A15/ER/ALL/21

NOAA-TM-NMFS-SWR-044: Understanding the co-occurrence of large whales and commercial fixed gear fisheries off the west coast of the United States.

Lauren Saez, Dan Lawson, Monica DeAngelis,
Elizabeth Petras, Sarah Wilkin, Christina Fahy

INTERNATIONAL
WHALING COMMISSION

NOAA Technical Memorandum NMFS

This TM series is used for documentation and timely communication of preliminary results, interim reports, or special purpose information. The TMs have not received complete formal review, editorial control, or detailed editing.

September 2013

Understanding the co-occurrence of large whales and commercial fixed gear fisheries off the west coast of the United States

Lauren Saez
Dan Lawson
Monica DeAngelis
Elizabeth Petras
Sarah Wilkin
Christina Fahy

NOAA National Marine Fisheries Service
Southwest Regional Office
Protected Resources Division
501 West Ocean Boulevard
Long Beach, California, USA 90802-4213

NOAA-TM-NMFS-SWR-044

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Regional Office

Table of Contents

Acronyms and Abbreviations

ALWTRT	Atlantic Large Whale Take Reduction Team
CA	California
CDCTF	California Dungeness Crab Task Force
CDFW	California Department of Fish and Wildlife
DEM	Digital Elevation Model
ESA	Endangered Species Act
FMP	Fishery Management Plan
GIS	Geographic Information System
IPHC	International Pacific Halibut Commission
MMPA	Marine Mammal Protection Act
MSA	Magnuson-Stevens Fishery Conservation and Management Act
NCCOS	National Center for Coastal Ocean Sciences
NGDC	National Geophysical Data Center
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NWFSC	Northwest Fisheries Science Center
ODFW	Oregon Department of Fish and Wildlife
OR	Oregon
PacFIN	Pacific Fisheries Information Network
PSMFC	Pacific States Marine Fisheries Commission
SWFSC	Southwest Fisheries Science Center
SWR	Southwest Regional Office
U.S.	United States
WA	Washington
WDFW	Washington Department of Fish and Wildlife

Acknowledgements

Thank you to the Marine Mammal/Sea Turtle team at the NMFS Southwest Regional Office and the Southwest Fisheries Science Center for their support and edits. We thank Brent Norberg, Kristen Wilkinson, and the Northwest Regional Office for their collaboration and review of the draft final report. Special thanks to Karin Forney, Elizabeth Becker, and Jessica Redfern for their assistance with the co-occurrence model. We would also like to thank Bruce Mate, Dave Weller, Wayne Perryman, John Calambokidis, and John Durban, for their assistance with the gray whale model, Craig D'Angelo and Adam Obaza for help with fishery data, and Mathew Dorsey, Jeanne MacNeil, and Richard Morse with GIS assistance. Thanks to Sheila Garber of Englund Marine & Industrial Supply, Marlene Bellman of the West Coast Groundfish Observer Program, Charles Villafana of the NMFS Southwest Observer Program, John Kenney of the NMFS Northeast Regional Office, Pieter Folkens of the Alaska Whale Foundation, and the many California, Oregon, and Washington state fishery managers and representatives for their feedback on commercial fishery information and gear configuration. Thank you to Ocean Associates, Inc. for providing contracting services. We are thankful for the knowledge shared by those involved in large whale entanglements on the United States east coast including: Jamison Smith, David Morin, and Amanda Johnson. We are very thankful to Ed Lyman and the large whale disentanglement networks in California, Oregon, and Washington for their continued dedication to the rescue of entangled whales and marine mammals. Thank you to the reviewers of the draft final report.

Understanding the co-occurrence of large whales and commercial fixed gear fisheries off the west coast of the United States

Lauren Saez[1], Dan Lawson[2], Monica DeAngelis[2], Elizabeth Petras[2], Sarah Wilkin[2], and Christina Fahy[2]

[1] Contractor for Ocean Associates, Inc. at the Southwest Regional Office, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 501 West Ocean Boulevard, Long Beach, California, 90802 USA
[2] Protected Resources Division, Southwest Regional Office, National Marine Fisheries Service, National Oceanic & Atmospheric Administration, 501 West Ocean Boulevard, Long Beach, California, 90802 USA

Abstract

Large whale entanglement in commercial fishing gear off the U.S. west coast has been identified as an issue of concern by NOAA's National Marine Fisheries Service (NMFS) because of the potential impacts to both large whales (individually and at a stock/population level) and the commercial fishing industry. Large whales entangled in gear may be injured and/or impared which could affect the ability of individuals to survive and a population's ability to recover. Blue whales (*Balaenoptera musculus*), fin whales (*Balaenoptera physalus),* gray whales (*Eschrichtius robustus),* humpback whales (*Megaptera novaeangliae)* and sperm whales (*Physeter macrocephalus)* were included in this study based on their distribution and density associated with habitat, as modeled through multi-year ship-based surveys or migration studies and/or historic entanglement records. Along the U.S. west coast, an average of 10 large whales have been reported entangled between 2000 and 2012. Little information has been confirmed from entanglement reports about the origin of the entangling fishing gear; therefore NMFS has developed analytical tools to assess the potential entanglement risk associated with various fixed gear fisheries relative to their co-occurrence with large whale species. A primary tool includes the development of a model to represent the spatial and temporal distributions of commercial fishing effort, focusing on fixed gear fisheries with gear that has been confirmed as entangling whales through sightings and strandings of entangled animals and or has the potential for causing entanglement based on similarities in the general configuration of gear across the fisheries. Fishing effort represented in this study, both state and federally managed, was derived from landings data obtained through the Pacific Fisheries Information Network (PacFIN). The relative density of fishing effort throughout the calendar year was overlaid with species-specific whale distribution patterns, modeled from systematically-collected marine mammal survey data, to help identify spatial and temporal overlap between whales and fisheries. The other tool developed, a co-occurrence model, identified potential species-specific elevated risk areas where and when large whales are more likely to encounter fishing gear, which is the first step in assessment of whale entanglement risk associated with fixed-gear fisheries on the U.S. west coast. Co-occurrence "scores" were calculated based on correlated area, time, and density of overlap between fixed gear fisheries and whale distribution. Overall, the Dungeness crab trap fishery had the highest co-occurrence scores, and associated entanglement risk, with all whale species included in the model. Confirmed entanglement reports were compared with model results. Alignment of known entanglement locations with areas of higher co-occurrence scores

supported the use of the co-occurrence model for assessment of whale entanglement risk off the U.S. west coast. Research on the identified elevated risk areas, combined with the ability to trace gear continued gear research, and strengthened outreach to improve reporting, should improve the ability to minimize or mitigate the risk of large whale entanglements.

Executive Summary

Large whale interactions with commercial fishing gear are an issue of global concern primarily because such entanglements can lead to injury and mortality of whales, and most whale populations are protected due to relatively low population levels and the general threats associated with long-lived species. Entanglement of large whales in commercial fishing gear also affect the fishing industry in terms of lost gear and potential increase in regulations to reduce entanglements. Off the coast of California, Oregon, and Washington, there have been 308 large whales documented as entangled between January 1, 1982 and December 31, 2012 (Saez *et al.*, in prep). Gray whales (*Eschrichtius robustus*) and humpback whales (*Megaptera novaeangliaes*) were the most frequently reported species, with 185 and 66 entangled whales, respectively, between 1982 and 2012. Both of these species are seasonally abundant and generally found nearshore off the U.S. west coast. Fin whales (*Balaenoptera physalus*), minke whales *(Balaenoptera acutorostrata),* and sperm whales (*Physeter macrocephalus)* have also been reported entangled in fishing gear.

Entanglement reports originate from a variety of sources and most are based on opportunistic sightings of entangled whales. The 10 reports averaged per year (1982-2012) are likely a large underrepresentation of total entanglements off the U.S. west coast (Saez *et al.*, in prep). In another report, the entanglement rate for humpback whales off California, Oregon, and Washington is estimated as at least 50% of the population, based on scarification analyses of photographs, from 2004 to 2006, where at least half of the whales off the U.S. west coast photographed exhibited scarring indicative of prior entanglements (Robbins *et al.*, 2007). These findings indicate that many whales are being affected by entanglements.

Based upon the entanglement reports, it is often not possible to identify the source of the gear or fishery involved. The majority of entanglements reported between 2000 and 2012 involved trap/pot gear (45%). There are also many cases, 34% between 2000 and 2012, where gear is unidentifiable to a source or specific fishery, although fixed commercial fishing gear is suspected to be involved in many of those cases, not only because of the large number of individual pots and traps set in the water, for example, but also because of the longer soak time and lack of real-time monitoring of this type of gear. In order to provide means for protection of large whales, there is a need to identify: 1) the origin of gear reported on entangled whales; and 2) potential spatial and temporal areas where large whales are most likely to encounter gear. The identification of these two aspects will be important to develop a better understanding of entanglements and provide a foundation for the potential development of effective strategies to minimize the number of entanglements. In response to the uncertainty surrounding the identification of fisheries that may be responsible for these entanglements, NMFS developed two models - a fishery effort model and a co-occurrence model - to assess the potential entanglement risk associated with various fixed gear fisheries relative to their co-occurrence with specific large whale species.

Fishery Model

The fishery model quantifies relative commercial fishing effort, focusing on fisheries using gear that has been confirmed or is suspected of being capable of entangling whales. The fishery model includes 11 fixed gear commercial fisheries: 8 trap/pot fisheries, 2 set longline fisheries, and 1 set gillnet fishery off of California, Oregon, and Washington. Fishing effort represented in the fishery model, for both state and federally managed fisheries, was derived from landings data obtained through the Pacific Fisheries Information Network, known as PacFIN. Potential fishing areas were mapped for the entire U.S west coast using the common operational fishing depths as boundaries for each fishery. The model then combined the port-based commercial landings, in pounds, with the potential fishing areas to illustrate regional patterns of relative fishing effort along the U.S. west coast from California to Washington. In this model, we used landings as a proxy for effort (i.e. higher landings equal high level of effort). When possible, fishery model results were validated by comparing to alternative sources of fishery data from states and NMFS. Relative effort in the fisheries was scored on a scale of 1 to 7.

Co-occurrence Model

The co-occurrence model was designed to assess entanglement risk by overlaying the fishery model with species-specific whale distribution patterns to produce relative co-occurrence scores. The large whale species included in the co-occurrence model were: blue, fin, gray, humpback, and sperm whales. Minke whale density was not available, therefore they were not included. The whale data was obtained from two sources. Density maps (number of whales per 625 m^2) for blue, fin, humpback, and sperm whales created by Becker *et al.* (2012). These density maps were modeled for the California Current Ecosystem based on systematically collected data from 16 ship-based surveys which were conducted, and therefore modeled, for July to November. For gray whales, the DeAngelis *et al.* (in prep, data available online at cetmap.noaa.gov) gray whale migration model was used to create relative monthly densities of gray whales (number of whales per 1 m^2) based on data from telemetry and shore-based surveys from December through June, representing the time frame that migrating gray whales are present in California, Oregon, and Washington. As with the fishery model, the relative density of whales, per species, was scored from 1 to 7.

The co-occurrence model identified species-specific spatial and temporal areas of low and elevated entanglement risk for individual fisheries as well as all of those fisheries combined. The underlying assumption of this co-occurrence model is that entanglement risk is linearly related to the level of overlap reflected by the magnitude of these co-occurrence scores. The Dungeness crab trap fishery had the highest co-occurrence scores of any of the fisheries modeled. The model identified the Dungeness crab trap fishery as an elevated risk fishery for every whale species included in the co-occurrence model, with elevated risk areas ranging from San Francisco through coastal Washington. This is likely due to the high level of effort in areas of relatively high whale abundance.

The co-occurrence model results were compared with entanglement reports where the fishery and general gear set location was known to check for consistency and validation of modeling methodology. Entanglement reports with confirmed gear/fisheries were associated with co-occurrence model medium to high scores, and were also associated with areas of higher co-occurrence scores relative to surrounding areas during the same quarter/month of the year. This supports the use of the co-occurrence model for assessment of whale entanglement risk off the U.S. west coast and led to the classification of co-occurrence scores medium or higher to be considered elevated entanglement risk for this analysis, shown as yellow to red on co-occurrence model maps in Section 3.0.

The outcomes of this report may be used as a guide to improve our understanding of the potential for interactions between commercial fisheries and large whales along California, Oregon, and Washington. The threat of entanglement, combined with other anthropogenic pressures such as ship-strikes, increasing noise in the ocean, coastal development, and alternative energy production, should be given consideration early in the decision making process of future management to address large whale conservation, recognizing that there are still many challenges in understanding the risk of whale entanglements and identifying gear.

Six priorities for future contributions to this initiative:

1. Further investigate elevated risk areas and associated time periods identified by the co-occurrence model focused to understand and possibly mitigate large whale entanglements in the future.
2. Filling in data gaps for future co-occurrence modeling: include to the extent possible year-round density data for all species and available information on the Western Pacific gray whales and the Pacific Feeding Group of gray whales.
3. Continue gear research to understand mechanisms of large whale entanglements, and investigate the creation of a gear density-based fishery model.
4. Consider the feasibility of new/improved gear marking to assist in the identification and traceability of entangling gear.
5. Support future co-occurrence modeling efforts, especially with inclusion of research addressing the limitations of the co-occurrence model in this paper.
6. Improve reporting through increased public awareness and outreach; expand geographic coverage; and improved documentation and information collected from each entanglement report.

1.0 Introduction

The National Oceanic and Atmospheric Administration's (NOAA) mission of Science, Service and Stewardship includes the conservation and management of coastal and marine ecosystems and resources. These resources include large whales protected under the Marine Mammal Protection Act (MMPA), the Endangered Species Act (ESA). Interactions of large whales in fishing gear and vessels may injure and kill these protected animals and collisions may also result in damage to the vessel or gear. These injuries or deaths of whales are a concern for NOAA's National Marine Fisheries Service, the agency responsible for protecting species under the aforementioned statutes. NMFS also manages federal fisheries under the Magnuson-Stevens Fishery Conservation and Management Act (MSA). Among the requirements of the MSA is that fishing activities reduce or minimize the capture and subsequent discard of non-target species, including marine mammals. NMFS also works with individual states along the U.S. west coast to promulgate fishing regulations to minimize the impact of state fisheries on non-target species such as marine mammals.

There are nine species of large whales found along the U.S. west coast. They include seven mysticetes: blue whale (*Balaenoptera musculus),* fin whale (*Balaenoptera physalus*), gray whale (*Eschrichtius robustus*), humpback whale (*Megaptera novaeangliae),* minke whale *(Balaenoptera acutorostrata),* North Pacific right whale (*Eubalaena japonica*), sei whale (*Balaenoptera borealis*). They also include one odontocete: sperm whale (*Physeter macrocephalus).* All of these species are protected under the MMPA. The following are also listed under the ESA: blue, fin, humpback, North Pacific right, sei, and sperm whales.

For over 30 years, NMFS has been receiving reports of entangled large whales typically with limited ability to identify the origin of the entangling gear. These reports come from other government agencies, NOAA commercial fishery observers, researchers, volunteers working for stranding networks, fishermen, and the general public. Observations from California to Washington of entangled or stranded whales indicate that the animals may encounter gear from a number of distant areas, including Mexico, Alaska (e.g., gray whale observed off California coast entangled in Alaskan crab pot gear) and Asia (e.g., dead sperm whale stranded in 2008 with stomach full of nets including nets from Asia). As a result, familiarity with local gear may not be sufficient to identify all gear types that may potentially be involved in a large whale entanglement observed on the U.S. west coast.

From 2000 to 2012, an average of 10 entanglements were observed and reported per year with gray and humpback whales the most commonly entangled cetacean species in California, Oregon, and Washington, with 56 and 55 individuals total, respectively (NMFS stranding databases; Saez *et al.,* in prep). NMFS also receives many reports where the species of the entangled large whale is unknown; 25 individuals from 2000 to 2012 (Saez *et al.*, in prep). Confirmed reports of entangled animals likely represent only a small fraction of the total number of entanglements that are actually occurring. The majority (45%) of entanglements reported between 2000 and 2012 involved trap/pot gear (Saez *et al.,* in prep).

Researchers have developed a variety of methods to help quantify whale entanglement rates beyond opportunistic sightings. For example, Robbins and Mattila (2004) examined photographs and used scar-based analysis to determine that an average of 12% of the U.S. east coast humpback whale population becomes entangled annually. The number of reported entangled whales was estimated to be only 10% of the actual number of whales entangled (Robbins and Mattila, 2004). The reporting rate is dependent on many factors such as total number and rate of entangling events, likelihood of detection based on location (e.g., remote areas vs. congested areas), and awareness and/or willingness of the person or people to report an entanglement. Assuming a similar 10% reporting rate for the all whale species on the U.S. west coast that have been recorded in the database (n=308 from 1982-2012), an average of 103 whale entanglements per year may be occurring, with 93 unobserved and undocumented with their ultimate fates unknown.

In addition to scar-based analyses, initiatives have been designed to quantify whale entanglement risk using Geographic Information System (GIS) based tools to assess the overlap of fishing gear and whale densities. These initiatives include the Atlantic Large Whale Take Reduction Team's co-occurrence model (nero.noaa.gov), the Sandilands *et. al*. (2009) study overlaying effort corrected humpback and gray whale sightings data with commercial fishery landing data in British Columbia, and the Walk *et. al.* (2009) study overlapping concurrent whale watching sightings of baleen whales with lobster end-line gear positions in the Gulf of Maine.

Building from the foundation of the whale entanglement initiatives listed above, NMFS SWR created two models, a GIS-based fishery model and co-occurrence model, unique to the data available for California, Oregon, and Washington. The tools were designed with three goals: 1) identify areas and times of the year with the highest potential for large whales to encounter and, because of their presence and fishing effort, have the potential to become entangled in active fishing gear; 2) identify which fisheries most commonly co-occur with predicted distributions and densities of large whales; and 3) improve future management efforts to mitigate and minimize entanglement by allowing for focused and targeted actions that could be effectively directed towards times/areas/fisheries most likely to interact with large whales. Blue, fin, gray, humpback, and sperm whales were included in the study based on comprehensive information available on their density and distribution and/or historic entanglement records with fixed gear fisheries.

NMFS SWR staff worked closely with other NMFS Regions and Science Centers, the three U.S. west coast states, and individual fishermen and associations to gather the information described and analyzed in this report. The co-occurrence model focused primarily on fixed gear commercial fisheries including trap/pot, bottom set longline, and set gillnet because these gear types had been identified as or potentially suspected of causing the majority of U.S. west coast entanglements between 2000 and 2010 (Saez *et al.,* in prep). Fixed gear fisheries operate by soaking gear in the water, unattended, for periods of time ranging from a few hours to several days. These gear types are used throughout the U.S. west coast and have varying spatial and temporal patterns of effort. Fishing effort represented in the co-occurrence model included both state and federally managed fisheries, and was derived from landings data obtained through the Pacific Fisheries Information Network (PacFIN).

As of 2012, there are fifty-two commercial fisheries recognized by the MMPA's List of fisheries that operate off the coast of California, Oregon, and Washington (76 Federal Register 73912, November 19, 2011). This document characterized and considered eleven of the fifty-two commercial fisheries in this entanglement risk assessment, including: California halibut/white seabass and other species set gillnet (>3.5 in mesh), California nearshore finfish live trap/hook-and-line; California coonstripe shrimp, Washington/Oregon/California Dungeness crab pot, Oregon/California hagfish pot, Washington/Oregon north Pacific halibut longline/setline, California rock crab trap, Washington/Oregon/California groundfish, bottomfish longline/setline, Washington/Oregon/California sablefish pot, California spiny lobster trap, and Washington/Oregon/California spot prawn pot.

The following sections are intended to provide a baseline of knowledge surrounding the presence of large whales, commercial fisheries, and potential for entanglement risk of large whales in commercial fishing gear in the waters off the coasts of California, Oregon, and Washington. Section 2.0 describes the fishery model and characterizes eleven fixed gear fisheries. Descriptions of fishing effort were available for some fisheries in California prior to this analysis, but this section is the first known publication that includes all of these fixed gear fisheries along the entire coast. This section also served as the basis of a Fixed Gear Guide, designed to be a reference that can be used in the field to help the reporting party identify whale species and gear type/specific fisheries that may be involved in the large whale entanglement they are observing (Appendix A). Section 3.0 describes the integration of large whale density maps with the fishery model outcomes into a co-occurrence model. The co-occurrence model is designed to quantify the relative entanglement risk of blue, fin, gray, humpback, and sperm whales in different fixed gear fisheries in different areas and at different times of year. While the co-occurrence model was used to evaluate entanglement risk for large whales, the analytical tool could be used with a variety of species, including other marine mammals (i.e., other large whale species, dolphins, seals, sea lions, and otters) and sea turtles if similar population density or distribution maps are available for those species.

2.0 Fixed Gear Commercial Fishery Characterization: California, Oregon, and Washington

2.1 Data and Methods

Fishery characterization

A number of methods were used to characterize the fisheries. These include research on harvest methods, gear configuration, gear marking, and operational fishing depths conducted through port visits, published literature, and interviews with fishery experts and managers. Port visits to the major ports along the U.S. west coast were conducted between 2009 and 2010. Interviews with fishermen were conducted opportunistically during port visits.

Fishery model

The fishery effort model was developed to quantify the distribution and seasonality of fixed gear commercial fisheries along the U.S. west coast. The model was created through a series of steps outlined below.

1. <u>Data source</u>

Traditional methods of documenting the location and intensity of commercial fishing effort include logbook self–reporting, observer records, or on-board vessel monitoring systems. These methods are not required or available for many of the fixed-gear fisheries occurring off the U.S. west coast covered in this document. When available, these sources do not always provide specific information on the location of fishing effort or amount of gear that is used, but were compared with the results of the fishery model created in this analysis, when applicable. One source of data that is consistent across all fisheries is landing data, as reported by the fishing industry to the state fishery agencies of California, Oregon, and Washington.

California, Oregon, and Washington state fishery agencies provide landing data, in the form of fish-ticket and vessel registration data, to the Pacific Fisheries Information Network (PacFIN) (PSMFC, 2010). Data used in the characterization and the fishery model were queried from PacFIN. Appendix C defines of the fishery, target species, and gear type for each of the 11 fisheries included in this document. Fish dealers or processors submit fish-ticket records to the state. Data reported on fish-tickets include date of transaction, retained species, landed weight per species (pounds), fisherman's name and vessel registration number, gear used, and port of landing. Since catch data are recorded to the port of landing, this can be used to approximate geographic location and quantity of fish/invertebrates associated with effort. Although landings are not a direct measure of effort (i.e. number of traps, number of hooks fished, or amount of gillnet used) they provide insight into relative effort on a broad scale when comparing a particular fishery or aggregations of fisheries across regions. Landing data will be used to represent relative commercial fishing effort throughout this report.

2. <u>Landing data processing</u>

PacFIN landing data, in pounds, were summarized by gear, target species, port complex, and quarter of the year. The quarters of the year are defined as follows: Quarter 1 is January to March; Quarter 2 is April to June; Quarter 3 July to September; and Quarter 4 is October to December. The data were temporally grouped by annual quarter and then averaged over three five-year time frames to capture the range of landings for each fishery and region over a specific period of time and geographic scale. For example, all of the landings data from the first quarter for a five-year time period were grouped to calculate an annual average landing value, in pounds, for that quarter. The time frames analyzed are 1994 to 1998, 1999 to 2003, and 2004 to 2008. The most recent time frame, 2004 to 2008, was used in the fishery model to describe the distribution of fishing effort presented in this analysis; however future analysis could include the older time frames to assess how relative risk may have changed. Appendix D provides the PacFIN data request and an overview of the processing.

The number of fish tickets associated with each landing value in the fishery model was also queried to ensure preservation of fishermen confidentiality, as required by the Magnuson-Stevens Fishery Conservation and Management Act. Each landing value is unique to a fishery, port complex, and quarter of the year and is representative of 3 or more fishermen during the five-year time period. In the few cases where the “rule of 3” was not met; the landings from the port complex with 3 or less fishermen was grouped with the nearest port complex to ensure the summed landings were reflective of at least 3 fishermen.

3. Port complex

A port complex represents a grouping of ports from which vessels fish in a common area. Although landing data were originally recorded to a single port, landings were aggregated in port groupings to form larger port complexes to present a more general regional representation of fishing effort and also allows for preservation of anonymity. The port groupings, based on the PacFIN database, are defined in Table 1 below. For example, LLA represents vessels that fish in the coastal waters off Los Angeles and Orange Counties and land in the ports of Los Angeles, Long Beach, and Dana Point.

In general, the port complexes are defined by the U.S. west coast coastline to the east, and extend westward to the Exclusive Economic Zone, 200 nautical miles offshore. The northern and southern boundaries for each port complex are east/west lines (90 degrees perpendicular) drawn from the coastline. They incorporate the ports associated with a port complex code in the PacFIN database and often coincide with county boundaries. Special modifications, away from the 90 degree line, were made to the southern boundaries of Santa Barbara and Los Angeles port complexes to account for the offshore islands fished by the fishermen within the port complex (Figure 1). The southern boundary of the Santa Barbara complex was modified to include the northern Channel Islands: San Miguel, Santa Rosa, Santa Cruz, and Anacapa. The southern boundary of the Los Angeles port complex was extended south to the northern end of San Clemente Island to include the islands of Santa Barbara, San Nicolas and Santa Catalina.

