SEABIRDS - RISK ASSESSMENT

Thomas P. Good[1], Jameal Samhouri[1], William Sydeman[2]

1. NOAA Fisheries, Northwest Fisheries Science Center
2. Farallon Institute

TABLE OF CONTENTS

Soundbite 1

Executive Summary 1

Detailed Report 1

- Introduction 1
- Methods 2
  - Focal species 2
  - Non-fisheries pressures 3
  - Seabird datasets 3
  - Overview of exposure calculation 4
- Results 5
  - Seabird distribution 5
  - Exposure 5
  - Other sources of risk 6
- Conclusions 6

Seabirds Appendix A 50

References Cited 52

LIST OF TABLES AND FIGURES

Table SB.R.1. Surveys from the California Current portion of the North Pacific Pelagic Seabird Database (v.2.1) used to create seabird distribution layers....4

Figure SB.R.1. Map of surveys from the California Current portion of the North Pacific Pelagic Seabird Database (v.2.1) used to create seabird distribution layers....9

Figure SB.R.2. Exposure scores for 17 non-fisheries pressures in the California Current for three seabird species....10

Figure SB.R.3. Cumulative exposure scores for 17 non-fisheries pressures in the California Current for three seabird species....11

Figure SB.R.4. At-sea distribution of common murre *Uria aalge*....12

Figure SB.R.5. At-sea distribution of sooty shearwater *Puffinus griseus*....13

Figure SB.R.6. At-sea distribution of rhinoceros auklet *Cerorhinca monocerata*....14

Figure SB.R.7. Exposure to atmospheric deposition for common murre, sooty shearwater and rhinoceros auklet....16

Figure SB.R.8. Exposure to coastal engineering for common murre, sooty shearwater and rhinoceros auklet....18

Figure SB.R.9. Exposure to coastal trash for common murre, sooty shearwater and rhinoceros auklet....20

Figure SB.R.10. Exposure to direct human impacts (beach attendance) for common murre, sooty shearwater and rhinoceros auklet....22

Figure SB.R.11. Exposure to inorganic pollution for common murre, sooty shearwater and rhinoceros auklet....24

Figure SB.R.12. Exposure to light pollution for common murre, sooty shearwater and rhinoceros auklet....26

Figure SB.R.13. Exposure to nutrient input for common murre, sooty shearwater and rhinoceros auklet....28

Figure SB.R.14. Exposure to ocean acidification for common murre, sooty shearwater and rhinoceros auklet....30

Figure SB.R.15. Exposure to ocean-based pollution for common murre, sooty shearwater and rhinoceros auklet....32

Figure SB.R.16. Exposure to offshore oil activities for common murre, sooty shearwater and rhinoceros auklet....34

Figure SB.R.17. Exposure to organic pollution for common murre, sooty shearwater and rhinoceros auklet....36

Figure SB.R.18. Exposure to power plants for common murre, sooty shearwater and rhinoceros auklet....36

Figure SB.R.19. Exposure to sediment runoff decrease for common murre, sooty shearwater and rhinoceros auklet 38

Figure SB.R.20. Exposure to sediment runoff increase for common murre, sooty shearwater and rhinoceros auklet 40

Figure SB.R.21. Exposure to shipping activity (commercial) for common murre, sooty shearwater and rhinoceros auklet 42

Figure SB.R.22. Exposure to species invasions for common murre, sooty shearwater and rhinoceros auklet 44

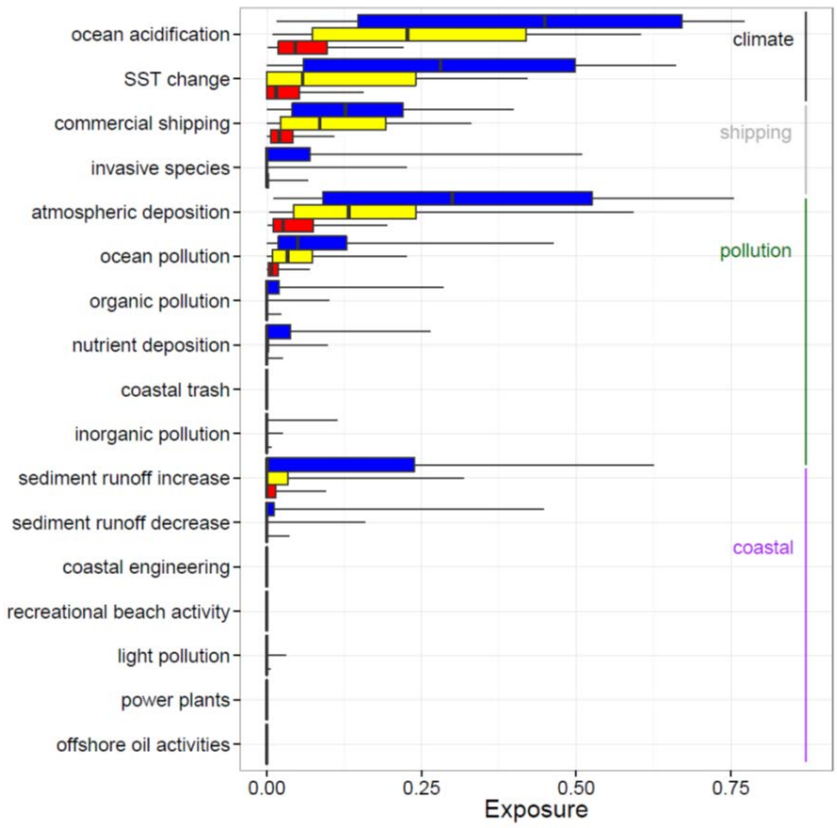
Figure SB.R.23. Exposure to sea surface temperature anomalies for common murre, sooty shearwater and rhinoceros auklet 46

Figure SB.R.24. Exposure to combined pressures for common murre, sooty shearwater and rhinoceros auklet. 48

SOUNDBITE

Based on an initial evaluation of non-fisheries pressures on three focal species, seabirds face the highest exposure to large-scale, ecosystem-wide factors like sea surface temperature anomalies and ocean acidification. Common murres were the most exposed to those pressures examined, followed by sooty shearwaters and rhinoceros auklets. This evaluation is a first step towards assessing the risk from exposure to such pressures to seabird species throughout the California Current.

EXECUTIVE SUMMARY



Median exposure scores for 17 non-fisheries anthropogenic pressures in the California Current for common murre (blue), sooty shearwater (yellow), and rhinoceros auklet (red).

Seabird populations worldwide are confronted by a multitude of anthropogenic pressures. Bycatch from commercial fisheries, resource competition, habitat disturbance and global climate change are just some examples. We assessed the relative exposure of three seabird species in the California Current to 17 non-fisheries anthropogenic pressures (atmospheric deposition, coastal engineering, direct human impacts, inorganic pollution, light pollution, nutrient input, ocean-based pollution, offshore oil activity, organic pollution, power plants, sediment runoff decrease, sediment runoff increase, shipping activity, species invasions, coastal trash, ocean acidification, and sea-surface temperature anomalies). We determined this exposure by overlapping relative density estimates for each seabird species with the spatial distribution and intensity of a variety of non-fisheries pressures. Exposure to climate pressures was greatest for the three seabird species examined, followed by shipping pressures, pollution pressures, and coastal pressures. This pattern held even for for the more nearshore species--common murre and rhinoceros auklet. Nonetheless, there was considerable variability in exposure scores, such that all three species appeared to be highly exposed to at least climate and shipping pressures somewhere in their respective distributions, while in other parts of their distribution, they were virtually unexposed to those same pressures. Future work will combine these exposure estimates with an analysis of the sensitivity of each species to each pressure in order to provide an estimate of risk to a broader array of seabird species in the California Current.

DETAILED REPORT

INTRODUCTION

Seabirds worldwide face variety of anthropogenic pressures, including invasive alien species, fisheries bycatch, pollution, human disturbance, coastal development, overfishing of food resources, and climate change (Croxall et al. 2012). In the California Current Large Marine Ecosystem, important anthropogenic pressures include oil spills, gillnet and other fisheries, contaminants, habitat destruction, introduced predators, and human disturbance (Mills et al. 2005).

Quantitative risk assessment is a general analytical approach for describing the likelihood of adverse consequences due to exposure to particular pressures (and, potentially, cumulative impacts of multiple pressures). In ecotoxicology, risk is generally described using the response (or sensitivity) of a species to different levels of exposure to a pressure such as a chemical contaminant (Suter 2007). Quantification of exposure to a pressure is critical for evaluating risk and represents a Level 2 (more focused and semi-quantitative approach) analysis in a hierarchical approach that ranges from a qualitative analysis of risk (Level 1) to a highly focused and fully quantitative "model-based" approach (Level 3; Hobday et al. 2011).

An approach modified from the ecotoxicological/productivity-susceptibility analysis approach to assess multiple non-fishery pressures on marine ecosystems (Samhouri and Levin 2012) has been used with some success on ecosystem components in the California Current. Risk assessments of California Current groundfish (Hamel et al. 2013; http://www.noaa.gov/iea/CCIEA-Report/risk/groundfish.html) and indicators of ecological integrity (Samhouri et al. 2013; http://www.noaa.gov/iea/CCIEA-Report/risk/ecological-integrity.html) employed this exposure-sensitivity approach, while a risk assessment of marine mammals (Feist et al. 2013; http://www.noaa.gov/iea/CCIEA-Report/risk/marine-mammals.html) modeled exposures only. At the heart of these assessments lie estimates of exposure, or overlap analyses, which are the foundation for comprehensive risk assessment (Zacharias & Gregr 2005).

In this analysis, we assess the relative exposure associated with non-fisheries pressures for three focal seabird species in the California Current; we consider this a first step to a full-blown risk assessment using the exposure-sensitivity approach (*sensu* Samhouri and Levin 2012). Subsequent analyses will assess exposure to non-fisheries pressures for a more complete list of California Current seabird species as well as assess sensitivities of seabird species to the pressures to which they are exposed.

METHODS

FOCAL SPECIES

We examined the relative exposure of a variety of non-fisheries related pressures to three seabird species in the California Current: common murre (*Uria aalge*), sooty shearwater (*Puffinis griseus*), and rhinoceros auklet (*Cerorhinca monocerata*). Seabirds are a key ecosystem component in the California current, with the California Current Large Marine Ecosystem supporting >75 seabird species, including breeding, non-breeding, and migratory populations (Zamon et al. 2012; http://www.noaa.gov/iea/CCIEA-Report/key-ecosystem-components/protected-species/seabird/seabirds.html). The three species examined represent relatively common and widespread seabird species for which high-quality were available; future iterations may examine a broader variety of seabird species. Seabirds are protected species under the Migratory Bird

Treaty Act (1918) and, for a few species, the Endangered Species Act (1973), and NOAA Fisheries has legal, management, and conservation mandates to understand and protect seabird populations. In particular, Executive Order 13186 (2001) requires NOAA Fisheries to incorporate migratory birds into Agency planning, address migratory bird concerns, and cooperate with other agencies that have responsibilities for managing or protecting migratory birds. The three focal species display varied spatial and temporal distribution patterns, which makes them good candidates for this initial exercise of assessing non-fisheries pressures to this key ecosystem component.

Common murres (*Uria aalge*) are large-bodied members of the seabird family Alcidae. On the Pacific coast of North America, they breed from Alaska south to central California, laying single eggs on island tops or ledges. Common murres can dive as deep as 180 meters. They forage widely between coastlines and outer parts of the continental shelf, but are most common in inshore waters, especially during breeding; adult murres are central-place foragers and feed near colonies. Feeding flocks have been linked to coastline and bathymetric features that can aggregate prey at "fronts" between water types (local topographic features, tides, and river plumes). Murres are mainly piscivorous, although adults can also feed on other types of prey; observed diets include schooling fishes, juvenile rockfish (*Sebastes* spp.), euphausiids, squid, crab megalops, and euphausiids (Manuwal et al. 2001).

Sooty shearwaters (*Puffinis griseus*) are medium-large members of the seabird family Procellariidae. Sooty Shearwaters occur in the California Current and breed on islands in the south Pacific mainly around New Zealand, Australia, and Chile. They breed beginning in October, laying a single egg and nesting in burrows dug under tussock grass or low scrub and trees. In New Zealand, about 250,000 of these "titi" or "mutton birds" are harvested for oils, food and fats each year by the native Māori. Their numbers have been declining in recent decades, and the species is presently classified as Near Threatened by the IUCN. Every summer, after their post-breeding migration from the South Pacific, millions of sooty shearwaters arrive off the coasts of California, Oregon and Washington, often forming huge flocks that can be seen from shore. They can dive to a depth of up to 68 meters for food, but more commonly feed near the surface. They prey on small fish and squid, shrimp and other crustaceans, and jellyfish (BirdLife International 2013).

Rhinoceros auklets (*Cerorhinca monocerata*) are medium-sized members of the family Alcidae. They are found throughout the North Pacific, breeding in North America from California north to the Aleutian Islands. They nest in burrows dug mainly into grassy or shrubby sea-facing slopes and level areas near island edges, laying a single egg. Some birds remain near breeding colonies throughout the year, while many move southward after breeding, where most of population winters off California. From October to April, these auklets occur mainly in continental-shelf and shelf break waters, preferring water >15 m deep. They feed inshore during the breeding season, catching prey by diving up to 57 meters. At sea, they feed on schooling fishes, while taking some krill and squid. During breeding season, diet is mostly sandlance and other small schooling fishes, juvenile rockfish, and planktonic crustacea, especially euphausiids. In winter, diet is small pelagic schooling fish and squid (Gaston and Dechesne 1996).

NON-FISHERIES PRESSURES

We initially focus on 17 non-fisheries related pressures (and all of them in combination) used in Halpern et al (2009): atmospheric deposition, coastal engineering, direct human impacts, inorganic pollution, light pollution, nutrient input, ocean-based pollution, offshore oil activity, organic pollution, power plants, sediment runoff decrease, sediment runoff increase, shipping activity, species invasions, coastal trash, ocean acidification, and sea-surface temperature anomalies (see Appendix SB.A.1). These data describe the relative spatial intensity of each pressure within 1-km^2 grid cells of the California Current. The maximum intensity of

each pressure is assigned a value of 1, and all other pressures are scaled relative to the maximum. We obtained the GeoTiff files projected in Arc System Zone 2 for each pressure (or impact) from the National Center for Ecological Analysis and Synthesis's website (http://www.nceas.ucsb.edu/globalmarine/ca_current_data). We created pyramids for each of the files using ArcCatalog version 9.3 and then brought each of the files into ArcView. Each file was then converted into a GRID file using the RasterToOther Conversion tool in the ArcView Toolbox. Each pressure is described in detail in the supporting material of Halpern et al (2008; 2009) and Groundfish Appendix B in Hamel et al. (2013).

The anthropogenic pressures explored here have been used to examine exposure of, and potential impacts on, other marine species throughout the California Current as well as globally. In contrast with some previous analyses (e.g., Halpern et al. 2009; Maxwell et al. 2013), we make no assessment beyond the extent of exposure. We recognize that non-fisheries pressures may affect seabirds directly or indirectly, depending upon the pressure, and leave it to future analyses to estimate the expected magnitude of response of the focal species examined here. Such sensitivity estimates will consider how the various pressures may influence survival or reproduction directly, and act indirectly through effects on prey species or habitat degradation or elimination.

Fisheries-related pressures were not included in these analyses; risk assessments of some other ecosystem components in the CCIEA have also focused on exposure to non-fisheries pressures. Exposure to fisheries under federal management in the California Current has been assessed for black-footed (*Phoebastria nigripes*), short-tailed (*P. albatrus*) and Laysan albatrosses (*P. immutabilis*) using similar overlap analyses (Guy et al. 2013); black-footed albatrosses alone represents 33% of the seabird bycatch observed between 2002-2009 (Jannot et al. 2011). Maxwell et al. (2013) also explored exposure to fisheries pressures in the California Current for seabirds based on electronic tracking data for a trio of pelagic seabirds (black-footed albatrosses, Laysan albatrosses, and sooty shearwaters). Future risk analyses may include fisheries pressures.

SEABIRD DATASETS

We used individual datasets from the North Pacific Pelagic Seabird Database (NPPSD v. 2; courtesy of John Piatt and Gary Drew/USGS) for this analysis. The NPPSD database integrates a variety of data sets obtained over the past 30-40 years in the North Pacific; these data sets are primarily standardized shipboard surveys of seabirds (for a detailed description, consult http://alaska.usgs.gov/science/biology/nppsd/index.php). For the California Current, the NPPSD primarily contains datasets from three long-term studies: the California Cooperative Oceanic Fisheries Investigations (CalCOFI), the National Marine Fisheries Service Juvenile Rockfish Survey (NMFS-JRS), and the Canadian Line P program (Line P). The CalCOFI data set provides information for the Southern California Bight offshore to ~700 km, the NMFS-JRS provides information on shelf-based habitats primarily from central-northern coastal California, and Line P provides information on southern British Columbia and offshore to station Papa, approximately 1425 km from the coast. These three studies contain data from the mid-1980s to late 2000s and form the primary basis for this study (Table SB.R.1).

Table SB.R.1. Surveys from the California Current portion of the North Pacific Pelagic Seabird Database (v.2.1) used to create seabird distribution layers (See also Figure SB.R.1.).

Survey	Provider	Begin Year	End Year	Area Surveyed	Transects
CalCOFI/	Sydeman	1987	2006	California Coast	138299

NMFS-JRS CWS/ Line P	Morgan	1982	2005	B.C. Coast	22996
FW5011	Benson	1975	1975	Seattle to Alaska Peninsula South	95
FW5004	Hatch	1975	1975	Gulf of Alaska	434
FW5002	Isleib	1975	1975	Seattle-Northest Gulf of Alaska-Seattle	131
FW5013	Hatch	1975	1975	Southern California to Nome, AK	174
FW5015	Rauzon	1975	1975	NE Pacific, Gulf of Alaska, South. Bering Sea	223
FW5018	Nysewander	1975	1975	NE Pacific to E. Bering Sea	148
FW5032	Hatch	1975	1975	Kodiak Basin, Alaska Peninsula, Southern WA	60
FW5021	Sowls	1975	1975	Long Beach, CA. to Point Barrow, AK	197
FW5033	Kirchhoff	1975	1975	Bering Sea and N. Pacific	105
FW5034	Hardy	1975	1975	N. Gulf AK, BC, Queen Charlotte I., Str. Juan de Fuca	59
FW6077	Metzner	1976	1976	Seattle to Kodiak	50
FW6087	Baird	1976	1976	Seattle to Dutch Harbor	25
FW6070	Baird	1976	1976	Gulf of Alaska, Bering Sea & NE Pacific	85
FW6002	Sanger	1976	1976	Seattle to Kodiak	72
TR0609	Wiens	1976	1976	Northeast Pacific Ocean	39
FW6005	Hardy	1976	1976	Seattle to Kodiak	119
FW6008	Handel	1976	1976	Seattle to Kodiak	50
FW7027	Sanger	1977	1977	Port Angeles, WA to Homer, AK	109
FW7026	Baird	1977	1977	Seattle to Kodiak	91
F85045	Day	1985	1985	Along 155' W to Newport, OR	259
F85046	Day	1985	1985	Newport, Oregon to Hakodate, Japan	478
F87041	Day	1987	1987	Seward to Seattle	245
F87042	Day	1987	1987	Seattle to N. Pacific	969

With few data available in the NPPSD for fall and winter, analyses focused on spring and summer, when most surveys were conducted. The avifauna of the California Current varies seasonally, with an influx of southern hemisphere migrants in the spring and summer (*e.g.*, sooty shearwater), and an influx of northern hemisphere migrant species in the fall. Our analysis, therefore, is limited to a portion of the annual seabird community and does not adequately consider many of the species that breed in Alaska and winter to the south in the California Current (generally not germane to the present analysis). One of the benefits of the NPPSD is that all species counts were recorded continuously during surveys; these data are then grouped in successive "bins", with most being 0.9 km^2. The mid-point of bins was taken as the geo-location of observation, and each bin was assigned to a 10-km^2 grid cell, making it possible to produce relatively high-resolution distribution maps for most of the common species.

The seabird data consist of counts of individuals of species observed on oceanographic survey transects of varying duration (typically from 5 to 30 minutes). Each transect is of known length and width (producing area) and has associated geo-referencing codes. For analysis, transects with areas between 0.1 to <25 km2 were retained; surveys >25km2 were rare and could not be assigned to grid cells (see below). Data were collated for March-August each year to focus on the spring and summer seasons; during this period, resident birds are breeding and southern hemisphere migrants are wintering in the region. All behavioral codes, such as flying, sitting on the water, foraging, and ship-following, were used. Transect data were binned on a grid of 10 x 10 km (100 km2) cells. For each cell, the total counts for each species was divided by the survey effort (sample size of transects), resulting in an average count-per-unit-effort for each species. Finally, a Kernel Density Smoothing (KDS) function (Silverman 1986, Keating and Cherry 2009) was applied to these raster data, using a bandwidth (i.e., smoothing radius) of 25 km. The result of this process was a smoothed density

distribution map for each species with a 1x1 km resolution. Additional details on seabird data processing can be found in Sydeman et al. (2012).

OVERVIEW OF EXPOSURE CALCULATION

We assessed the exposure of populations of common murre, rhinoceros auklet, and sooty shearwater within the U.S. borders of the California Current Large Marine Ecosystem to various non-fisheries pressures. Future analyses will include the complementary "sensitivity axis" (*sensu* Samhouri and Levin, 2012) and possibly more seabird species that regularly use the California Current.

We estimated exposure quantitatively and in a spatially explicit manner for all three seabird species. Using GIS data, we calculated exposure intensity (hereafter "exposure") as the overlap between the spatial distribution (relative density in 1-km^2 grid cells) of each seabird species and the relative intensity of each non-fisheries pressure. Both species relative density and exposure were scored as continuous variables with values in the range 0-1. All values were rescaled to the maximum of the original scale. We used ESRI ArcGIS version 10 to calculate an estimate of relative exposure in each grid cell by multiplying each species distribution layer with each pressure data layer (using raster representations of each data type). Below (Figure SB.R.2) we present the median exposure for each species-pressure combination across each species' range, along with the 5th, 25th, 75th, and 95th percentiles. To evaluate exposure of the three seabird species to all of the 17 pressures (cumulative exposure), we summed their relative intensities within each cell of a species' range. As with the individual species-pressure combinations, below (Figure SB.R.3) we present the median exposure to the cumulative pressures across each species' range, along with the 5th, 25th, 75th, and 95th percentiles.

RESULTS

SEABIRD DISTRIBUTION

The at-sea distributions of the three focal seabird species based on survey data are depicted below (Figures SB.R.4-6). Common murres had the highest relative densities over the California Current area of analysis; followed by intermediate densities for sooty shearwaters and lowest densities for rhinoceros auklets. The highest densities of common murres were observed in nearshore waters off the northern outer coast of Washington, the northern and southern coasts of Oregon, and the central coast of California. The highest densities of sooty shearwaters were observed in nearshore and offshore waters off the northern outer coast of Washington, the northern and southern coasts of Oregon, the central coast of California, and around Point Conception and the Channel Islands in southern California. The highest densities of rhinoceros auklets were observed in the inland waters of northern Puget Sound, nearshore and offshore waters off the northern outer coast of Washington, offshore waters in central Oregon, offshore waters of the central coast of California, and nearshore and offshore waters of the Channel Islands in southern California.

EXPOSURE

The exposure to each of the 17 pressures varied considerably for all seabird species (Figure SB.R.2), while the cumulative exposure was greatest for common murres, intermediate for sooty shearwaters, and lowest for rhinoceros auklets (Figure SB.R.3). The greatest pressures in terms of median exposure index values were climatic and of large spatial-scale—*e.g.*, ocean acidification, atmospheric deposition, and sea surface

temperature anomalies (Figure SB.R.2). The variability of exposure to atmospheric deposition (SB.R.7), ocean acidification (SB.R.14), and sea surface temperature anomalies (SB.R.23) was due to variability in observed seabird distribution as well as variability over space in the pressures themselves. Exposure to other anthropogenic pressures of large spatial scale--ocean-based pollution and commercial shipping activity--was relatively high (Figure SB.R.2) and varied across the seascape (Figures SB.R.15 and 21). Pressures stemming largely from coastal point sources--*e.g.*, coastal engineering, coastal trash, recreational beach activity, offshore oil activities, and power plant activities—showed the least overlap with seabird distributions and hence resulted in low exposure scores (Figures SB.R.8-10, 16, and 18). Exposure to pressures with inshore/offshore gradients (inorganic pollution, light pollution, nutrient pollution, organic pollution, sediment runoff decrease/increase, and species invasions) were relatively low to moderate due to relatively high exposure along coastal areas and little to no exposure for offshore portions of seabird distributions (Figures SB.R.11-13, 17, 19-20, and 22).

In general, the analysis indicates that spatially expansive pressures overlap most with each of the three seabird species, as compared with pressures related to point-sources. However, without a real link between the current and anticipated levels of the pressure and the impacts, these results indicate expansiveness/overlap of each pressure, and not the potential impact.

Risk is often thought of as the probability that something harmful will occur along with the consequences should it occur (Rowe 1977). In this analysis, we combined seabird density and anthropogenic pressures to identify exposure -- the first step in assessing probability of harm. As we did not formally assess changes in population growth as a function of a given non-fisheries pressure's influence, this effort is essentially an assessment of relative exposure. Further work on sensitivity of seabird species to stressors induced by anthropogenic activities is needed for a complete risk assessment; our analyses are an important first step in characterizing the spatio-temporal patterns of seabird exposure to anthropogenic pressures in the California Current.

OTHER SOURCES OF RISK

There are many risks to seabird populations occurring in the CCLME in addition to the anthropogenic pressures assessed by Halpern et al (2008, 2009), including pressures from commercial fishing, particularly the fixed-gear long-line (Guy et al. 2013) and gillnet fleets (Hamel et al. 2009, Zydelis et al. 2013). Common murres are particularly susceptible to oil spills, bycatch in gillnet fisheries, and human disturbance (Mills et al. 2005). Sooty shearwaters are subject to the harvest ('muttonbirding') of a quarter million birds annually on their south Pacific breeding colonies (del Hoyo et al. 1992; Heather and Robertson 1997), and longline fisheries are responsible for large numbers of deaths of this species (Birdlife International 2013). Again, Maxwell et al. (2013) explored exposure to fisheries pressures in the California Current for a guild of pelagic seabirds based on electronic tracking data. Rhinoceros auklets are also threatened by oil contamination, fisheries interactions, particularly gillnet fisheries, habitat degradation, and introduced mammals. These species may be exposed to toxins and contaminants via their prey (Good et al. 2014), which may result in bioaccumulation and biomagnification (Jarman et al. 1996). While not exhaustive, these additional factors provide some context for the range of anthropogenic pressures to which seabirds are subjected. Quantifying the exposure and sensitivity of seabirds to these additional pressures would be an important next step toward a more comprehensive risk assessment.

CONCLUSIONS

Our analysis builds on the risk assessment framework used to examine other components of the CCIEA, making progress towards a method that will allow for comparison of relative risk among multiple pressures as well as cumulative risk. This framework can show which pressures are relevant to focal species and provides a basis for prioritizing which of them are in need of management actions. Rapid assessments of other species can then be easily integrated into this framework.

