi:10.1016/j.dsr2.2013.03.031