PacFIN has a north and south port complex for Puget Sound, Washington, but those landings were not considered in this analysis. We assumed that landings in the Puget Sound accounted for fishing within Puget Sound and not in the coastal wasters offshore of Washington, and we would not expect interactions of fishing gear from Puget Sound with coastal populations of the marine mammals. However, it should be noted there are occasions where coastal catch is landed into a Puget Sound port (personal communication with Heather Reed, Coastal Marine Resources Policy Coordinator, WDFW, November 14, 2010) so effort may be slightly higher along the coasts of Washington than indicated in the model.

One of the assumptions made in the model is that landings into a port complex are assumed to be from effort in waters adjacent to that port complex. We acknowledge that this assumption is not always valid; although it was the most straightforward way to use the available information to create spatial representations of fisheries on a common scale. However, the assumption is reasonable in most cases since most fishermen in these fisheries use relatively small boats and have a relatively small fishing range when compared to the large spatial area of their port complex. There are fisheries that may not fit this assumption, such as the Dungeness crab and sablefish fisheries. These fisheries sometimes have larger fishing vessels that are capable of traveling and operating farther from port. For example: Dungeness crab boats originating from Oregon are known to travel to northern California to take advantage of the earlier season opening, but return to fish in their home port complex later once the Oregon season opens. The port complexes, shown in Figure 1, are used for all fisheries regardless of limitations throughout this document to illustrate the general pattern of fishing effort based on landings.

4. Spatial definitions

Fishing areas were spatially defined per fishery using operational depth ranges, described in fathoms (Table 2). Depth is an appropriate variable for defining potential fixed gear fishing area since each of the fixed gear fisheries characterized in this report operates by setting gear on the bottom of the ocean in depths where the target species generally occur. For example, rock crab fishermen commonly place traps between 10 to 35 fathoms depth. Operational depth ranges were determined based on published literature and expert opinion. Depth contour lines were created from the NOAA National Geophysical Data Center (NGDC)'s bathymetric digital elevation model (DEM) with a 90-meter resolution for the entire U.S. west coast.

The fishery model assumes that fishermen utilized all the potential fishing area defined by the operational fishing depths. Fishing area restrictions, such as marine protected areas and groundfish conservation areas, were removed from each fishery's map, where applicable, based on existing regulations. Trap fishermen in southern California are also restricted from California Department of Fish and Wildlife (CDFW) marine management zones 19A, Santa Monica Bay, and 20, the front side of Catalina Island, so these areas were also removed from the trap fisheries, as appropriate.

Once fishing areas were mapped for individual fisheries, based on operational depths, the fishing areas were divided into port complex regions, resulting in unique and distinct areas for each fishery/port complex combination.

5. Integration of data

Summarized fishery landing data, in terms of average pounds landed per quarter over 5 years, were combined using the geographic information system (GIS) program with fishing areas through the port complex code (Table 1). The fishery model integrated landing data with fishing areas for fixed gear commercial fisheries in California, Oregon, and Washington. The pounds landed in a port complex during a quarter of the year was assigned equally over the entire fishing area associated with the individual port complex, meaning that the pounds landed are assumed to originate from anywhere within the fishing area of the port complex. Model results were mapped to portray these generalized seasonal patterns of fishery effort.

Model validation

When possible, fishery model results were visually compared with mapped commercial fisheries landings or effort data provided by CDFW, Oregon Department of Fish and Wildlife (ODFW), and Washington Department of Fish and Wildlife (WDFW), and the National Marine Fisheries Service (NMFS). Available data were summarized into quarters, and superimposed over the fishery model results on a map for visual comparison.

CDFW provided hagfish, rock crab, sablefish, spiny lobster, and spot prawn landings by catch block. The entire coast of California is broken into 10x10 nautical mile longitude square blocks used for reporting catch location on fish-tickets. There are many blocks that intersect with the coastline that are not square so they encompass less area. Since reporting of landings typically occurs through fish dealers and processors and not the fishermen themselves, there is some question about the precise accuracy of these locations as reported on the landing receipts. Since only one catch block can be recorded on each fish-ticket, the catch block might not always be the most accurate reflection of where the traps were set if fishing occurred in multiple fishing blocks. CDFW has directed fish dealers and processors to report the block where the majority of fishing occurred.

ODFW and WDFW do not use a 10x10 nautical mile statistical block system; however, they do record Dungeness crab trapping effort through logbooks in fishing areas along the coastline distinguished by boundaries of latitude. ODFW and WDFW provided monthly summarized Dungeness crab commercial trap log records, aggregated to represent the number of traps set per defined fishing area. Trap log records were also separated at the 30-fathom line into nearshore and offshore landings. State data was only provided for the Dungeness crab trap fishery in Oregon and Washington.

NMFS provided set locations obtained from fisheries observers monitoring the California halibut/white seabass set gillnet fishery. Set locations are shown for the entire year to protect fishermen anonymity.

Table 1. Port complex codes, geographic range, and major ports

Port Complex Code	Geographic Rage	Major Ports
NPS/SPS*	Puget Sound, Strait of Juan de Fuca	Bellingham, Port Townsend, Seattle, Everett, Port Angeles
CWA	Cape Flattery south to Cape Disappointment, Washington	Westport, La Push, South Bend, Neah Bay
CLW	Cape Disappointment south along the Washington side of the Columbia River[1]	Illwaco, Chinook
CLO	Oregon side of the Columbia River to the southern border of Clatsop County	Astoria, Warrenton, Seaside
TLA	Coastal border of Tillamook County, Oregon	Tillamook, Garibaldi
NPA	Coastal border of Lincoln County, Oregon	Newport, Depoe Bay
CBA	Coastal border of Lane, Douglas, and Coos Counties, Oregon	Coos Bay, Winchester Bay, Bandon
BRA	Coastal border of Curry County, Oregon to the Oregon/California border	Brookings, Port Orford
CCA	Coastal border of Del Norte County, California	Crescent City
ERA	Coastal border of Humboldt County, California	Eureka, Trinidad
BGA	Coastal border of Mendocino County, California	Fort Bragg
BDA	Coastal borders of Sonoma and Marin counties, California	Bodega Bay
SFA	Coastal borders of San Francisco and San Mateo counties, California	San Francisco
MNA	Coastal borders of Santa Cruz and Monterey counties, California	Monterey
MRA	Coastal border of San Luis Obispo County, California	Morro Bay
SBA	Coastal borders of Santa Barbara and Ventura counties, California	Santa Barbara, Ventura, Oxnard
LLA	Coastal borders of Los Angeles and Orange counties, California	Los Angeles, Long Beach, Dana Point
SDA	Coastal border of San Diego County, California	San Diego, Oceanside

***Not considered in this analysis, [1]Geographic range is small, major ports fish north of Columbia River in Washington or south into Oregon waters.**

Table 2. Fishery operational depths (in fathoms) summarized by state

Fishery	CA depth (fm)	OR depth (fm)	WA depth (fm)
Coonstripe shrimp	20-30[1]	20-30[2]	X
California nearshore live fish	0-20[3]	X	X
California halibut/white seabass set gillnet	15-50[4]	X	X
Dungeness crab	10-40[1]	5-50[2]	5-60[5]
Hagfish	50-125[1]	80-120[2]	50-125[5]
Pacific halibut longline	X	30-150[6]	30-150[6]
Rock crab	10-35[1]	X	X
Sablefish longline	100-450[7]	100-450[7]	100-450[7]
Sablefish traps	100-375[7]	100-375[7]	100-375[7]
Spiny lobster	0-40[1]	X	X
Spot prawn	100-150[1]	60-175[2]	70-120[5]

X= fishery is not active in that state. Sources: 1. CDFW;2. ODFW; 3. CDFW fishery regulations, Title 14 CCR § 1.90 (d);4. NMFS (2008); 5.WDFW; 6.IPHC; 7. NMFS West Coast Groundfish Observer Program

Figure 1. Geographic representation of port complex regions as defined by the PacFIN database. Western boundary is the United State Exclusive Economic Zone. Port complexes are as follows (major port): PS (Seattle), CWA (Westport), CLW (Illwaco), CLO (Astoria), TLA (Tillamook), NPA (Newport), CBA (Coos Bay), BRA (Brookings), CCA (Crescent City), ERA (Eureka), BGA (Fort Bragg), BDA (Bodega Bay), SFA (San Francisco), MNA (Monterey), MRA (Morro Bay), SBA (Santa Barbara), LLA (Los Angeles), SDA (San Diego).

2.2 Fishery characterization and model results

California Halibut/White Seabass Set Gillnet Fishery

Characterization
Set gillnets are used by fishermen in southern California to target California halibut (*Paralichthys californicus)* and white seabass (*Atractoscion nobilis)*. Set gillnets may also be used to target rockfish.

Gillnets in this fishery are set in depths ranging between 10 to 50 fathoms, with concentrated effort between 10 to 35 fathoms. The nets are held in place by anchors at each end. The bottom line, or leadline, utilizes approximately 100 pounds of weight for every 600 feet of line (NMFS, 2005). The mesh size selected for the net depends on the target species. For California halibut, stretched mesh size is between 8.5 and 14 inches (FGC §8625). For seabass, stretched mesh size is between 6 and 14 inches (FGC §8623). The amount of time set gillnets are left in the water, referred to as soak time, are typically 8-10, 19-24, or 44-49 hours (NMFS, 2010a).

Distribution of fishery effort – five year average from 2004 through 2008
Due to depth restrictions in the Monterey area, the majority of the recent set gillnet fishing effort is in southern California. California halibut and white seabass landings are combined to show set gillnet fishery effort. From 2004 to 2008, the highest landings were in Quarter 2 and 3 (Figure 2 and 3). Santa Barbara (SBA) had the highest average landings throughout the year, followed by Los Angeles (LLA) and San Diego (SDA). Morro Bay had limited effort with average landings never exceeding 1,000 pounds per quarter.

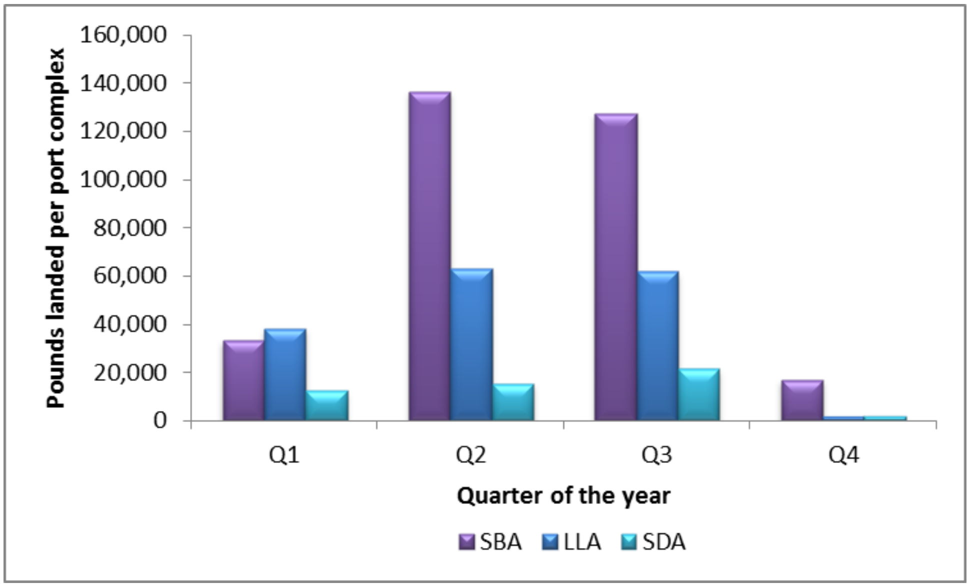


Figure 2. Average landings of California halibut/white seabass per port complex per quarter; 2004-2008

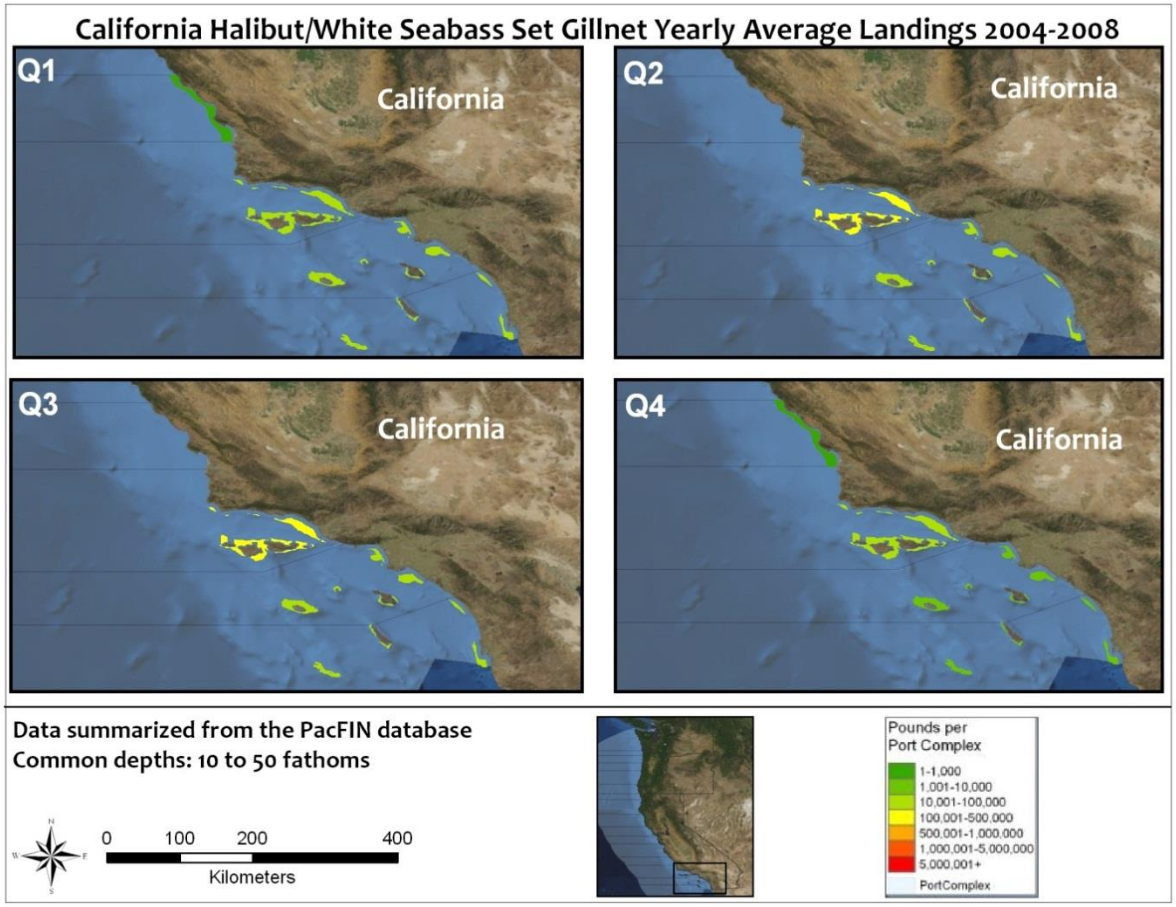


Figure 3. California halibut/white seabass set gillnet fishery yearly average landings, indicated by the green to red colored bands, from 2004 to 2008 are shown per port complex and by quarter of the year. Fishing area within a port complex is defined by operational fishing depth range.

Comparison with NMFS observer data

The fishery model based on 2004 to 2008 landings data was compared with NMFS observer set gillnet set locations from 2010 and 2011. As shown in Figure 4, the fishery model and NMFS observed sets show a strong overlap in the southern California nearshore areas: mainly Ventura, Long Beach, Oceanside, and San Diego. However, there were very few observed sets around the offshore islands, indicating that the fishery model could be overestimating the potential area utilized by the set gillnet fishery. Logbook data, turned in by the commercial fishermen, might provide more specific information about the geographic range of the fishery.

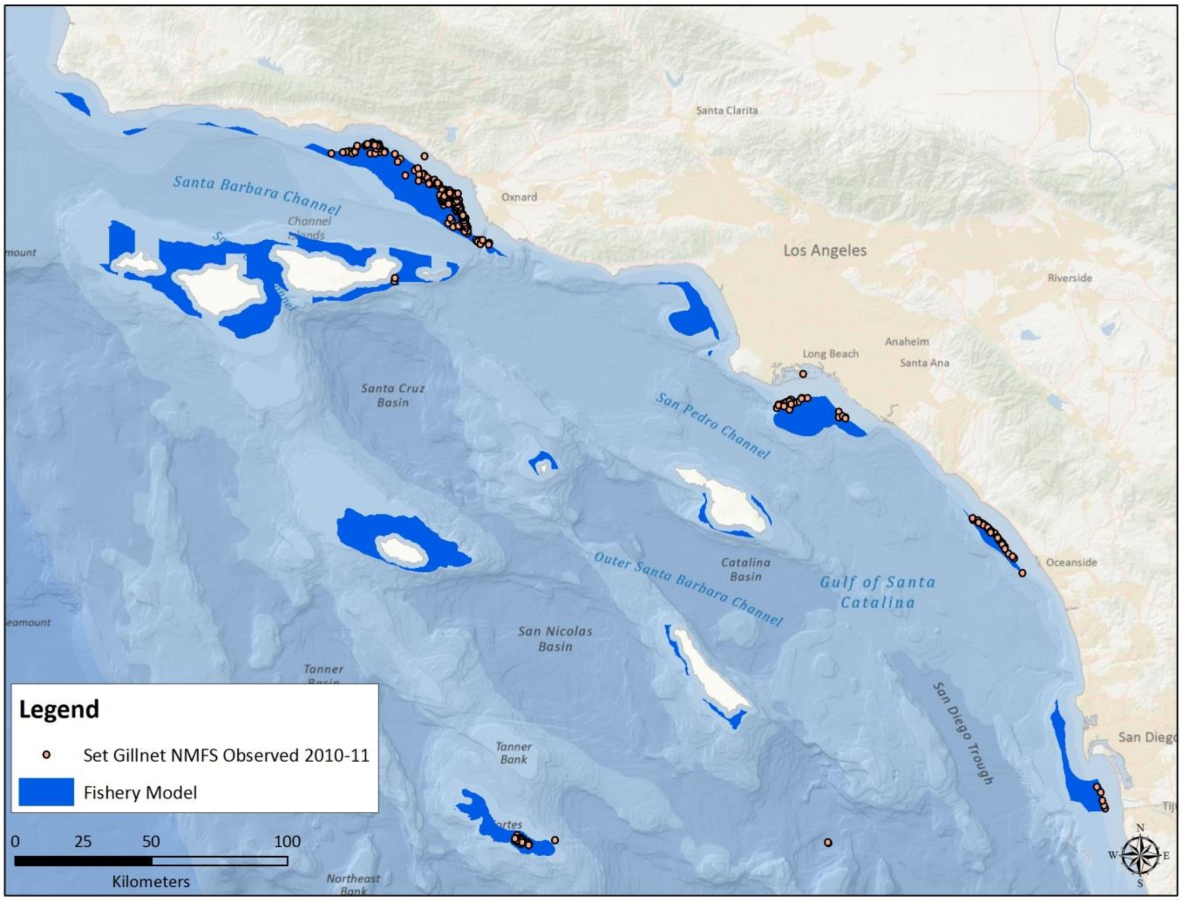


Figure 4. Comparison of modeled fishing areas with NMFS observed sets. Orange dots indicate where set gillnet were deployed during 2010 and 2011. Blue areas indicate active port complexes in the fishery model.

California Nearshore Live Finfish Trap Fishery

Characterization
California has a trap fishery that targets nearshore finfish species including: black-and-yellow rockfish (*Sebastes chrysomelas)*, cabezon (*Scorpaenichthys marmoratus*), California scorpionfish (*Scorpaena guttata)*, California sheephead (*Semicossyphus pulcher)*, China rockfish (*Sebastes nebulosus)*, gopher rockfish (*Sebastes carnatus)*, grass rockfish (*Sebastes rastrelliger)*, greenlings in the genus *Hexagrammos*, and kelp rockfish (*Sebastes atrovirens)*. Hook and line gear and trapping are the primary fishing methods used to target nearshore fish, representing 72% and 22.4% of effort, respectively, from 2000 to 2006 (NMFS, 2008).

Nearshore finfish are landed live in wire mesh traps. The fishery commonly operates from nearshore out to 20 fathoms deep. Single rectangular wire mesh traps attached to a single buoy are used to catch finfish during the day. Buoys must be marked with the fisherman's license number followed by the letter "Z" (FGC § 9006). Traps left overnight must be unbaited with the trap door securely open (FGC § 9001.7d). Fishing permits restrict the fishermen to a maximum of 50 traps within state waters (FGC § 9001.7h).

Distribution of fishery effort – five year average from 2004 through 2008
Live-fish trapping is open year round in Eureka and Crescent City although little or no landings are recorded. The rest of California is open year round except March and April. Average landings from 2004 to 2008 were highest in Quarter 2 and 3, and dropped for most port complex groups in Quarters 1 and 4 (Figures 5 and 6). Highest landings were recorded in San Diego (SDA), followed by Los Angeles (LLA), Morro Bay (MRA) and Santa Barbara (SBA).

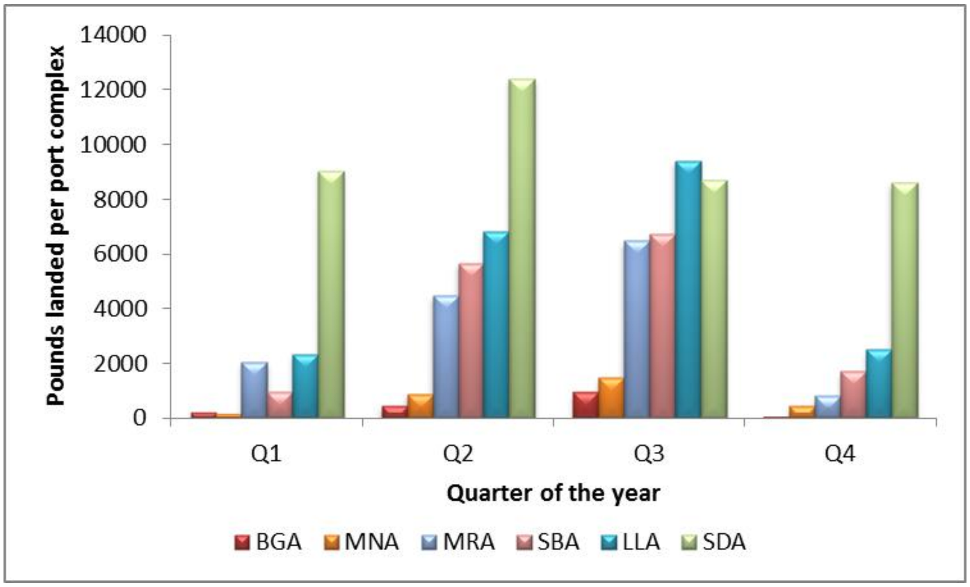


Figure 5. Average landings of California nearshore live finfish per port complex per quarter; 2004-2008

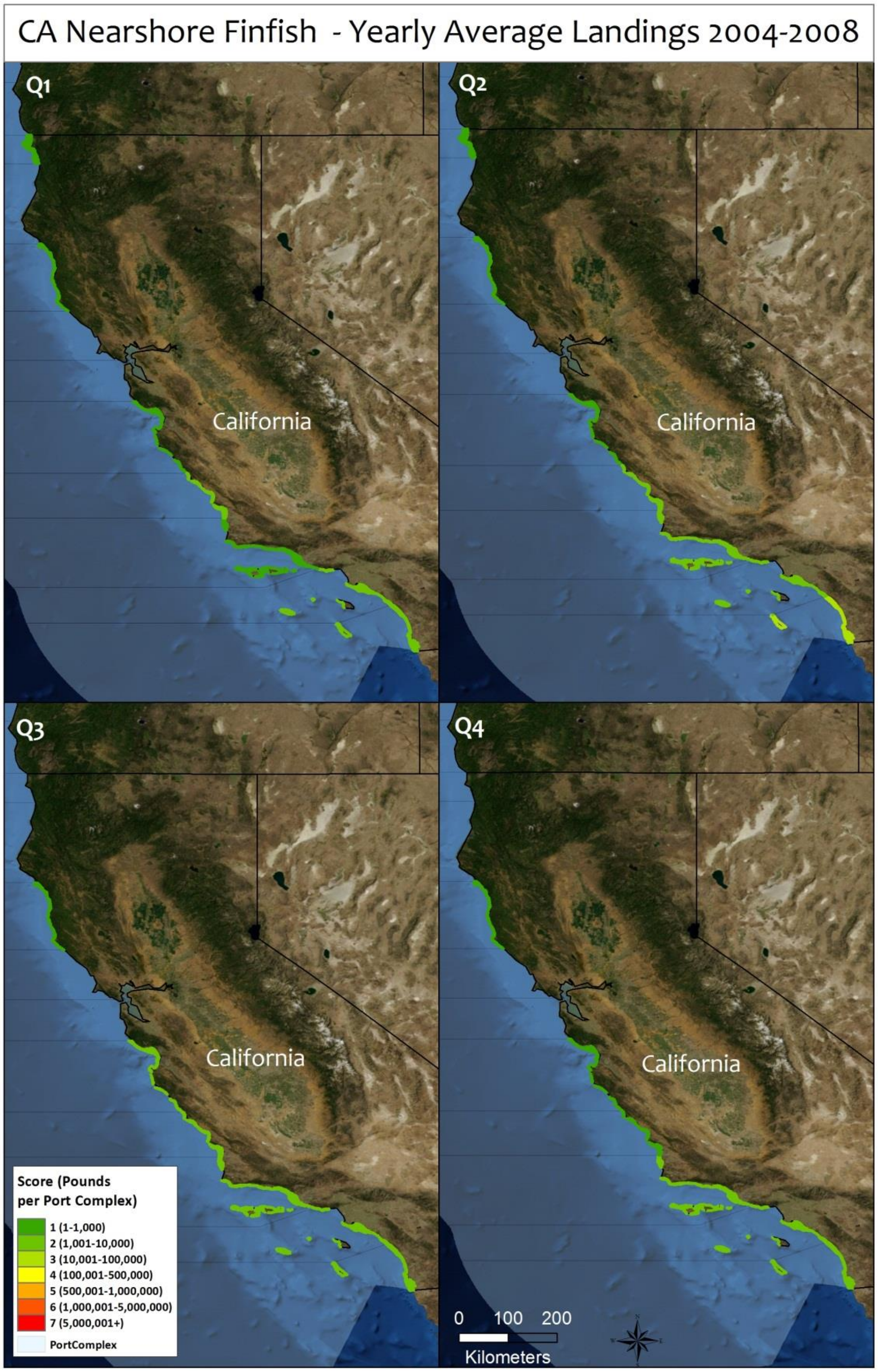


Figure 6. California nearshore live finfish trap fishery yearly average landings, indicated by the green to red colored bands, from 2004 to 2008 are shown per port complex and by quarter of the year. Fishing area within a port complex is defined by operational fishing depth range.