Our results are consistent with other analyses of anthropogenic pressures on the US West Coast (Halpern et al. 2009, Maxwell et al. 2013, Samhouri et al. 2013, Hamel et al. 2013). A similar analysis for groundfish found large-scale, climatic pressures posed the greatest threat for bocaccio (*Sebastes paucipinis*) and canary (*S. pinniger*) rockfish, Pacific hake (*Merluccius productus*), and sablefish (*Anoplopoma fimbria*) (Hamel et al. 2013). Similarly, an ecosystem risk assessment of pressures on marine habitats in the Monterey Bay National Marine Sanctuary found large-scale pressures such as sea surface temperature changes and shipping tended to exceed land-based pressures like coastal pollution (Samhouri et al. 2012). We found that exposure to climate pressures was greatest for the three seabird species examined, followed by shipping pressures, pollution pressures, and coastal pressures. Somewhat surprisingly, this pattern held for the two alcids, which are more 'nearshore species' (Gaston and Dechesne 1996, Manuwal et al. 2001, BirdLife International 2013). Nonetheless, there was considerable variability in exposure scores, such that all three species appeared to be highly exposed to at least climate and shipping pressures somewhere in their respective distributions, while in other parts of their distribution, they were virtually unexposed to those same pressures.

An assessment of human impacts on marine predators in the California Current also found that widespread climate stressors were greater contributors to their cumulative utilization and impact (CUI) metric than fishing, pollution, shipping and coastal stressors (Maxwell et al. 2013). This is notable, because, while their stressor data layers were also derived from Halpern et al. (2008, 2009), their distribution data layers were derived from electronic tracking studies rather than at-sea surveys. Their focal seabird species were all members of the Order Procellariiformes (sooty shearwater, black-footed albatross *Phoebastria nigripes*, and Laysan albatross *Phoebastria immutabilis*); however, their analyses were presented lumped into a seabird group rather than individual species, as we have done. By using tracking data over at-sea surveys, their analyses may have better coverage than ours in some parts of the California Current where survey efforts have been lacking (e.g., from south of Cape Mendocino, CA to Cape Blanco, OR, see figure SB.R.1).

As our analysis interpolates bird presence over small spatial scales, areas of low at-sea survey coverage can create spatial gaps in the data which then may become misleading areas of low exposure. Modeled distributions of the sort generated by Nur et al. (2011) fill in such data gaps but are based in part on the very environmental variables/pressures, such as sea surface temperature, that we are evaluating. False negatives (absence of birds that is really absence of sampling) could be problematic if they occur in locations that are highly heterogeneous in the intensity of different non-fisheries pressures, and/or if the densities of the three bird species are very different in the region where there is a data gap. Neither of these seems likely for the area of lowest survey coverage near the California-Oregon border, although there are breeding colony hotspots for common murre in northern California (Sydeman et al. 2012). Sooty shearwater tracking has identified hotspots to the north and south of the California-Oregon border area where our at-sea data are most lean (Adams et al. 2012). Absent these problems, data gaps in general would alter our absolute but not relative estimates of exposure.

While our assessment did not include pressures from fisheries, Maxwell et al. (2013) included fishing stressors, finding higher fishing cumulative utilization and impact (CUI) values along the shelf break, an area of high distribution for seabirds. In other analyses of fisheries pressures to North Pacific albatrosses (black-footed, Laysan, and short-tailed albatross *Phoebastria albatrus*), Guy et al. (2013) used data from electronic tracking studies, at-sea surveys, and fisheries-dependent data (longline and trawl surveys) and found the

shelf-break to be an area of high overlap of black-footed albatross density and longline and trawl fisheries. Further analyses of pressures potentially exerted on additional seabird species by fisheries in the California Current should be undertaken.

For at least locally breeding seabird species, a concurrent spatial analysis of pressures on terrestrial breeding habitats on nearshore islands, pillars, and rocky headlands used for breeding is critical to assessing overall risk posed by anthropogenic factors to this important ecosystem component. One obstacle to such assessments is that either the appropriate data layers akin to the ones of Halpern et al. (2008, 2009) have not been compiled for the relevant anthropogenic pressures (*e.g.*, non-native mammals and plants on breeding colonies) or for the relevant seabird metrics (*e.g.*, colony attendance, breeding performance). It may be that some of the coastal pressures with lower exposure scores for at-sea seabirds (*e.g.*, beach attendance, coastal engineering, and light pollution) may pose more of a risk for seabirds via their terrestrial breeding habitats.

As with overlap analyses of averaged values over time, there is the potential for overestimation of exposure if pressures are intermittent or seasonal and there is temporal mismatch. Distributions of both animals and anthropogenic pressures are not static, planned updates of data layers will improve future analyses of exposure to anthropogenic pressures for seabirds and other ecosystem components. Refinements of data layers should also improve updated analyses, especially for pressures that appeared from our analyses to have no relevance to at-sea seabirds (*e.g.*, coastal trash). Marine debris is, in fact, a very real pressure for seabirds and other taxa in the form of plastics and other items that can be ingested or fishing and shipping gear that can entangle individuals (Laist et al. 1997). One approach to refining such a data layer is to estimate marine debris density at sea using coastal trash survey data in a model of oceanic drift and then to model impacts on focal species based on encounter rate using the spatial overlap in the predicted debris density and the focal species (Wilcox et al. 2013). We plan to employ this data layer refinement and approach to more fully assess the pressure of marine debris on seabirds in the California Current.

Finally, a full assessment of risk should account for the probability of a particular hazard causing an adverse consequence to seabirds (cf. Burgman 2005). While our exposure estimates serve as a proxy for the likelihood of a pressure influencing each species, the analysis presented here does not speak to the potential consequences of exposure or vulnerability to alternate pressures. Future analyses should develop species-specific estimates of sensitivity, and perhaps adaptive capacity, to a pressure as a first approximation to how each seabird species is likely to cope with exposure to different pressures (Turner et al. 2003). Including these elements will help to identify the key pressures confronting these important ecosystem components in the California Current (Samhouri and Levin 2012, Maxwell et al. 2013), and suggest avenues for scenario-based analyses intended to evaluate the effectiveness of alternative management strategies.

ACKNOWLEDGMENTS

We gratefully acknowledge the North Pacific Pelagic Seabird Database (NPPSD v. 2; courtesy of John Piatt and Gary Drew/USGS) for the datasets used in this analysis and R. Cotton Rockwood and L. Ignacio Vilchis for comments on an earlier draft of this report.

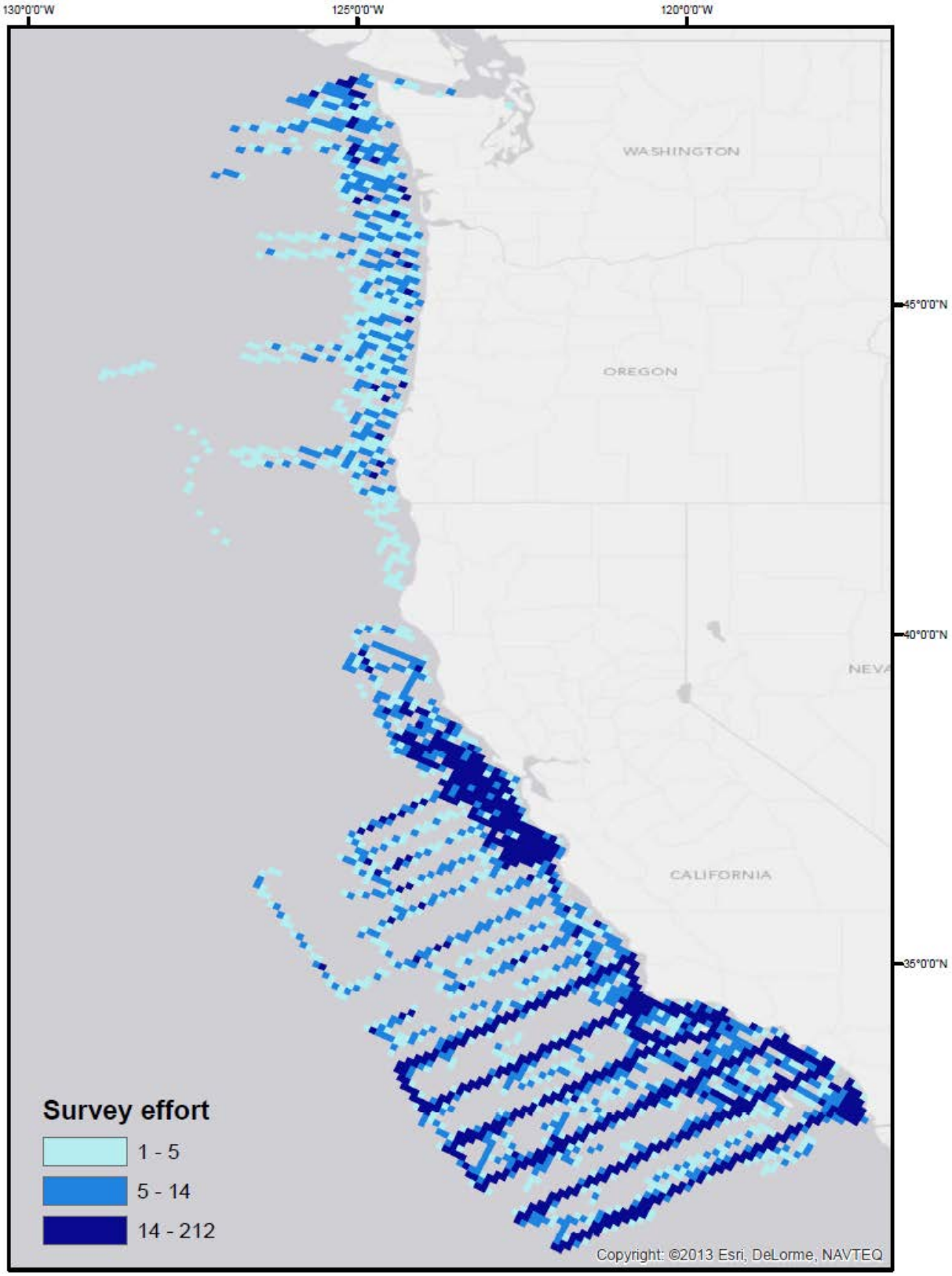


Figure SB.R.1. Map of surveys from the California Current portion of the North Pacific Pelagic Seabird Database (v.2.1) used to create seabird distribution layers.

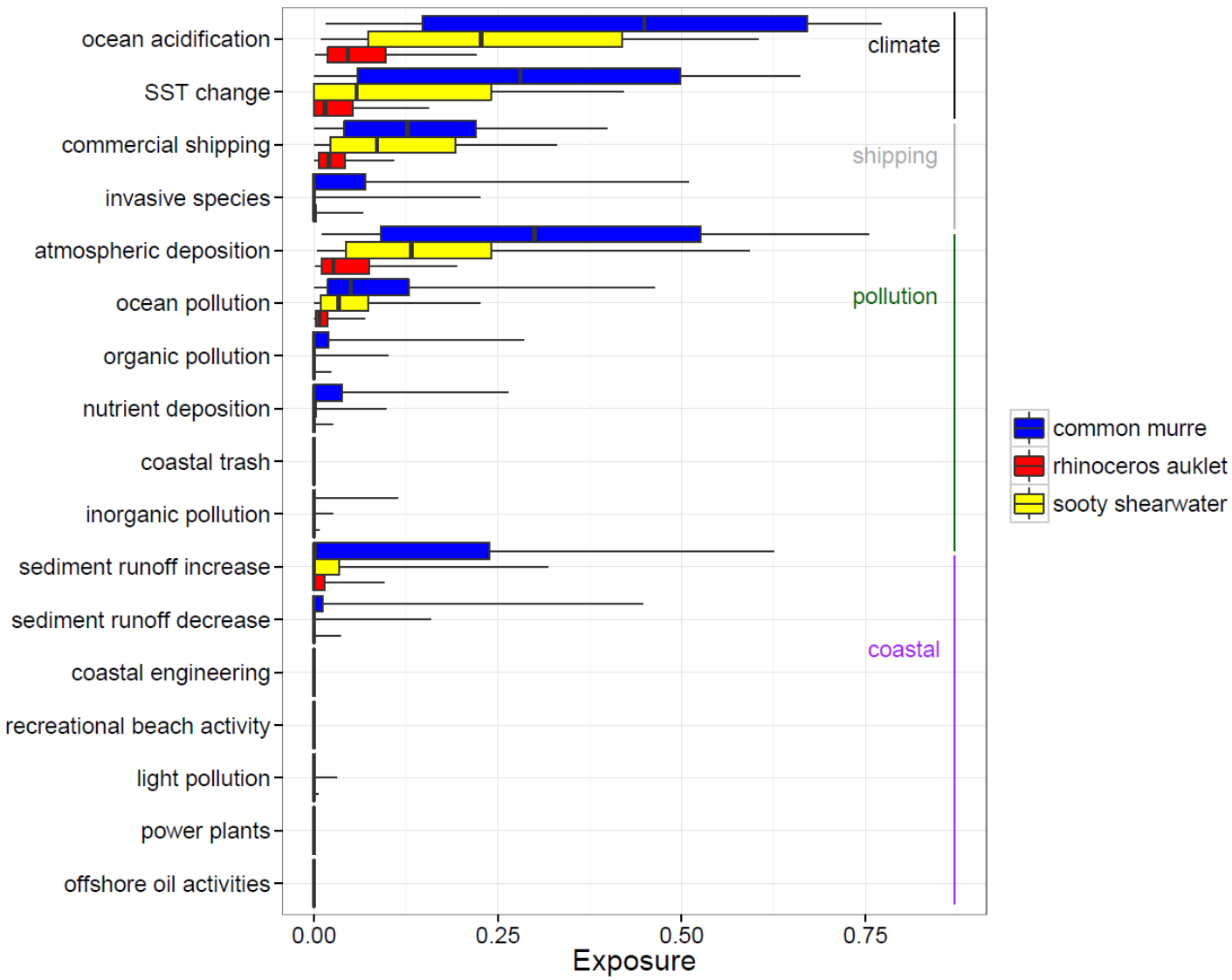


Figure SB.R.2. Median **e**xposure scores (plus 5th, 25th, 75th, and 95th percentiles) for 17 non-fisheries pressures in the California Current for three seabird species.

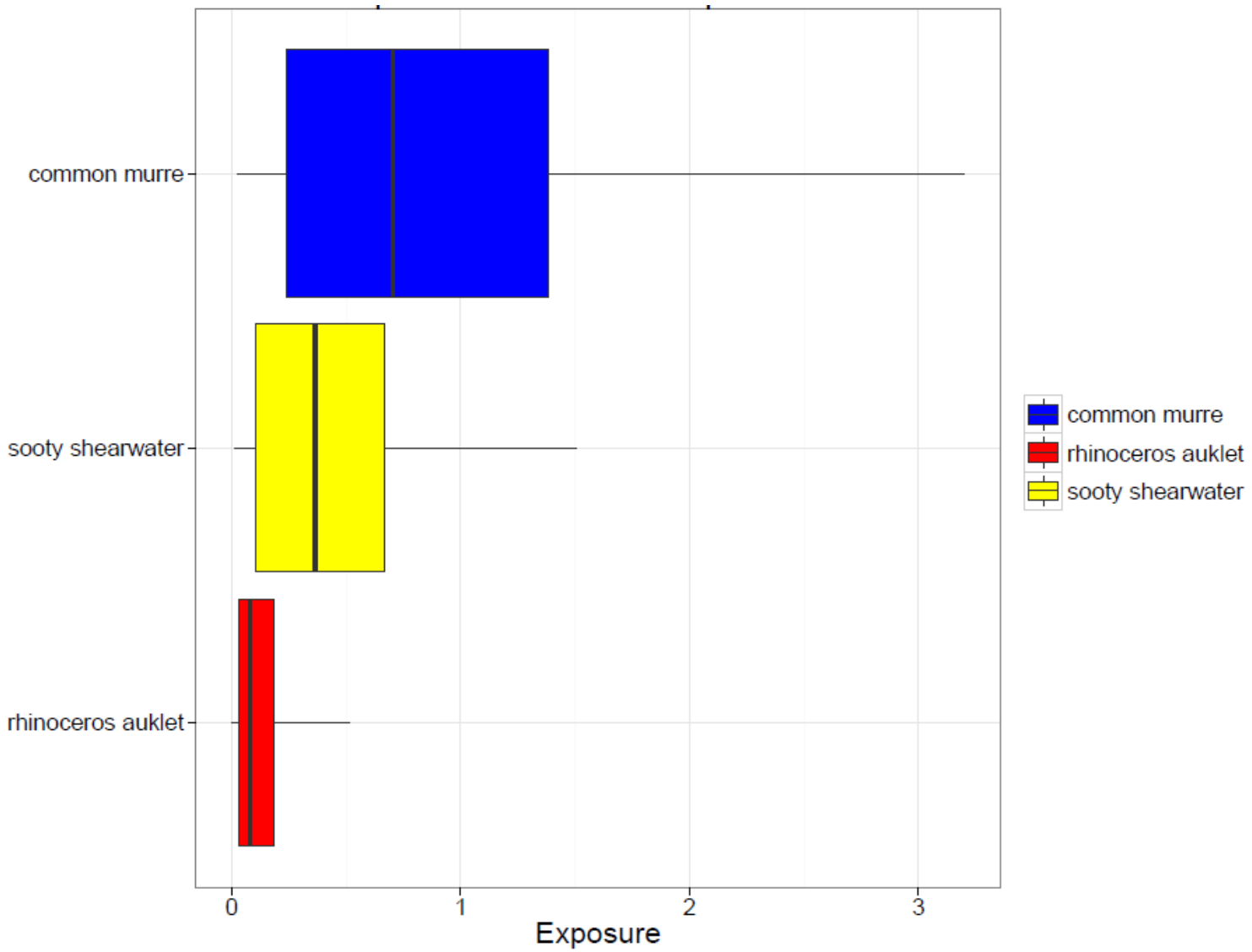


Figure SB.R.3. Median exposure scores (plus 5th, 25th, 75th, and 95th percentiles) for combined 17 non-fisheries pressures in the California Current for three seabird species.

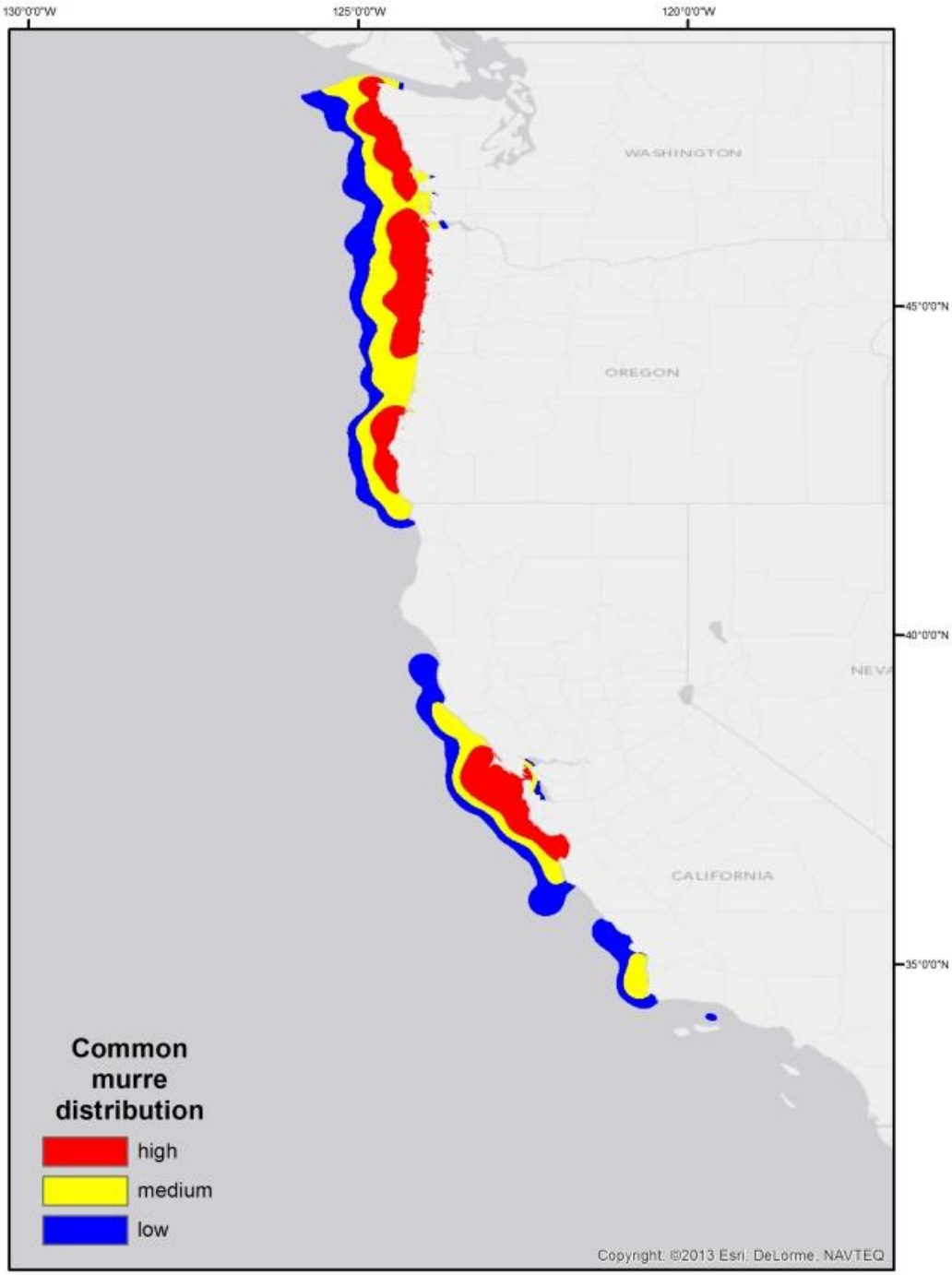


Figure SB.R.4. At-sea distribution of common murre *Uria aalge* (smoothed densities plotted as terciles).

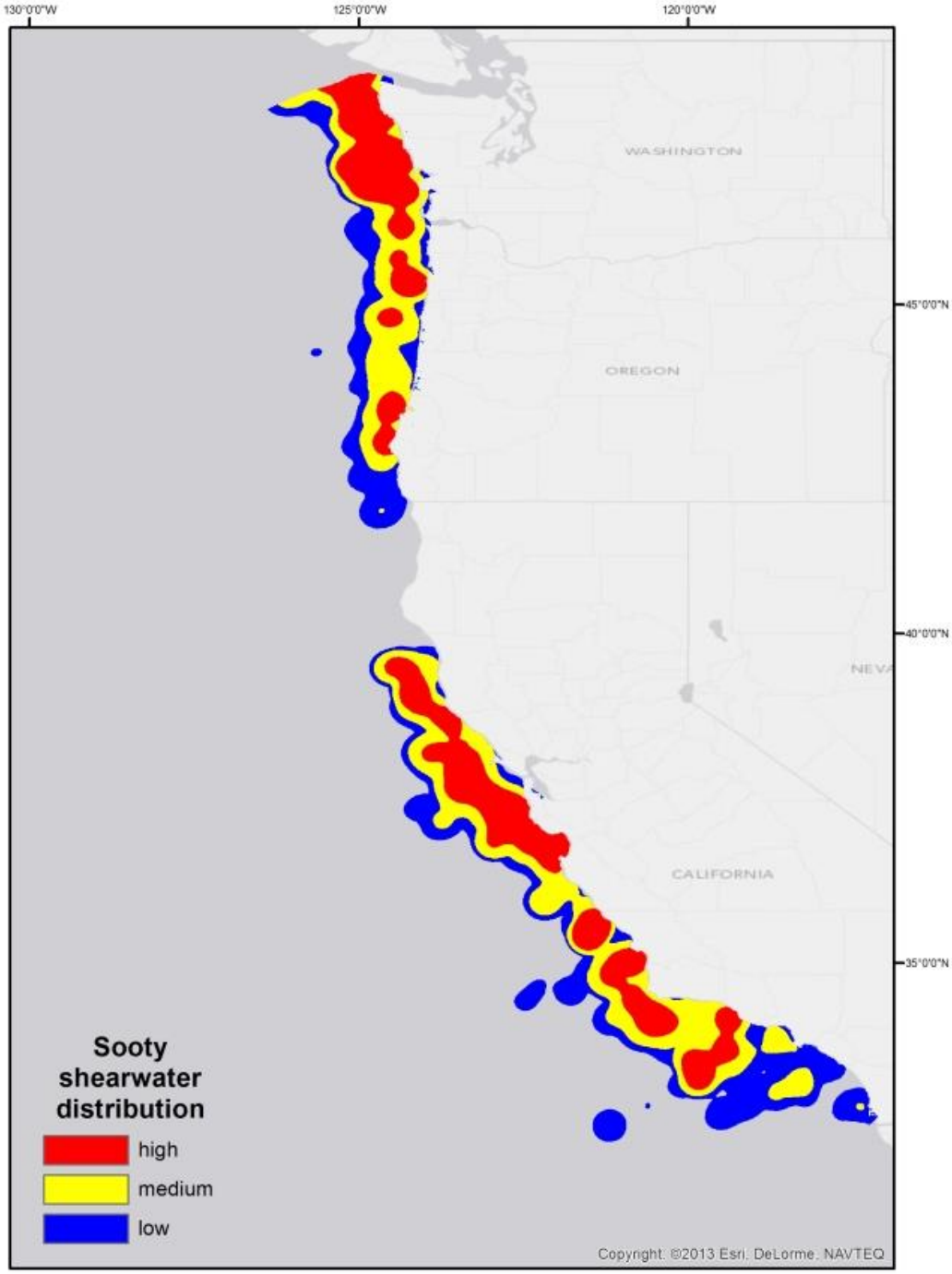


Figure SB.R.5. At-sea distribution of sooty shearwater *Puffinus griseus* (smoothed densities plotted as terciles).