Coonstripe Shrimp Trap Fishery

Characterization

The California coonstripe shrimp (*Pandalus danae)* trap fishery is relatively new, beginning in 1995. The average harvest was 70,000 pounds per year from 2000-2005 (NMFS, 2008). In 2008, there were 7 active participants in the coonstripe shrimp fishery. Coonstripe shrimp fishermen are primarily Dungeness crab fishermen who fish for coonstripe shrimp in their off season (McVeigh, 2010). Most coonstripe shrimp are sold live to fish buyers, bringing in as much as $7.50 per pound (McVeigh, 2010).

Gear is generally fished in a relatively narrow depth range of 20 to 30 fathoms, concentrated around the 25-fathom line, although some gear is set as shallow as 12 fathoms (McVeigh, 2010). Fishermen leave the strings of traps in the water for several days before pulling.

Distribution of fishery effort – five year average from 2004 through 2008

From 2008 to 2008, fishing effort was concentrated around Crescent City, California, in the Crescent City (CCA) port complex (Figures 7 and 8). Highest landings were recorded in Quarter 2 and 3. Landings were also made in Brookings, Oregon and other ports in California including: San Francisco, Eureka, and Monterey but were not represented on the figures below due to confidentiality reasons.

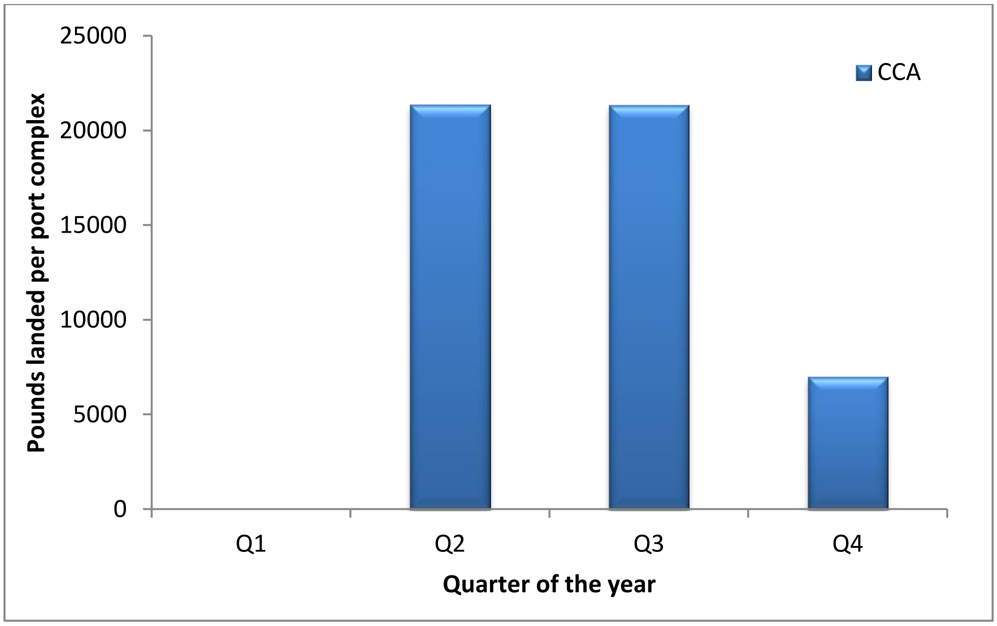
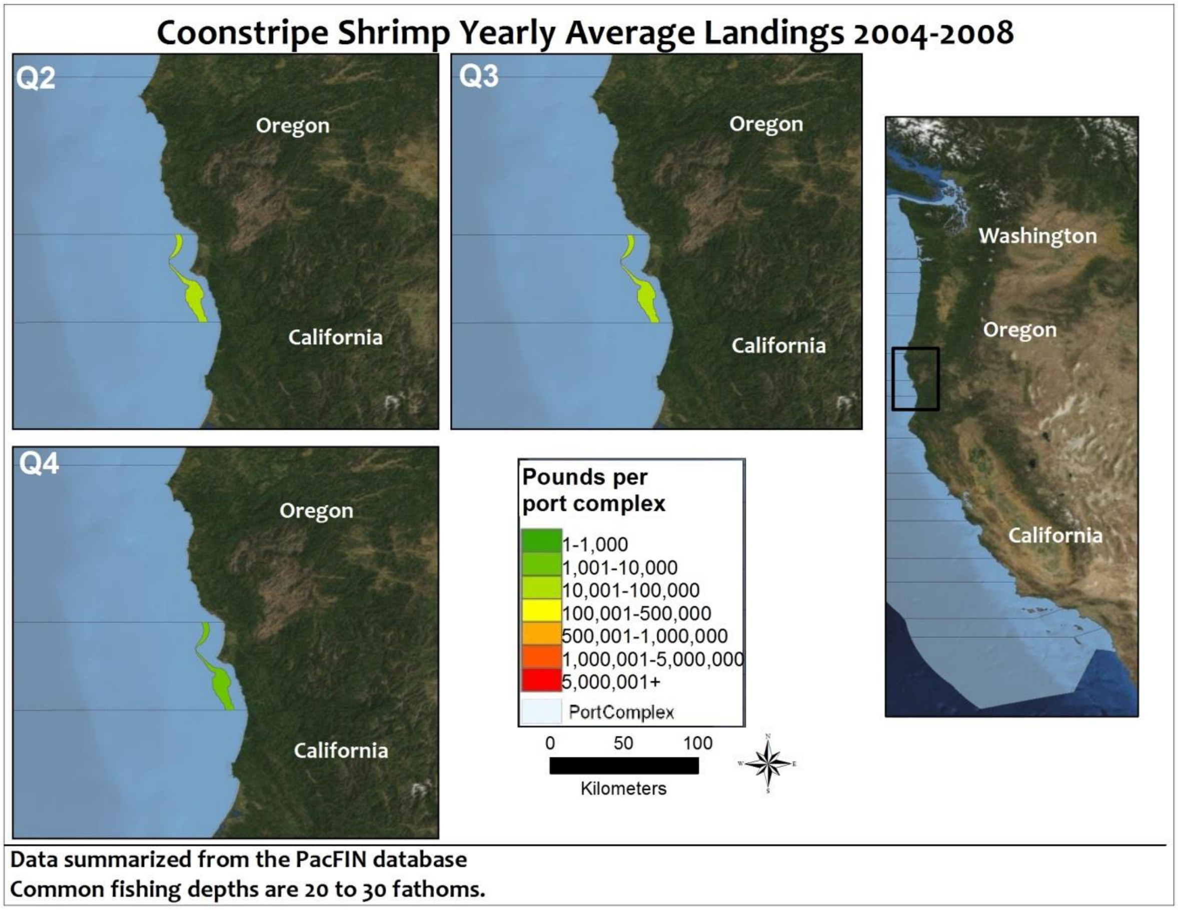


Figure 7. Average pounds of coonstripe shrimp landed per port complex per quarter; 2004-2008


Coonstripe Shrimp Yearly Average Landings 2004-2008

Data summarized from the PacFIN database
Common fishing depths are 20 to 30 fathoms.

Figure 8. Coonstripe shrimp trap fishery yearly average landings, indicated by the green to red colored bands, from 2004 to 2008 are shown per port complex and by quarter of the year. Fishing area within a port complex is defined by operational fishing depth range.

Dungeness Crab Trap Fishery

Characterization

Dungeness crab (*Cancer magister*) is caught throughout the west coast of North America. California, Oregon, and Washington represent the southern portion of the Dungeness crab species range. Dungeness crab is also caught commercially in British Columbia, Canada and Alaska.

Dungeness crab traps are different from other traps used along the west coast, which are generally rectangular or conical. In contrast, traps targeting Dungeness crab are circular steel frames three to four feet in diameter, 1 foot high, wrapped with 3 to 4 inch diameter mesh made from 3/4 inch stainless steel wire (NMFS, 2005).. Traps are fished individually, attached to a single vertical line, 3/8th inch polypropylene, with one or two bullet buoys. One fisherman may fish 30 to 100 traps in a row along a fathom contour (NMFS, 2005). These traps are not attached to one another, unlike other trap fisheries that may have traps connected via a ground line. Common spacing is 15 pots per mile, varying from 10 to 25 pots per mile (NMFS, 2005). Most traps weigh between 85 and 115 pounds (NMFS, 2005). Traps are left to soak unattended for one to seven days. However, Oregon logbooks indicate that soak times can vary from 0.5 to 30 days, varying greatly with time of year (personal communication with Kelly Corbett, ODFW, Marine Fisheries Biologist, November 9, 2011).

Common fishing depths vary per state. California Dungeness crab fishermen set trap gear between 10 and 40 fathoms depth. Oregon Dungeness crab fishermen commonly set their gear between 5 and 60 fathoms depth, however, logbook data indicate some effort out to 100 fathoms depth (personal communication with Kelly Corbett, Marine Fisheries Biologist, ODFW, November 9, 2011). Washington Dungeness crab fishermen commonly fish between 5 and 60 fathoms, but logbook data indicates that fishermen south of Grays Harbor will set gear as deep as 75 fathoms or more. Washington tribes commonly set gear around 35 fathoms (personal communication with Joe Schumacker, Quinault Department of Fisheries, Marine Resources Scientist, April 21, 2011). Tribal fishery landings and associated effort were not mapped in this document.

Distribution of fishery effort – five year average from 2004 through 2008

Landings are made into each port complex except Santa Barbara, Los Angeles, and San Diego, California (Figure 9). Dungeness crab landings are made during most of the year (Figure 10). The Dungeness crab season is closed to non-tribal members in all states from September 15th through November 15th. However, the Washington tribal fisheries start fishing again as early as October. From 2004 to 2008, the average landings for the Dungeness crab trap fishery in Quarter 1 were the highest of all fixed gear fisheries analyzed in this report.

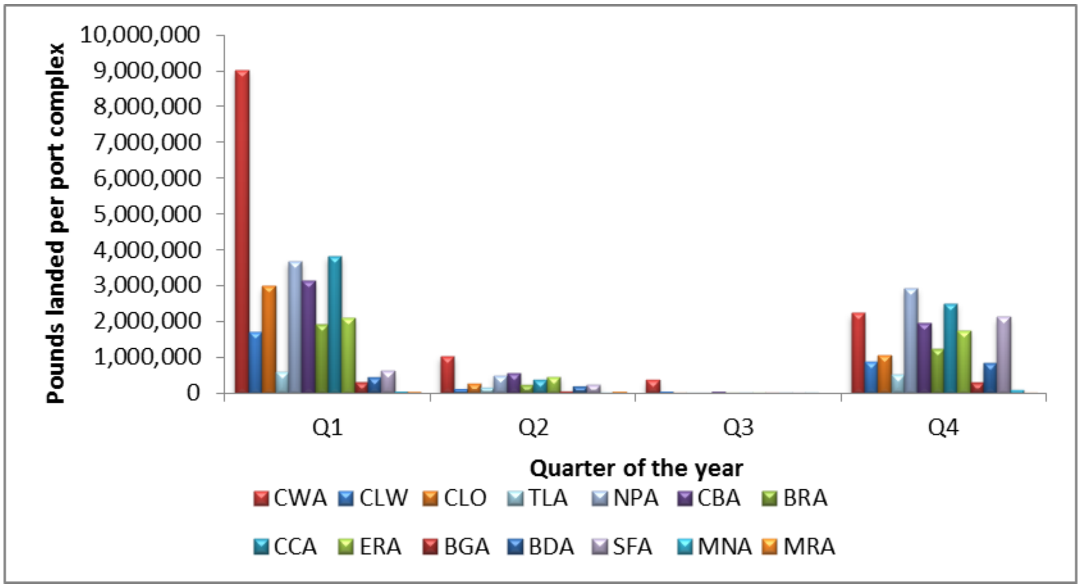


Figure 9. Average pounds of Dungeness crab landed per port complex per quarter; 2004-2008

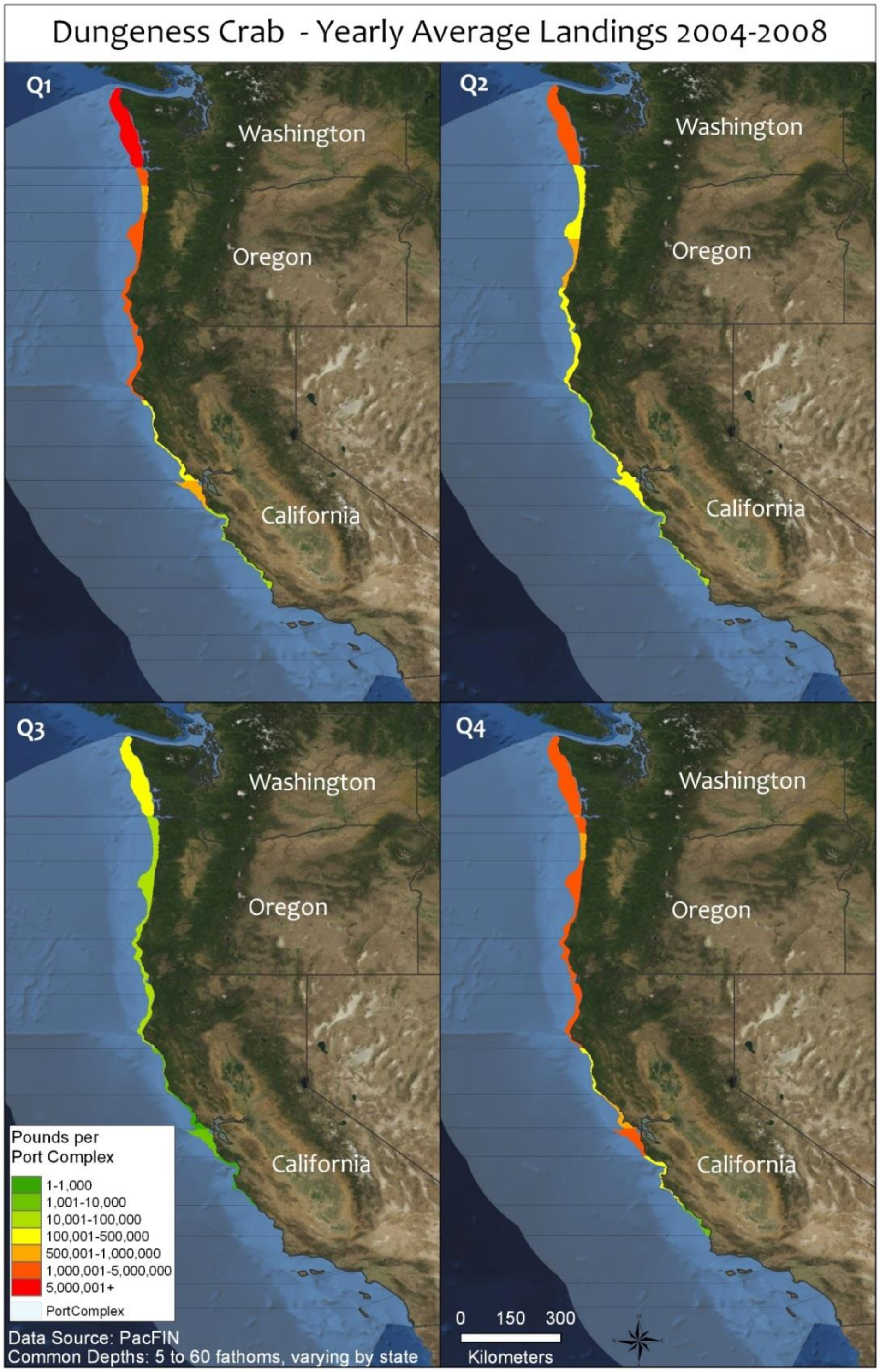


Figure 10. Dungeness crab trap fishery yearly average landings, indicated by the green to red colored bands, from 2004 to 2008 are shown per port complex and by quarter of the year. Fishing area within a port complex is defined by operational fishing depth range.

Comparison with Oregon and Washington logbook data

ODFW and WDFW provided monthly summaries of total traps fished, by fishing areas, from commercial trap logs. The states defined the boundaries of fishing areas by latitude and depth range. The fishing areas were digitized and data was integrated in a process similar to the port complex creation presented in this document. Monthly trap usage data was scaled in this model to show low, medium, and high traps per fishing area (Figure 11). When the spatial extents of fishing areas were compared, the fishery model was very similar to state fishing areas. The main difference was seen in Oregon were the fishery model shows fishing area to 50 fathoms but an ODFW biologist suggested the inclusion of depths to 100 fathoms as documented from logbook data (personal communication with Kelly Corbett, ODFW, Marine Fishery Biologist, April 1, 2011).

When the trap density was compared to the fishery effort model, based on landings, the fishery model showed a similar pattern of effort with lower landings in northern Oregon coordinating with areas where less traps were set. The trap logbook data provided by the states allows for a closer look at the Washington Dungeness crab fishery when compared to the fishery model, where a single port complex represents Washington landings (Figure 11). The Tribal Usual and Accustomed fishing grounds in northern Washington waters are closed to commercial fishermen for a portion of the fishing season, which is reflected in the trap density map from WDFW. The fishery model does not separate tribal from commercial landings, however, tribal landings are included in the total.

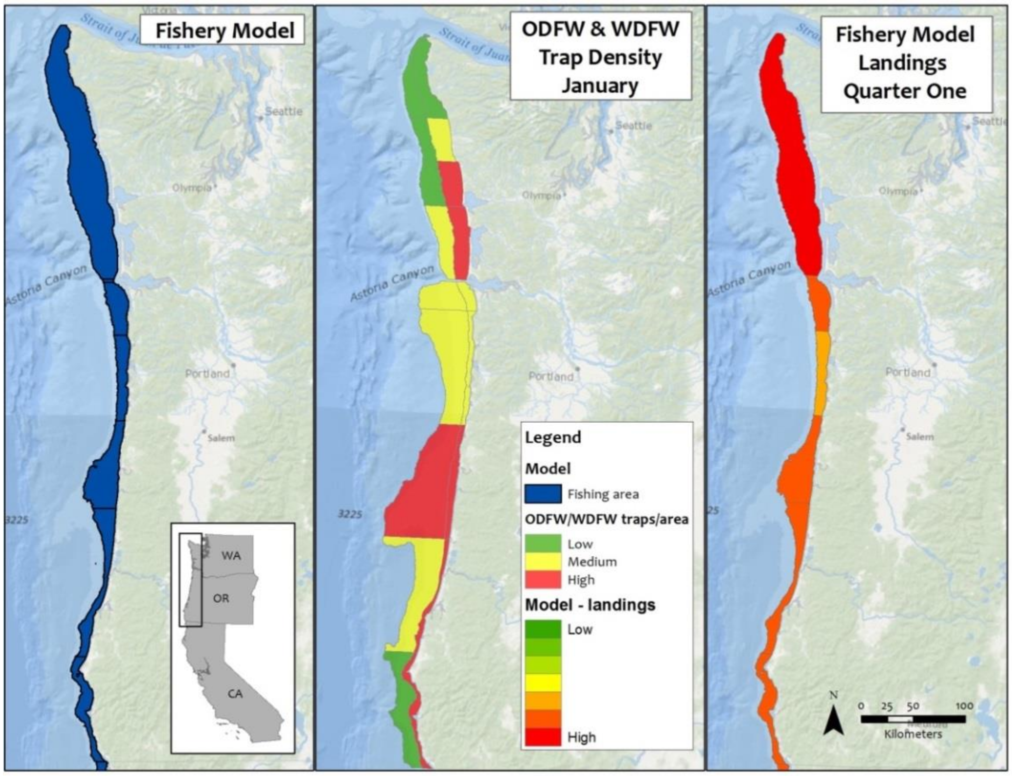


Figure 11. Modeled fishing area (2004-08), by port complex, compared to Dungeness crab traps/area, shown on a green to red scale with red representing high traps/area, summarized from ODFW and WDFW commercial logbook data (2009-10), and fishery model landings show on a green to red scale with red representing the highest landings (2004-2008, Quarter One).

Hagfish Trap Fishery

Characterization

Hagfish trap fishing occurs throughout California, Oregon, and Washington. Pacific hagfish (*Eptatretus stoutii*) are targeted although black hagfish *(Eptatretus deani*) are also caught. Hagfish in general are found throughout the Pacific Ocean at depths between 50 and 500 fathoms, although the operational depth of the west coast fishery ranges from 50 to 125 fathoms (Barss, 1993).

Hagfish landings were high in the late 1980s and early 1990s, followed by a period where little or no landings were recorded until 2001 (NMFS, 2008). Landings were reported again starting in 2004, and continue to occur. The recent surge in landings is the result of a developing South Korean market for hagfish, and higher effort is seen in the hagfish trap fishery in California to Washington when the Korean hagfish season is closed.

All three types of traps commonly used in the fishery have plastic funnels with “fingers” that allow fish to enter but prevent them from exiting (NMFS, 2008). Hagfish traps, regardless of type, are fished in a string with 10 or 20 traps attached to a common ground line. The ground line is weighted at one or both ends and marked at the surface with a large buoy, pole, flag, radar reflector, and light.

Distribution of fishery effort – five year average from 2004 through 2008

The hagfish fishery is operational in all port complex groups except Fort Bragg and San Francisco (Figures 12 and 13). Fishing activity in the Monterey (MNA) port area ceased by the end of summer 2008, due to market issues (personal communication with Travis Tanaka, CDFW, Associate Marine Biologist, January 28, 2010). No seasonal patterns in catch or effort are apparent, probably due to the emerging nature of the fishery and the fluctuating demand from Asian markets (NMFS, 2008). The Coos Bay (CBA) port complex had the highest landings recorded throughout the year, with consistent average landings of over 100,000 pounds (Figure 12).

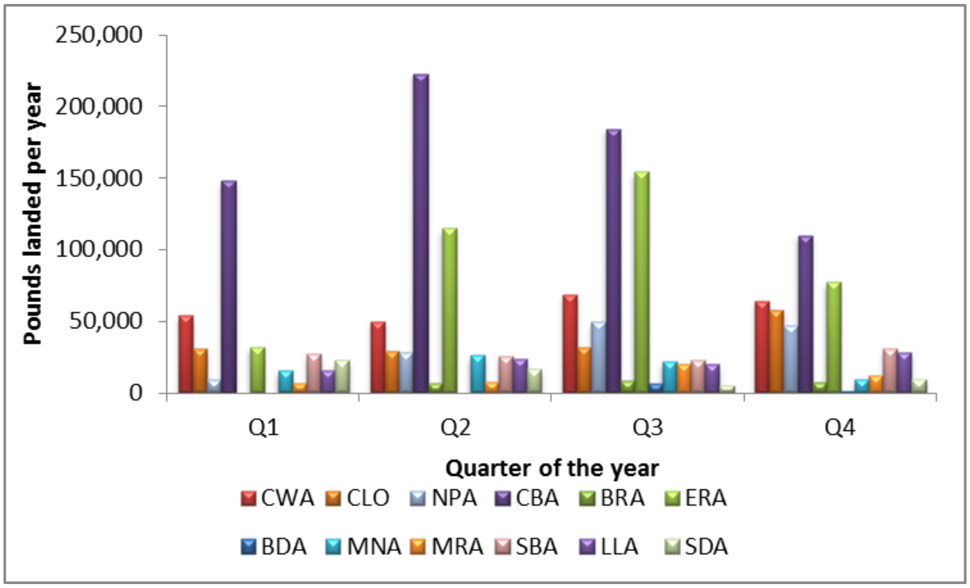


Figure 12. Average pounds of hagfish landed per port complex per quarter; 2004-2008

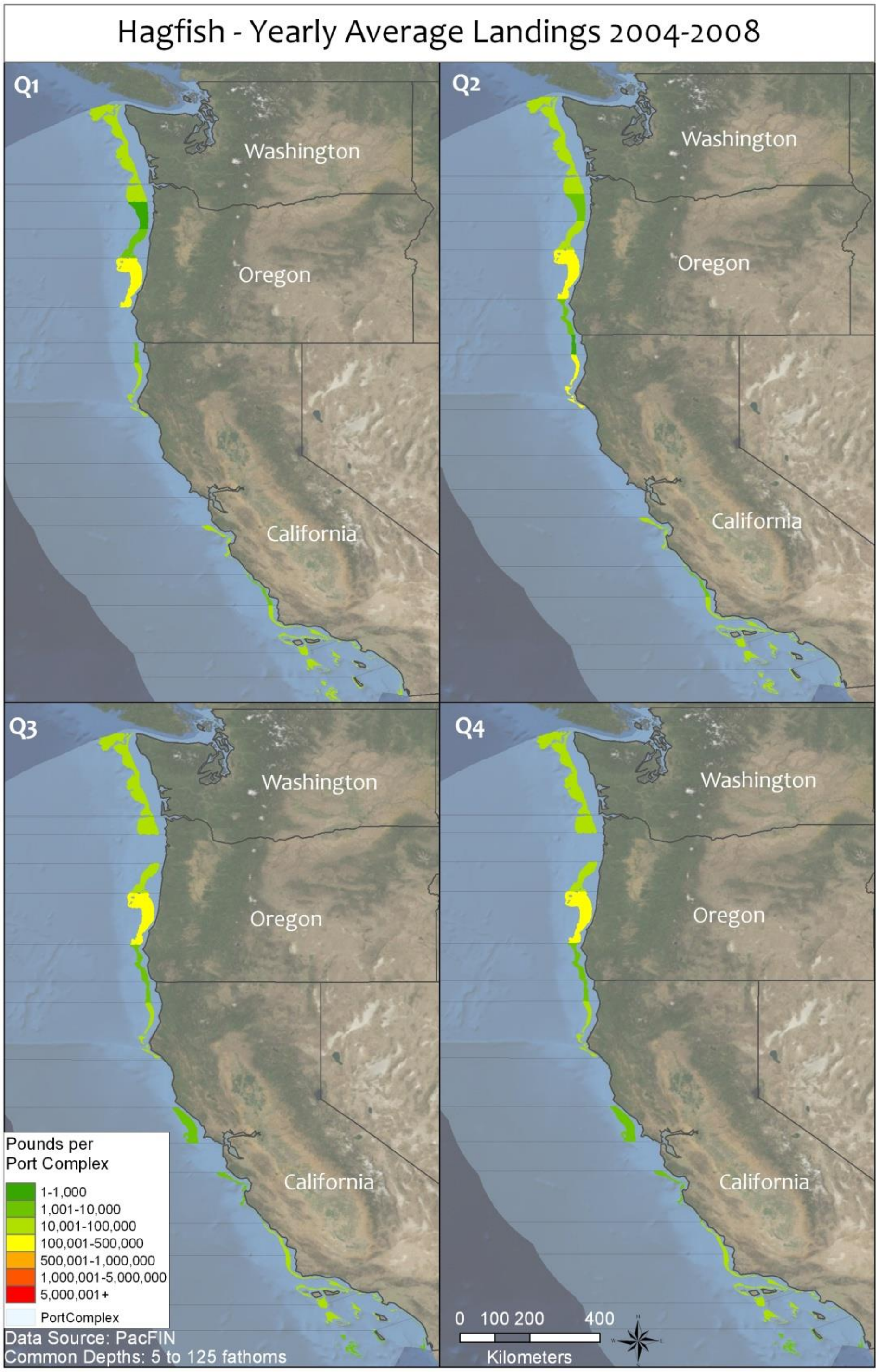


Figure 13. Hagfish trap fishery yearly average landings, indicated by the green to red colored bands, from 2004 to 2008 are shown per port complex and by quarter of the year. Fishing area within a port complex is defined by operational fishing depth range.

Comparison with California landing records

Catch location is recorded by CDFW 10x10 nautical mile catch block when hagfish are commercially landed in California. The catch blocks have a different spatial resolution than the fishery effort model. The catch blocks can show smaller concentrations of effort without regard to depth, while the fishery model can show a more accurate reflection of depth but effort is spread over a larger region. California landing data, from 2004 to 2008, was used to create a footprint of "active" catch blocks for comparison with the fishery model (Figure 14). The fishery model and state landing data overlap in some areas: southern California, Morro Bay, and Monterey Bay. However, there are portions of the modeled fishing area that do not overlap with active catch blocks, indicating that the fishing model may be overestimating the total area covered by the fishery.

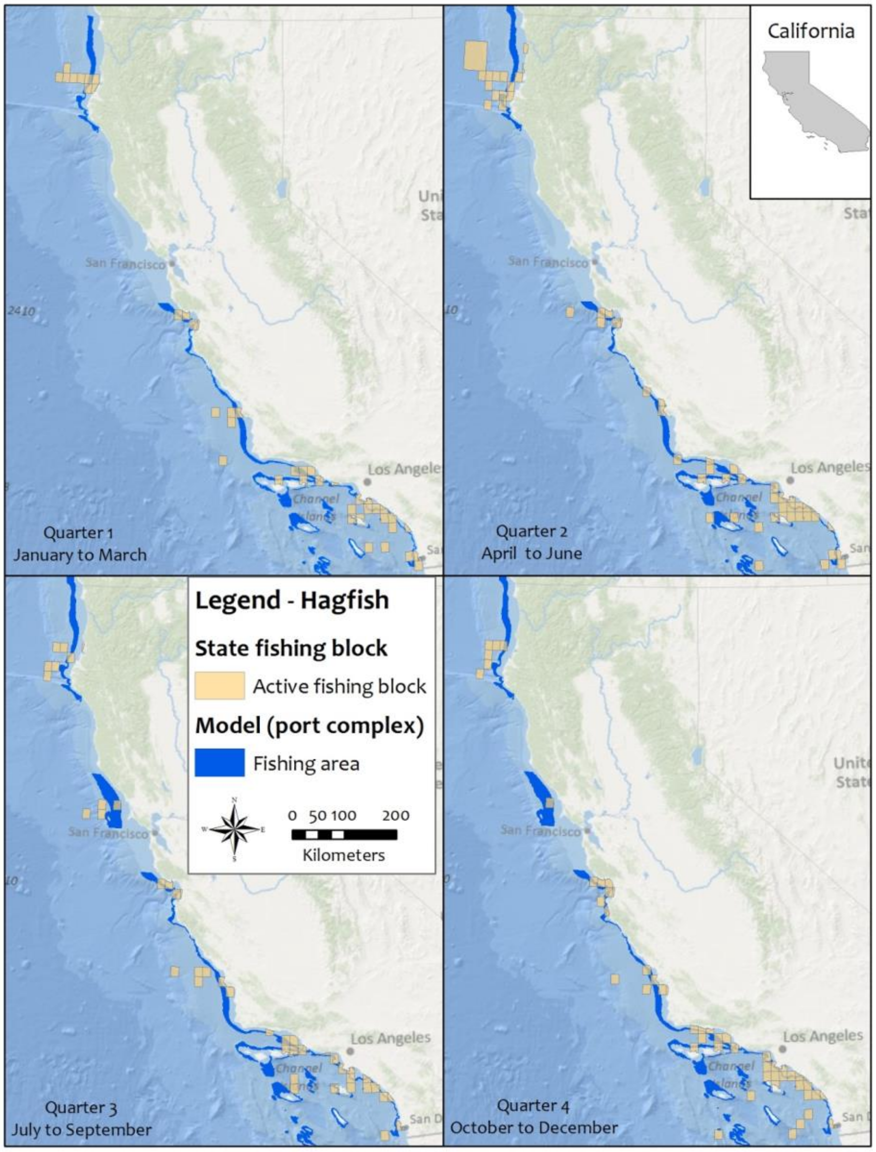


Figure 14. Comparison of modeled fishing areas with CDFW fishing block data. Orange blocks indicate that commercial landings were recorded during that quarter between 2004 and 2008. The blue areas indicate an active port complex in the fishery model during that quarter of the year.

Pacific Halibut Longline Fishery

Characterization
Pacific halibut (*Hippoglossus stenolepis*) inhabit ocean waters from Nome, Alaska to Santa Barbara, California (IPHC, 2010). There are active commercial and recreational fisheries for Pacific halibut throughout most of their range. The only gear allowed for commercial retention of Pacific halibut in California, Oregon, and Washington is longline. A longline involves setting a horizontal line (ground line) along the bottom of the ocean with baited hooks attached at regular intervals. The ground line is weighted at both ends and also connected to the surface via a vertical line and marked at each terminal end with a surface buoy, pole, flag and radar reflector.

A Pacific halibut ground line, usually 5/16 inch nylon or another non-buoyant material line, can be up to three nautical miles in length and contain up to 800 hooks (NMFS, 2005). Polypropylene line with a lead fiber core is also used for ground lines (NMFS, 2005). Hooks are spaced an average of 26 feet, but spacing can range from 18 feet to 36 feet (NMFS, 2005). Pacific halibut are targeted in 30 to 150 fathoms depth (NMFS, 2005). Circle hooks, size 16/0, are commonly used to target Pacific halibut with longline gear (NMFS, 2005).

Distribution of fishery effort – five year average from 2004 through 2008
Pacific halibut longline landings were concentrated in central Oregon and Washington (Figures 15 and 16). Although there are historic records of catch in California, no effort was seen in California during this time period. Coastal Washington (CWA) had landings through all quarters of the year, while Oregon only records landings in Quarter 2 and 3 (Figure 15).

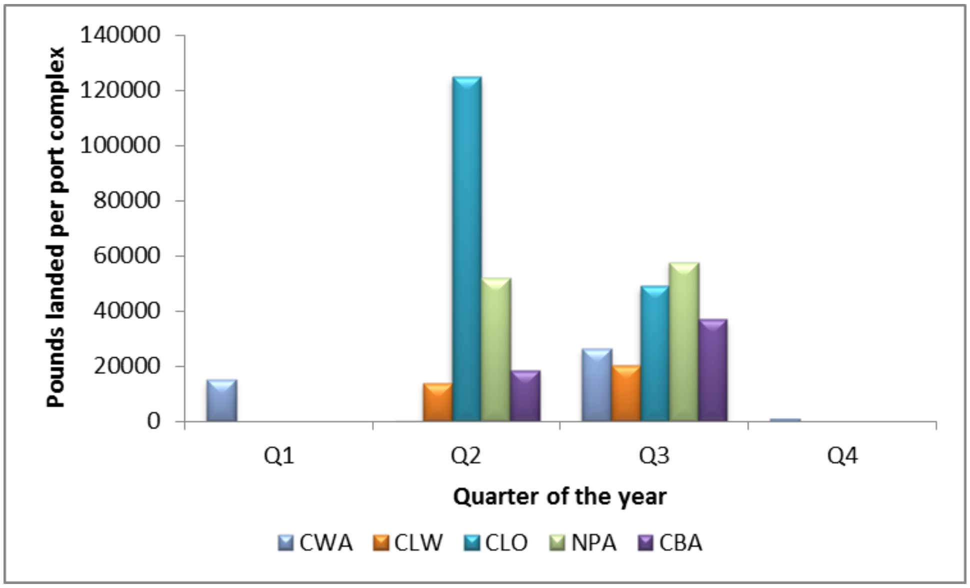


Figure 15. Average pounds of Pacific halibut landed per port complex per quarter; 2004-2008

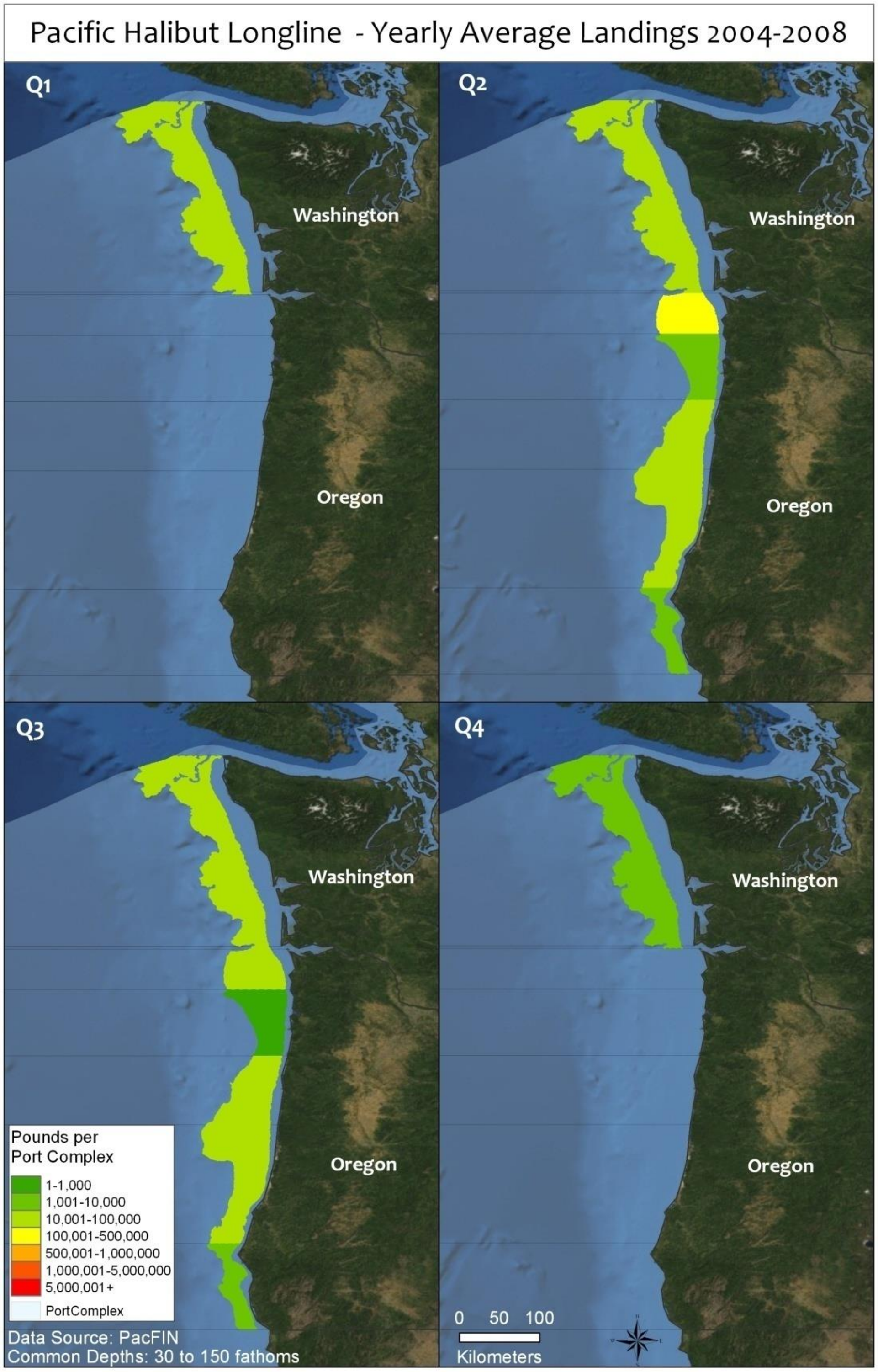


Figure 16. Pacific halibut longline fishery yearly average landings, indicated by the green to red colored bands, from 2004 to 2008 are shown per port complex and by quarter of the year. Fishing area within a port complex is defined by operational fishing depth range.

Rock Crab Trap Fishery

Characterization

Commercial trapping for rock crab (*Cancer spp.*) has been recorded in California since 1950. The fishery has expanded from nearshore areas around ports in southern California to include more distant mainland ports and the Channel Islands over the past 50 years. The rock crab fishery in California has very consistent annual landings averaging just over one million pounds per year from 2000 to current.

There are no restrictions on the number of traps that may be fished per permit, but the typical number of traps operated at any given time is less than 200 per permit (NMFS, 2008). Traps are usually buoyed individually or in pairs, but fishing strings (multiple traps attached to a common ground line between two buoys) are allowed (NMFS, 2008). Buoys are required to be marked with the license number of the operator. The normal working depth of traps in this fishery is 10 to 35 fathoms. Fishermen will set traps for 48 to 96 hours prior to pulling them up.

Distribution of fishery effort – five year average from 2004 through 2008

Rock crab is landed consistently throughout the year, with Quarters 2 and 3 producing marginally higher catches (Figures 17 and 18). The majority of the landings occur from Morro Bay south. The Santa Barbara (SBA) port complex has the highest average landings throughout the year for rock crab, accounting for approximately 65% of total catch.

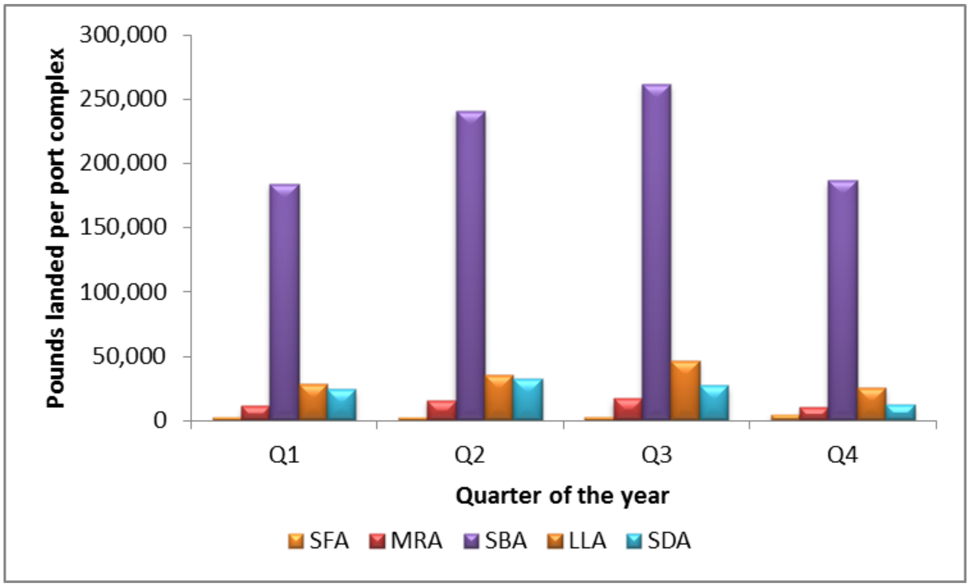


Figure 17. Average pounds of rock crab landed per port complex per quarter; 2004-2008

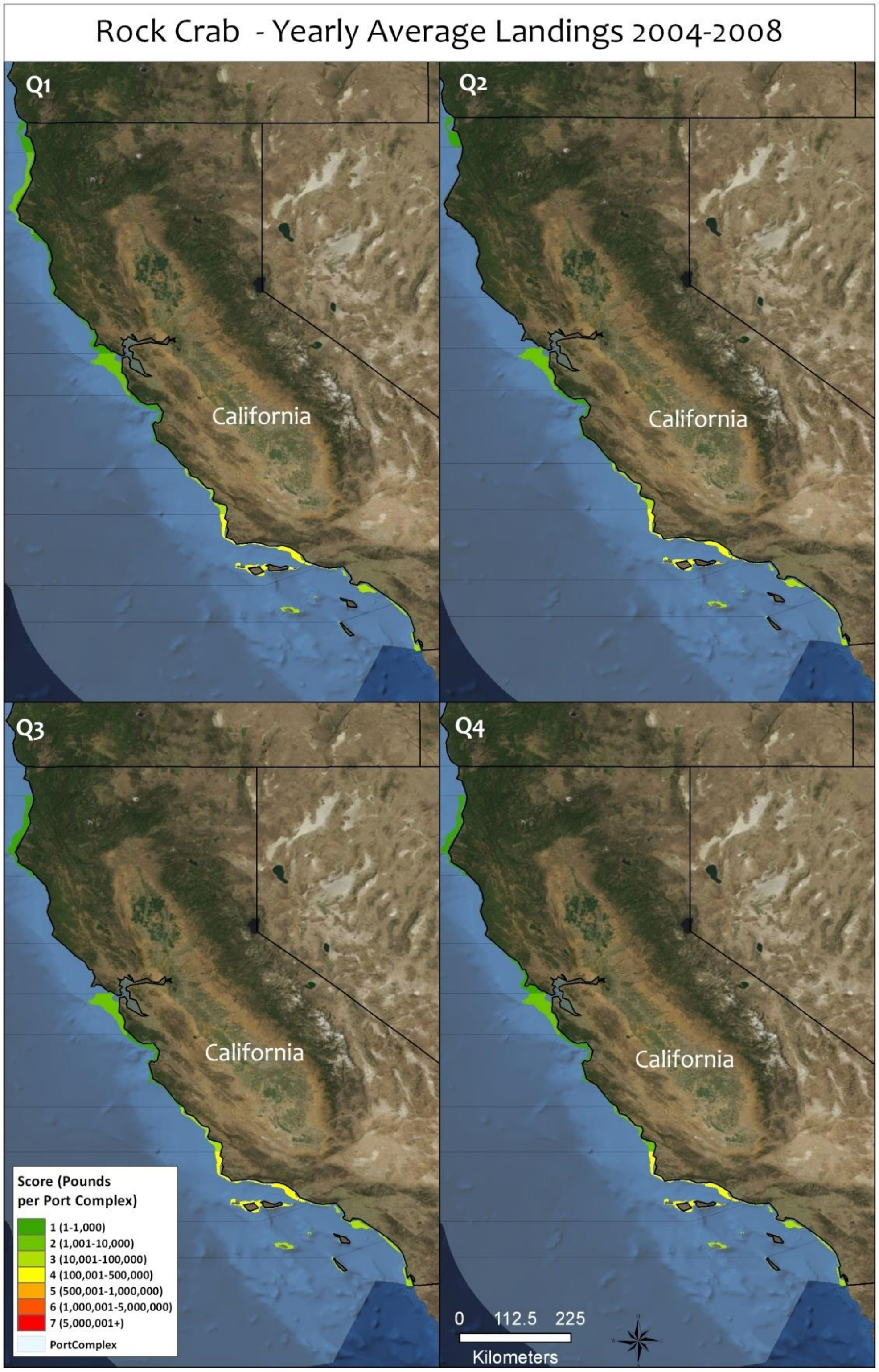


Figure 18. Rock crab trap fishery yearly average landings, indicated by the green to red colored bands, from 2004 to 2008 are shown per port complex and by quarter of the year. Fishing area within a port complex is defined by operational fishing depth range.

Comparison with California landing records

Catch location is recorded by CDFW 10x10 nautical mile catch block when rock crabs are commercially landed in California. The catch blocks have a different spatial resolution than the fishery effort model. The catch blocks can show smaller concentrations of effort without regard to depth, while the fishery model can show a more accurate reflection of depth but effort is spread over the larger port complex area. California landing data, from 2004 to 2008, was used to create a footprint of “active” catch blocks for comparison with the fishery model (Figure 19). The fishery model and state landing data show the same general distribution of effort, with the majority in southern California and some near Morro Bay and Monterey Bay.

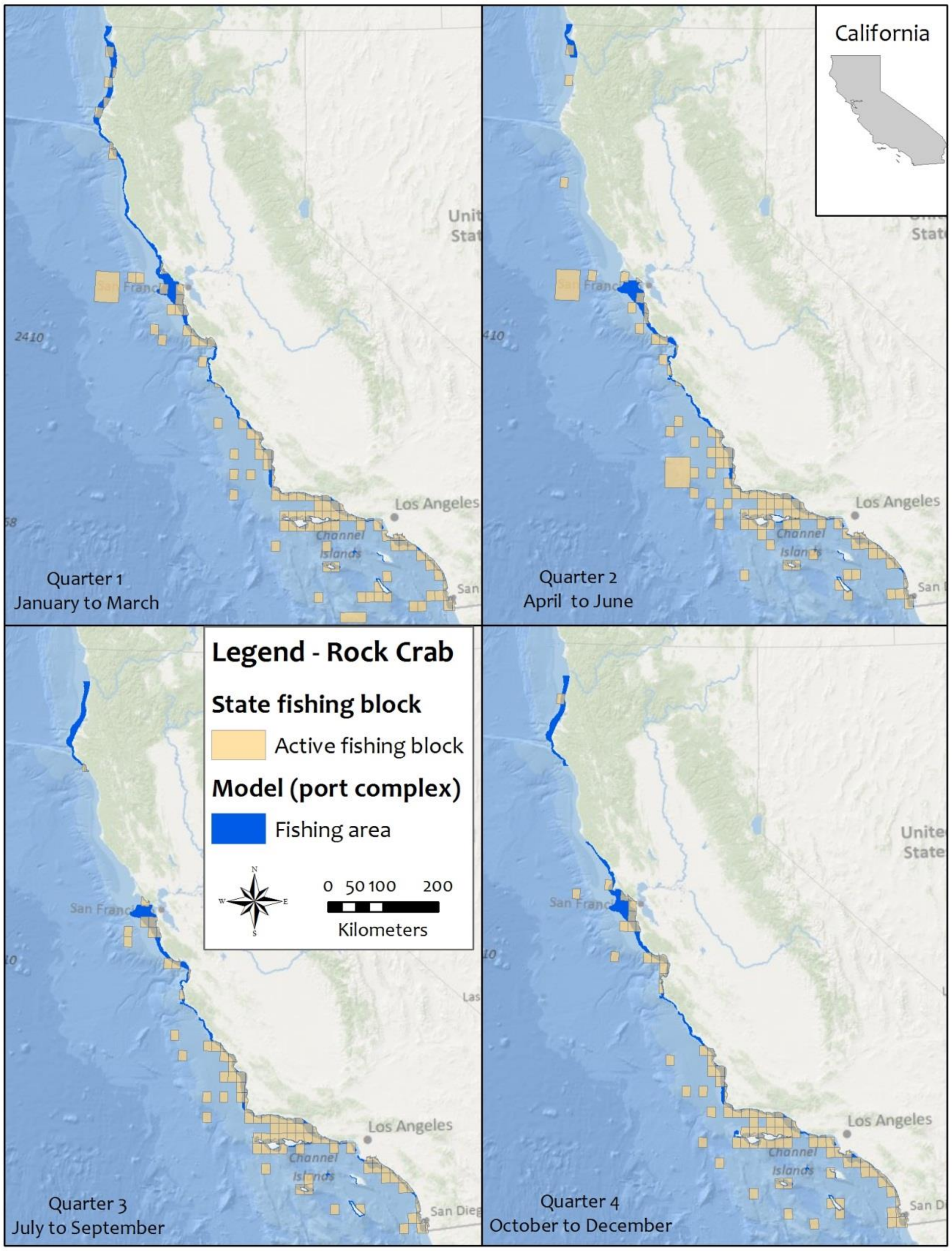


Figure 19. Comparison of modeled fishing areas with CDFW fishing block data. Orange blocks indicate that commercial landings were recorded during that quarter between 2004 and 2008. The blue areas indicate an active port complex in the fishery model during that quarter of the year.