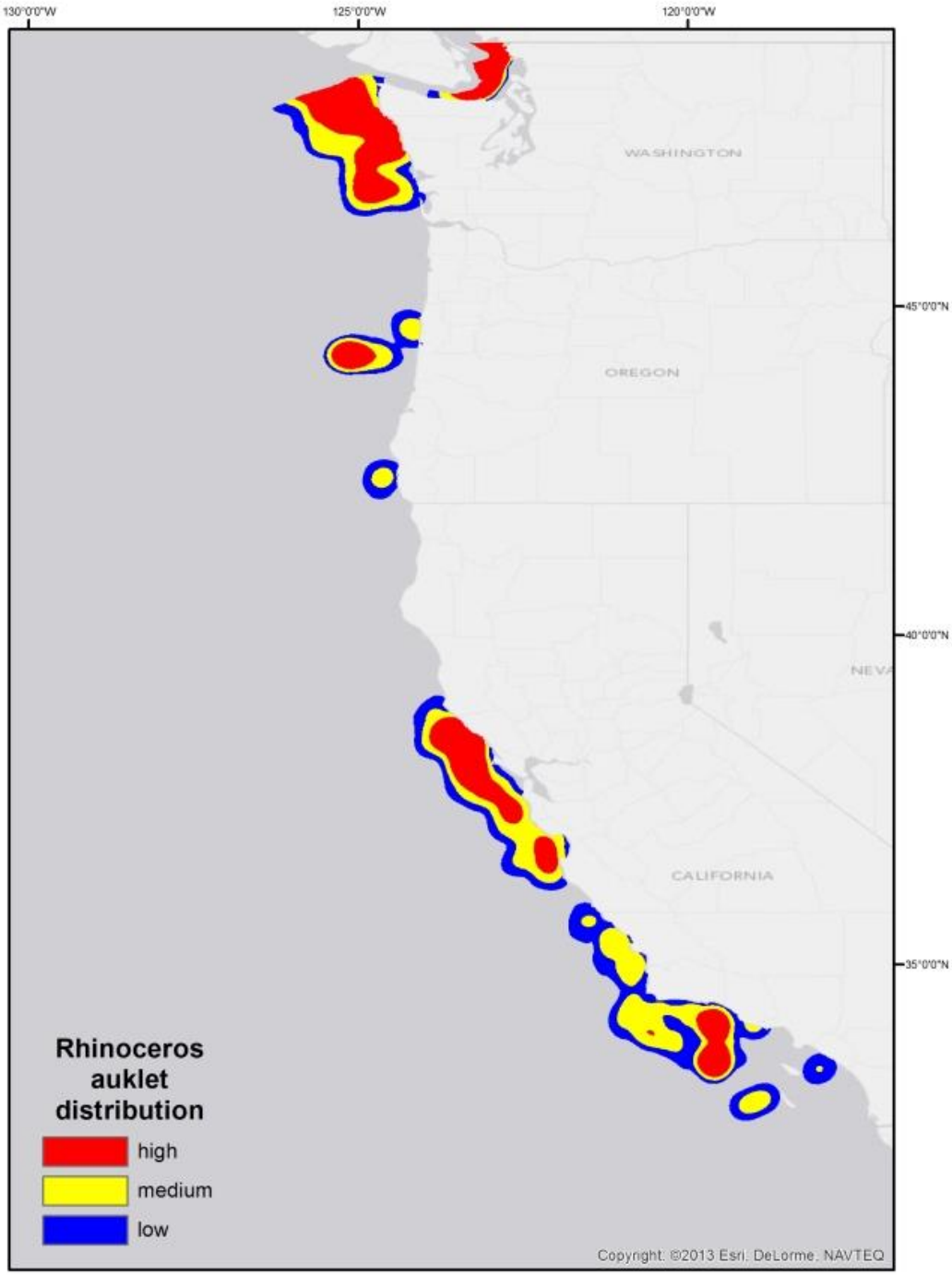


Figure SB.R.6. At-sea distribution of rhinoceros auklet *Cerorhinca monocerata* (smoothed densities plotted as terciles).

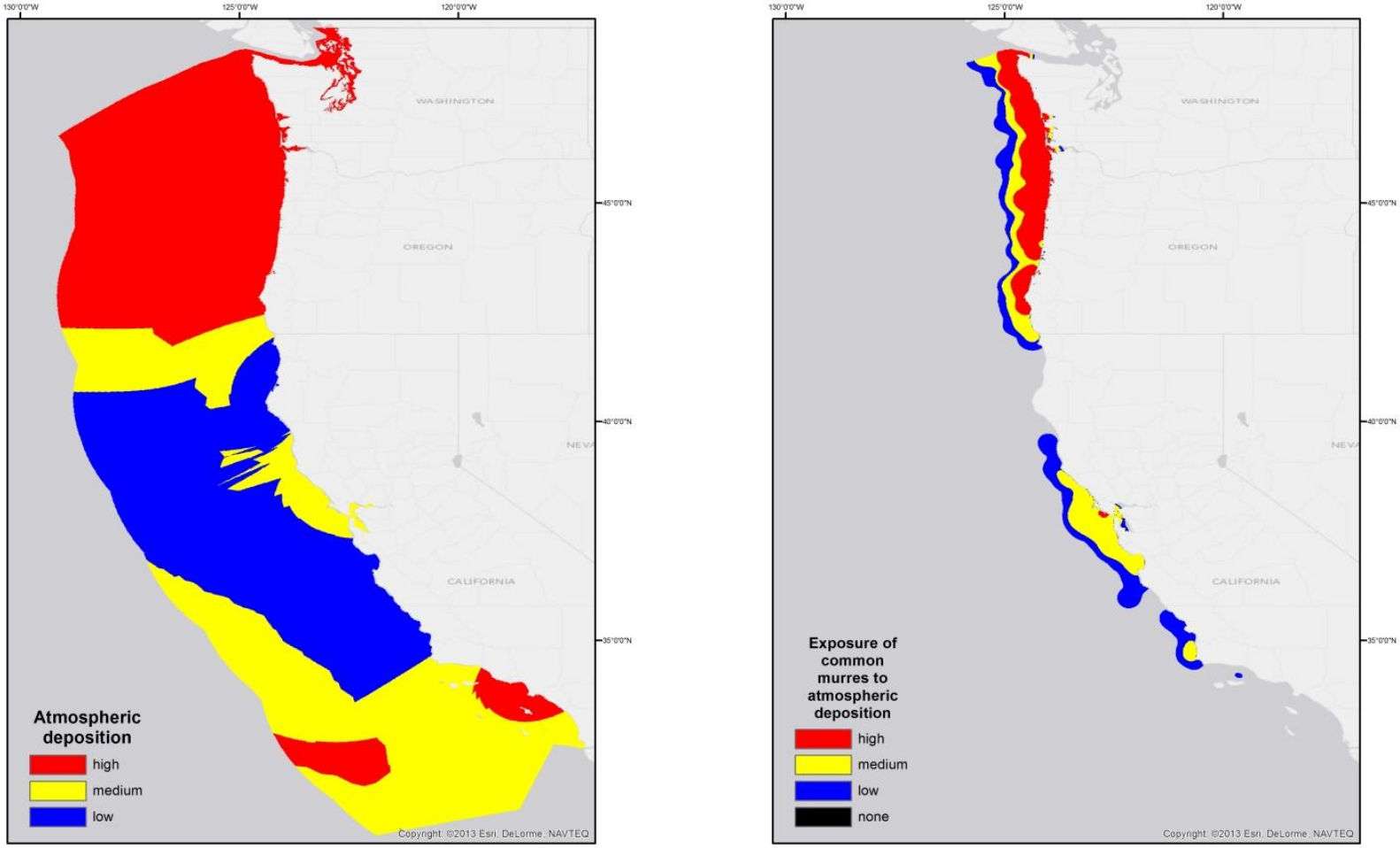
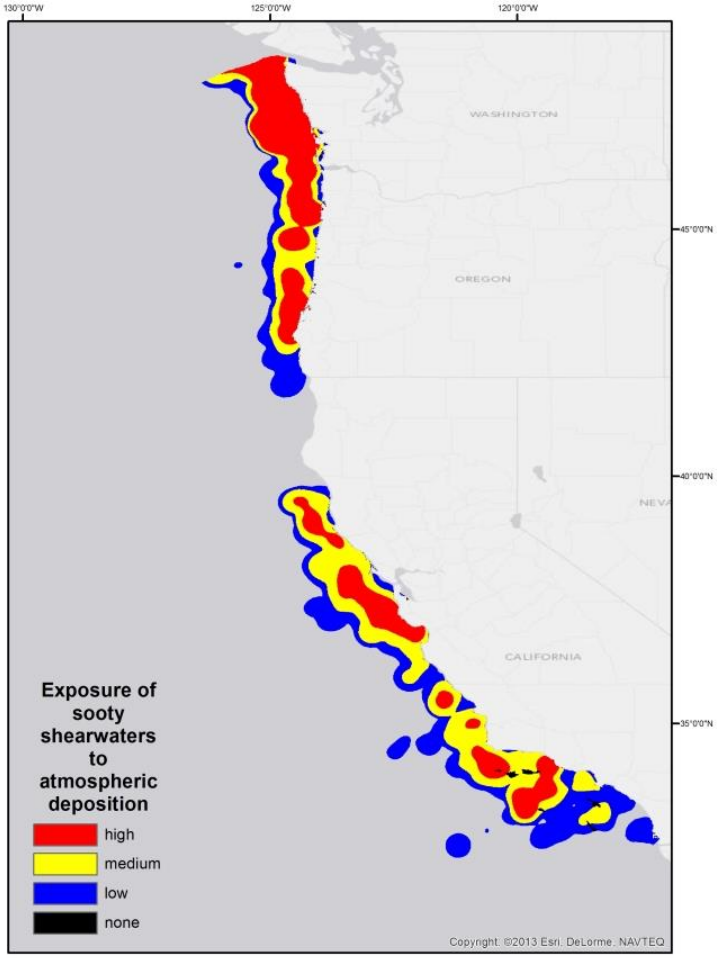


Figure SB.R.7. Exposure to atmospheric deposition for common murre, sooty shearwater and rhinoceros auklet.



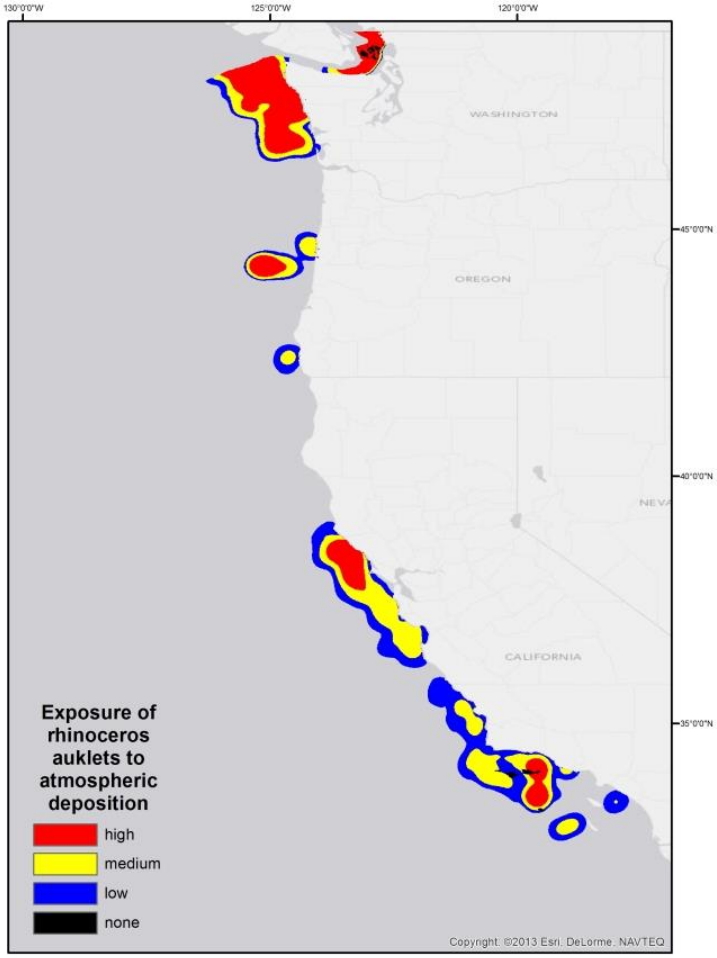


Figure SB.R.7 (continued).

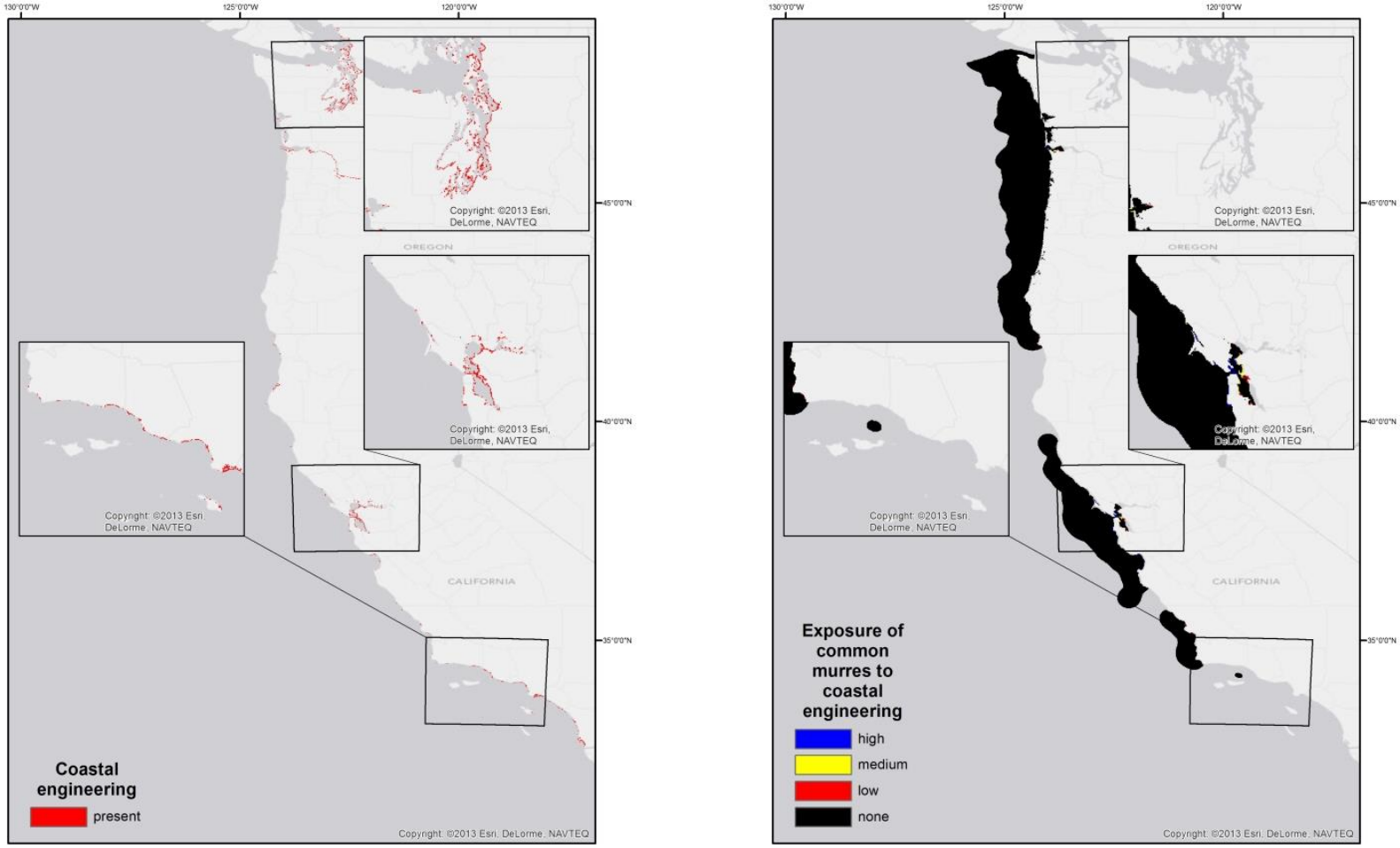
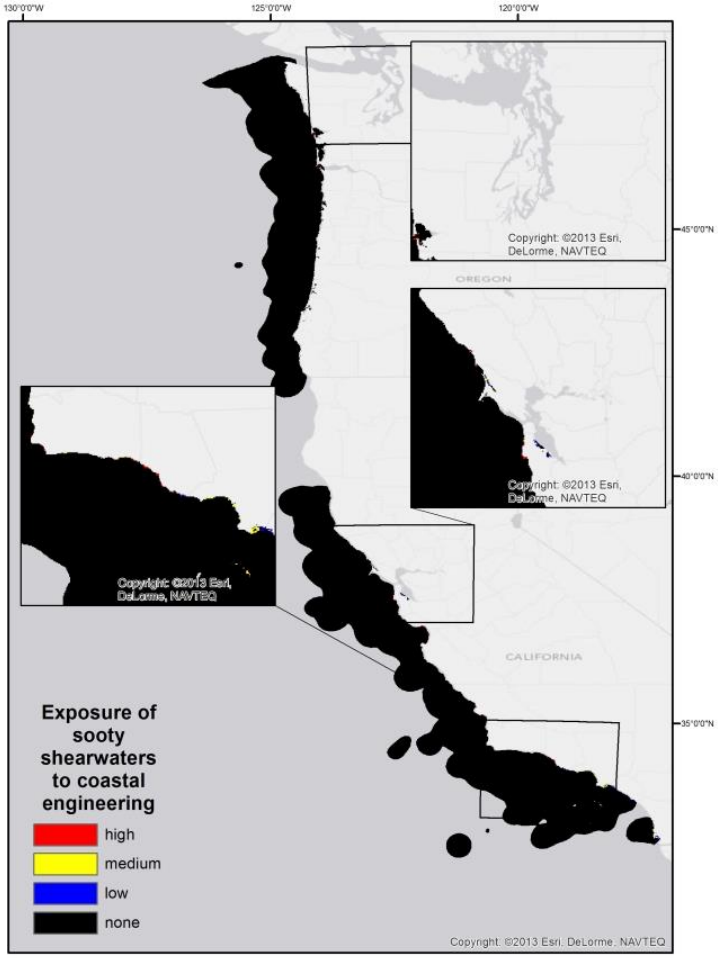


Figure SB.R.8. Exposure to coastal engineering for common murre, sooty shearwater and rhinoceros auklet.



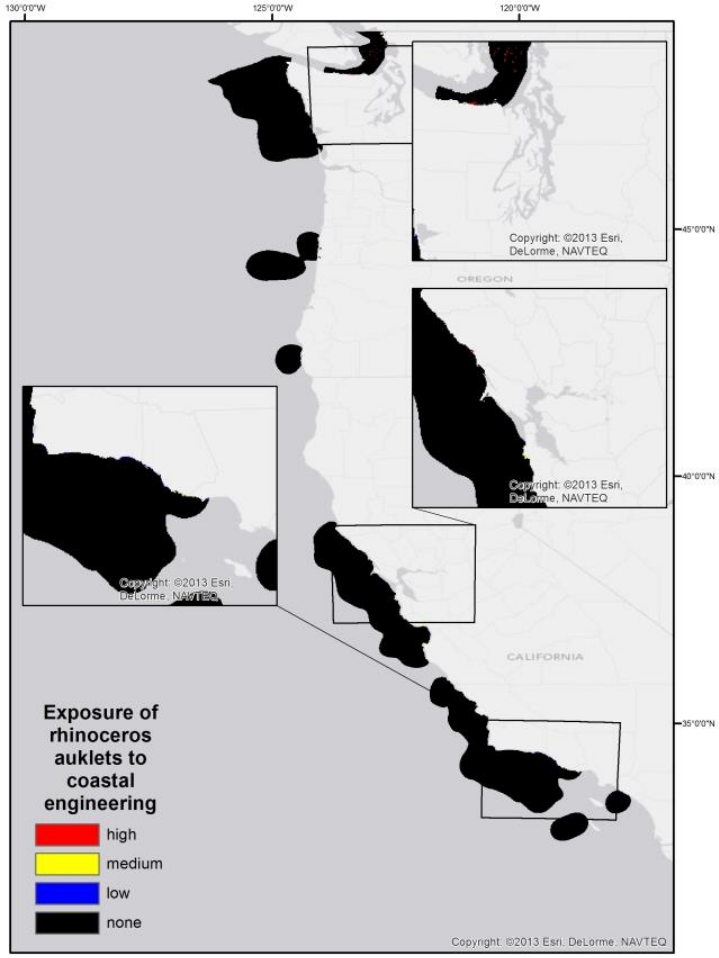


Figure SB.R.8 (continued).

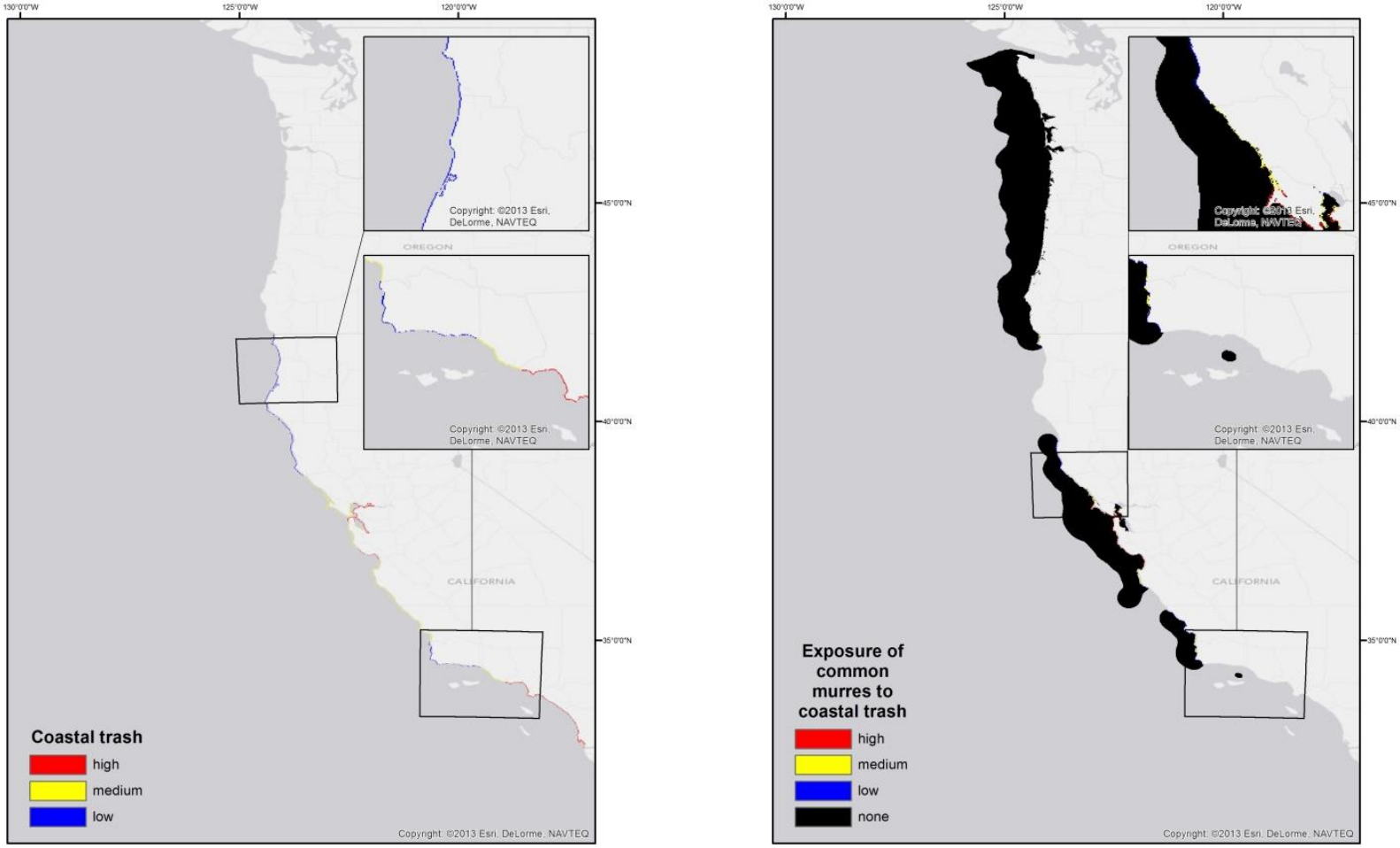
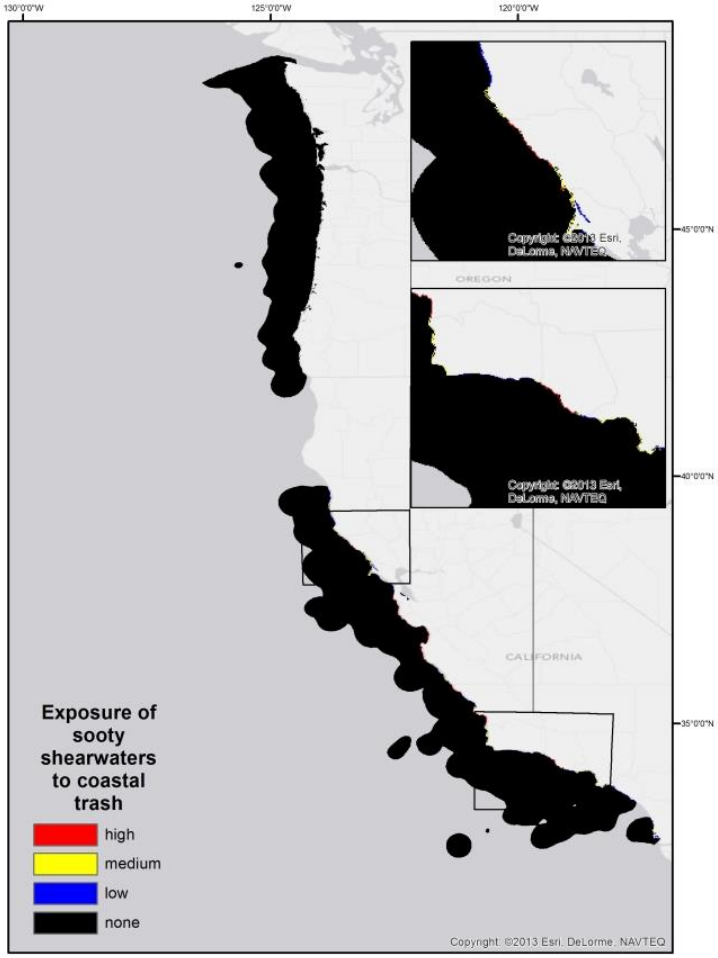


Figure SB.R.9. Exposure to coastal trash for common murre, sooty shearwater and rhinoceros auklet.



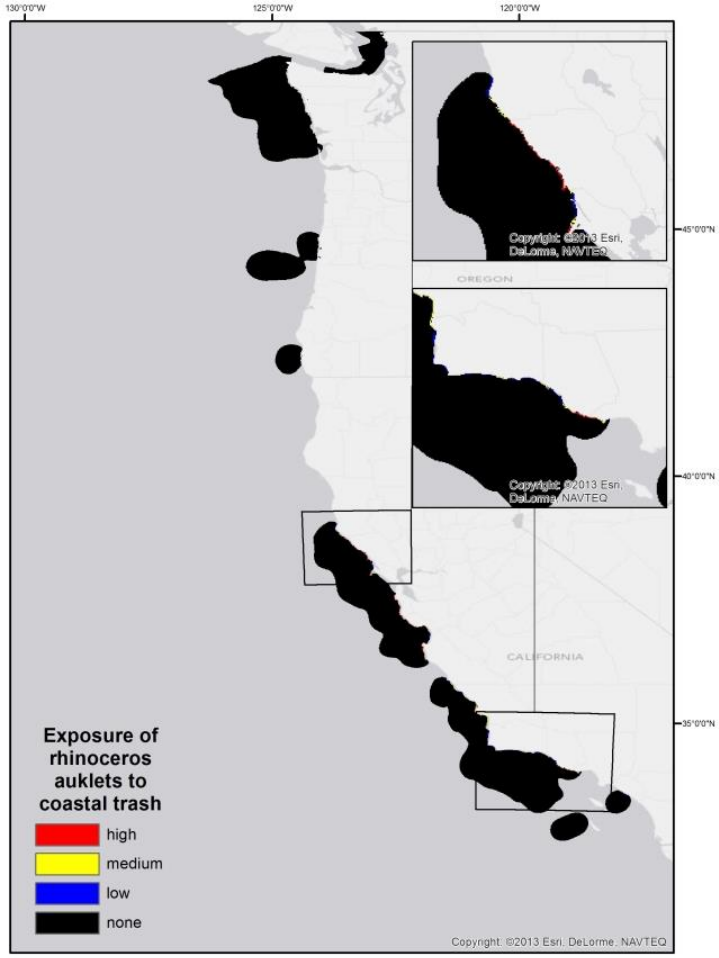


Figure SB.R.9 (continued).