Sablefish Longline Fishery

Characterization

There are more than 80 species of bottom dwelling finfish fish that are considered groundfish and are managed under the Pacific Coast Groundfish Fishery Management Plan adopted in 1982 (http://www.pcouncil.org/groundfish/fishery-management-plan). Sablefish (*Anoplopoma fimbria*), also referred to as black cod, comprise most of the groundfish landings caught with longline gear.

Fishermen targeting sablefish will set their longline with baited hooks attached every 3 to 4 feet in depths between 100 and 450 fathoms (Goblirsh and Theberge, 2003). Longlines are anchored at each end and marked at the surface with a large buoy, pole, flag, and radar reflector. A positively buoyant ground line is used, most likely polypropylene. A series of weights are used to sink the ground line (NMFS, 2005).A sablefish ground line can be as long as 1.5 nautical miles and contain up to 3,000 hooks (NMFS, 2005). Circle hooks, size 7/0, are common for targeting sablefish with a longline (NMFS, 2005). Since sablefish can easily become unhooked and are often victims of depredation, longlines are set for short periods of time between 4 and 6 hours (Goblirsh and Theberge, 2003).

Distribution of fishery effort – five year average from 2004 through 2008

Landings included in the fishery model for sablefish caught using longline occur throughout the year. From 2004 to 2008, Quarter 3 had the highest average landings (Figures 20 and 21). The coastal Washington (CWA) port complex group had the highest landings per quarter: 331,600 pounds in Quarter 2, followed by Newport (NPA), 250,000 pounds in Quarter 3.

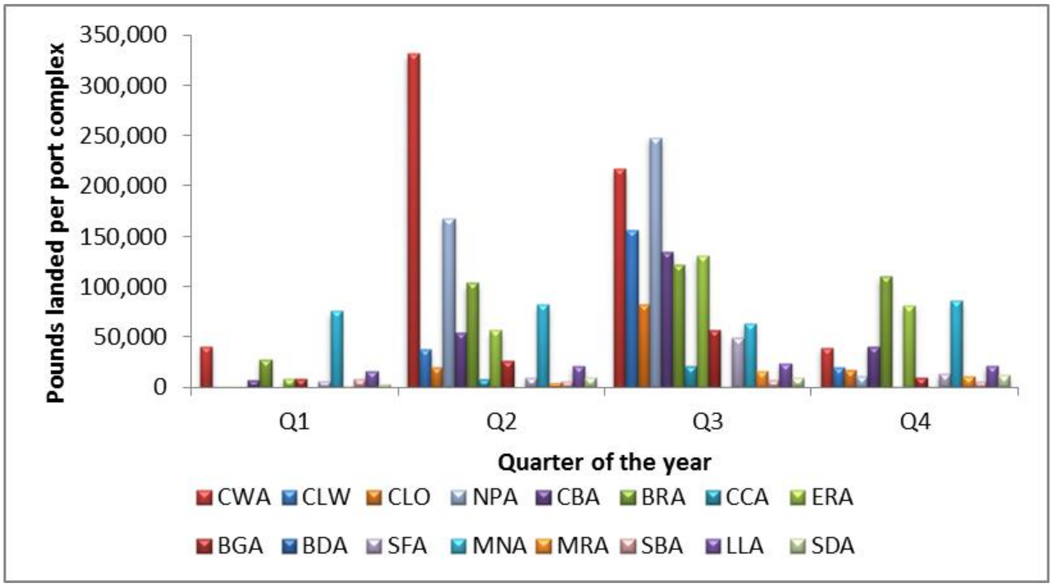


Figure 20. Average pounds of sablefish landed with longline per port complex per quarter; 2004-2008

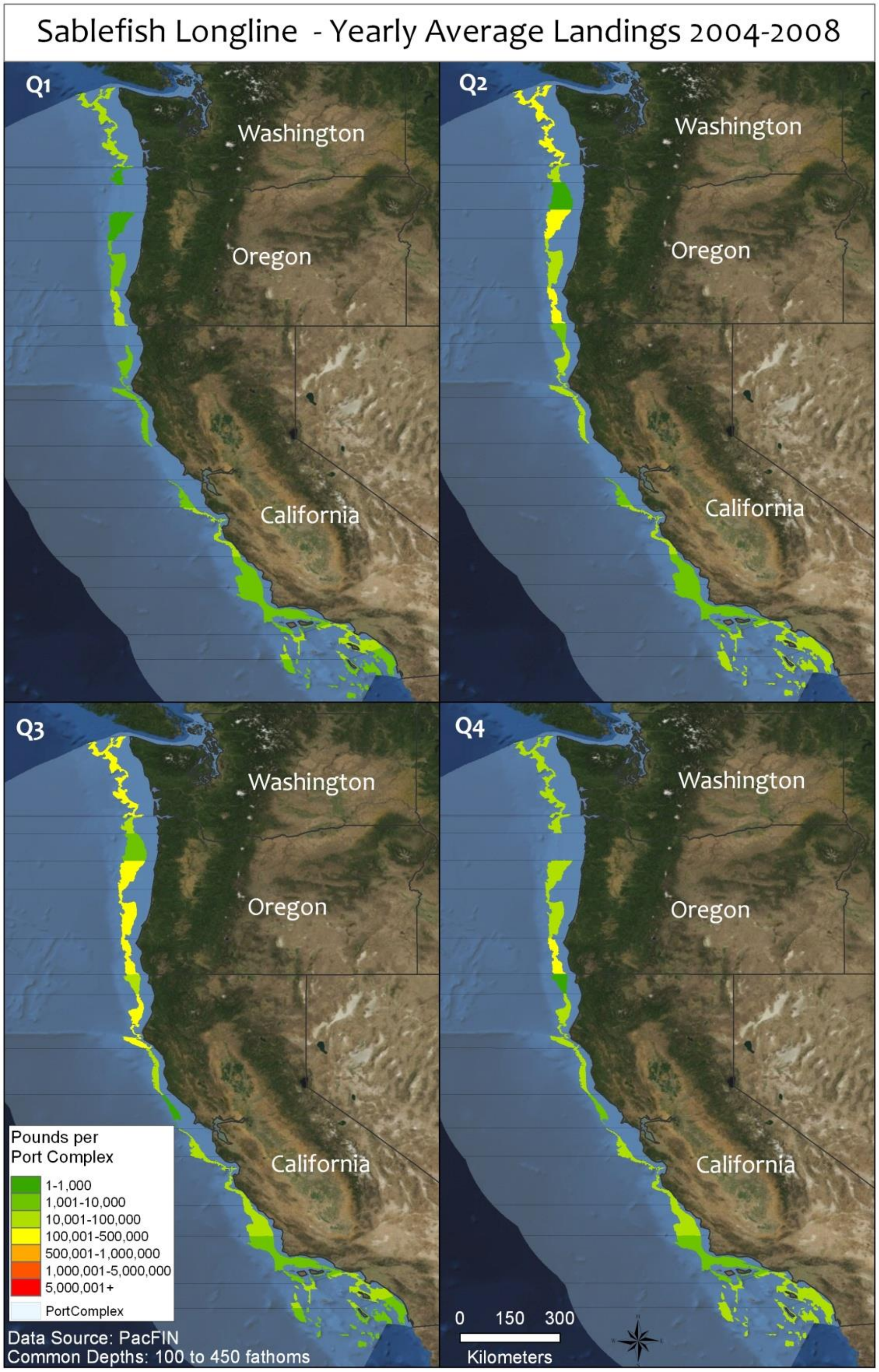


Figure 21. Sablefish longline fishery yearly average landings, indicated by the green to red colored bands, from 2004 to 2008 are shown per port complex and by quarter of the year. Fishing area within a port complex is defined by operational fishing depth range.

Comparison with California landing records

Catch location is recorded by CDFW 10x10 nautical mile catch block when sablefish, caught with a longline, are commercially landed in California. The catch blocks have a different spatial resolution than the fishery effort model. The catch blocks can show smaller concentrations of effort without regard to depth, while the fishery model can show a more accurate reflection of depth but effort is spread over a larger region. California landing data, from 2004 to 2008, was used to create a footprint of “active” catch blocks for comparison with the fishery model (Figure 22). The fishery model and state landing data show the same general distribution of effort along the coast. However there are areas where the fishery model maybe overestimating the total area actually fished, particularly around Point Conception and areas in northern California.

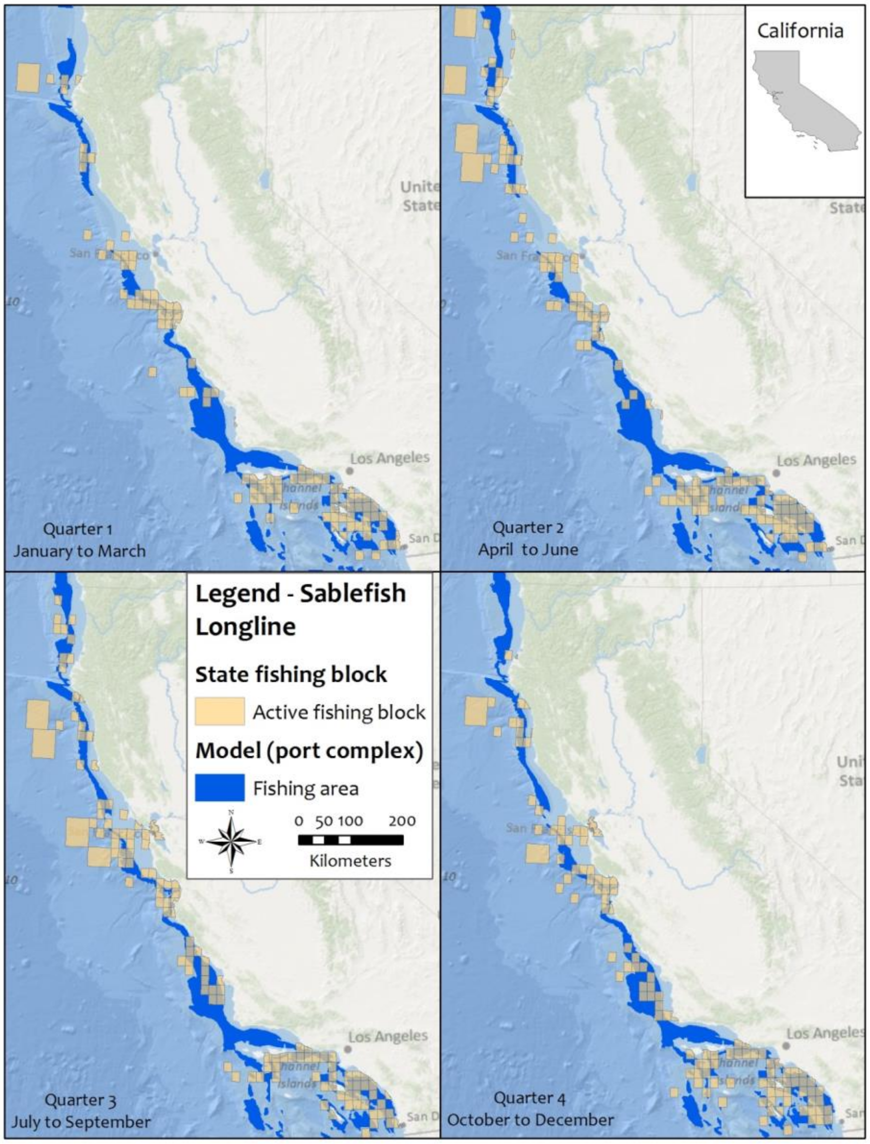


Figure 22. Comparison of modeled fishing areas with CDFW fishing block data. Orange blocks indicate that commercial landings were recorded during that quarter between 2004 and 2008. The blue areas indicate an active port complex in the fishery model during that quarter of the year.

Sablefish Trap Fishery

Characterization

Sablefish comprise most of the landings of groundfish caught with trap gear. Fishermen targeting sablefish use trapezoid, conical, or rectangular steel frame traps, wrapped with 3.5 inch nylon webbing (NMFS, 2005). Trapezoidal traps commonly weigh 55 pounds and are approximately 6 foot by 2.5 foot in size (NMFS, 2005). Conical pots weigh about the same and are 4 to 5 feet in bottom diameter. Rectangular traps are the largest, weighing up to 100 pounds and are 8 feet long by 34 inches wide (NMFS, 2005; Hipkins, 1974). Multiple traps are connected to a common ground line, usually ¾ inch nylon line. Ground line can range from 5/8 inch to 1 1/8 inch (NMFS, 2005). Traps are set as shallow as 95 fathoms and as deep as 725 fathoms, with the majority of observations occurring between 100 and 375 fathoms, which is the depth used for the fishery model. Additional smaller portions of effort have been observed between 550-700 fathoms (NMFS, 2010b). The mean observed depth of fishing for sablefish with fixed gear traps according to NMFS observer data is near 250 fathoms for all sectors/states.

Distribution of fishery effort – five year average from 2004 through 2008

Based on data collected from 2004 to 2008, landings for sablefish caught with traps were seen throughout the year with the highest average landings recorded during Quarter 3 (Figures 23 and 24). The Newport (NPA) port complex group had the highest landings per quarter, 268,000 pounds, in Quarter 3. Low effort was seen in southern California year round.

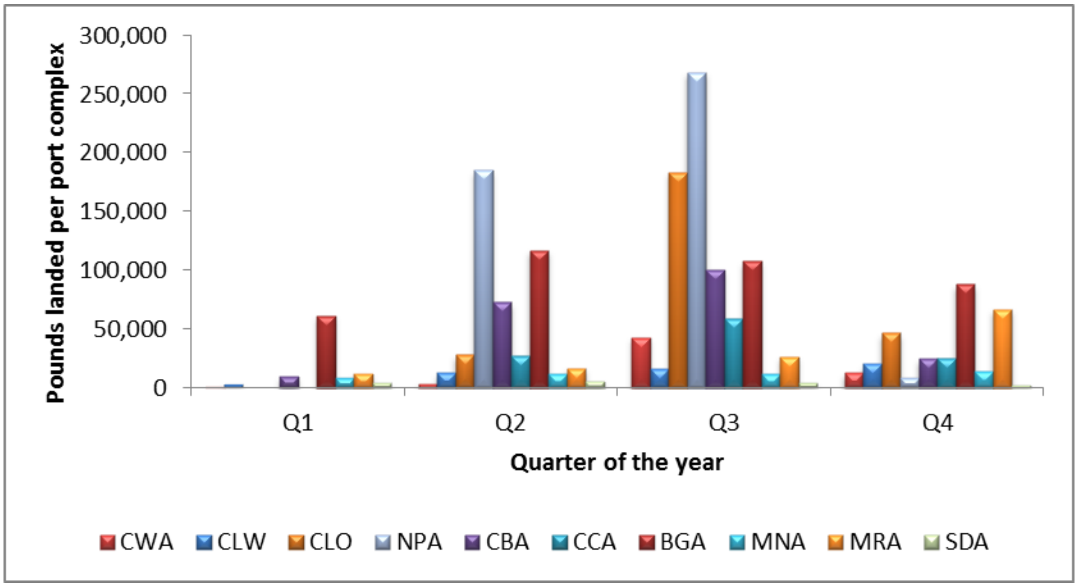


Figure 23. Average pounds of sablefish landed with traps per port complex per quarter; 2004-2008

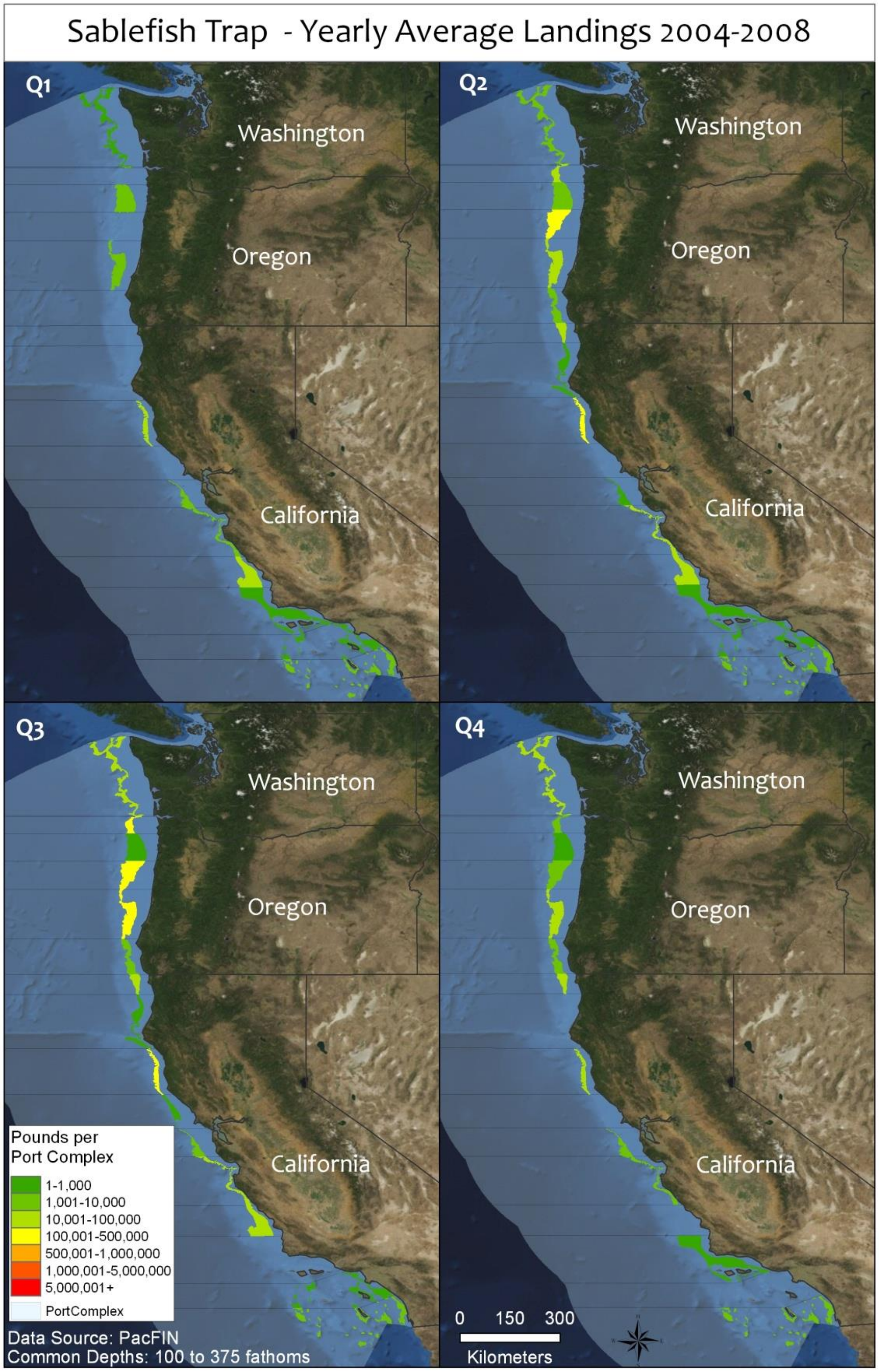


Figure 24. Sablefish trap fishery yearly average landings, indicated by the green to red colored bands, from 2004 to 2008 are shown per port complex and by quarter of the year. Fishing area within a port complex is defined by operational fishing depth range.

Comparison with California landing records

Catch location is recorded by CDFW 10x10 nautical mile catch block when sablefish, caught with traps, are commercially landed in California. The catch blocks have a different spatial resolution than the fishery effort model. The catch blocks can show smaller concentrations of effort without regard to depth, while the fishery model can show a more accurate reflection of depth but effort is spread over a larger region. California landing data, from 2004 to 2008, was used to create a footprint of "active" catch blocks for comparison with the fishery model (Figure 25). The fishery model and state landing data show the same general distribution of effort along the coast, with concentrations around Fort Bragg, San Francisco, Morro Bay, and San Diego. However there are areas where the fishery model maybe overestimating fishing areas, particularly around Point Conception, areas in northern California, and the offshore islands in southern California. Also, there are areas were the state landings data indicate effort off central and northern California outside of the common operational depth range suggesting that the fishery may be utilizing deeper fishing grounds or misreporting the location of landings.

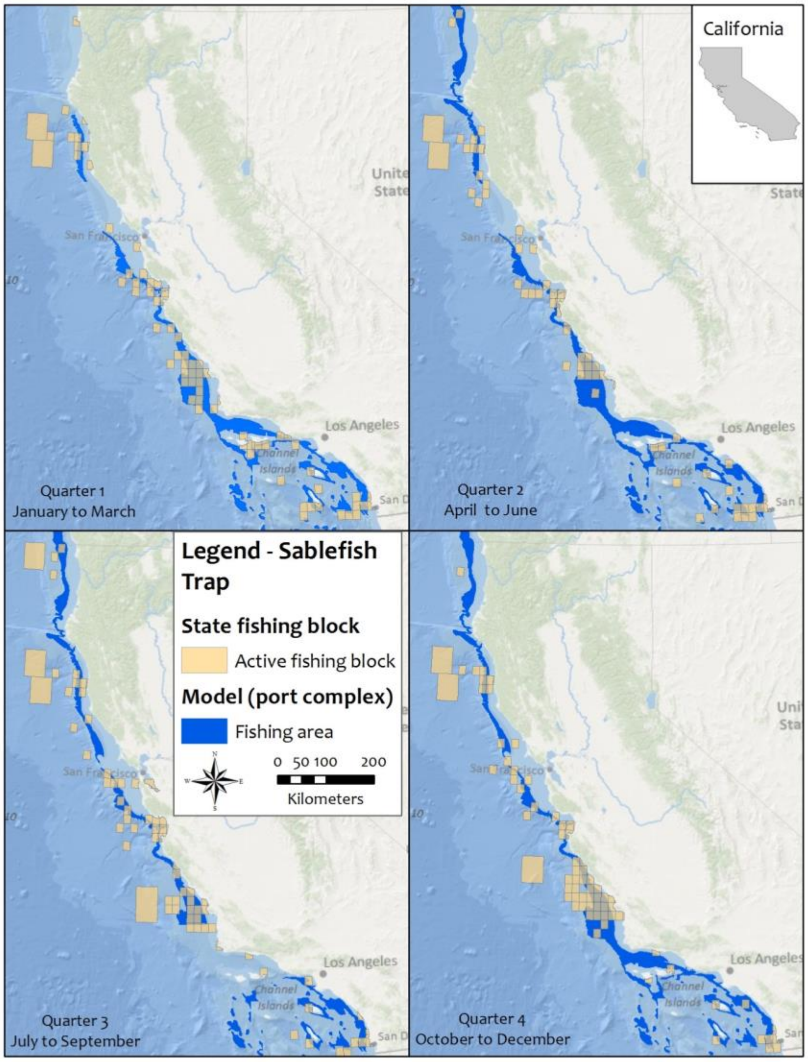


Figure 25. Comparison of modeled fishing areas with CDFW fishing block data. Orange blocks indicate that commercial landings were recorded during that quarter between 2004 and 2008. The blue areas indicate an active port complex in the fishery model during that quarter of the year.

Spiny Lobster Trap Fishery

Characterization

Commercial fishing for spiny lobster (*Panulirus interruptus*) has occurred since the late 1800s in southern California (CDFW, 2001). Landings of lobster have historically fluctuated through the years, strongly influenced by weather, El Niño and La Niña events, and the export market (CDFW, 2001). Since the 2000-01 season, total landings have averaged 660,000 pounds a season.

Traps are individually fished and have their own buoy(s). The buoy must be marked with the fisherman's commercial license number, followed by the letter "P" to signify that it is a spiny lobster trap. The first two months of the season, October and November, fishermen generally set their traps from 0 to 10 fathoms. As the season progresses, the water cools nearshore and winter storms cause lobster to move offshore (CDFW, 2001). The fishermen respond to this movement by setting their traps in deeper water, reaching 17 fathoms and occasionally deeper. Since 80% of the season's total landings are usually made before the end of January and sometimes December; some fishermen pull their traps and stop fishing at the same time (personal communication with Kristine Barsky, CDFW, Senior Biologist, January 17, 2012).

Distribution of fishery effort – five year average from 2004 through 2008

Since spiny lobster is only present in the Southern California Bight, up to Point Conception, fishing effort is limited to the Santa Barbara (SBA), Los Angeles (LLA), and San Diego (SDA) port complexes (Figures 26 and 27). The fishery only operates in Quarter 1 and Quarter 4 due to seasonal restrictions. Fishing effort is highest and closest to shore at the first half of lobster season in October to December, Quarter 4.

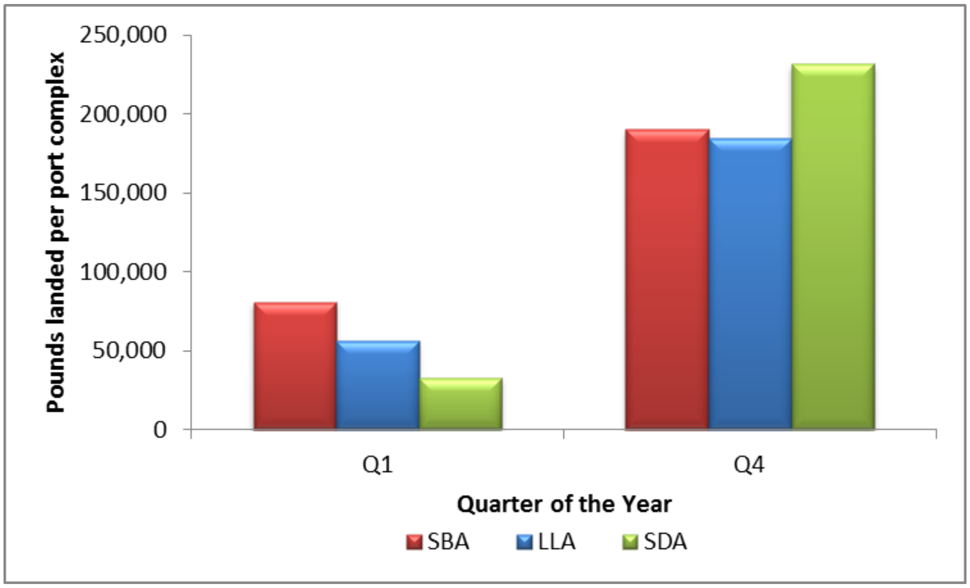
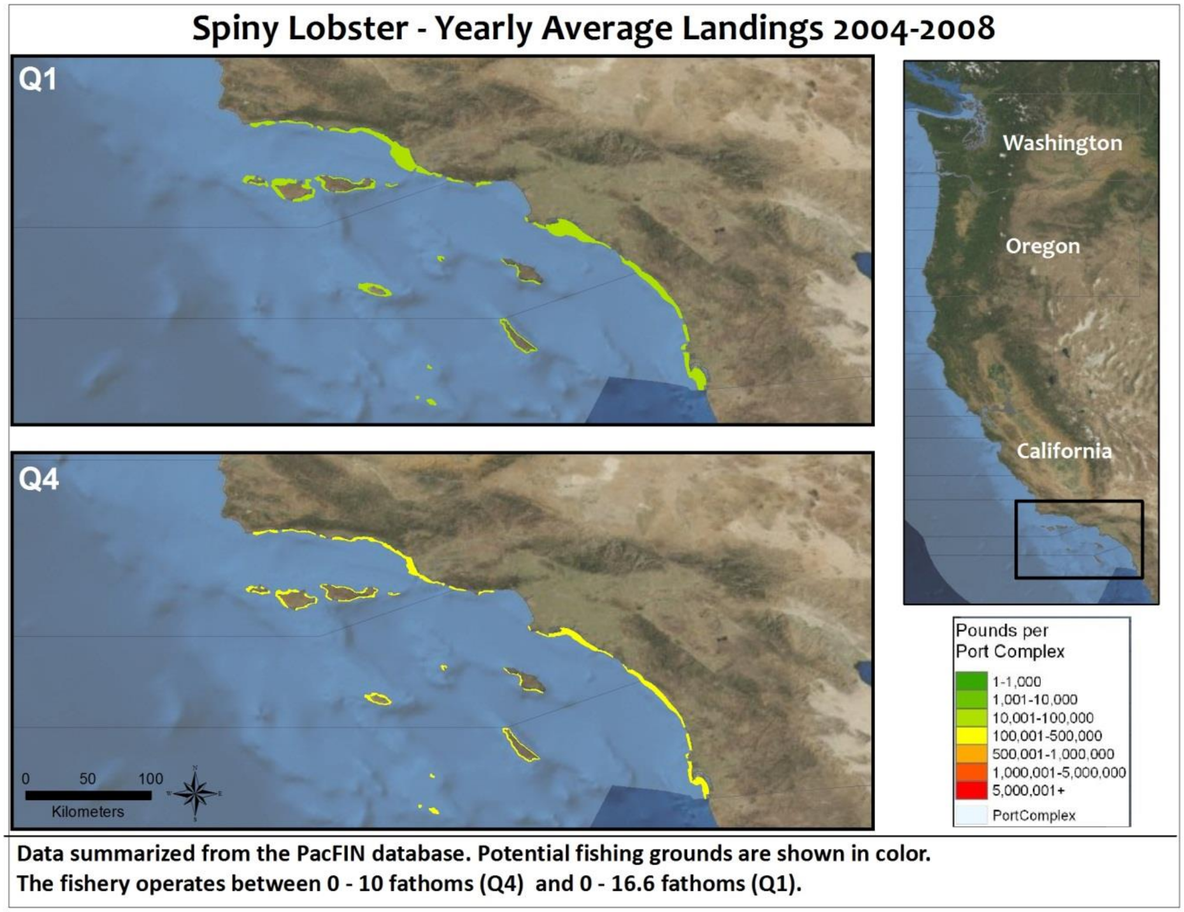


Figure 26. Average pounds of spiny lobster landed per port complex per quarter; 2004-2008



Data summarized from the PacFIN database. Potential fishing grounds are shown in color.
The fishery operates between 0 - 10 fathoms (Q4) and 0 - 16.6 fathoms (Q1).

Figure 27. Spiny lobster trap fishery yearly average landings, indicated by the green to red colored bands, from 2004 to 2008 are shown per port complex and by quarter of the year.

Comparison with California landing data

Catch location is recorded by CDFW 10x10 nautical mile catch block when spiny lobsters are commercially landed in California. California landing data, from 2004 to 2008, was averaged by quarter of year for comparison with the fishery effort model. The model and landing data show the same general distribution of effort, with concentrations nearshore and around the Channel Islands (Figure 28). The fishery model was updated for this figure to reflect the marine protected areas introduced in southern California effective January 2012.

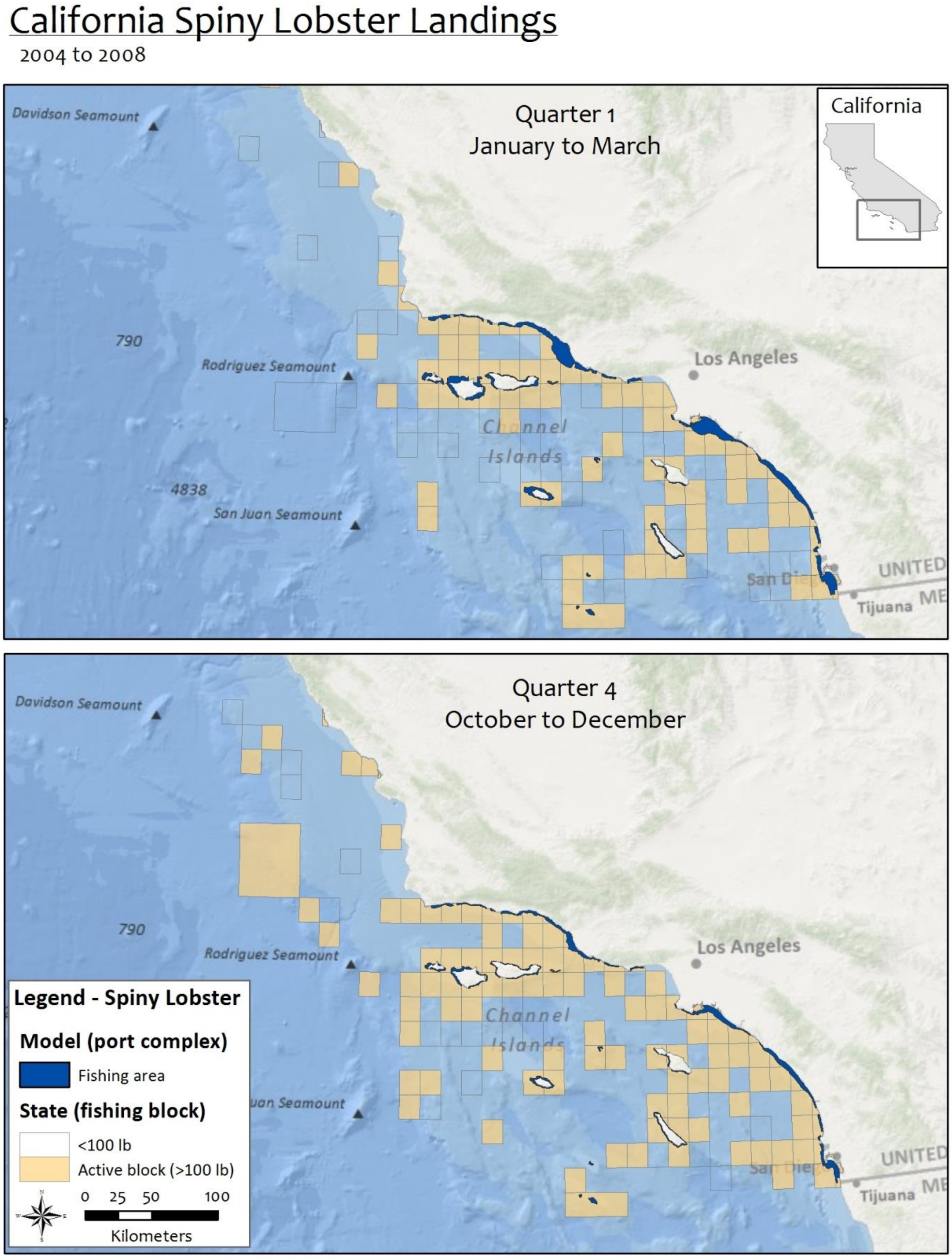


Figure 28. Comparison of modeled fishing areas with CDFW fishing block data. Orange blocks indicate that commercial landings were recorded during that quarter between 2004 and 2008. The blue areas indicate an active port complex in the fishery model during that quarter of the year.

Spot Prawn Trap Fishery

Characterization

Spot prawn (*Pandalus platyceros*) trap fishing occurs throughout California, Oregon, and Washington and is also a popular fishery in British Columbia, Canada. There are differences in the trap gear used to fish for spot prawn and depths fished in each state.

California

The California spot prawn fishery went through a dramatic change in response to a ban on trawling, implemented in 2003. Although traps were used as a fishing method for more than 20 years, the trawl fishery had been the dominant method until the trawl ban (NMFS, 2008). After the trawl ban, average spot prawn landings dropped almost 50% in 2004. Landings have increased since 2004, with an annual average of 270,000 pounds from 2006 to 2010 (personal communication with Kristine Barsky, CDFW, Senior Invertebrate Biologist, January 17, 2012). The spot prawn trap fishery operates in deep water, with traps set in waters 100 to 150 fathoms (NMFS, 2008). Strings of 10 to 30 wire mesh traps are common and must be marked on at least one end with a buoy bearing the fisherman's commercial license number (NMFS, 2010c). Usually both ends are marked with a buoy and a radar reflector.

Oregon

Oregon has a small number of well-defined areas that produce commercially harvestable densities of spot prawns. These areas are located at depths of 80 to 140 fathoms on rocky substrate. A range of 300 to 500 cord mesh conical traps are used on average and generally set 60 to 80 traps per string (personal communication with Kelly Corbett, ODFW, Marine Fisheries Biologist, April 8, 2010).

Washington

The Washington spot prawn fishery also went through a dramatic change in response to a ban on trawling implemented in 2003 (NMFS, 2008). After the ban on trawling in 2003, landings have increased each year as the fishery adjusts to the regulation change and increased use of traps for targeting spot prawns (NMFS, 2008).

Spot prawns are found on the Washington coast between 70 and 120 fathoms and most fishing is concentrated in and around off-shore canyons (Grays, Quinalt, Juan de Fuca) along the 100 fathom curve (NMFS, 2008). Over 50% of the spot prawn harvest in Washington occurs during the months of April, May, and June (NMFS, 2008). Up to 500 cord mesh conical traps can be used per permit. A typical number of traps per string are 100, with some fishermen setting two strings with 50 traps each (personal communication with Lorna Wargo, WDFW, Marine Fish Biologist, April 20, 2010).

Distribution of fishery effort – five year average from 2004 through 2008

Based on landings data from 2004 to 2008, spot prawn trap landings were highest in southern California and coastal Washington (Figures 29 and 30). Spot prawn fishing effort was low in Oregon (personal communication with Kelly Corbett, Marine Fisheries Biologist, ODFW, April 8, 2010). In California, Los Angeles (LLA), Santa Barbara (SBA), and San Diego (SDA) port complexes had the majority of landings. Favorable spot prawn trapping area in central

California is much more limited and is concentrated around Monterey Bay (MNA) (personal communication with Kristine Barsky, CDFW, Senior Biologist, January 17, 2012). Quarter 2 had the highest average landings of spot prawn with 109,700 pounds summed across all port complex groups.

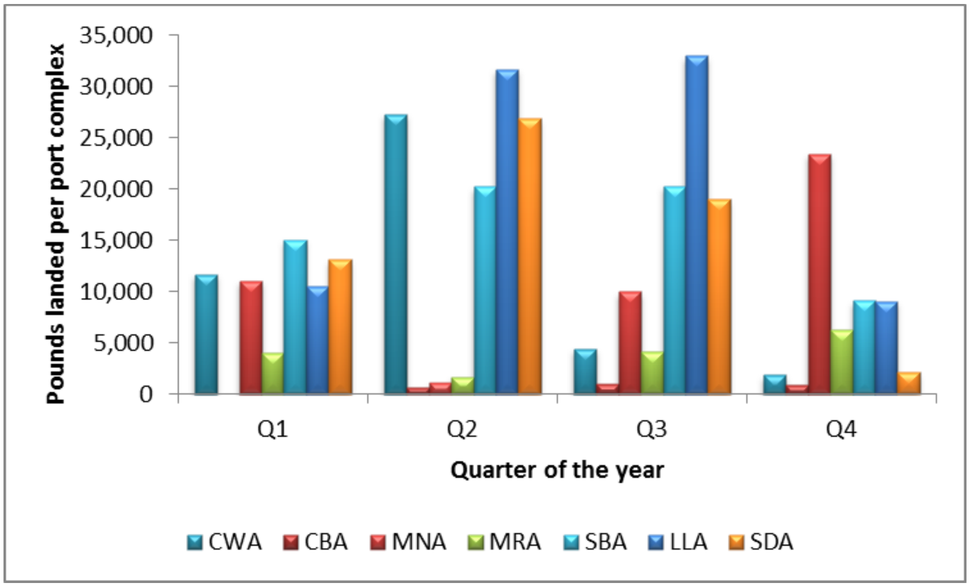


Figure 29. Average pounds of spot prawn landed per port complex per quarter; 2004-2008

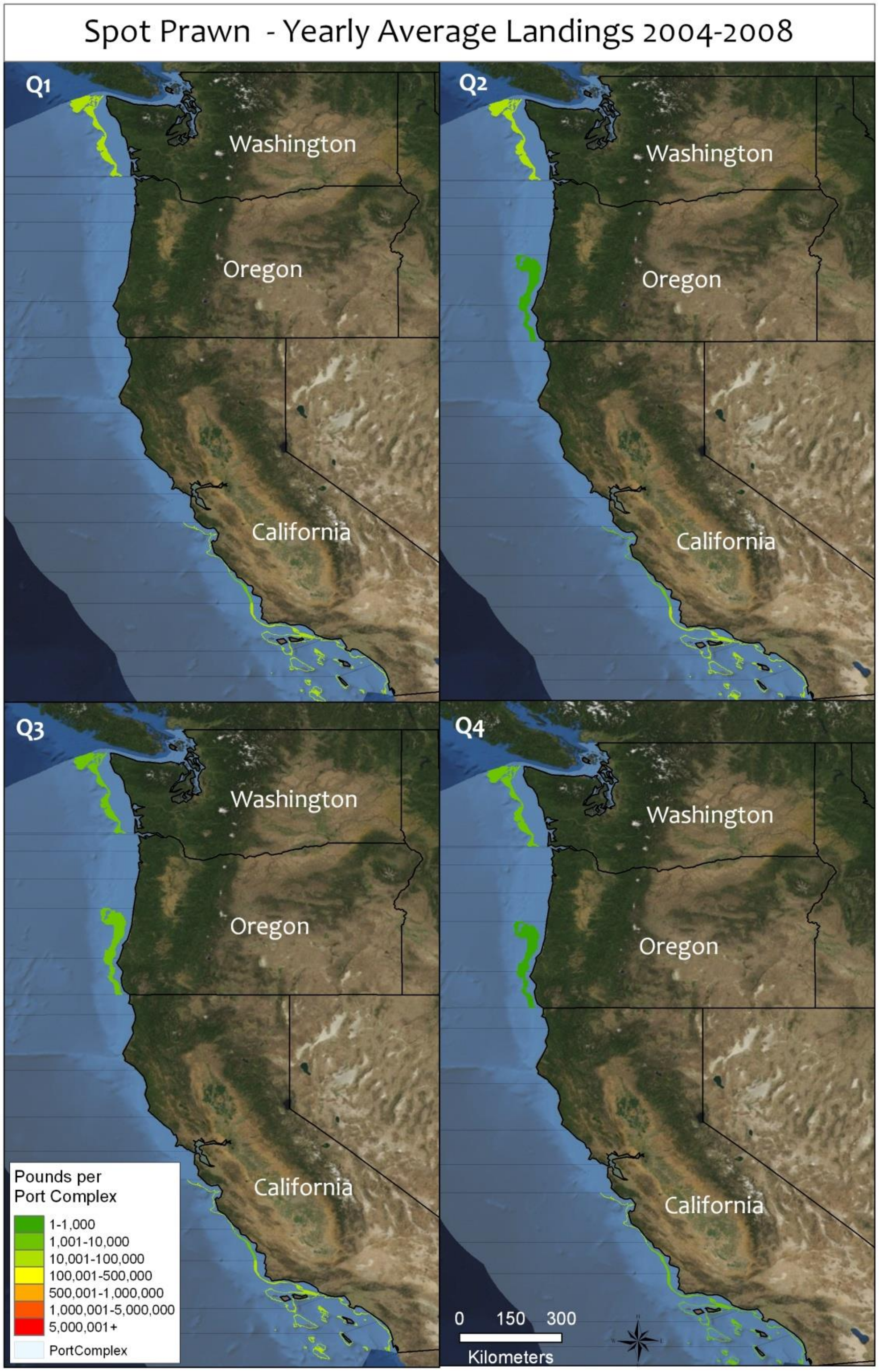


Figure 30. Spot prawn trap fishery yearly average landings, indicated by the green to red colored bands, from 2004 to 2008 are shown per port complex and by quarter of the year. Fishing area within a port complex is defined by operational fishing depth range. * Oregon landings (BRA and CBA port complexes) were combined to preserve confidentiality.

Comparison with California landing records

Catch location is recorded by CDFW 10x10 nautical mile catch block when spot prawns are commercially landed in California. The catch blocks have a different spatial resolution than the fishery effort model. The catch blocks can show smaller concentrations of effort without regard to depth, while the fishery model can show a more accurate reflection of depth but effort is spread over the larger port complex region. California landing data, from 2004 to 2008, was averaged by quarter of year for comparison with the fishery model. The fishery model and state landing data show the same general distribution of effort, with the majority in southern California and Monterey Bay area (Figure 31). However, the state data shows that effort is more concentrated when compared to the fishing area. There are portions of the modeled fishing area that do not overlap with active catch blocks, indicating that using the entire operational depth range, as used by the fishing model, may be overestimating fishing areas. The differences could be explained by a lack of suitable habitat and subsequent lack of fishing effort for spot prawn in the non-overlapping areas.

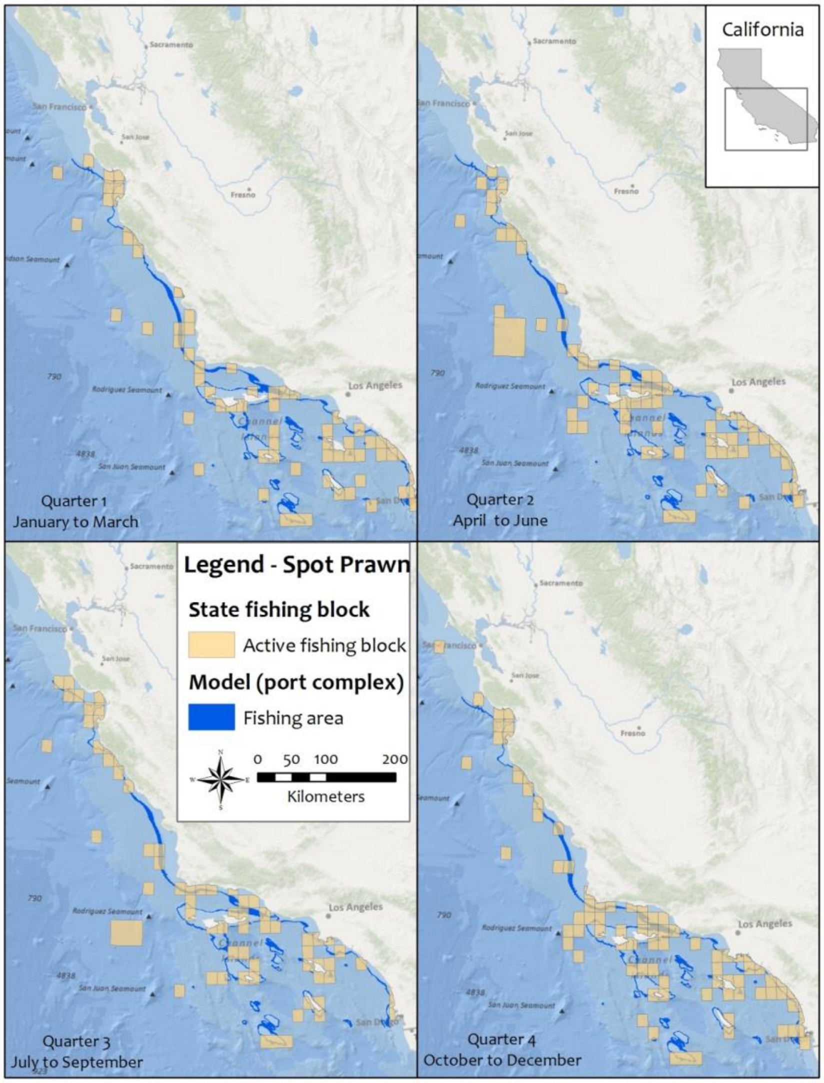


Figure 31. Comparison of modeled fishing areas with CDFW fishing block data. Orange blocks indicate that commercial landings were recorded during that quarter between 2004 and 2008. The blue areas indicate an active port complex in the fishery model during that quarter of the year.

2.3 Other Fisheries

There are other species caught with fixed gear along the west coast of the United States that were not included, for various reasons, in the fishery characterization above.

Rockfish caught with gillnet

Rockfish are occasionally targeted with deep set small mesh drift (personal communication from Dale Sweetnam, CDFW, Senior Marine Biologist, February 14, 2011). The California regulations are very stringent and restrict the area where gillnets are allowed. Take of rockfish using gillnets is allowed past varying depths, ranging from 40 to 100 plus fathoms, depending on which region of the State the fishermen are operating. The minimum mesh size for targeting rockfish is 4.5 inches. Since the small mesh drift gillnet fishing method of targeting rockfish is not "set" or anchored to the bottom, it was not included in the fishery characterization.

Rockfish caught with vertical longline

In addition to trap, gillnet, and bottom longline, rockfish are also caught using vertical longline, also called "stick gear". This gear type consists of a surface buoy connected to monofilament line with hooks attached at regular intervals. The line is weighted at the bottom. Fish are attracted to the baited hooks when the line jiggles due to wind and wave movement (CSC, 2011). This fishing method is used in California, Oregon, and Washington, most commonly in southern California and Oregon (NMFS, 2005). The number of participants did not meet the confidentiality threshold (at least three fishermen); therefore the fishery was not included in the characterization.

Nearshore live finfish in Oregon

Oregon has a fishery that targets black and blue rockfish as well as other nearshore finfish, similar to the nearshore live fish fishery operating in California. A maximum of 35 traps are allowed per "Black rockfish/Blue rockfish/Nearshore Fishery" Developmental Fisheries permit (OAR 635-004-0160). The fixed gear fleet typically fishes in shallow waters, less than 30 fathoms. The fishery is restricted by minimum size limits for many nearshore species as well as the groundfish FMP's two month cumulative trip limits and annual landing restrictions (NWFSC, 2012). The number of pounds landed and number of landings for the trap fishery did not meet the confidentiality threshold; therefore the fishery was not included in the characterization above. The nearshore live finfish fishery is primarily driven by hook and line fishermen.

Sheep Crab caught with traps

Sheep crab (*Loxorhynchus grandis*) are caught mostly as bycatch and therefore were not included in this document. However, when sheep crab is targeted, effort is mainly seen in the Santa Barbara Channel and the northern Channel Islands (CDFW, 2001). Landings of live sheep crab are recorded in port complexes from Morro Bay through San Diego, California. Modified rock crab and spiny lobster traps, with larger openings, are used to catch sheep crab in waters ranging from 5 to 40 fathoms depth (CDFW, 2001). The crabs are caught in deeper waters during the fall and winter months (CDFW, 2001). Set gillnet fishermen also record landings of sheep crab, mainly in the form of claws, since the crab cannot easily be removed from the net without pulling off the legs.