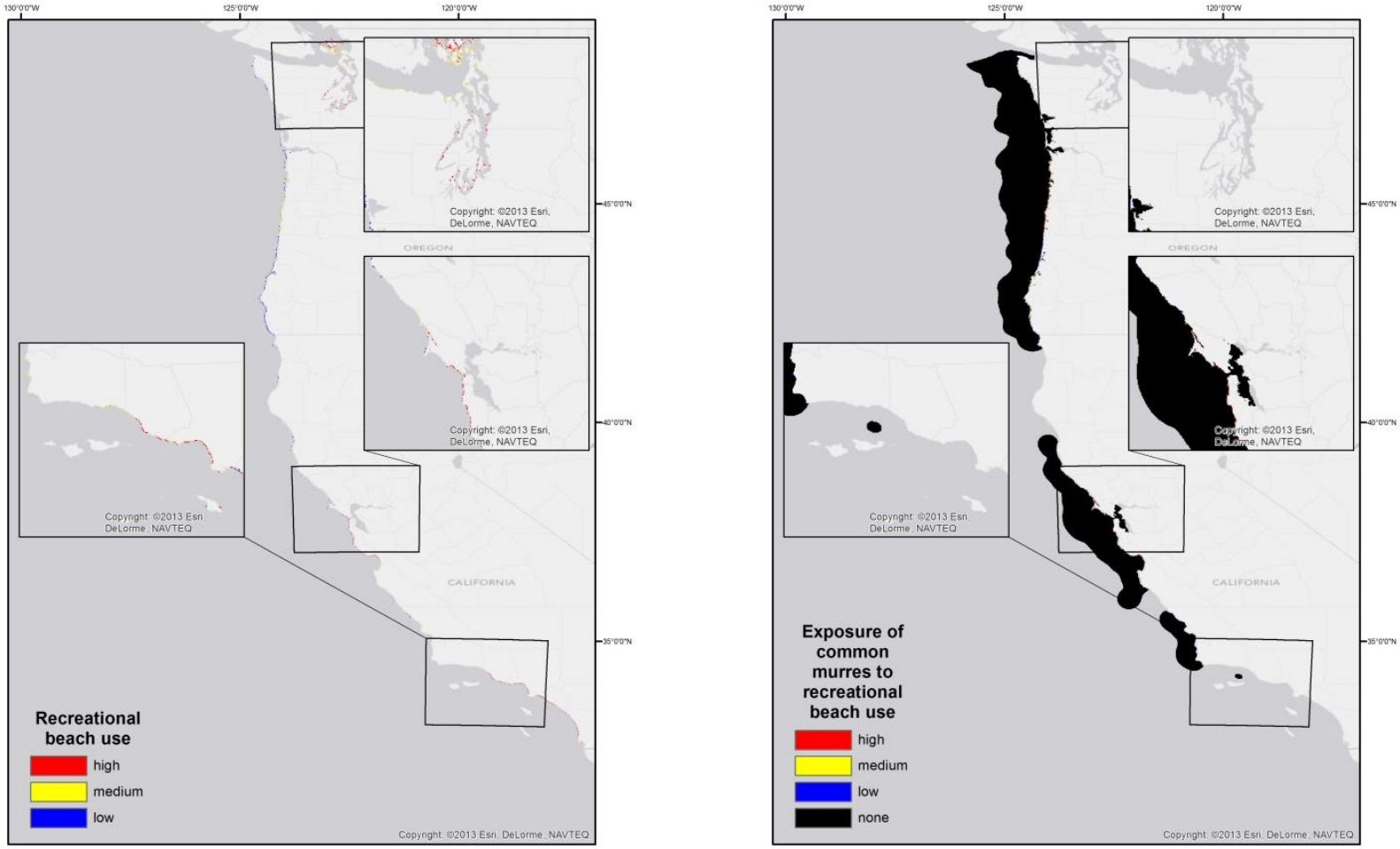
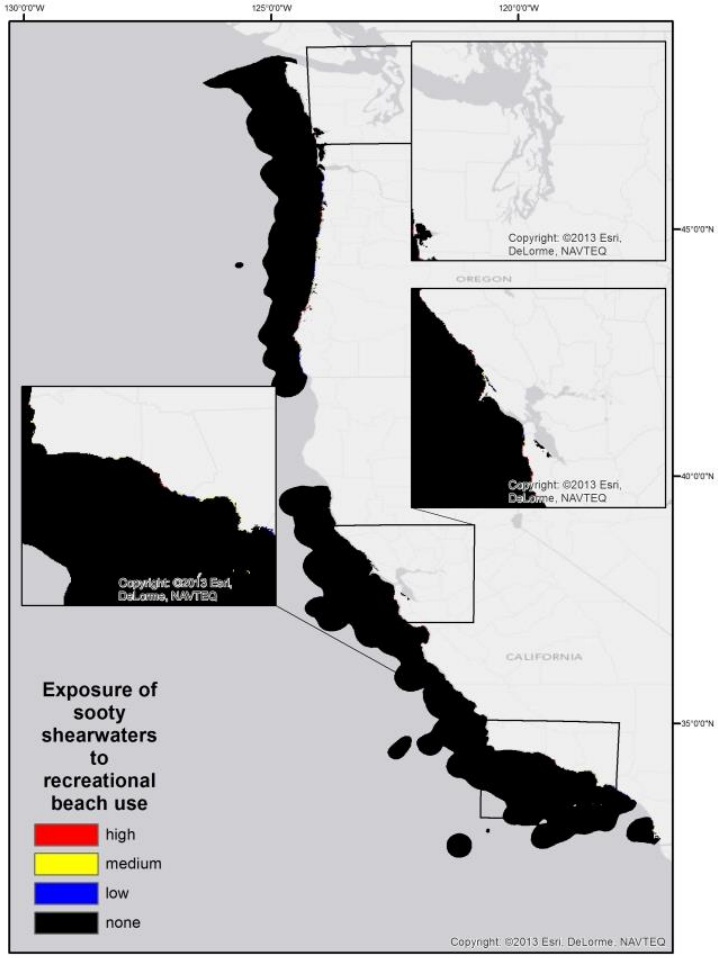


Figure SB.R.10. Exposure to direct human impacts (beach attendance) for common murre, sooty shearwater and rhinoceros auklet.



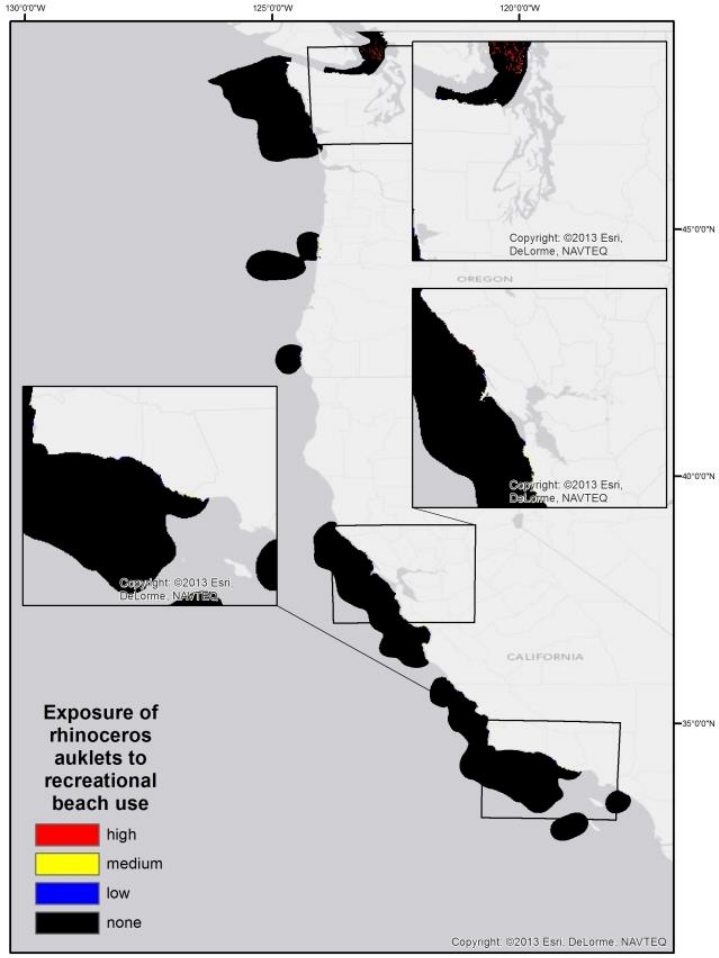


Figure SB.R.10 (continued).

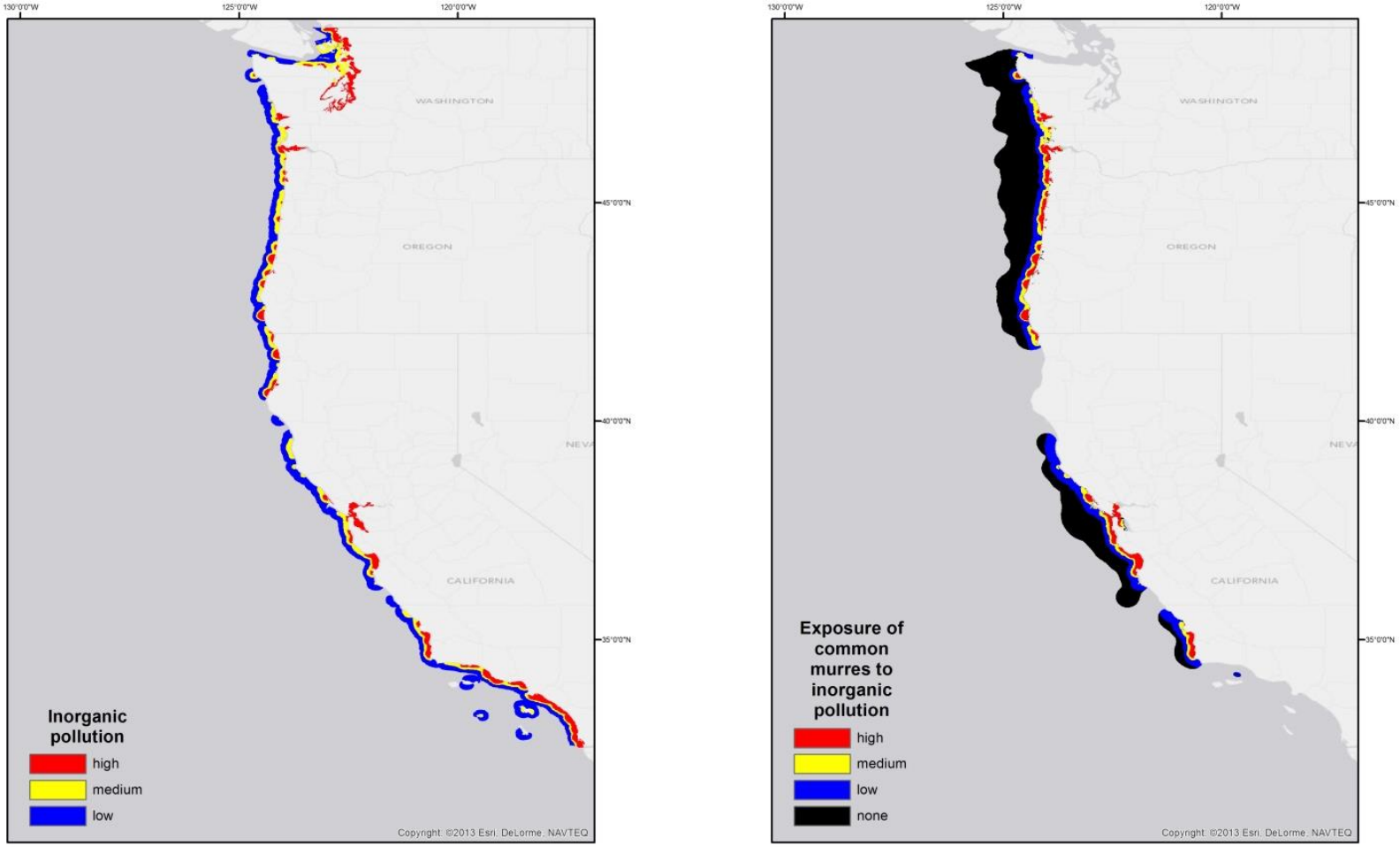
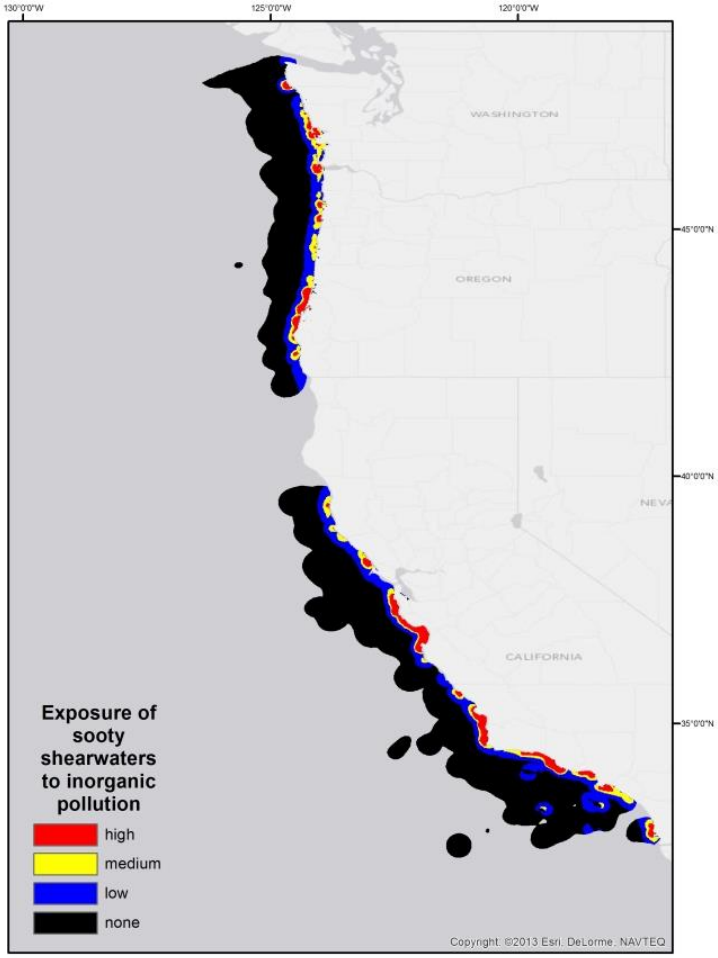


Figure SB.R.11. Exposure to inorganic pollution for common murre, sooty shearwater and rhinoceros auklet.



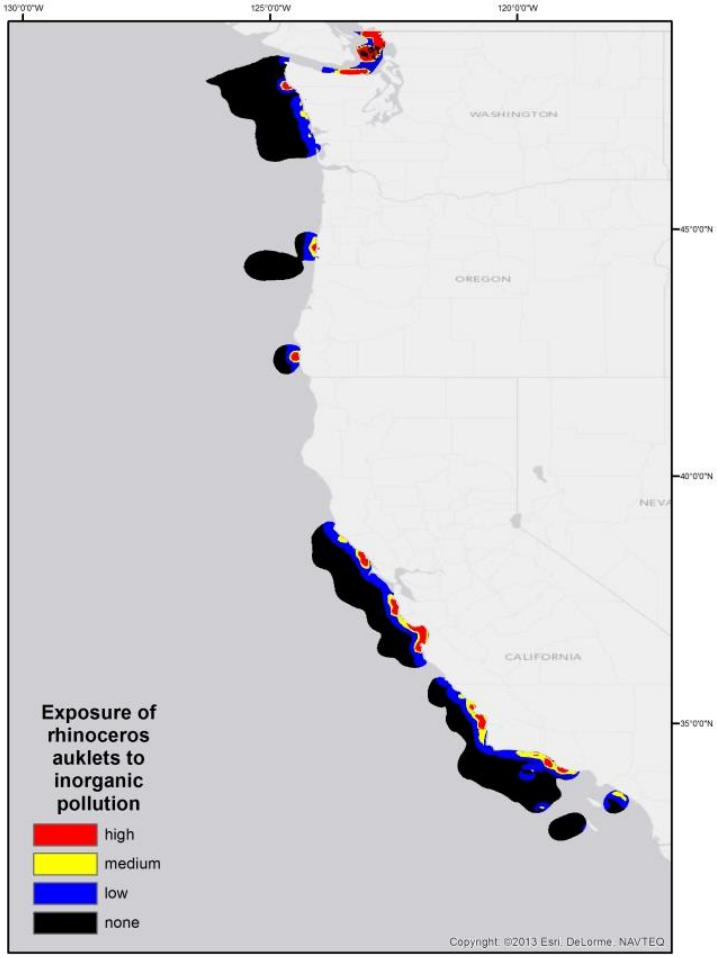


Figure SB.R.11 (continued).

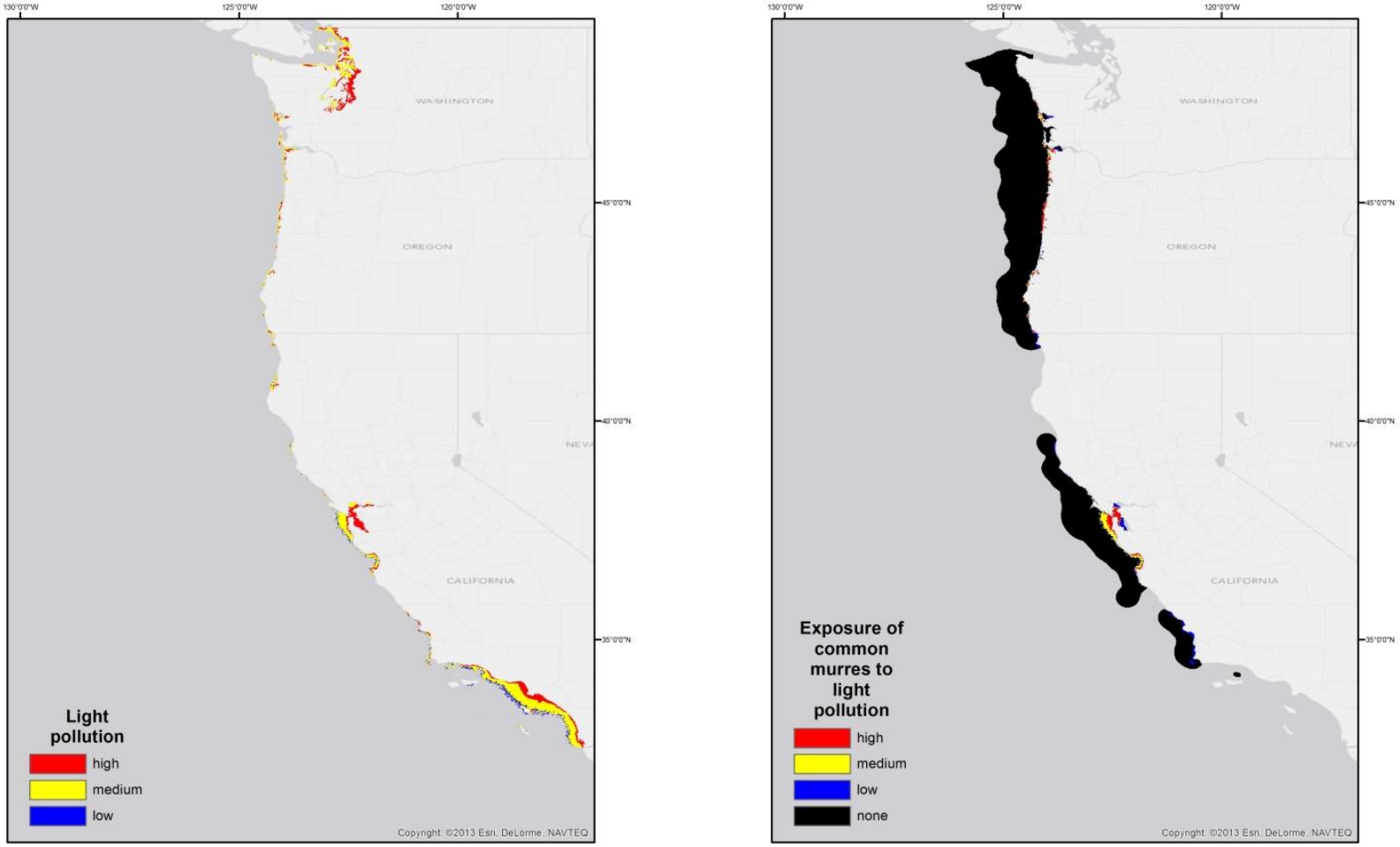
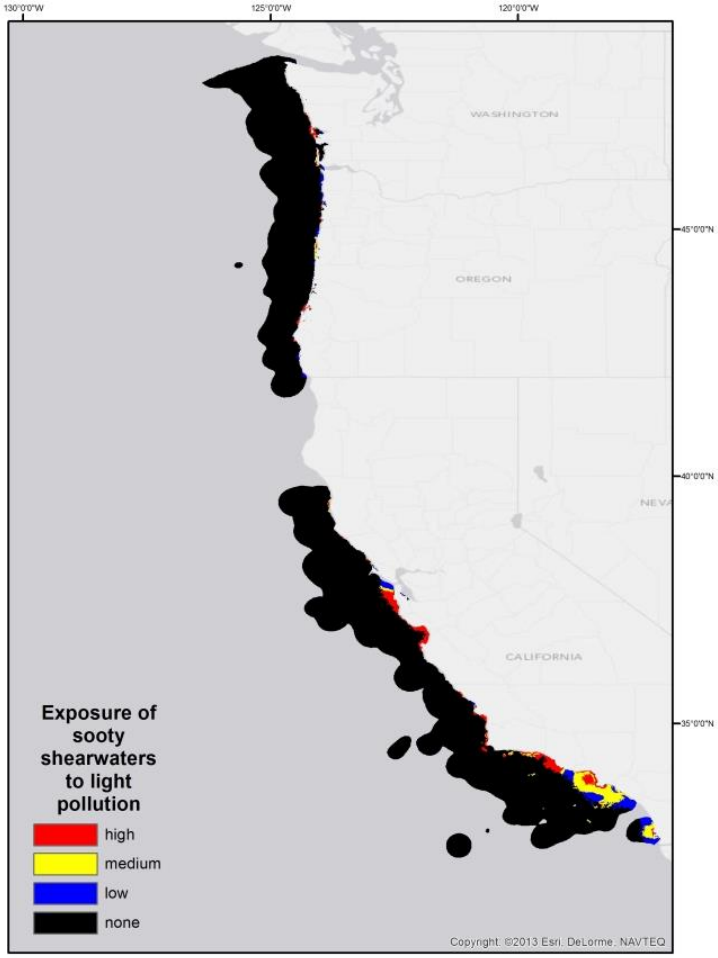


Figure SB.R.12. Exposure to light pollution for common murre, sooty shearwater and rhinoceros auklet.



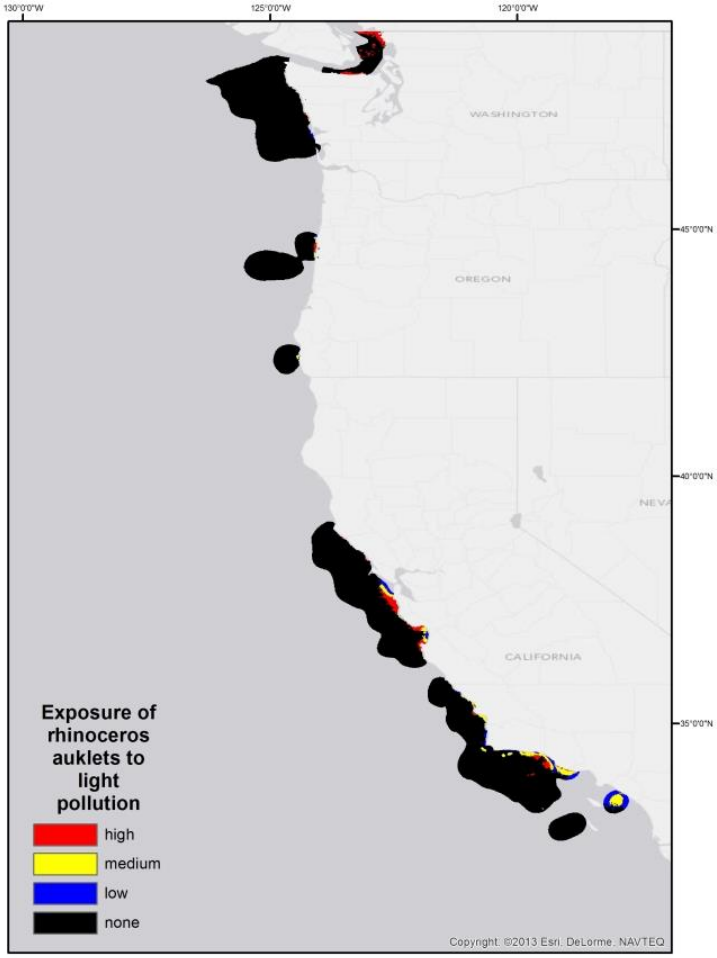


Figure SB.R.12 (continued).

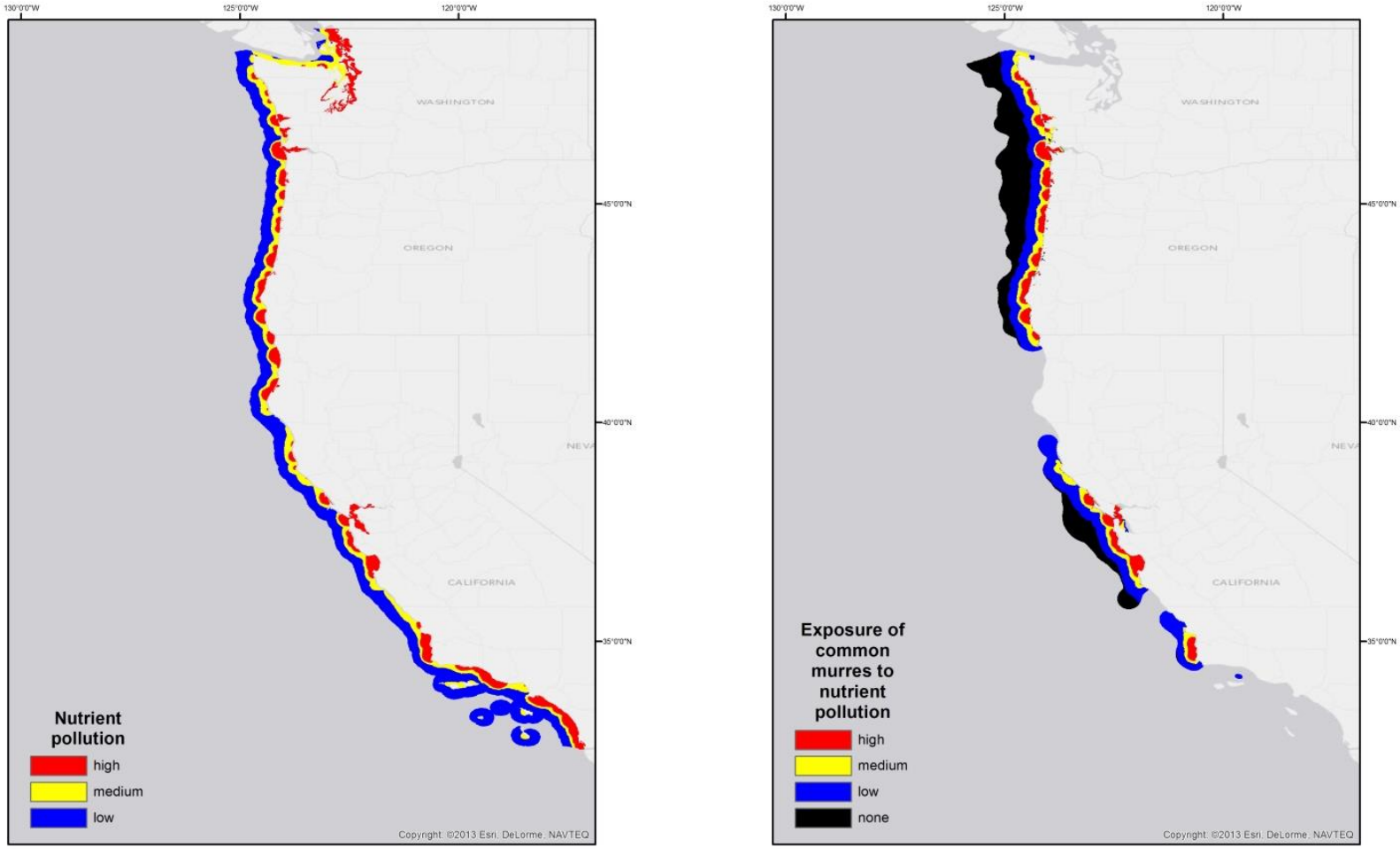
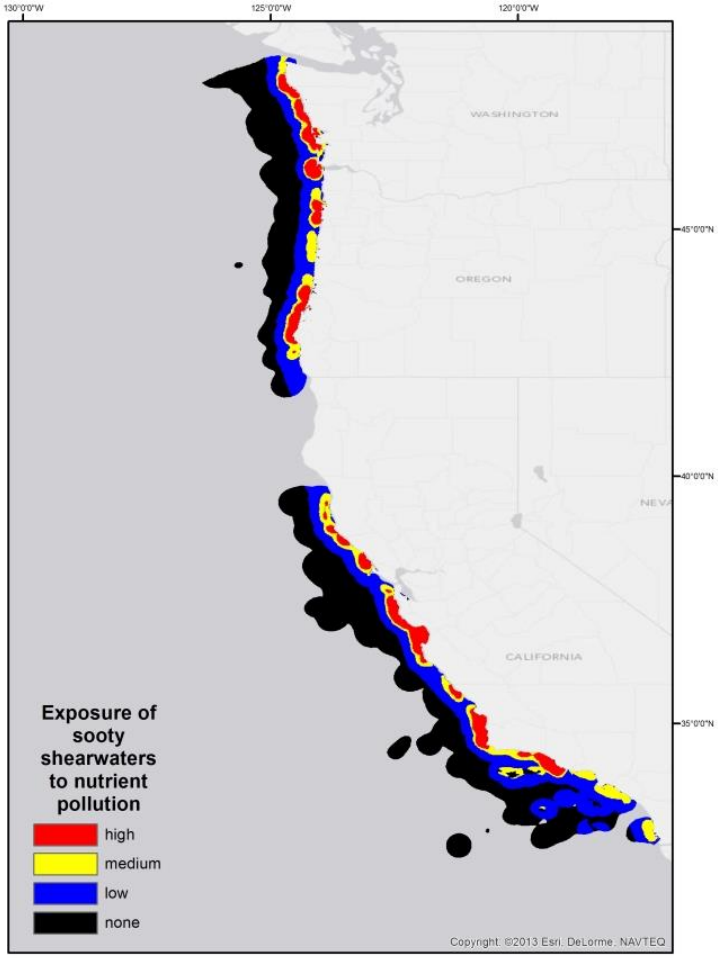


Figure SB.R.13. Exposure to nutrient input for common murre, sooty shearwater and rhinoceros auklet.



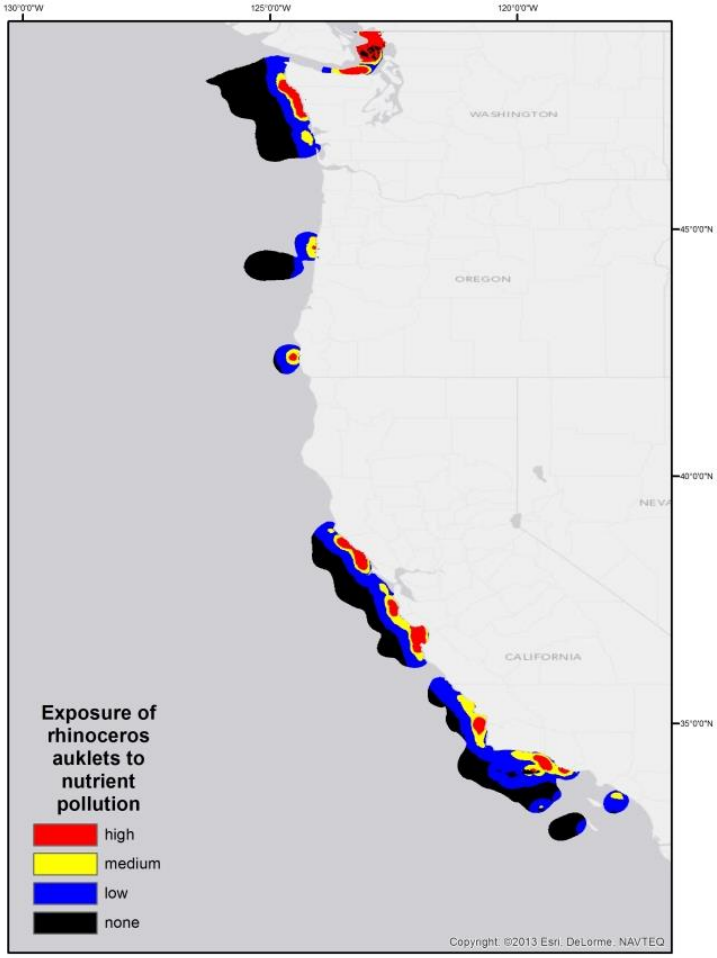


Figure SB.R.13 (continued).

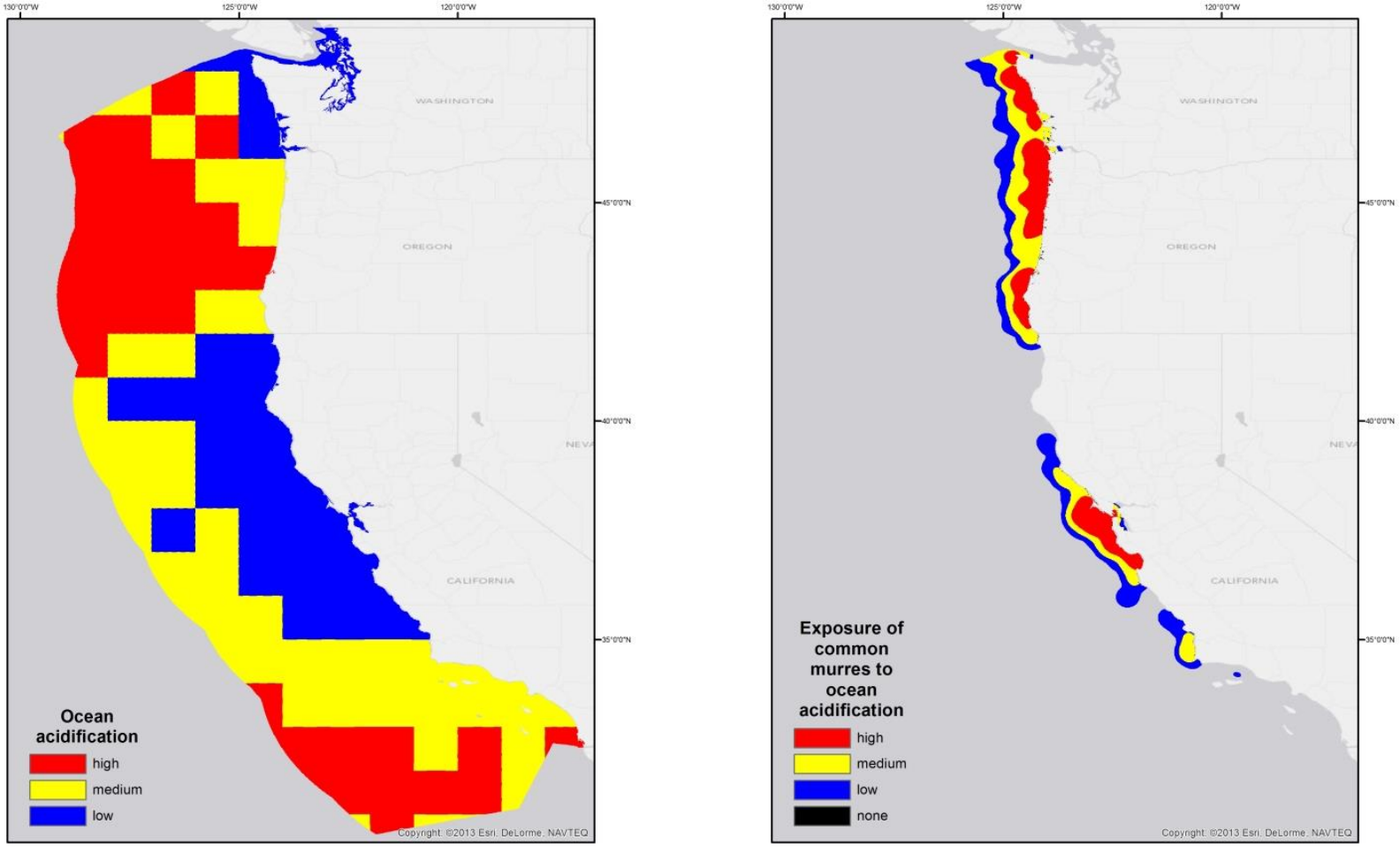
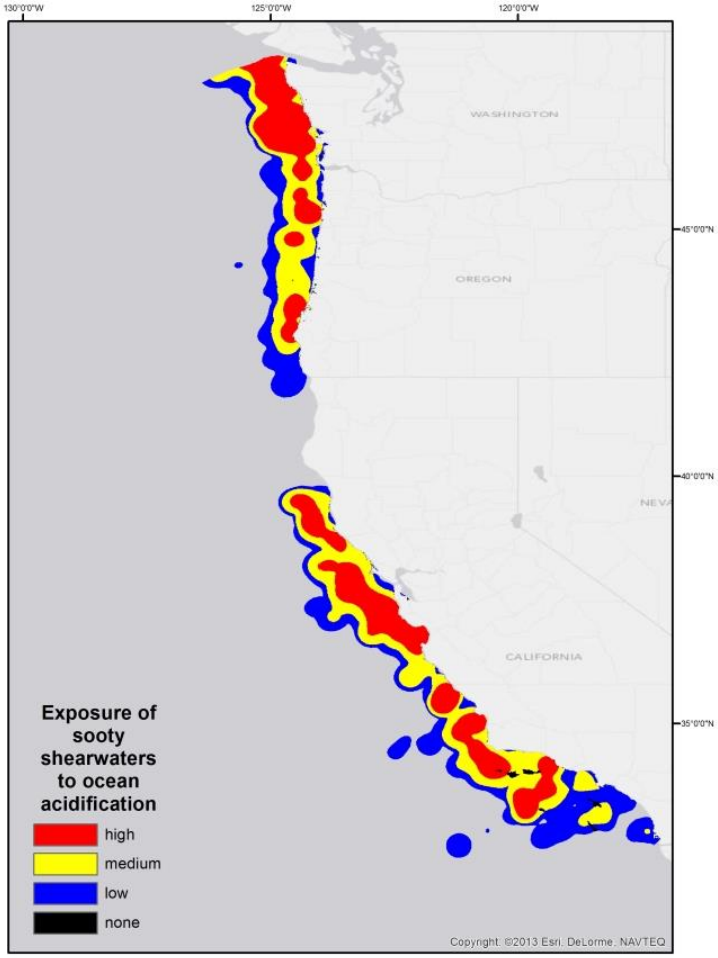


Figure SB.R.14. Exposure to ocean acidification for common murre, sooty shearwater and rhinoceros auklet.



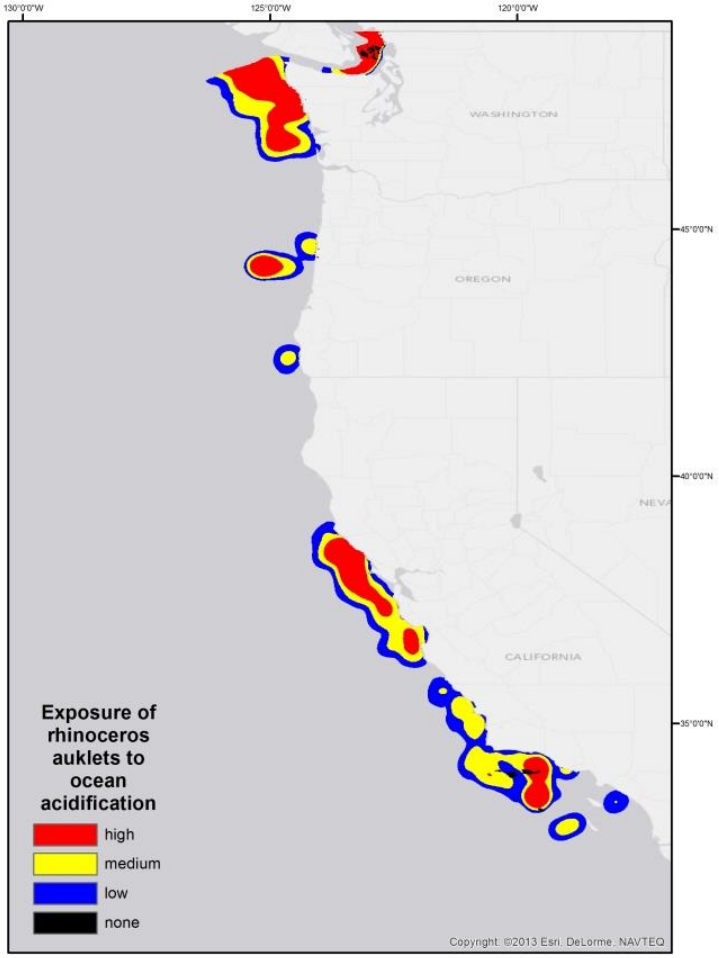


Figure SB.R.14 (continued).

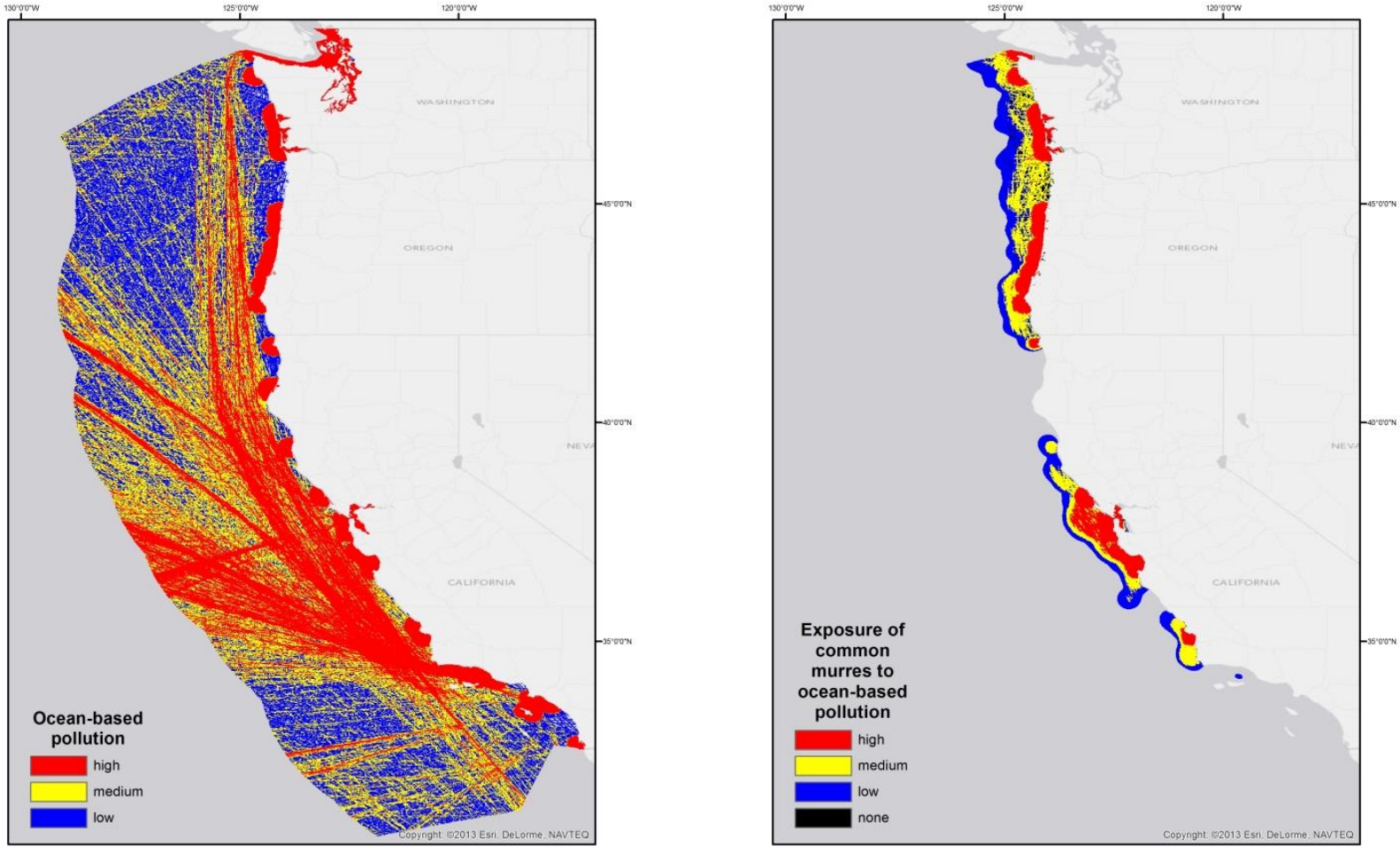
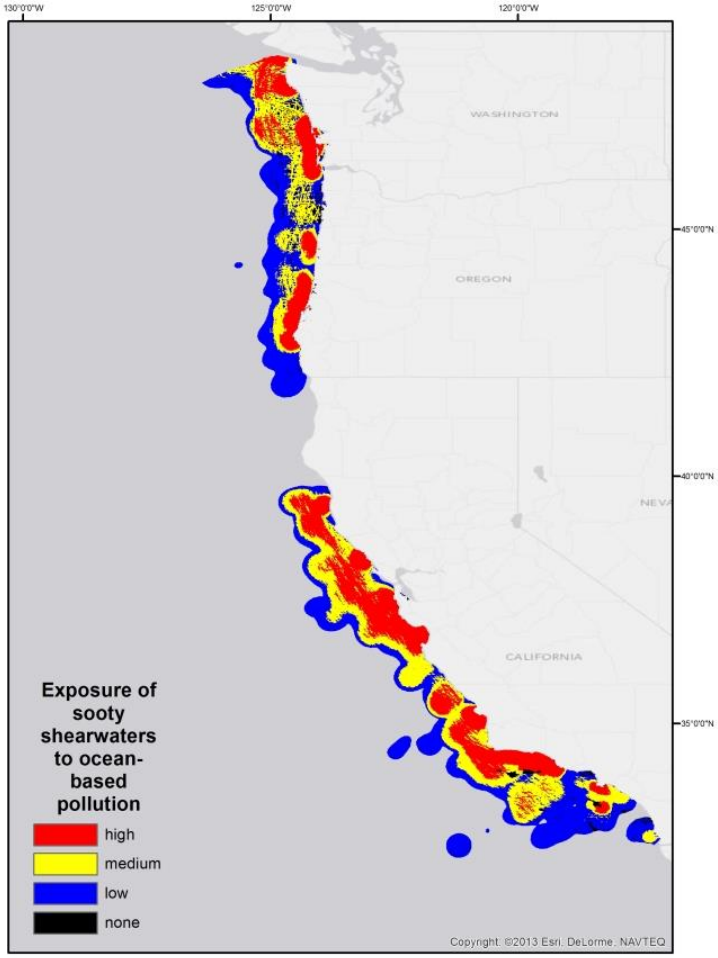


Figure SB.R.15. Exposure to ocean-based pollution for common murre, sooty shearwater and rhinoceros auklet.



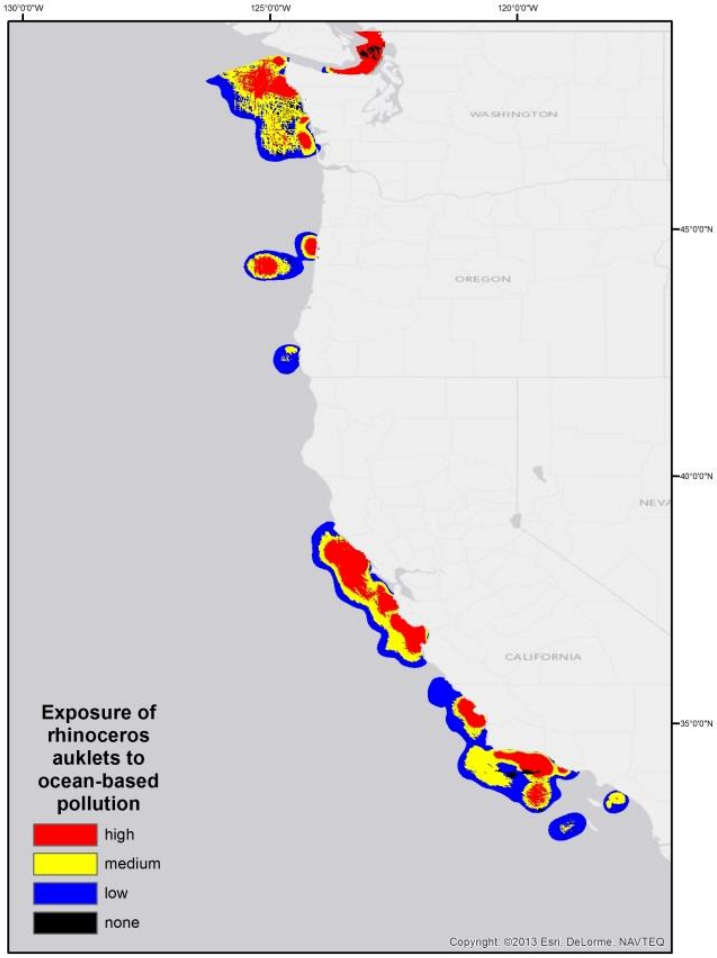


Figure SB.R.15 (continued).

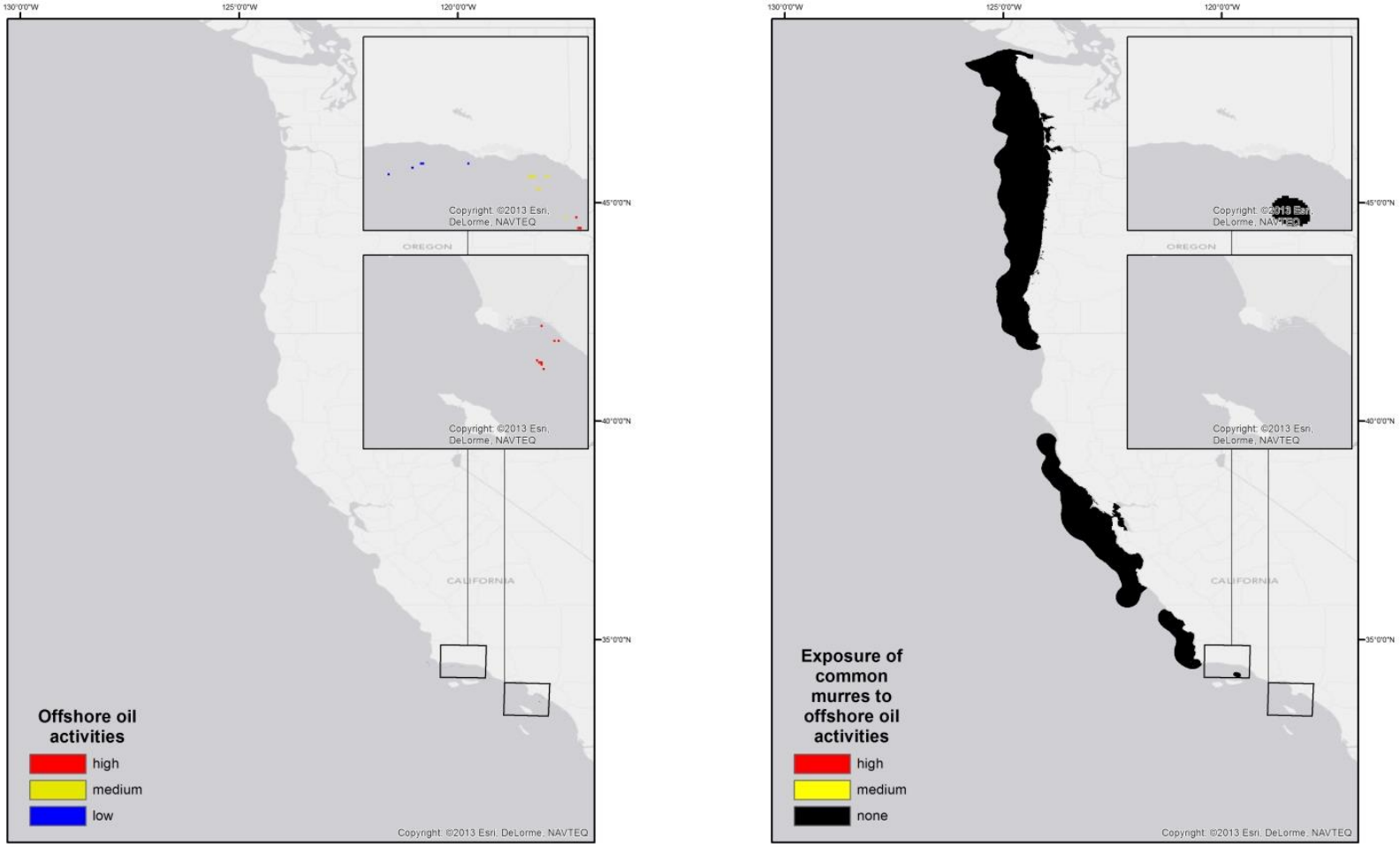
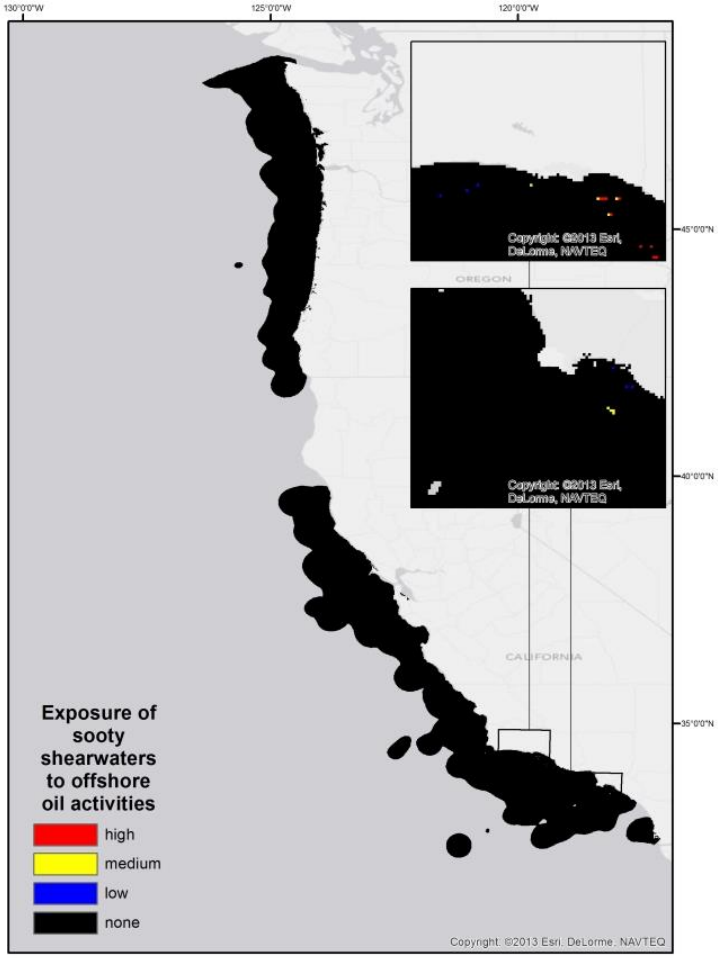


Figure SB.R.16. Exposure to offshore oil activities for common murre, sooty shearwater and rhinoceros auklet.