Box Crab caught with traps

Landings of box crab *(Lopholithodes foraminatus*) have been historically reported throughout California, Oregon, and Washington; however, recent catch levels are very minimal. In the time period from 2004 to 2008, the maximum landing of box crab caught using a trap in a single quarter of the year was 300 pounds. Port complexes reporting landings of box crab include Bodega Bay, Coos Bay, Los Angeles, Santa Barbara, San Diego, and San Francisco. Commercial landings of box crab are allowed as incidental take in the Dungeness crab fishery in California. Box crabs are also taken incidentally in the trawl fisheries. In Oregon, commercial take of box crab is only allowed using rings, pots, and crab longline gear. Oregon also restricts box crab fishing shoreward of the 40-fathom line and from November 1st until the opening of the next ocean Dungeness crab season in the area. Washington does not currently allow commercial landing of box crab. Since the catch level is minimal, this fishery was not included in the fishery characterization above.

2.4 Fishery model limitations

Fishery landings were used to represent effort in the fishery model to ensure that the data was consistent for all fisheries. Availability of more specific information from other sources was variable, including logbooks and fish tickets. Since the majority of fisheries included in the fishery model are state fisheries, no federal observer data was available for these fisheries, except set gillnet. NMFS acknowledges that landings may not the best measure of effort and could be misleading. Within a given fishery, the relative average catch per trap fished (catch per effort) could vary significantly depending on the time of year and the location being fished. Additionally, landings are only reflective of successful catch and do not capture effort where gear is set and is unsuccessful. Across different fisheries, comparisons of landings are problematic based on variable weights and expectations for catch per effort for different target species, making it more difficult to compare effort targeted at smaller species, such as shrimp, with larger fish, such as halibut. Effort is traditionally measured by the number of traps in trap fisheries, soak time for gillnets, and number of hooks for longline. However, for this exercise, this information was generally not available for the fisheries included in the model.

The fishery model represents “active” fishing effort since it is based on landings data reported to a port during a specific time frame. The model does not capture effort of recreational fisheries or derelict gear, although both can entangle large whales.

Using only landings may not represent the true level of effort in the fisheries. For example, the Dungeness crab fishery had the highest landings from 2004 to 2008, with 84% of the average pounds considered in this analysis. However, Dungeness crab might not necessarily account for 84% of total effort or gear in the water when using this characterization for co-occurrence modeling. Other trap fisheries like sablefish, rock crab, and spiny lobster may not have the highest landings, but have potentially larger number of traps in the water, given different fishing styles.

Although landing data was consistent across all fisheries and states, there were limitations to the use and processing of the data. Landings were averaged over 5-year time frames in an effort to capture seasonal patterns. However, management changes affecting effort, including trap limit implementation, might not be captured in the large time frame. A network of marine reserves in California state waters, implemented through the California Marine Life Protection Act, will likely affect the spatial distribution of commercial fishing effort in the future because commercial fishing is prohibited within the reserve (Appendix D).

Breaking the data into quarters of the year was useful for capturing inter-annual variability, but some fishing seasons did not align with the quarter break down. For example, the Dungeness crab fishery season does not open till mid-November in California and December in Oregon and Washington. Quarter 4 spans October to December, therefore Quarter 4 Dungeness crab fishing appears to be active across the U.S. west coast during October and early November.

Landing data were mapped geographically using potential fishing areas defined by common operational depths and were assigned across an entire port complex. Using common fishing depth ranges to map fishery effort is similar to the approach used for habitat suitability modeling (NCCOS, 2005). However, not all fishing area within the operational depth is utilized by the fishery, as suggested when state logbook data is compared with the model outputs. Future models of fixed gear commercial fishing effort should consider the incorporation of habitat data, such as substrate type, to further refine predicted fishing areas.

The major assumption of our approach is that the fishermen made their catch in the fishing area within their port complex where the fish was landed. This method does not account for fishermen who leave their port complex but return to land their fish in their “home” port complex. The model assumes equal chance that the fish landed were caught across all operational fishing depths within a port complex. Therefore, the model may be representing effort in areas that are not fished for a variety of reasons including, those areas may not be suitable habitat for the target species.

3.0 Co-occurrence of Large Whales and Fixed Commercial Fishing Gear: United States West Coast

3.1 Methods

3.1.1 Fishery Model: Commercial fisheries with fixed gear

Patterns of fixed gear commercial fishery effort for the U.S. west coast were modeled by combining port-based fishery landing data, in pounds, with depth-defined potential fishing areas. Generally, each fixed gear fishery sets gear at a range of different depths, which allows for definition of fishing areas for each fishery based on common minimum and maximum depths. Fishing effort was averaged over a five year time frame, from 2004 to 2008, and split by quarter of the year to account for seasonal and inter-annual variability. The fishery model includes 11 fixed gear commercial fisheries: 8 trap/pot fisheries, 2 bottom-set longline, and 1 set gillnet fishery. Fisheries considered in the model were: California halibut/white seabass set gillnet, California nearshore live finfish trap, coonstripe shrimp trap, Dungeness crab trap, hagfish trap, Pacific halibut bottom-set longline, rock crab trap, sablefish longline, sablefish trap, spiny lobster trap, and spot prawn trap. Fishing effort represented in the fishery model, for both state and federally managed fisheries, was derived from landings data obtained through the Pacific Fisheries Information Network, known as PacFIN. The summed quarterly fishing effort for all eleven of these fisheries used in the co-occurrence model can be seen in Figure 32. See Section 2.0 for more details on the methods and fishery-specific fishery effort model results.

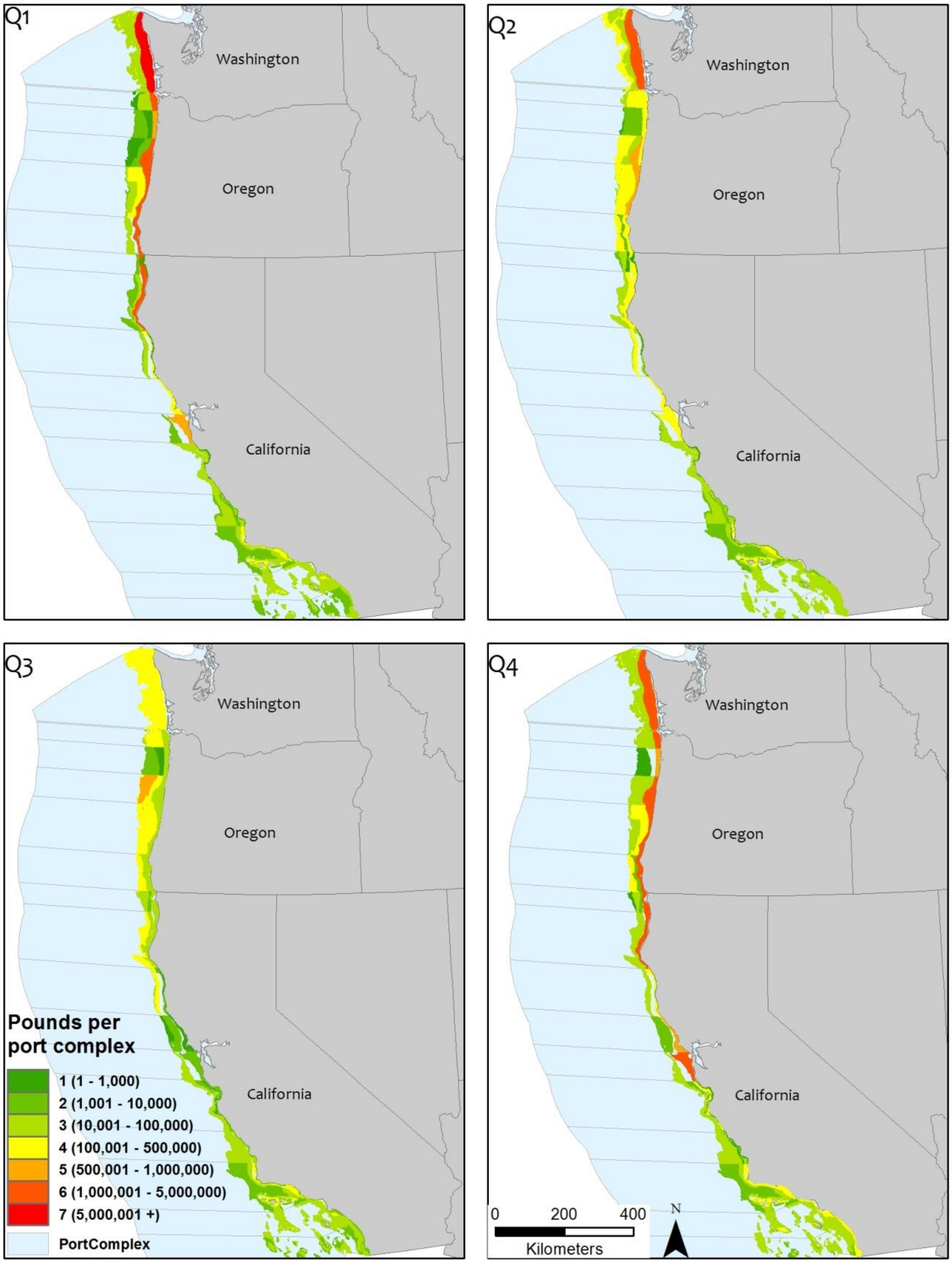


Figure 32. Annual average of pounds landed by active fishermen summed across all 11 fixed gear fisheries considered in this analysis (bottom-set longline, set gillnet, trap/pot) per port complex, per quarter, from 2004 through 2008. The scale is green to red, where red represents the highest fishing effort per port complex.

3.1.2. Whale Density Models

Two data sources were used to represent whale density and distribution in the co-occurrence model as described below.

<u>Blue, fin, humpback, and sperm whale habitat-based density model</u>

We used estimates of cetacean density and distribution based on habitat models for a study area extending from the U.S. west coast out to approximately 300 nautical miles offshore. Becker *et al.,* (2012) used data from six systematic ship-based cetacean and ecosystem assessment surveys conducted in summer and fall of 1991–2008 to build habitat-based density models for multiple species, including blue, fin, humpback, and sperm whales. Minke whale density was not available, therefore they were not included, despite the fact that minke whales have been documented entangled off the U.S. west coast. Generalized additive models were used to predict cetacean densities from habitat variables that included remotely sensed measures of sea surface temperature (SST) and the standard deviation of SST (to serve as a proxy for frontal regions); sea surface salinity (SSL), mixed layer depth (MLD; the depth at which temperature is 0.5ºC less than SST), and sea surface chlorophyll (CHL) collected *in situ* during the surveys; and water depth, bathymetric slope, and distance to the 2,000m isobath (Becker *et al.*, 2012). Predicted whale densities for each of the six individual years (1991, 1993, 1996, 2001, 2005, and 2008) were smoothed and then averaged to produce a composite grid, resolution of approximately 25 km^2, which represents the best estimate of average cetacean density and distribution over the past 20 years. Further details of these models can be found in Becker *et al.* (2012). The predicted multi-year average cetacean densities (number of animals per km^2) for blues, fins, humpback, and sperm whales were used in our analyses.

Similar to the classification of fishery landings into a broad ranging scale (see Section 2.0), an index score of whale density was created based on estimated whale density (Table 3). The species specific summer/fall density values were classified and given a score value ranging from 1-to-7 using the Natural Breaks[1] method in ArcGIS. The scaling allows for assessment and comparison of co-occurrence and associated entanglement risk amongst various fisheries for each of the four whale species and stocks considered in this analysis. The multi-year average whale density maps, from Becker *et al.* (2012), used in the co-occurrence model can be seen in Figure 33. The estimated whale densities associated with the scaled index varies by species, which limits the ability to draw direct comparisons of entanglement risk by species based purely on co-occurrence scores.

---

[1] A method of manual data classification that seeks to partition data into classes based on natural groups in the data distribution. Natural breaks occur in the histogram at the low points of valleys. Breaks are assigned in the order of the size of the valleys, with the largest valley being assigned the first natural break. (ESRI GIS dictionary)

Table 3. Range of estimated whale densities associated with scaled index for blue, fin, humpback, and sperm whales. Densities given per km^2 and 25x25km block (equal to 625km^2).

Whale species	Score	Density (per km2)	Density (per 25x25 km block)
Blue	1	0.0001525 – 0.0008646	0.0954 - 0.5404
	2	0.0008647 – 0.001853	0.5405 - 1.1585
	3	0.001854 – 0.003079	1.1586 - 1.9496
	4	0.003080 – 0.004464	1.9497 - 2.8149
	5	0.004465 – 0.005967	2.8150 - 3.7791
	6	0.005968 – 0.007470	3.7792 - 4.7186
	7	0.007471 – 0.010230	4.7187 - 6.3997
Fin	1	0.0003936 – 0.001690	0.2460 - 1.0566
	2	0.001691 – 0.003039	1.0567 - 1.9321
	3	0.003040 – 0.004855	1.9322 - 3.0669
	4	0.004856 – 0.006826	3.0670 - 4.2990
	5	0.006827 – 0.008849	4.2991 - 5.5960
	6	0.008850 – 0.01102	5.5961 - 6.9253
	7	0.01103 – 0.013622	6.9264 - 8.5141
Humpback	1	0.00001 - 0.0006138	0.0013 - 0.3837
	2	0.0006139-0.001837	0.3838 - 1.1484
	3	0.001838 - 0.003333	1.1485 - 2.0405
	4	0.003334 - 0.005032	2.0406 - 3.0176
	5	0.005033 - 0.007479	3.0177 - 4.3346
	6	0.007480 - 0.0109	4.3347 - 6.2882
	7	0.0110 - 0.0173	6.2883 - 10.8345
Sperm	1	0.0002636 – 0.0005187	0.1647 - 0.3242
	2	0.0005188 – 0.0007975	0.3243 - 0.5021
	3	0.0007976 – 0.001028	0.5022 - 0.6431
	4	0.001029 – 0.001177	0.6432 - 0.7357
	5	0.00178 – 0.001313	0.7358 - 0.8210
	6	0.001314 – 0.001467	0.8211 - 0.9174
	7	0.001468 – 0.001776	0.9175 - 1.1102

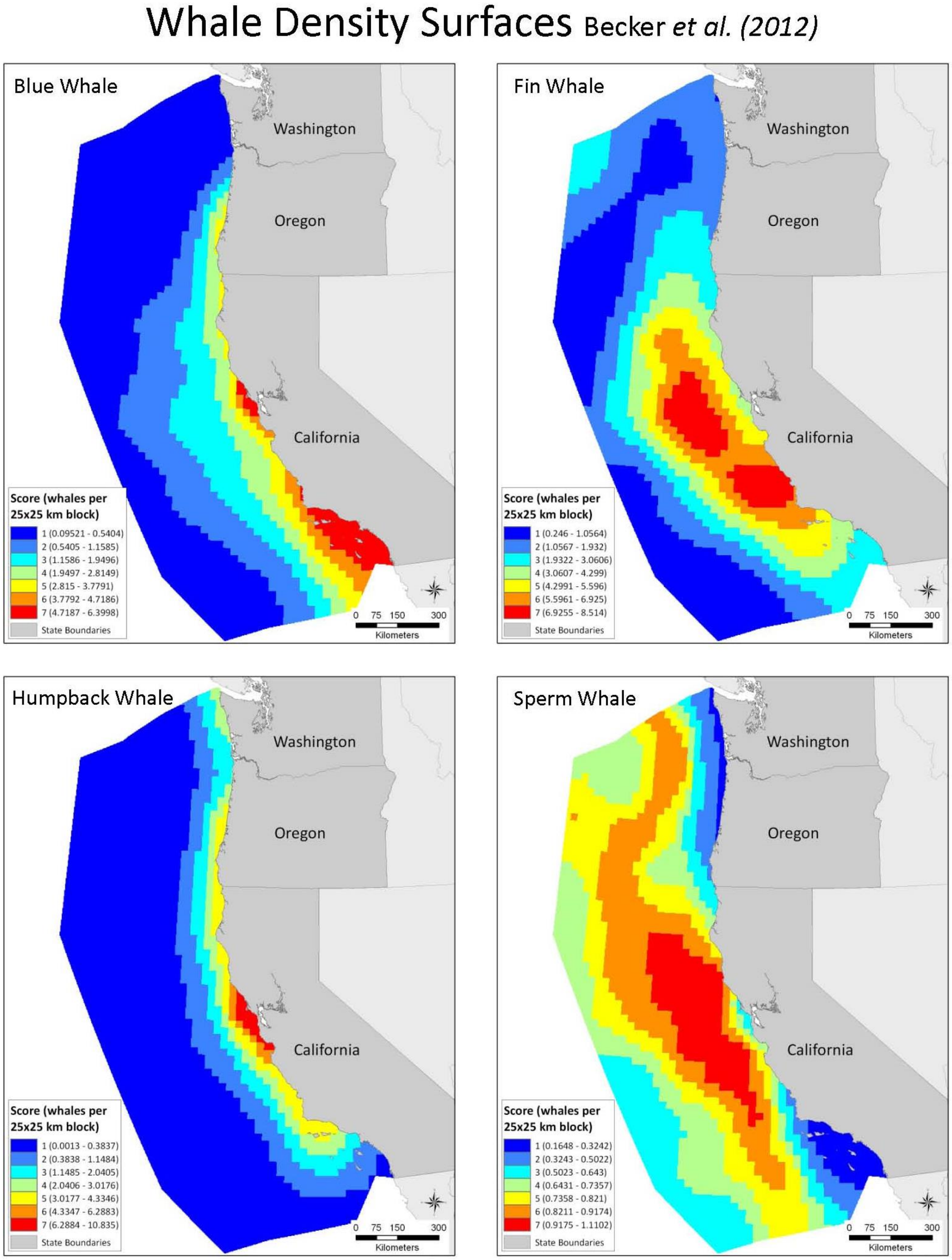


Figure 33. Multi-year average whale density maps for blue, fin, humpback, and sperm whales (recreated using data from Becker *et al.*, 2012). The density values unique to each species have been scaled, per 625km^2 blocks, from 1-to-7 corresponding to the blue to red color range, with blue representing the lowest density (1) and red representing the highest density (7) for that species. Note the density values associated with the scaled values in the legend are not equivalent between species.

Gray whales migration density model

Gray whale entanglements are of concern since they are historically the most reported entangled large whale species off the U.S. west coast (Saez *et al.*, in prep). Density models had not been generated for gray whales prior to this current analysis. Therefore, a basic method of quantifying their migration patterns and densities was created to assess entanglement risk (Figure 34). Full details of the gray whale migration model can be found in DeAngelis *et al.* (in prep) and DeAngelis *et al.* (2011). Data is available for download at www.cetsound.noaa.gov.

Gray whales migrate annually from their Arctic summer feeding grounds to winter breeding grounds in Baja California, Mexico. The migration corridors used by most gray whales are within 10 kilometers (6 miles) of the U.S. west coast, with the exception of southern California where migration paths include routes around the offshore islands. Daily whale counts and estimated migration speeds from land-based field stations were combined with satellite telemetry data to produce the gray whale model.

Gray whale migration can be loosely categorized into three phases: Southbound, Northbound Phase A, and Northbound Phase B. The Southbound phase includes animals of multiple life stages as they make their way south to the lagoons in Mexico. Northbound Phase A consists of mainly adults and juveniles that are among the first to leave Mexico on their northbound journey. Cow/calf pairs generally begin their northward migration later, referred to as Northbound Phase B. The three phases are not always distinct. For example, some whales may still be traveling south while others are already heading north. This can result in overlap of phases, which adds to the complexity of the model.

Migration corridors were created based on distance from shore for each phase then split into geographic segments representing 24 hour travel distance. The distance traveled per 24 hour period was based on average swim speed for whales in each phase, derived from satellite telemetry. The major assumption is that the gray whales are traveling within the migration corridor at the average speed outlined for their phase. Low densities of gray whales are expected from 10 km up to 47 km from shore but were not included in the co-occurrence model.

From a single field station, the observed number of migrating gray whales per day over time follows a pattern similar to a normal distribution; slowly increasing from a single animal per day to a one to two day peak, varying by migration phase and year, then slowly tapering. A true density estimate for the migration was calculated using the most recent population abundance estimate of 19,126 gray whales (Laake *et al.*, 2009). The daily density values, in whales per km^2, were averaged over 1-month time periods then given an index score from 1-to-7, with 7 being the peak monthly whale density (Table 4). The monthly average gray whale density maps used in the co-occurrence model can be seen in Figure 3.

We did not analyze the presence of non-migratory animals outside of the typical migrating season. There is a smaller subset of the gray whale population known to feed between northern California and Vancouver Islands during the summer month, referred to as the Pacific Coast Feeding Group (IWC, 2011). Gray whales from the Western North Pacific (WNP) stock were recently confirmed (Lang *et al*. 2010; Weller *et al.* 2012) to overlap with the Eastern North Pacific (ENP) stock's range along the U.S. west coast that was included in the gray whale model;

however, we assumed any gray whale migrating was an ENP for the purposes of this model. The WNP gray whale stock is endangered and numbers on the U.S. west coast are likely low.

Table 4. Range of estimated whale densities associated with scaled index for gray whales

Score	**Density (gray whales per km^2)**
1	0.0001 – 0.0191
2	0.0192 – 0.0383
3	0.0384 – 0.0805
4	0.0806 – 0.1457
5	0.1458 – 0.2798
6	0.2799 – 0.4064
7	0.4065 – 0.9777

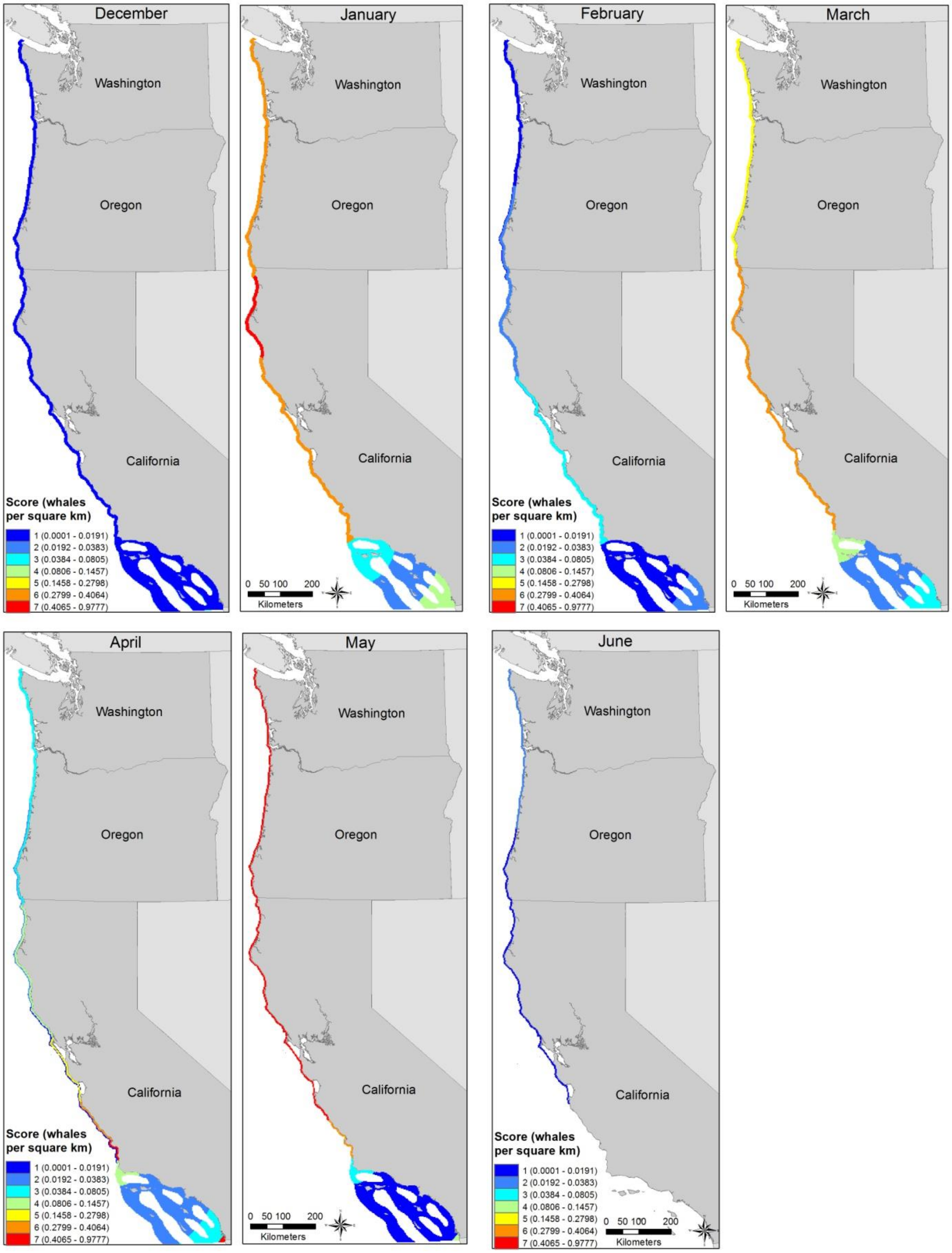


Figure 34. **Gray whale migration model maps showing average whale density per month. The monthly density values, per km^2, have been scaled from 1-to-7 corresponding to the blue to red color range, with blue representing the lowest density (1) and red representing the highest density (7) for that species. Note the density values associated with the scaled values in the legend, also in Table 2.**

3.1.3 Co-occurrence Model

Density surface maps for blue, fin, humpback and sperm whale (Becker *et al.,* 2012) and predictions from the gray whale migration model (DeAngelis *et al.,* in prep) were used to represent whale presence for combination with relative patterns in estimated seasonal fishing activity to assess areas of co-occurrence. An inherent assumption of the co-occurrence model is that entanglement risk is linearly related to the level of co-occurrence, i.e., higher densities of effort/gear associated with and in areas of higher densities of specific whale species results in a higher entanglement risk. The comparative likelihood of different gear types entangling whales (e.g., a single line with a trap versus a set gillnets) was not considered in this analysis. To identify locations where whales may be more likely to become entangled, we overlaid the predicted density of animals with the estimated amount of fishing effort (as represented by landings) over specific time periods. Although the fishery model outputs aligned well with available state and federal fishing effort data, some differences were found as outlined in Section 2.0; therefore, co-occurrence model results were also compared with the available data sources on a per-fishery basis.