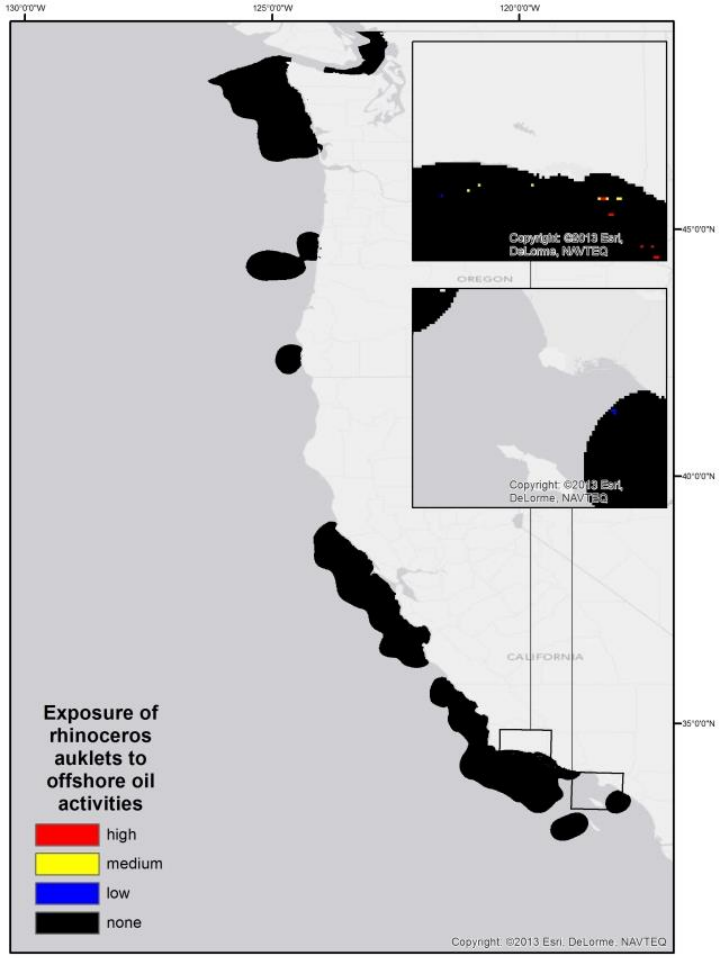


Figure SB.R.16 (continued).

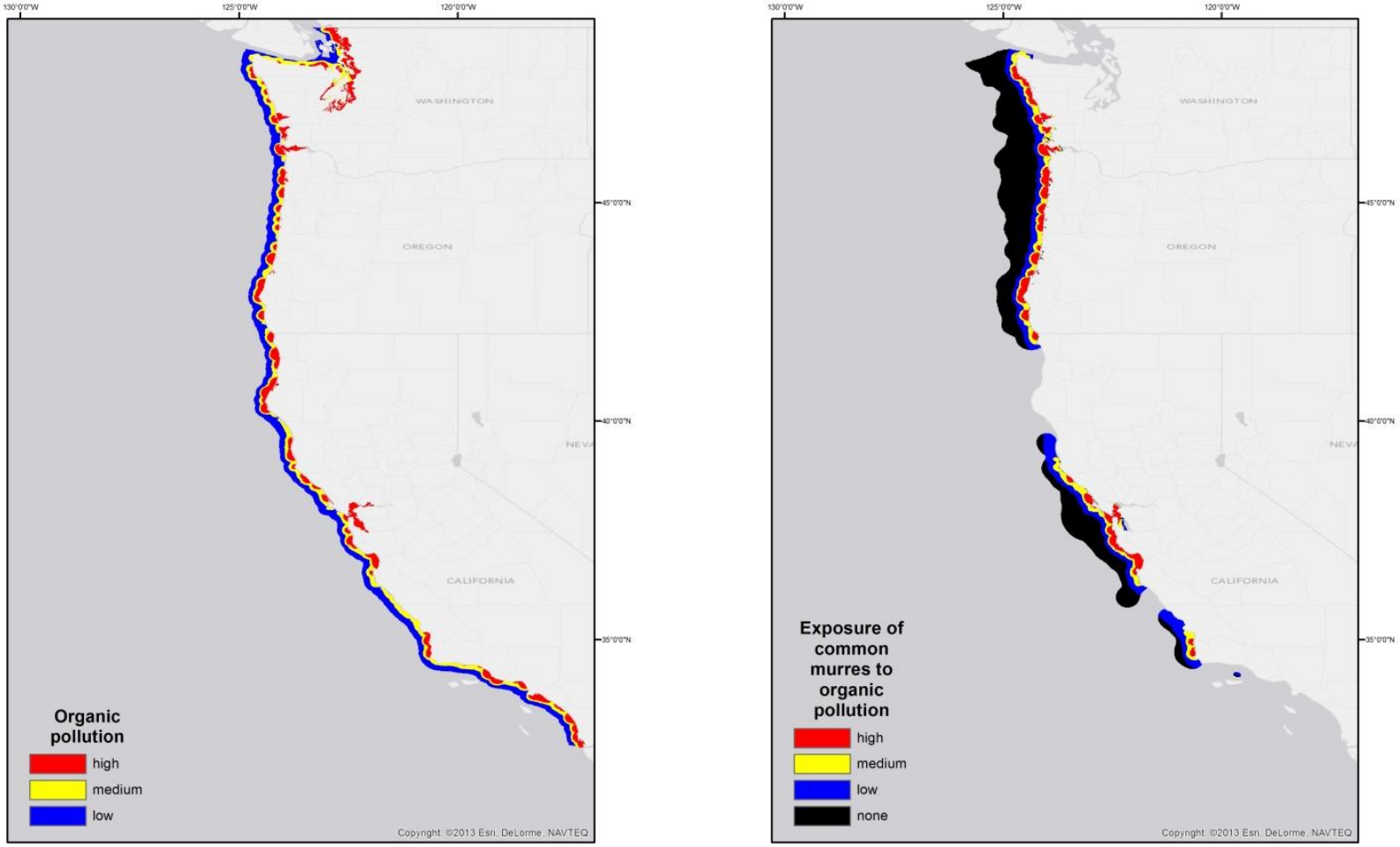
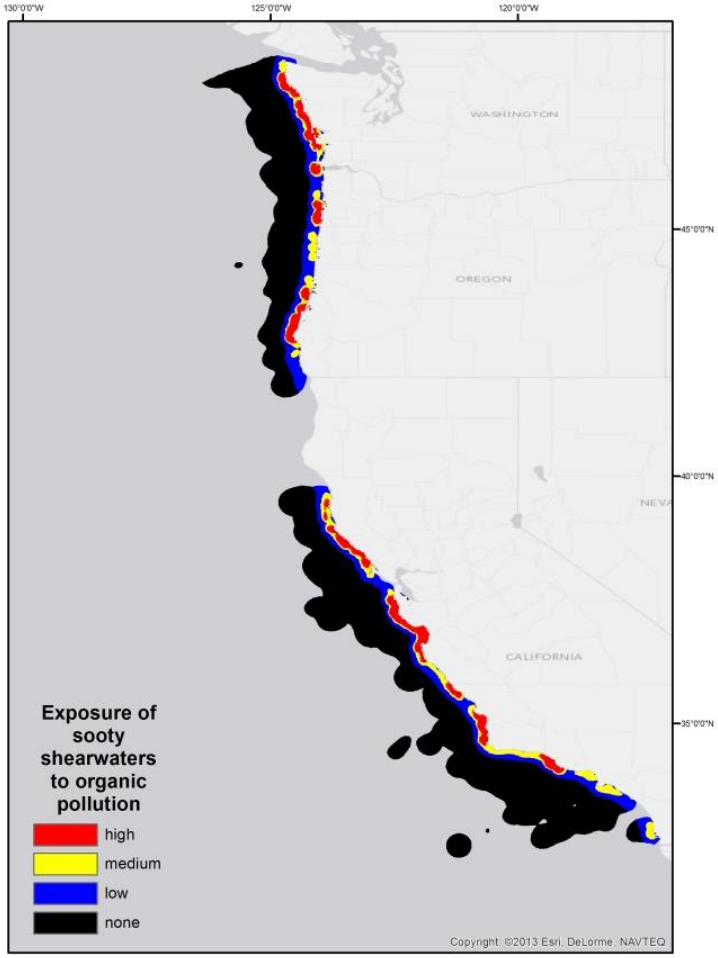


Figure SB.R.17. Exposure to organic pollution for common murre, sooty shearwater and rhinoceros auklet.



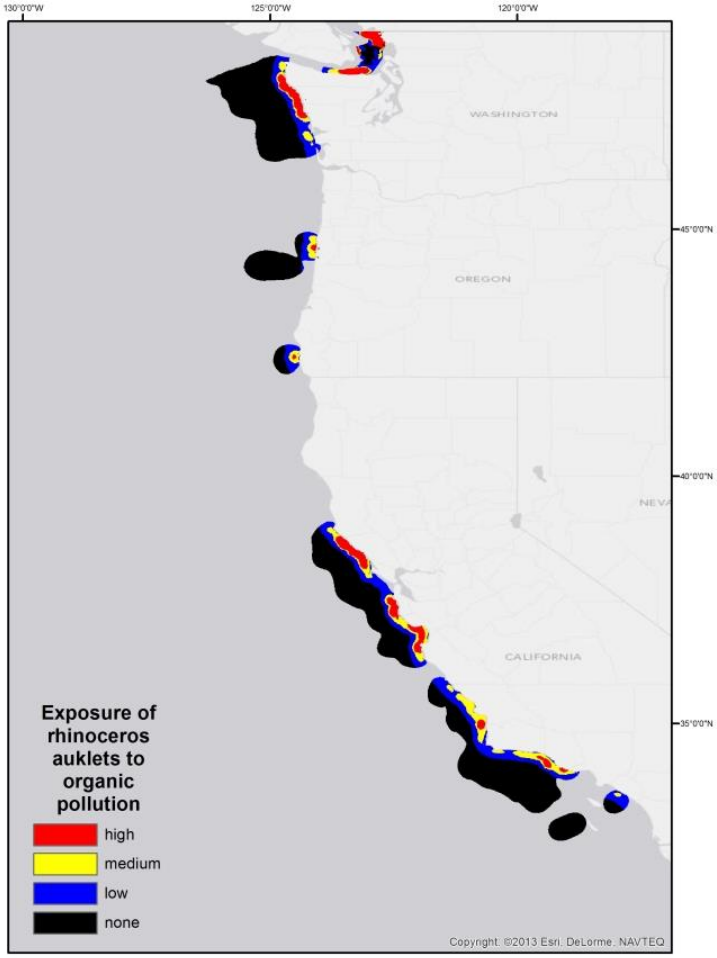


Figure SB.R.17 (continued).

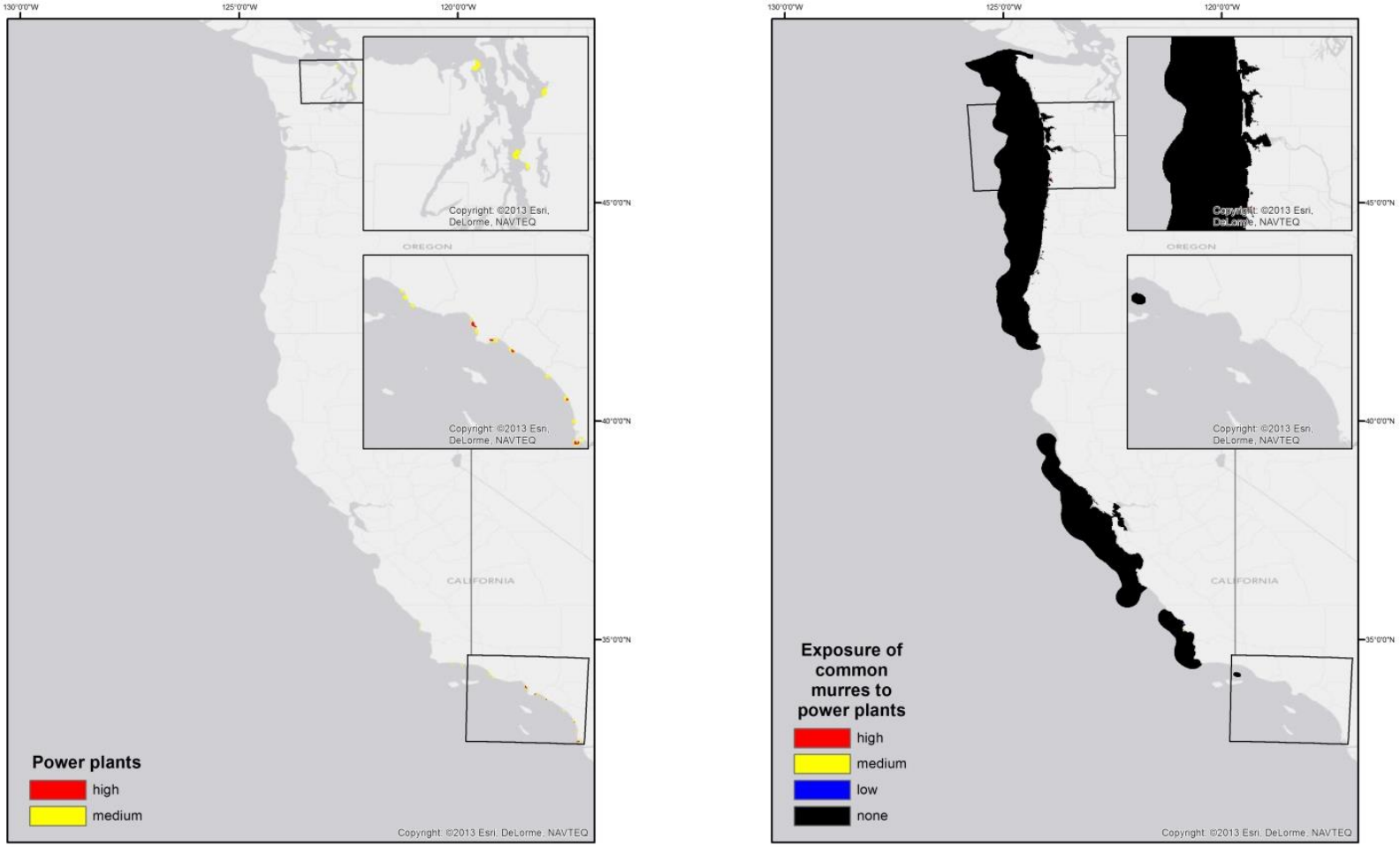
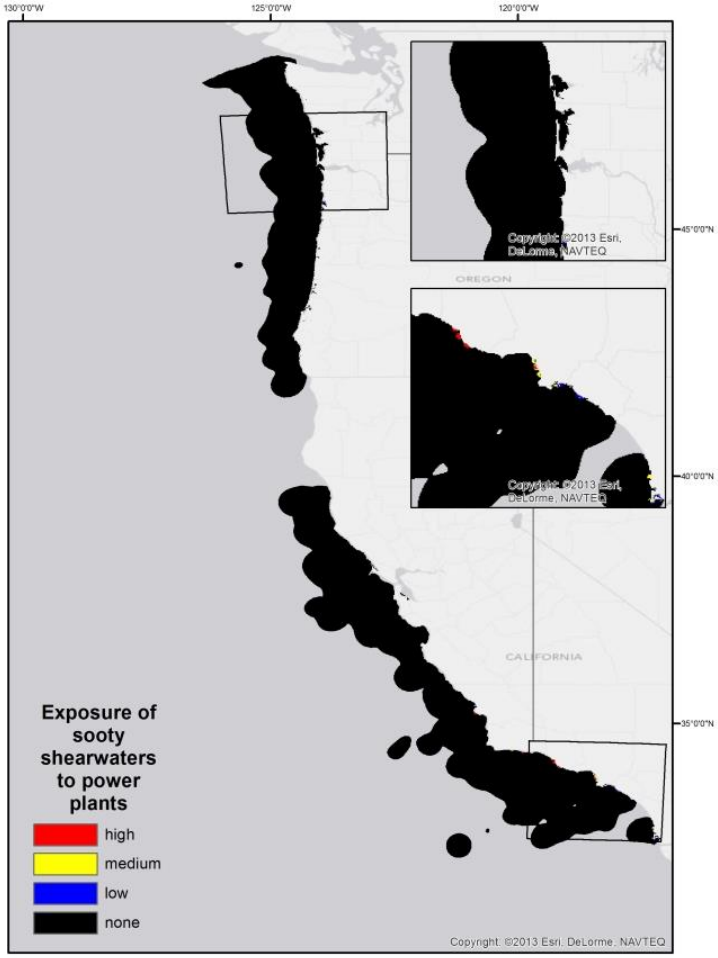


Figure SB.R.18. Exposure to power plants for common murre, sooty shearwater and rhinoceros auklet.



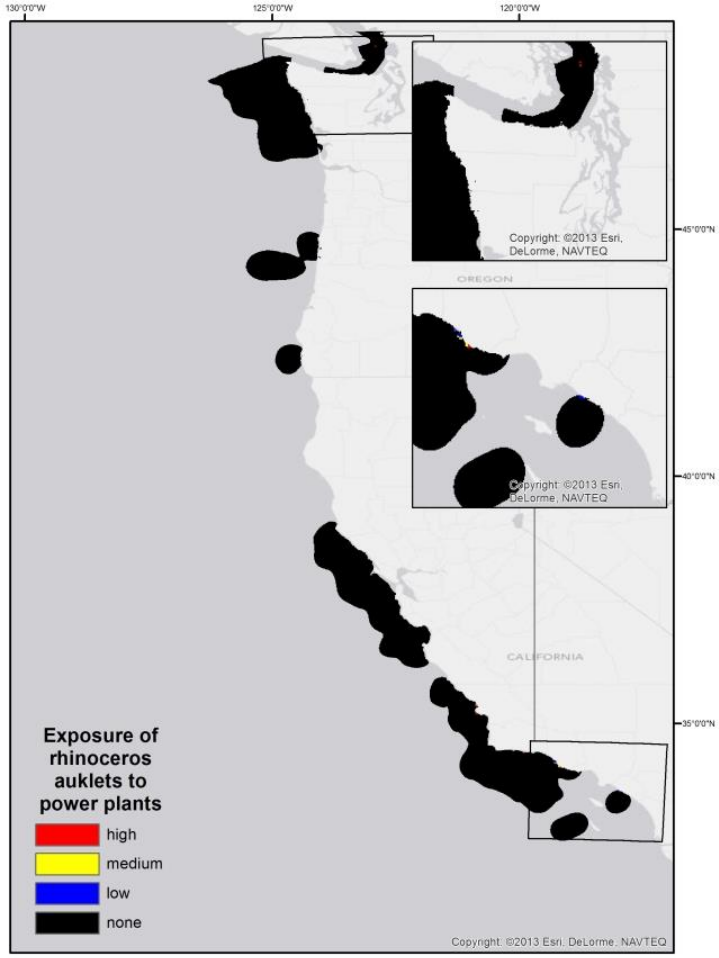


Figure SB.R.18 (continued).

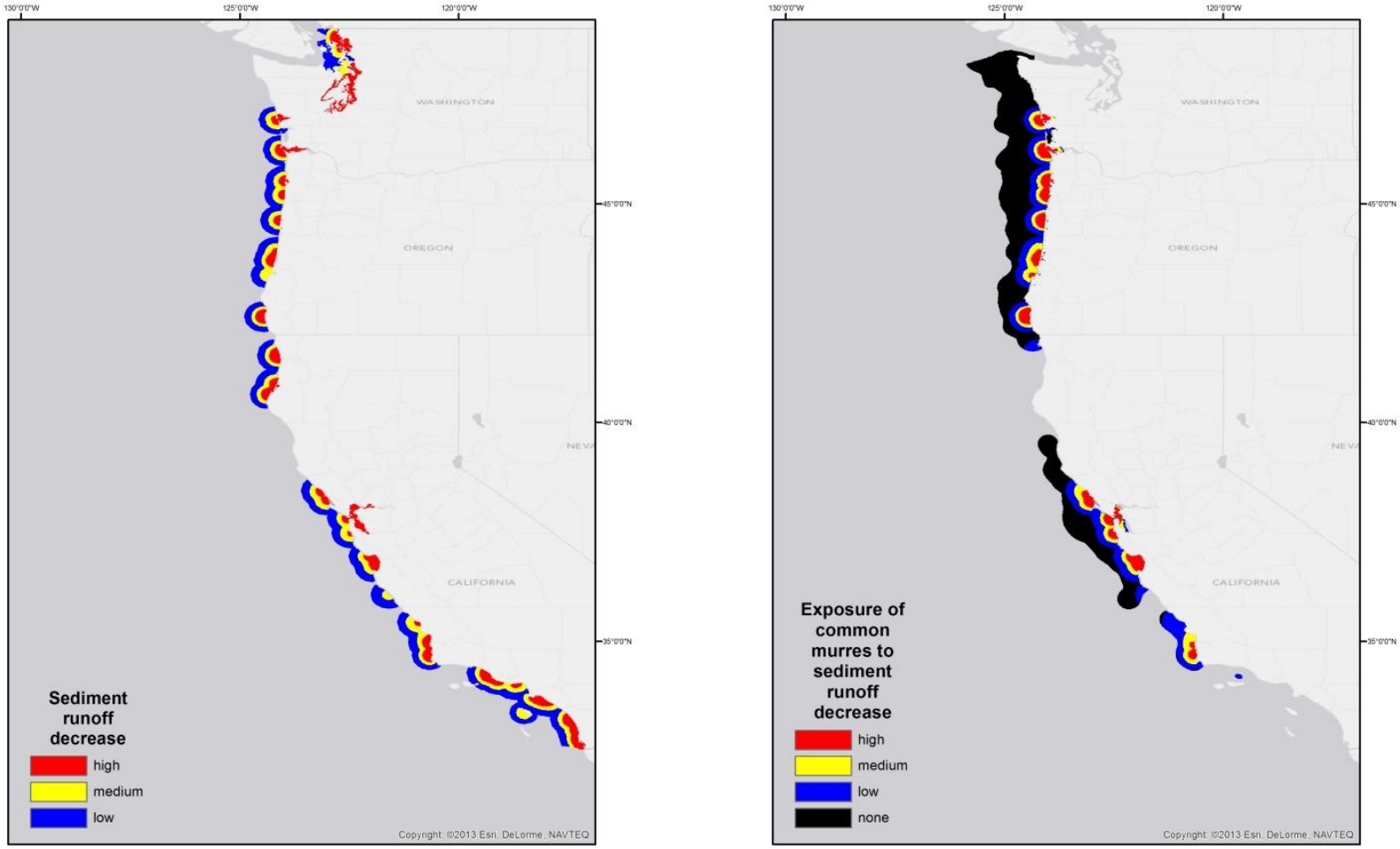
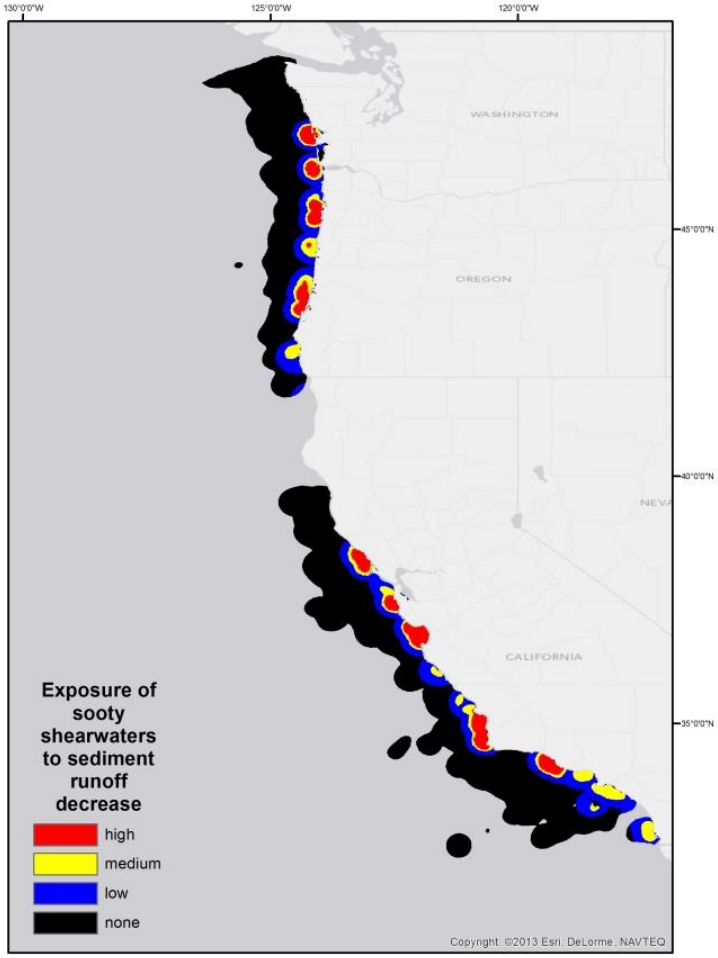


Figure SB.R.19. Exposure to sediment runoff decrease for common murre, sooty shearwater and rhinoceros auklet.



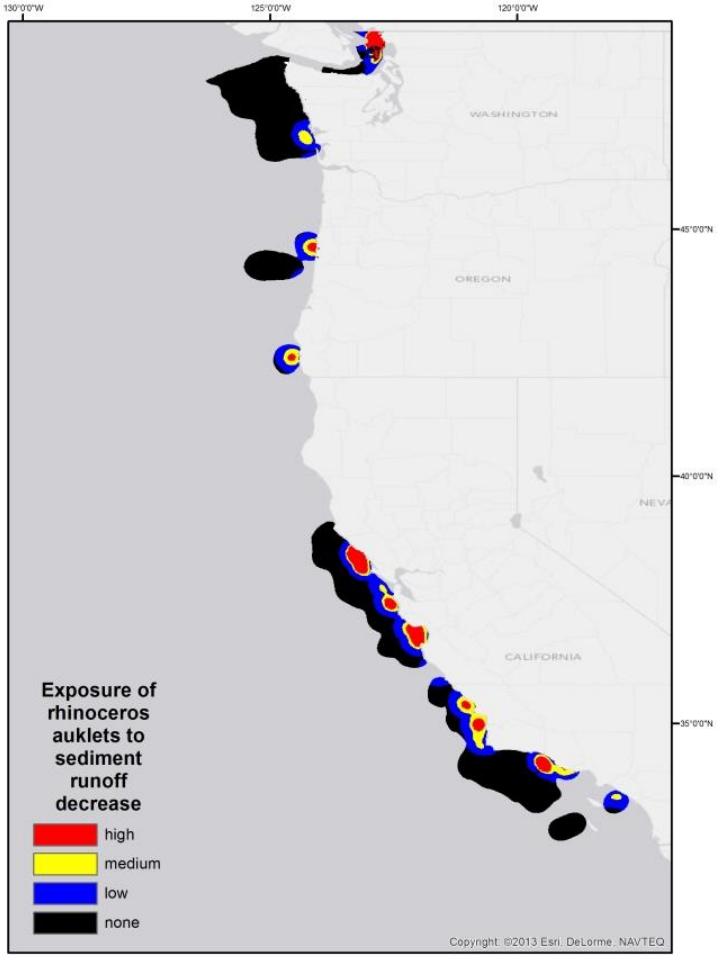


Figure SB.R.19. (continued).

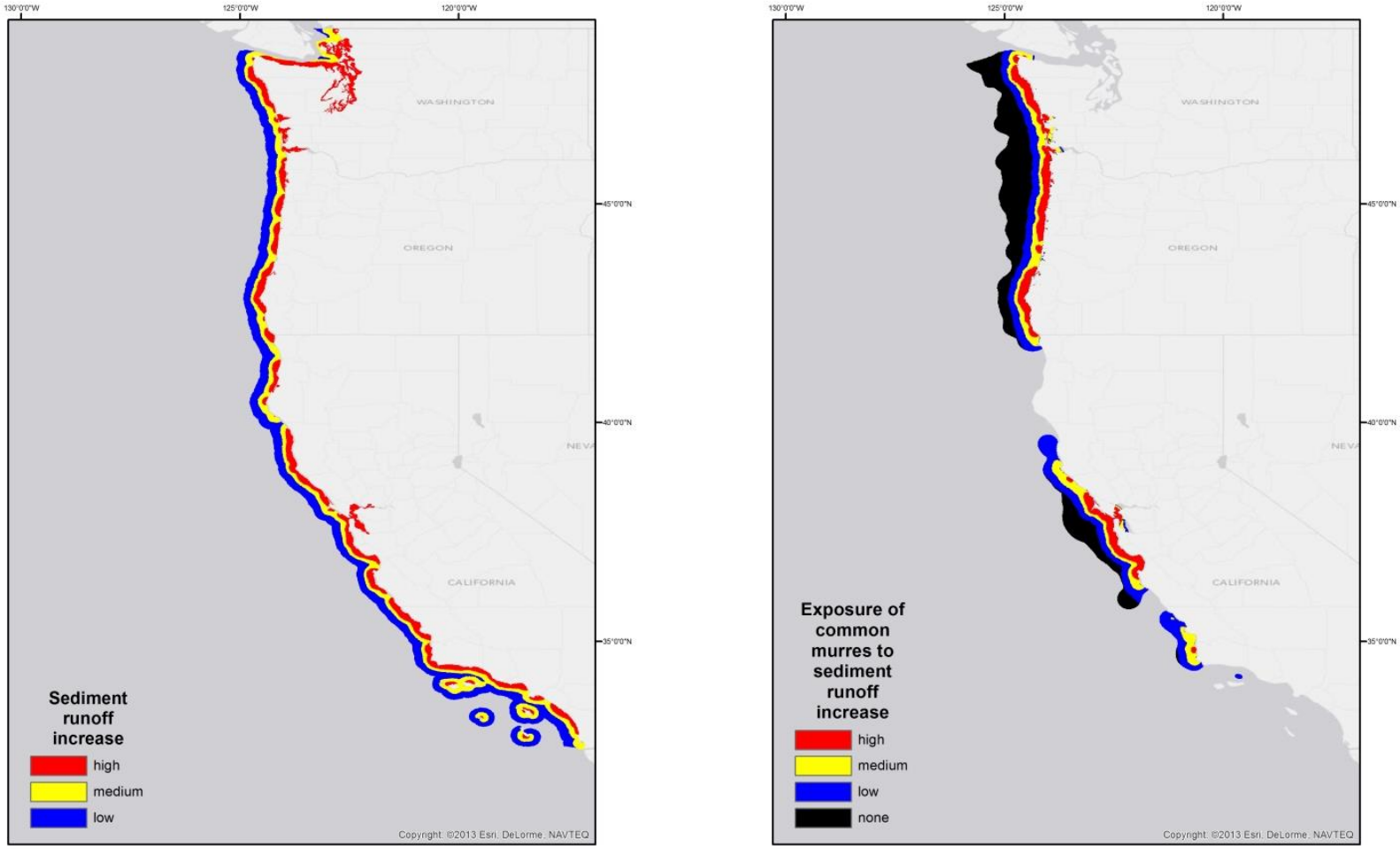
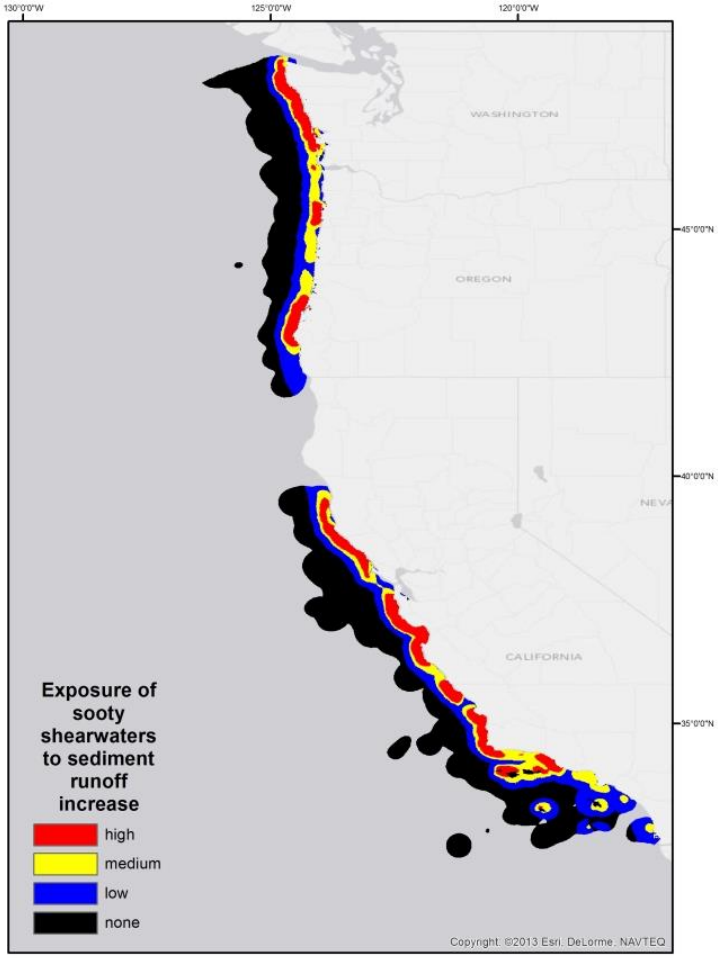


Figure SB.R.20 Exposure to sediment runoff increase for common murre, sooty shearwater and rhinoceros auklet.



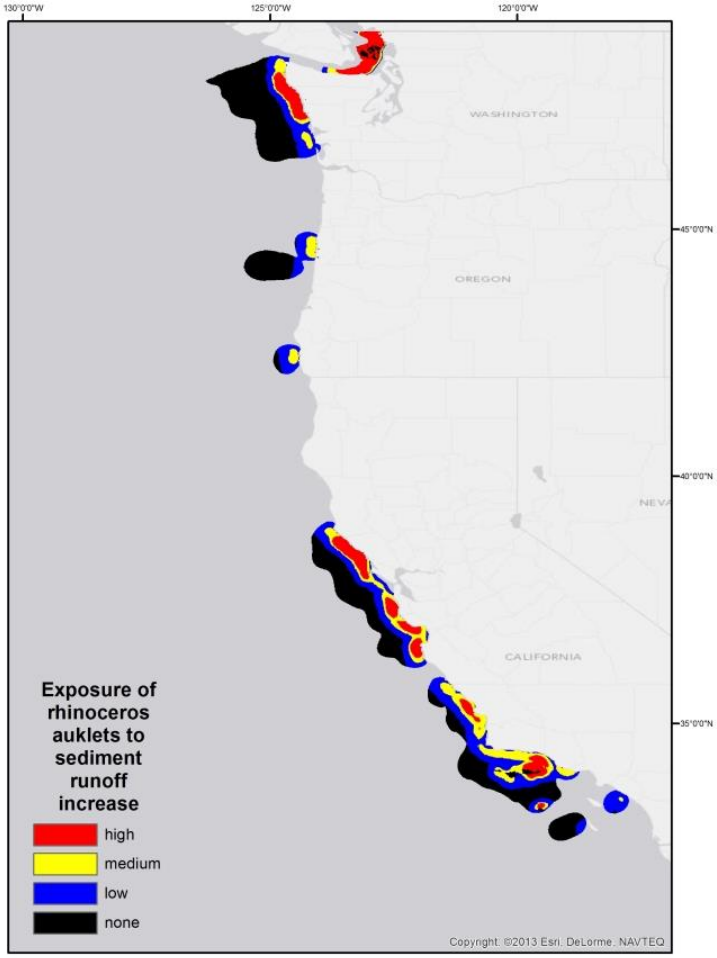


Figure SB.R.20 (continued).

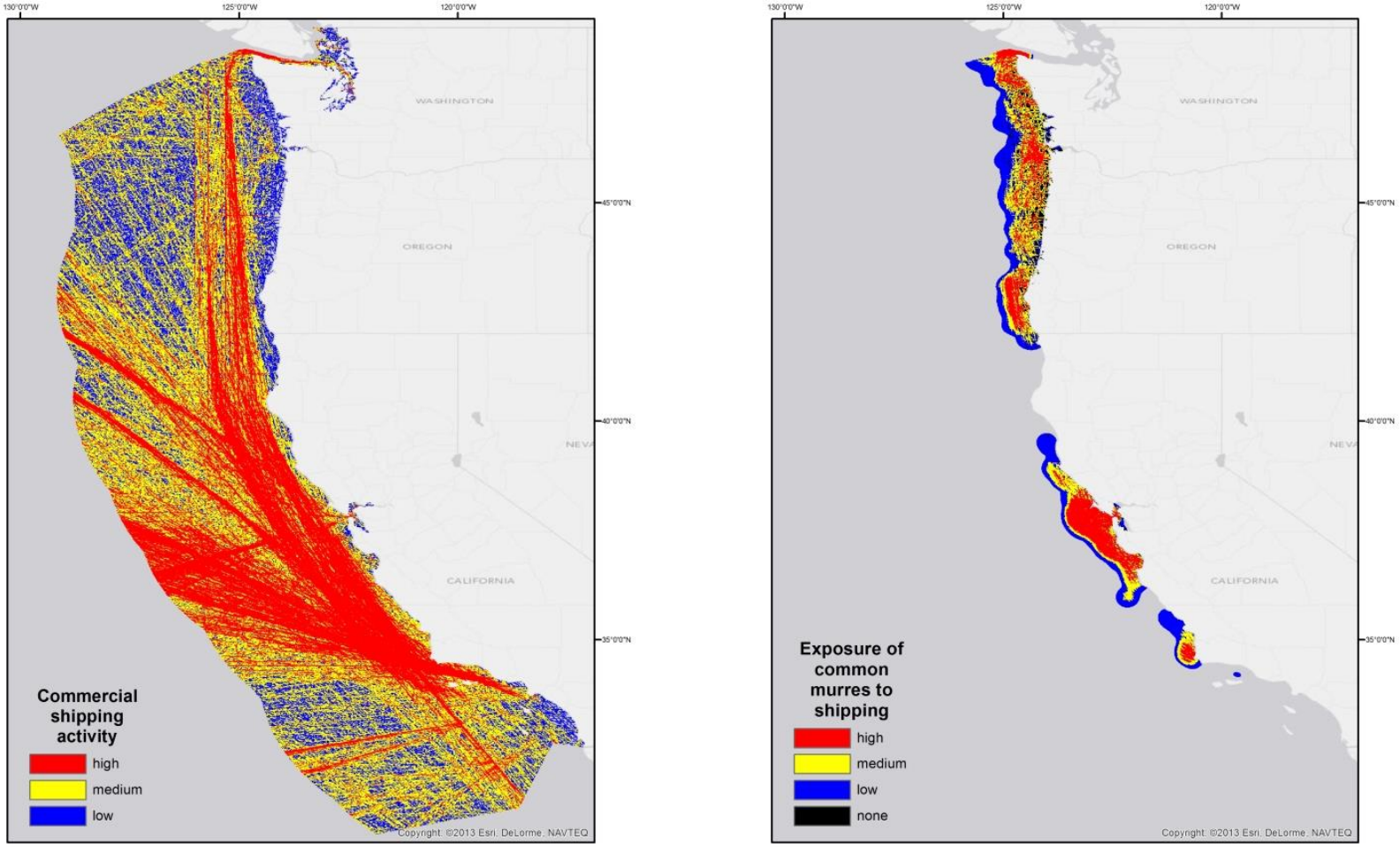
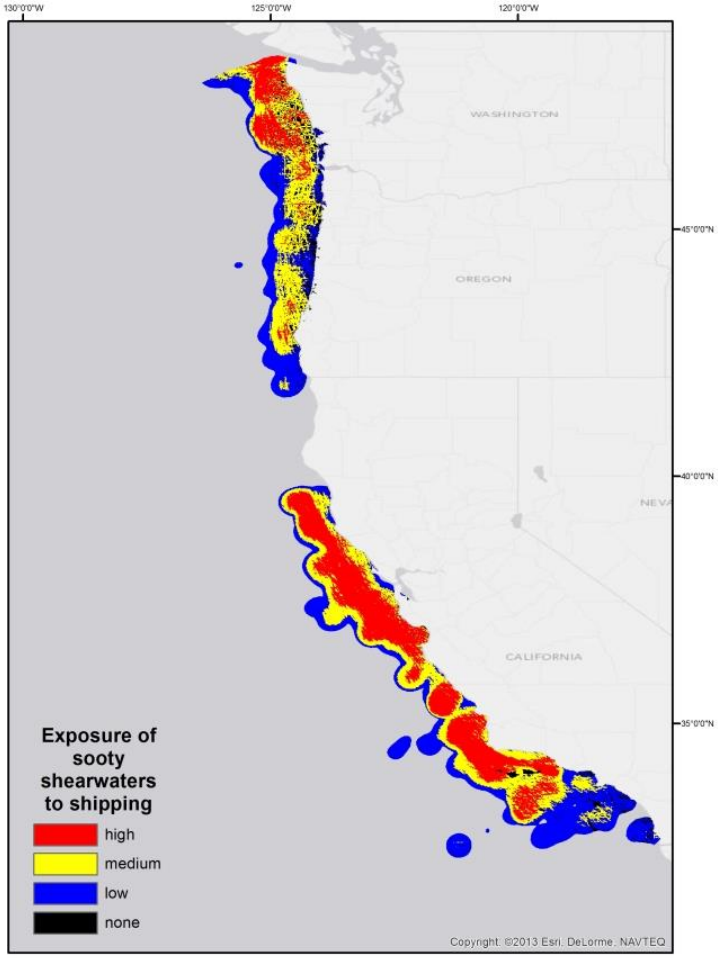


Figure SB.R.21. Exposure to shipping activity (commercial) for common murre, sooty shearwater and rhinoceros auklet.



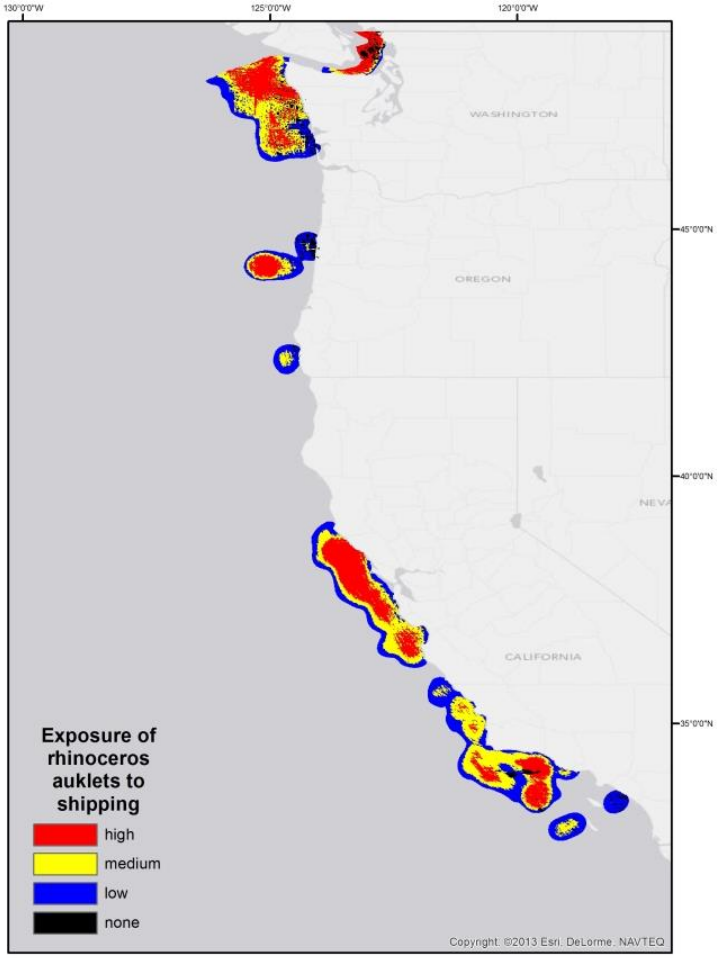


Figure SB.R.21. (continued).

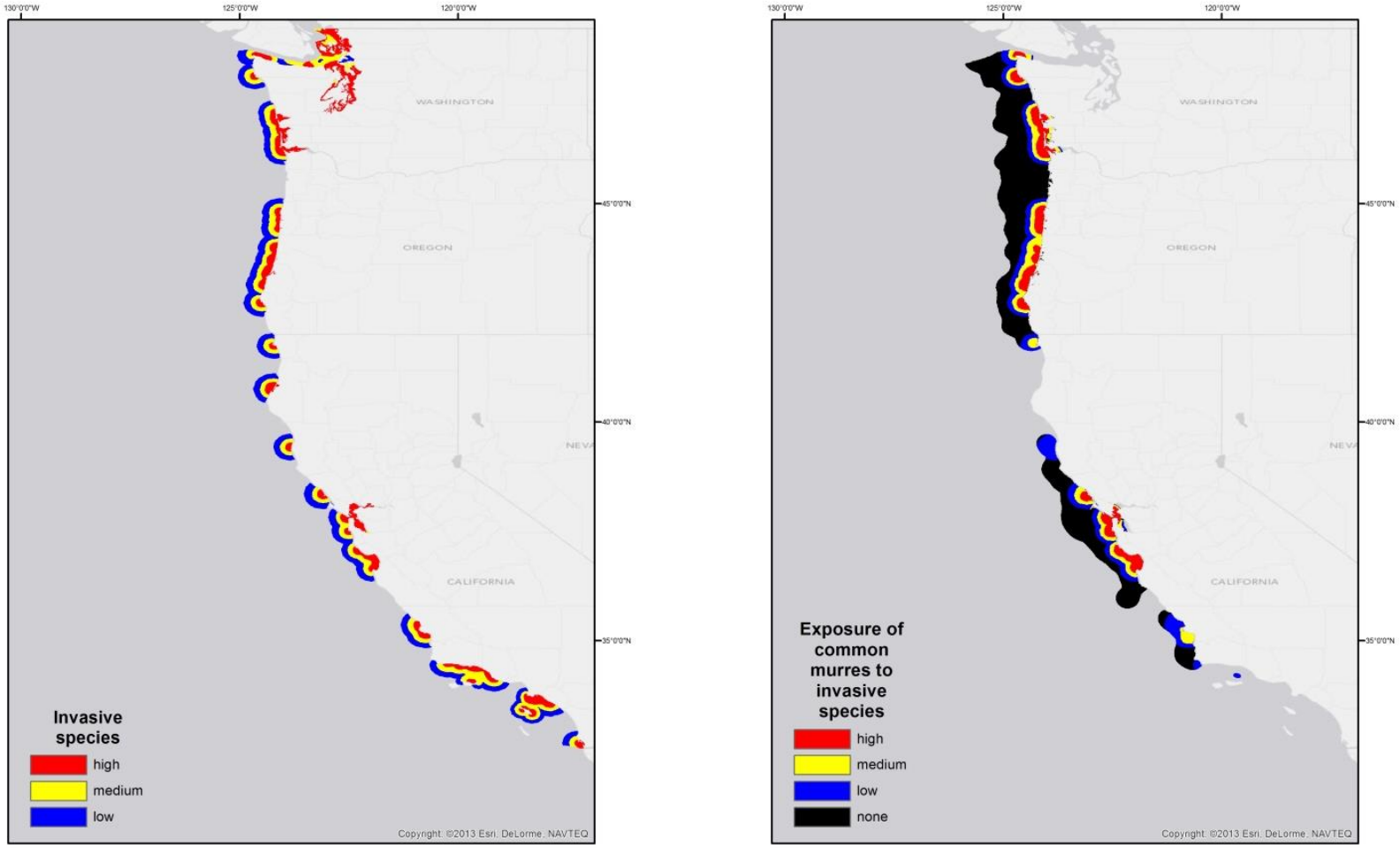
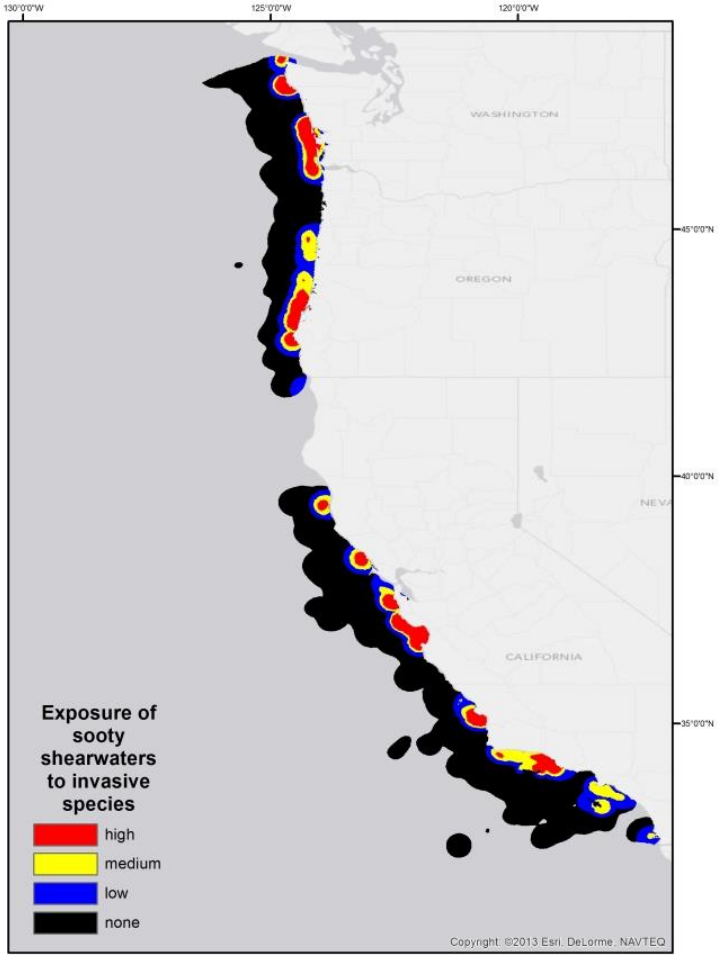


Figure SB.R.22. Exposure to species invasions for common murre, sooty shearwater and rhinoceros auklet.



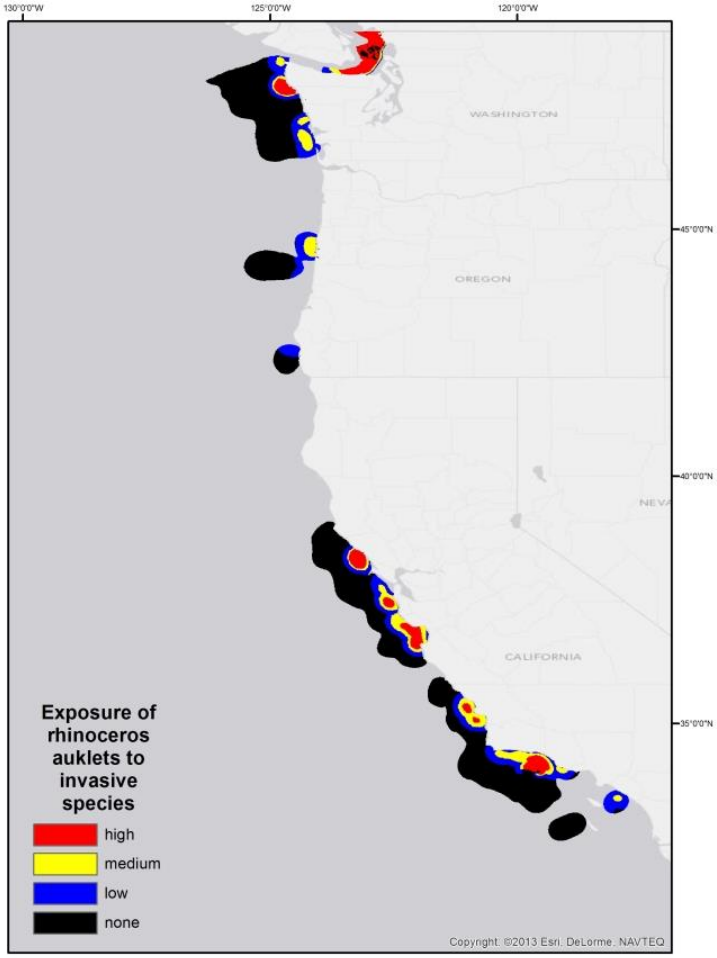


Figure SB.R.22 (continued).

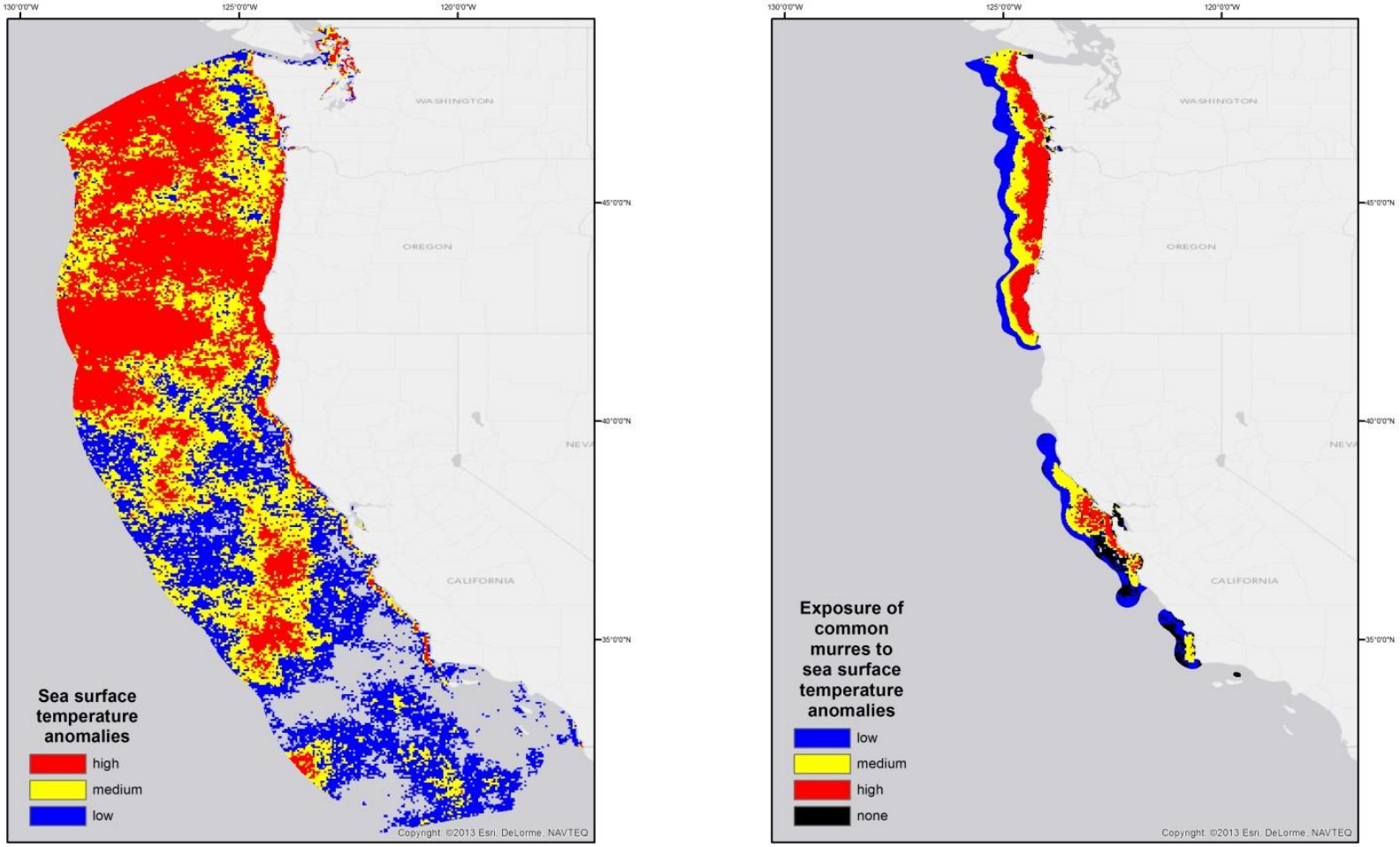
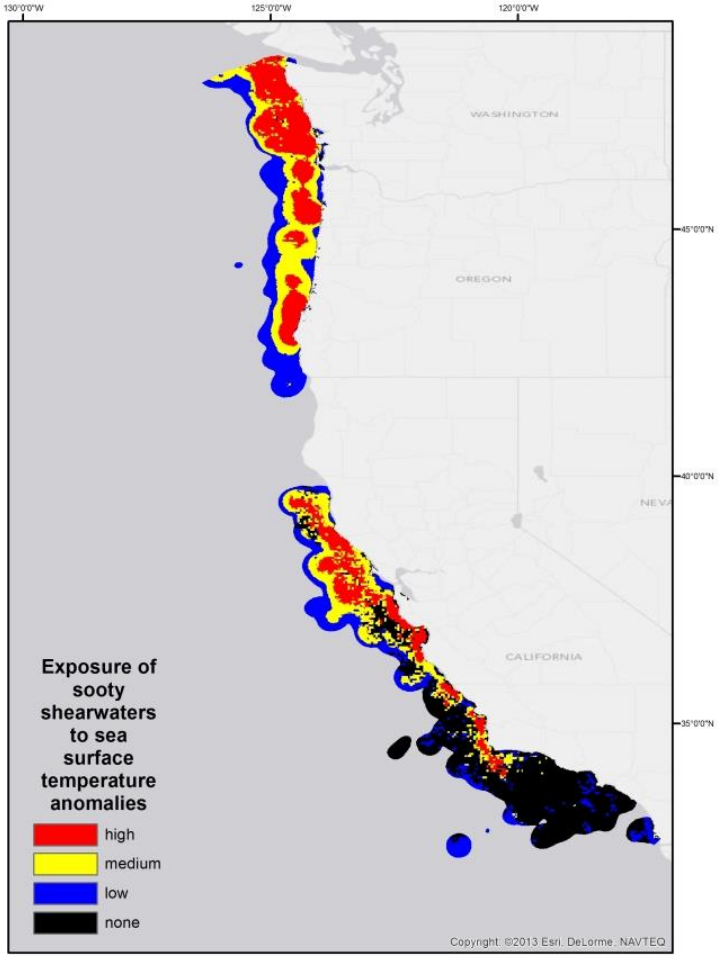


Figure SB.R.23. Exposure to sea surface temperature anomalies for common murre, sooty shearwater and rhinoceros auklet.



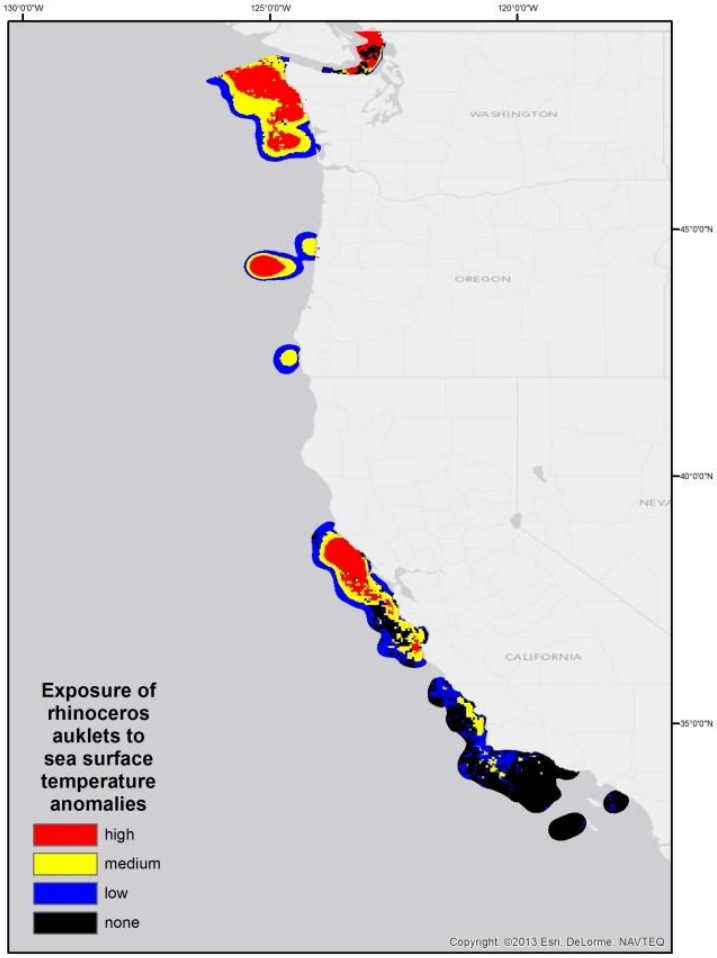


Figure SB.R.23 (continued).

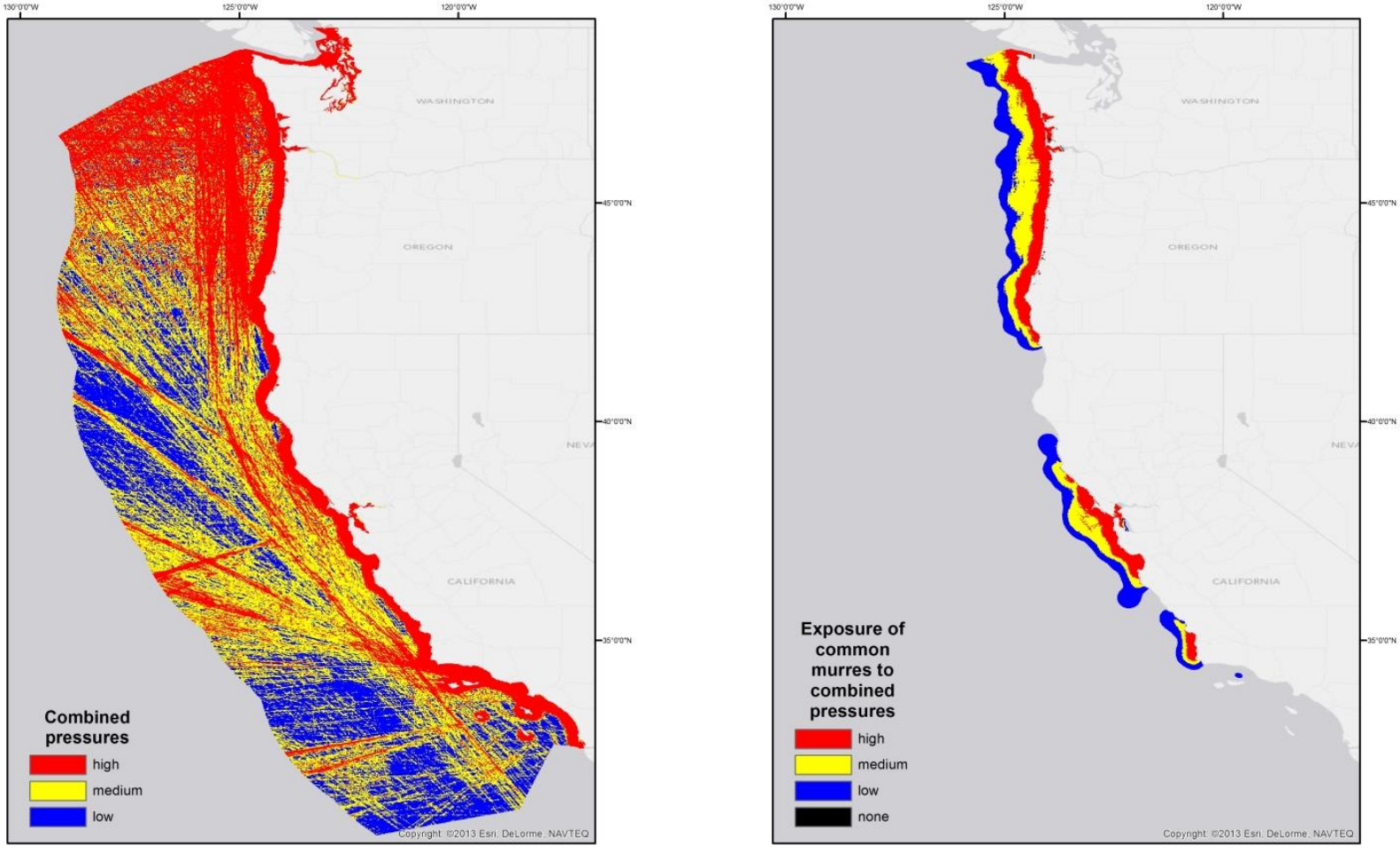
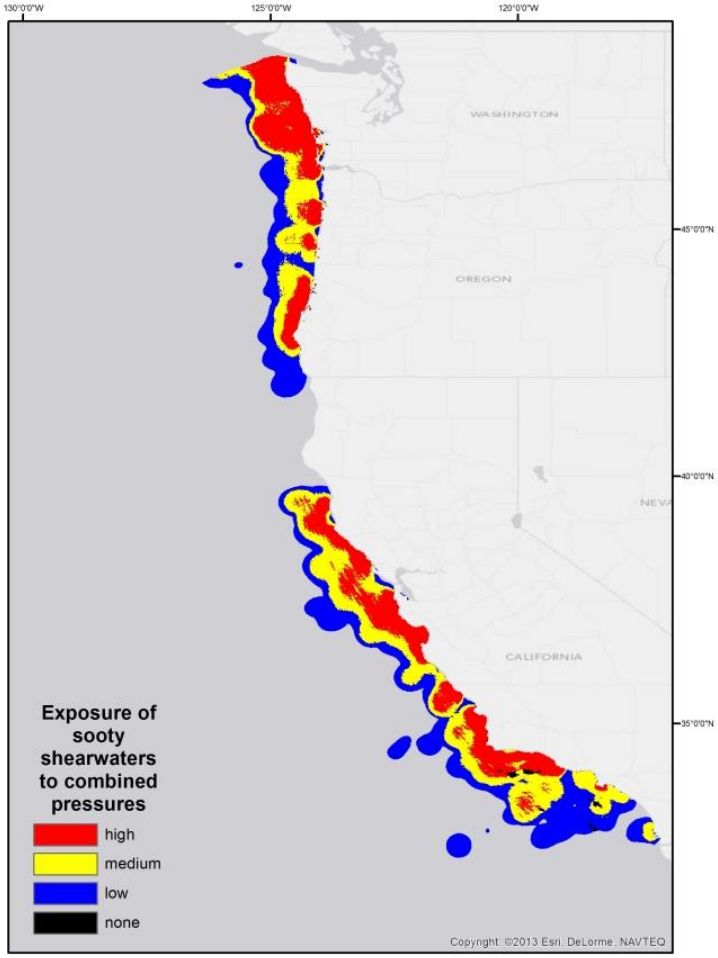


Figure SB.R.24. Exposure to combined pressures for common murre, sooty shearwater and rhinoceros auklet.



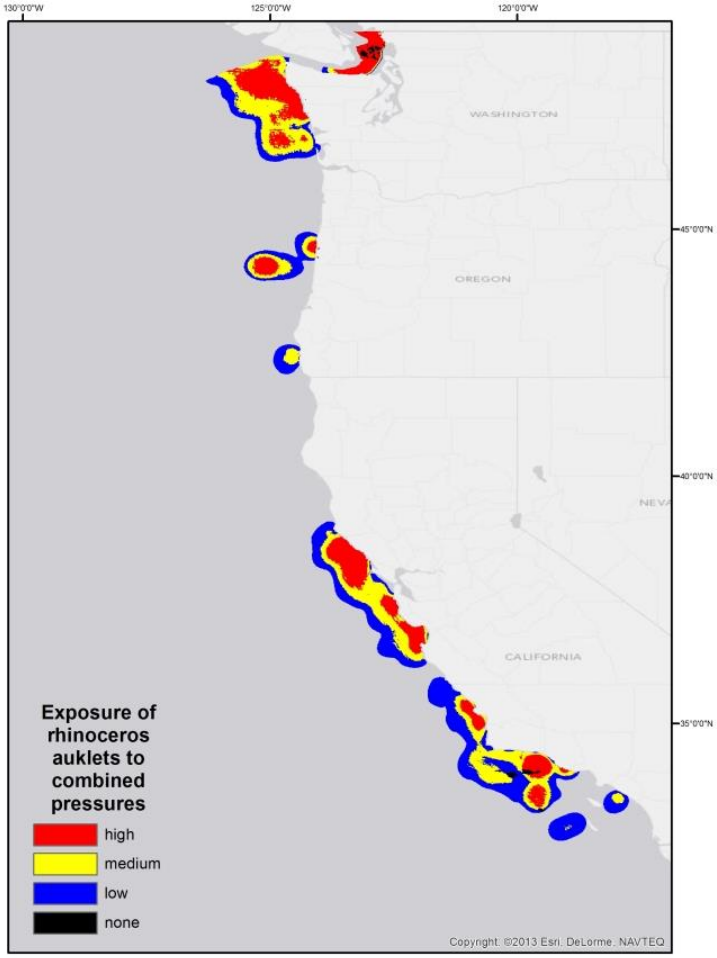


Figure SB.R.24 (continued).

SEABIRDS APPENDIX A

Appendix SB.A.1 Data used for each non-fisheries pressure index.

Pressure	Index metric	Definition and source of data	Time series	Sampling period
Atmospheric deposition	Atmospheric deposition of sulfate	Sulfate was used as a proxy for all atmospheric pollutants (Halpern et a. 2009) measured at sites within CA, OR, and WA; National Atmospheric Deposition Program (http://nadp.sws.uiuc.edu/data/ntndata.aspx)	1985 – 2010	yearly
Coastal engineering	Human population	Population size of West coast states (CA, OR, WA); United States Census 2010 (http://2010.census.gov/2010census/data/apportionment-pop-text.php)	1910 – 2010	decadal
Coastal trash	Beach trash	Counts of trash picked up on California beaches; California Coastal Commission's Public Education Program (www.coastal.ca.gov/publiced/ccd/data.xls)	1989 – 2010	yearly
Direct human impacts	Beach attendance	Total visitor attendance at 48 California state parks identified as "State Beach"; California State Park System Annual Statistical Reports: 2001 -2010 (http://www.parks.ca.gov/?page_id=23308)	2002 – 2010	yearly
Inorganic pollution	Total inorganic pollutants (lbs)	Total pounds of inorganic pollutants disposed of or otherwise released on site to the ground or water for '1988 core chemicals'; Environmental Protection Agency, Toxics Release Inventory (http://www.epa.gov/tri/)	1988 – 2009	yearly
Light pollution	Average visible light	Cloud-free composites of average visible light made using all available archived DMSP-OLS smooth resolution data for each calendar year. Data grid cell size is 1 km^2 at equator; NOAA's National Geophysical Data Center's Version 4 DMSP-OLS Nighttime Lights Time Series Average Lights X Pct (http://www.ngdc.noaa.gov/dmsp/downloadV4composites.html)	1992 – 2009	yearly
Nutrient input	Mean nitrogen	Mean nitrogen (nitrite + nitrate) in surface water samples, all land use types for Pacific coastal basins; USGS National Water Quality Assessment Data Warehouse (http://infotrek.er.usgs.gov/apex/f?p=NAWQA:HOME:5572182579967972)	1992 – 2011	yearly
Ocean acidification	Saturation state acidification	Modeled change in aragonite saturation state from pre-industrial times (1870) to modern times (2000-2009). Data based on projected CO2 levels from the IPCC SRES B2 scenario (Nakicenovic and Swart 2000),	1870; 2000-2009	-
Ocean-based pollution	Tons of cargo	Total tons of cargo moved through ports on the U.S. West Coast using waterway codes for CA, OR and WA; Data from US Army Corps of Engineers Navigation Data Center	1993 – 2009	yearly

Pressure	Index metric	Definition and source of data	Time series	Sampling period
		(http://www.ndc.iwr.usace.army.mil/data/datawcus.htm)		
Offshore oil activities	Offshore oil & gas wells	Data are the number of offshore oil and gas producing wells in state and federal waters; Annual reports - CA Dept of Conservation; Division of oil, gas, and geothermal resources (ftp://ftp.consrv.ca.gov/../pub/oil/annual_reports/)	1981 – 2009	yearly
Organic pollution	Concentrations of pesticides	Data are normalized grand mean concentrations of 13 pesticides and 3 degradates measured in 3,033 water samples from 27 stream-water sites along the West Coast; U.S. Geological Survey Scientific Investigations Report 2010-5139 (http://pubs.usgs.gov/sir/2010/5139/)	1993 – 2008	yearly
Power plants	Thermoelectric power saline water withdrawal	Gallons of saline water withdrawn by electric power plants in coastal states (CA, OR, WA); http://pubs.usgs.gov/circ/2004/circ1268/htdocs/table13.html; http://pubs.usgs.gov/circ/2004/circ1268/htdocs/figure14.html.	1950 – 2000	every 5 years
Sediment runoff decrease	Total reservoir storage area	Total reservoir storage area in CA and Pacific Northwest water resource regions; data from Figure 4 in Graf (1999) based on data from US Army Corps of Engineers from 1996.	1910 – 1993	varies
Sediment runoff increase	Suspended sediment (mg/L)	Suspended sediment levels [mg/L] from Pacific coastal basins, all land use classes; USGS surface water database http://infotrek.er.usgs.gov/apex/f?p=NAWQA:HOME:5572182579967972	1991 – 2010	yearly
Shipping activity	Tons of cargo	Total tons of cargo moved through ports on the U.S. West Coast using waterway codes for CA, OR and WA; Data from US Army Corps of Engineers Navigation Data Center (http://www.ndc.iwr.usace.army.mil/data/datawcus.htm)	1993 – 2009	yearly
Species invasions	Tons of cargo	Total tons of cargo moved through ports on the U.S. West Coast using waterway codes for CA, OR and WA; Data from US Army Corps of Engineers Navigation Data Center (http://www.ndc.iwr.usace.army.mil/data/datawcus.htm)	1993 – 2009	yearly
Sea surface temperature	SST anomalies	The number of times SST was higher in the most recent five years (2000-2005) relative to longer term (1985-2005) standard deviation. Data from NOAA National Oceanographic Data Center and the University of Miami's Rosenstiel School of Marine and Atmospheric Science (http://pathfinder.nodc.noaa.gov).	1985-2005	yearly

REFERENCES CITED

Adams J, MacLeod C, Suryan RM, Hyrenbach DK, Harvey JT (2012) Summer-time use of west coast US National Marine Sanctuaries by migrating sooty shearwaters (Puffinus griseus). Biological Conservation 156: 105-116

BirdLife International (2013) Species factsheet: *Puffinus griseus*. Downloaded from http://www.birdlife.org on 27/09/2013

Burgman MA (2005) Risks and decisions for conservation and environmental management. Cambridge University Press, Cambridge, UK. 314 p

Croxall JP, Butchart SHM, Lascelles B, Stattersfield AJ, Sullivan B, Symes A, Taylor P (2012) Seabird conservation status, threats and priority actions: a global assessment. Bird Conservation International 22: 1-34

Feist BE, Bellman MA, Ford MJ, Sheer MB, Levin PS (2013) Marine mammals risk assessment, In: Levin, P.S., Wells, B.K., and M.B. Sheer, (Eds.), California Current Integrated Ecosystem Assessment: Phase II Report. Available from http://www.noaa.gov/iea/CCIEA-Report/index

Gaston AJ, Dechesne SB (1996) Rhinoceros Auklet (*Cerorhinca monocerata*), The Birds of North America Online (A. Poole, Ed.). Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America Online: http://bna.birds.cornell.edu/bna/species/212

Good TP, Pearson SF, Hodum PJ, Boyd D, Anulacion BF, Ylitalo GM (2014) Persistent organic pollutants in forage fish preyed upon by rhinoceros auklets breeding in Puget Sound and the northern California Current. Marine Pollution Bulletin 86(1–2): 367–378

Guy TJ, Jennings SL, Suryan RM, Melvin EF, Bellman MA, Ballance LT, Blackie BA, Croll DA, Deguchi T, Geernaert TO, Henry RW, Hester M, Hyrenbach KD, Jahncke J, Kappes MA, Ozaki K, Roletto J, Sato F, Sydeman WJ, Zamon JE (2013) Overlap of North Pacific albatrosses with the U.S. west coast groundfish and shrimp fisheries. Fisheries Research 147: 222-234

Halpern BS, Kappel CV, Selkoe KA, Micheli F, Ebert CM, Kontgis C, Crain CM, Martone RG, Shearer C, Teck SJ (2009) Mapping cumulative human impacts to California Current marine ecosystems. Conservation Letters 2: 138-148

Halpern BS, Walbridge S, Selkoe KA, Kappel CV, Micheli F, D'Agrosa C, Bruno J, Casey KS, Ebert C, Fox HE, Fujita R, Heinemann D, Lenihan HS, Madin EMP, Myers R, Perry M, Selig E, Spalding M, Steneck R, Watson R (2008) A global map of human impact on marine ecosystems. Science 319: 948-952

Hamel NJ, Burger AE, Charleton K, Davidson P, Lee S, Bertram DF, Parrish JK (2009) Bycatch and beached birds: assessing mortality impacts in coastal net fisheries using marine bird strandings. Marine Ornithology 37: 41–60

Hamel OS, Fikse D, Andrews KS, Williams GD, Samhouri JF (2013) Groundfish risk assessment, In: Levin, P.S., Wells, B.K., and M.B. Sheer, (Eds.), California Current Integrated Ecosystem Assessment: Phase II Report. Available from http://www.noaa.gov/iea/CCIEA-Report/index

Hobday AJ, Smith ADM, Stobutzki IC, Bulman C, Daley R, Dambacher JM, Deng RA, Dowdney J, Fuller M, Furlani D, Griffiths SP, Johnson D, Kenyon R, Knuckey IA, Ling SD, Pitcher R, Sainsbury KJ, Sporcic M,

Smith T, Turnbull C, Walker TI, Wayte SE, Webb H, Williams A, Wise BS, Zhou S (2011) Ecological risk assessment for the effects of fishing. Fisheries Research 108(2–3): 372-384

Keating KA, Cherry S (2009) Modeling utilization distributions in space and time. Ecology 90: 1971-1980

Laist DW (1997) Impacts of marine debris: entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records. In: Coe JM, Rogers DB (eds) Marine debris: Sources, impacts, and solution. Springer, New York, pp. 99-139

Manuwal DA, Carter HR, Zimmerman TS, Orthmeyer DL, Eds (2001) Biology and conservation of the common murre in California, Oregon, Washington, and British Columbia. Volume 1: Natural history and population trends. U.S. Geological Survey, Biological Resources Division, Information and Technology Report USGS/BRD/ITR–2000-0012, Washington, D.C. 132 pp

Maxwell SM, Hazen EL, Bograd SJ, Halpern BS, Breed GA, Nickel B, Teutschel NM, Crowder LB, Benson S, Dutton PH, Bailey H, Kappes MA, Kuhn CE, Weise MJ, Mate B, Shaffer SA, Hassrick JL, Henry RW, Irvine L, McDonald BI, Robinson PW, Block BA, Costa DP (2013) Cumulative human impacts on marine predators. Nature Communications 4: 2688 [doi: 10.1038/ncomms3688]

Mills, KL, Sydeman, WJ, Hodum PJ, Eds. (2005) The California Current Marine Bird Conservation Plan, v. 1 (Ch. 6) - Predators, competitors, disease, and human interactions: "topdown" control of seabird population parameters and population dynamics. PRBO Conservation Science, Stinson Beach, CA. pp 144–159

Nur N, Jahncke J, Herzog MP, Howar J, Hyrenbach KD, Zamon JE, Ainley DG, Wiens JA, Morgan K, Balance LT, Stralberg D (2011) Where the wild things are: predicting hotspots of seabird aggregations in the California Current System. Ecological Applications 21: 2241–2257

Rowe WD (1977) An Anatomy of Risk. John Wiley & Sons, New York, NY • London, UK

Samhouri JF, Andrews KS, DeBeukelaer S, Feist BE, Sheer MB, Dunsmore R, DeVogelaere A, Levin PS (2013) Ecological integrity risk assessment, In: Levin, P.S., Wells, B.K., and M.B. Sheer, (Eds.), California Current Integrated Ecosystem Assessment: Phase II Report. Available from http://www.noaa.gov/iea/CCIEA-Report/index

Samhouri JS, Levin PS (2012) Linking land- and sea-based activities to risk in coastal ecosystems. Biological Conservation 145: 118-129

Silverman BW (1986) Density Estimation for Statistics and Data Analysis. Chapman and Hall. 175 p

Turner BL II, Kasperson RE, Matson PA, McCarthy JJ, Corell RW, Christensen L, Eckley N, Kasperson JX, Luers A, Martello ML, Polsky C, Pulsipher A, Schiller A (2003) A framework for vulnerability analysis in sustainability science. Proceedings of the National Academy of Sciences 100 (14): 8074-8079

Wilcox C, Hardesty BD, Sharples R, Griffin DA, Lawson TJ, Gunn R (2013) Ghostnet impacts on globally threatened turtles, a spatial risk analysis for northern Australia. Conservation Letters 6: 247–254

Zacharias MA, Gregr EJ (2005) Sensitivity and Vulnerability in Marine Environments: an Approach to Identifying Vulnerable Marine Areas. Conservation Biology 19: 86-97

Zydelis R, Small C, French G (2013) The incidental catch of seabirds in gillnet fisheries: A global review. Biological Conservation 162: 76–88