A "co-occurrence score" was calculated using two different methods to account for the two different sources of whale density described above: 1) for blue, fin, humpback and sperm whales, commercial fishing effort was multiplied with the predicted whale densities for each known quarter of the year, based on available ship-based survey data; and 2) for gray whales commercial fishing effort by quarter was multiplied with the scaled monthly densities from the migration model. Since both the whale density and fishing effort values were scaled from 0 to 7, possible co-occurrence scores are a result of multiplying the scores together and thus ranged from 0-49.

For blue, fin, humpback, and sperm whales, scaled fishery landing data, per port complex as a proxy for effort, and whale density estimates for individual species were multiplied (Equation 1). When combined, it was possible to create a relative index of co-occurrence and entanglement risk for the individual species over three month quarterly time periods per fishery. Density estimates for blue, fin, humpback, and sperm whales were only available for summer and fall. Although fishing data was available for all four fishing quarters, we were limited in our analyses by the seasonality of the available whale data. Therefore the co-occurrence of these species was only modeled with Quarter Three (July to September) and Quarter Four (October to December) fishing effort multiplied by a single density map for each species that represents both Quarters.

Equation 1: *Commercial fishery effort (by Quarter) x Whale density (July to November Average) = Score*

Co-occurrence scores were calculated for a) individual whale species density and all fixed gear fishery effort combined, and b) individual whale density and individual effort for each of the 11 fixed gear fisheries covered in this analysis. A visual walk through of the co-occurrence model can be found in Appendix E.

For gray whales, scaled quarterly fishery landing data and predicted monthly densities from the gray whale migration model were multiplied (Equation 2).

Equation 2: *Commercial fishery effort (by Quarter) x Whale density (monthly average) = Score*

Although the gray whale migration phases (Southbound, Northbound A, and Northbound B) each last approximately a month and a half, there are fluctuations in gray whale density along the coast within these phases. Thus aggregating to the three-month quarterly time scale for comparison with fishing effort would mask important variations in whale presence. Therefore monthly average whale densities were compared to the corresponding fishing effort represented by quarter. Gray whales are generally found in the study region between late December and June; therefore co-occurrence values were only calculated for Quarter One, Quarter Two, and for December of Quarter Four. Gray whale densities in December were overlaid with the aggregate three-month Quarter Four, January to March densities were overlaid with Quarter One, and April to June densities were overlaid with Quarter Two fishing effort.

Co-occurrence scores were calculated for gray whale monthly densities with all fixed gear fishery effort and also separately for each of the 11 fixed gear fisheries. An intersect analysis was also performed between potential fishing area and each gray whale migration path using ArcMap, to provide insight on the percentage of the potential commercial fishing grounds for given fisheries that overlap with the U.S. west coast gray whale migration corridor. Uncertainty regarding the actual fishing area used, noted in Section 2.0, could affect this part of the analysis for some of the modeled fisheries.

3.2 Co-occurrence Model Results

3.2.1 Summer/Fall co-occurrence model results

Entanglement risk for blue, fin, humpback, and sperm whales with fixed gear commercial fisheries, based on co-occurrence model results, was present during summer (Quarter Three) and fall (Quarter Four) throughout the U.S. west coast out to 80 kilometers offshore. Generally speaking, fixed gear fisheries do not operate further offshore than 80 km, since they are typically restricted to depths more commonly associated with shelf and slope waters. Full page maps of all co-occurrence model results can be found in Appendix F.

Blue whales

An assessment of the entanglement risk to blue whales from a combination of all 11 fixed gear fisheries yielded the highest risk occurs in the coastal waters near San Francisco (co-occurrence scores of 35 and 42) (Figure 35). The next highest risk scores were also in Quarter Four in nearshore southern California, Eureka, Crescent City, Coos Bay, and Newport (score of 30). The highest co-occurrence scores for blue whales in Quarter Three were in nearshore southern California (scores of 21 and 28). The risk areas align with higher predicted summer/fall densities of blue whales: near San Francisco Bay and a wide band throughout southern California (south of Point Conception) extending out to the offshore islands (Figure 33).

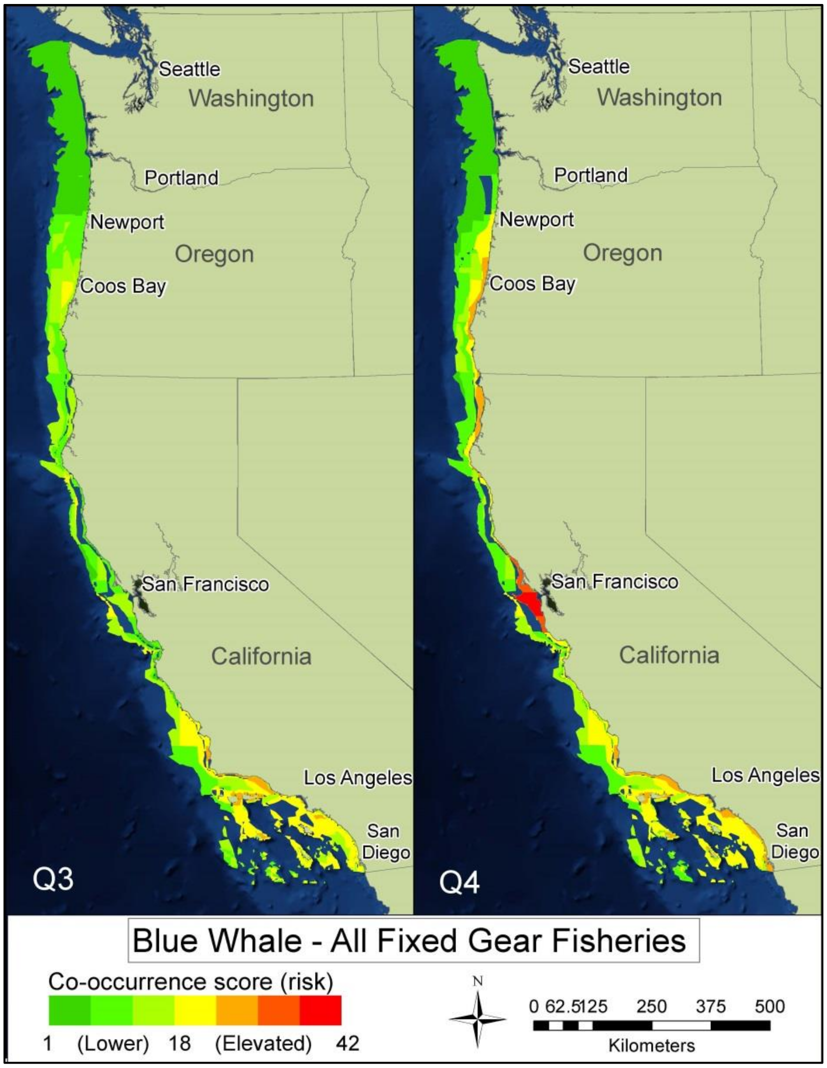


Figure 35. Co-occurrence of the multi-year average blue whale density and fishing effort for all 11 fisheries shown for Quarter Three and Four.

An assessment of the risk of individual fixed gear fisheries on blue whales showed that the highest risk was with the Dungeness crab fishery in Quarter Four (Table 5). The co-occurrence score of 42 was a result of a blue whale density score of 7 near San Francisco multiplied with a fishery effort score of 6. California halibut/white seabass set gillnet and rock crab trap had the next highest co-occurrence scores, 28, during Quarter Three near Santa Barbara in addition to the spiny lobster trap fishery throughout southern California in Quarter Four (Figures 36 and 37).

Table 5. Entanglement risk for blue whales, by fishery, ranked by peak co-occurrence score, and location of risk.

Rank	**Fishery name**	**Peak score**	**Quarter**	**Area**
1	Dungeness crab	42	Q4	San Francisco, Bodega Bay
2	California halibut/white seabass set gillnet	28	Q3	Santa Barbara
2	Rock crab trap	28	Q3, Q4	Santa Barbara
2	Spiny lobster	28	Q4	Santa Barbara
5	Hagfish trap	21	Q3, Q4	Santa Barbara
5	Sablefish longline	21	Q3, Q4	Santa Barbara to San Diego
5	Spot prawn trap	21	Q3	Santa Barbara to San Diego
8	Sablefish trap	20	Q3	Fort Bragg
9	Coonstripe shrimp trap	15	Q3	Crescent City
9	Pacific halibut longline	15	Q3	Coos Bay
11	California nearshore live finfish trap	14	Q3, Q4	Morro Bay to San Diego

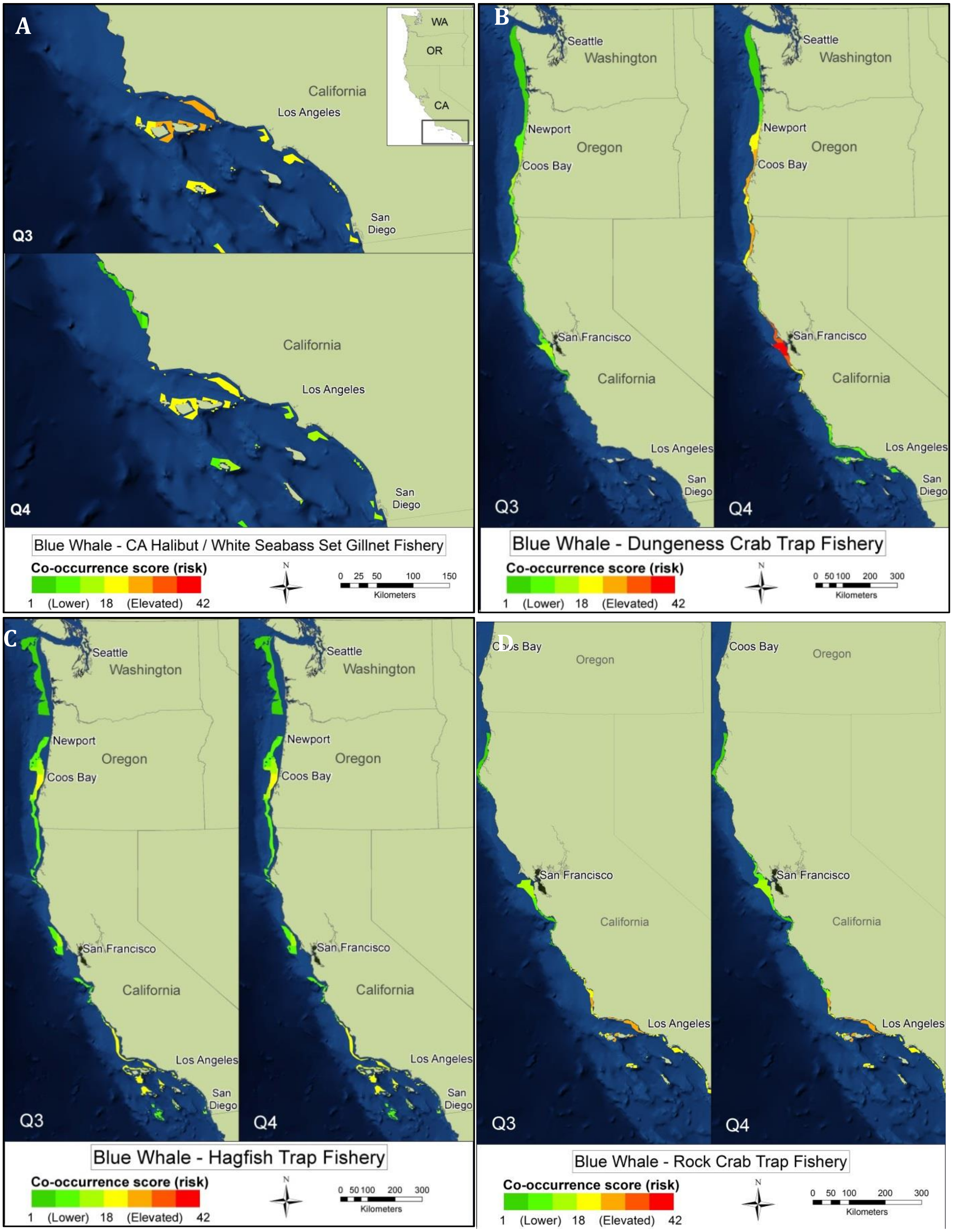


Figure 36. Co-occurrence of the multi-year average blue whale density and: A. California halibut/white seabass set gillnet, B. Dungeness crab trap, C. hagfish trap, and D. rock crab trap effort, shown for Quarter Three and Four.

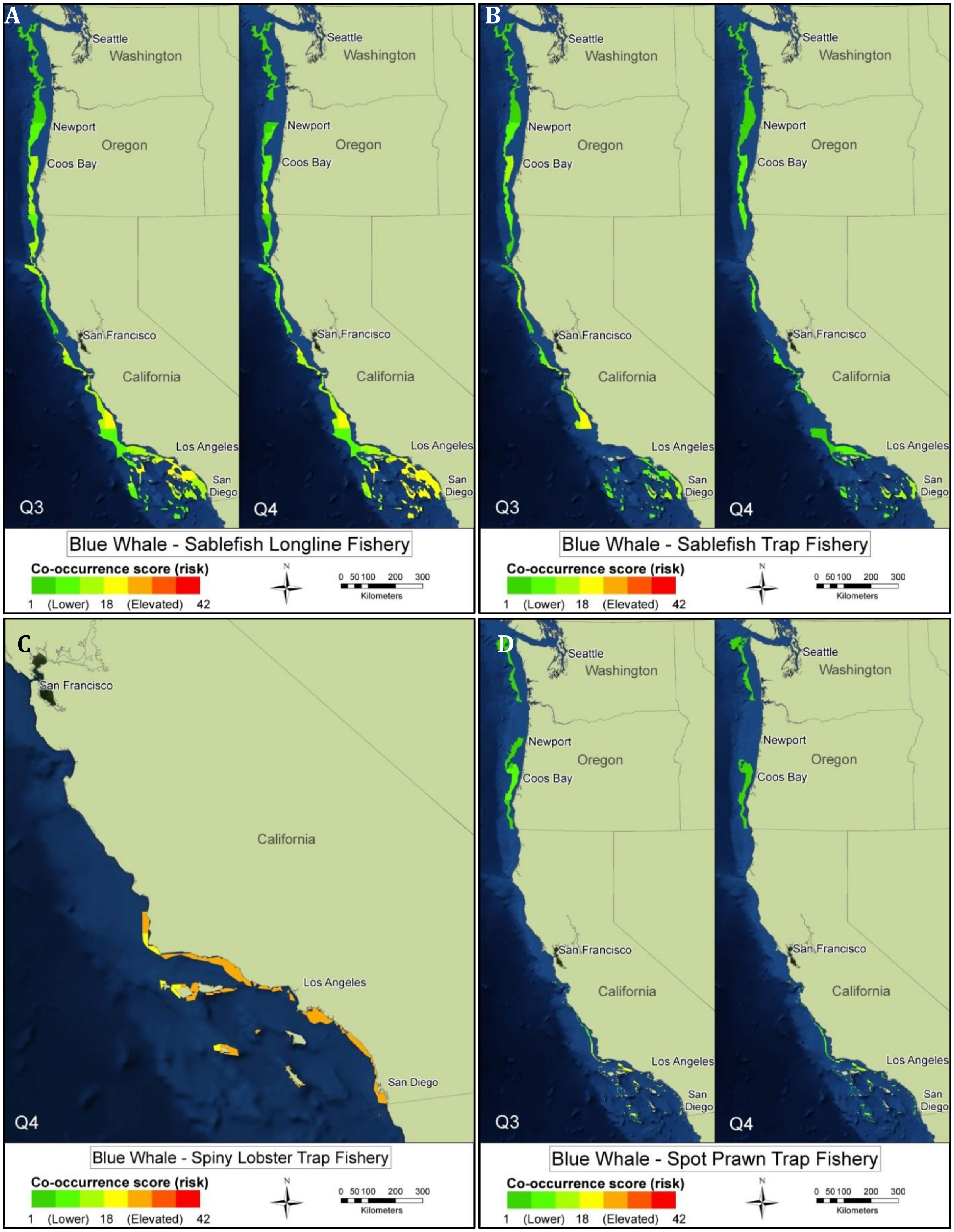


Figure 37. **Co-occurrence of the multi-year average blue whale density and: A. sablefish longline, B. sablefish trap, C. Spiny lobster trap, and D. spot prawn trap effort, shown for Quarter Three and Four.**

Fin whales

An assessment of the entanglement risk to fin whales from a combination of all 11 fixed gear fisheries yielded high co-occurrence scores in an area from Santa Barbara through Monterey in Quarter Three (co-occurrence scores up to 21) and Santa Barbara through San Francisco in Quarter Four (scores up to 30) (Figure 38). The entanglement risk areas align with the highest predicted summer/fall densities of fin whales off central and north central California (Figure 33). There was also an area of higher risk from Eureka to southern Oregon in Quarter Four (score of 21). Higher co-occurrence score areas were mostly coastal with the exception of an area offshore area Morro Bay in Quarter Three and Quarter Four. Mid-range co-occurrence scores were seen throughout most of the co-occurrence score areas in Quarter Four.

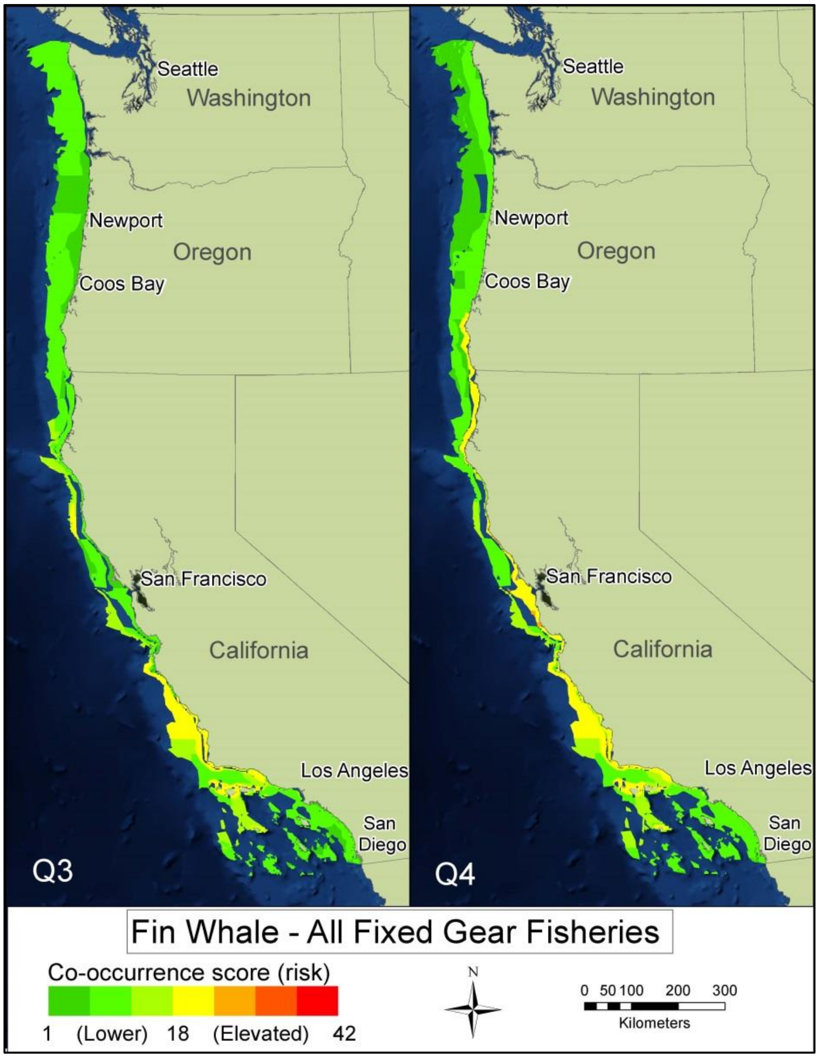


Figure 38. Co-occurrence of the multi-year average fin whale density and fishing effort for all 11 fisheries shown for Quarter three and four.

With respect to individual fisheries, Dungeness crab fishery was the highest risk for fin whales in an area between Monterey and San Francisco, California in Quarter Four (Table 6). The co-occurrence score of 30 was a result of a fin whale density score of 6 multiplied with a fishery effort score of 5. Other than Dungeness crab, the fixed gear fisheries with the highest co-occurrence scores, 24, with fin whales were: California halibut/white seabass set gillnet, rock crab trap, and spiny lobster trap in southern California (Figures 39 and 40).

Table 6. Entanglement risk for fin whales, by fishery, ranked by peak co-occurrence score and location of risk.

Rank	Fishery name	Peak score	Quarter	Area
1	Dungeness crab	30	Q4	San Francisco, and Monterey
2	California halibut/white seabass set gillnet	24	Q3	Santa Barbara
2	Rock crab trap	24	Q3, Q4	Morro Bay and Santa Barbara
2	Spiny lobster	24	Q4	Santa Barbara
2	Spot prawn trap	24	Q3	Santa Barbara through Monterey
6	Hagfish trap	21	Q3, Q4	Morro Bay
6	Sablefish longline	21	Q3, Q4	Morro Bay
6	Sablefish trap	21	Q3	Morro Bay
9	California nearshore live finfish trap	14	Q3	Morro Bay
10	Coonstripe shrimp trap	9	Q3	Crescent City
10	Pacific halibut longline	9	Q3	Coos Bay

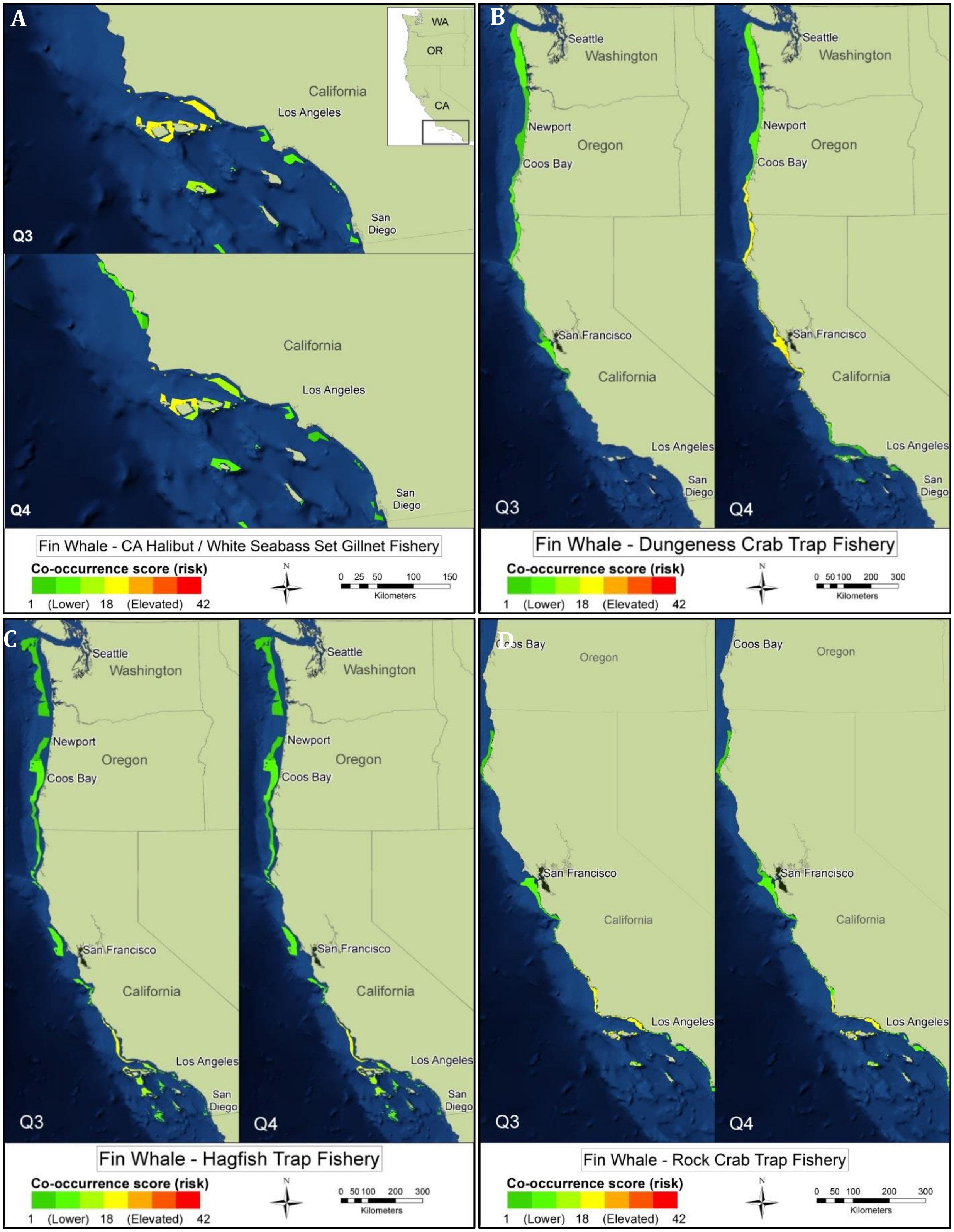


Figure 39. Co-occurrence of the multi-year average fin whale density and: A. California halibut/white seabass set gillnet, B. Dungeness crab trap, C. hagfish trap, and D. rock crab trap effort, shown for Quarter Three and Four.

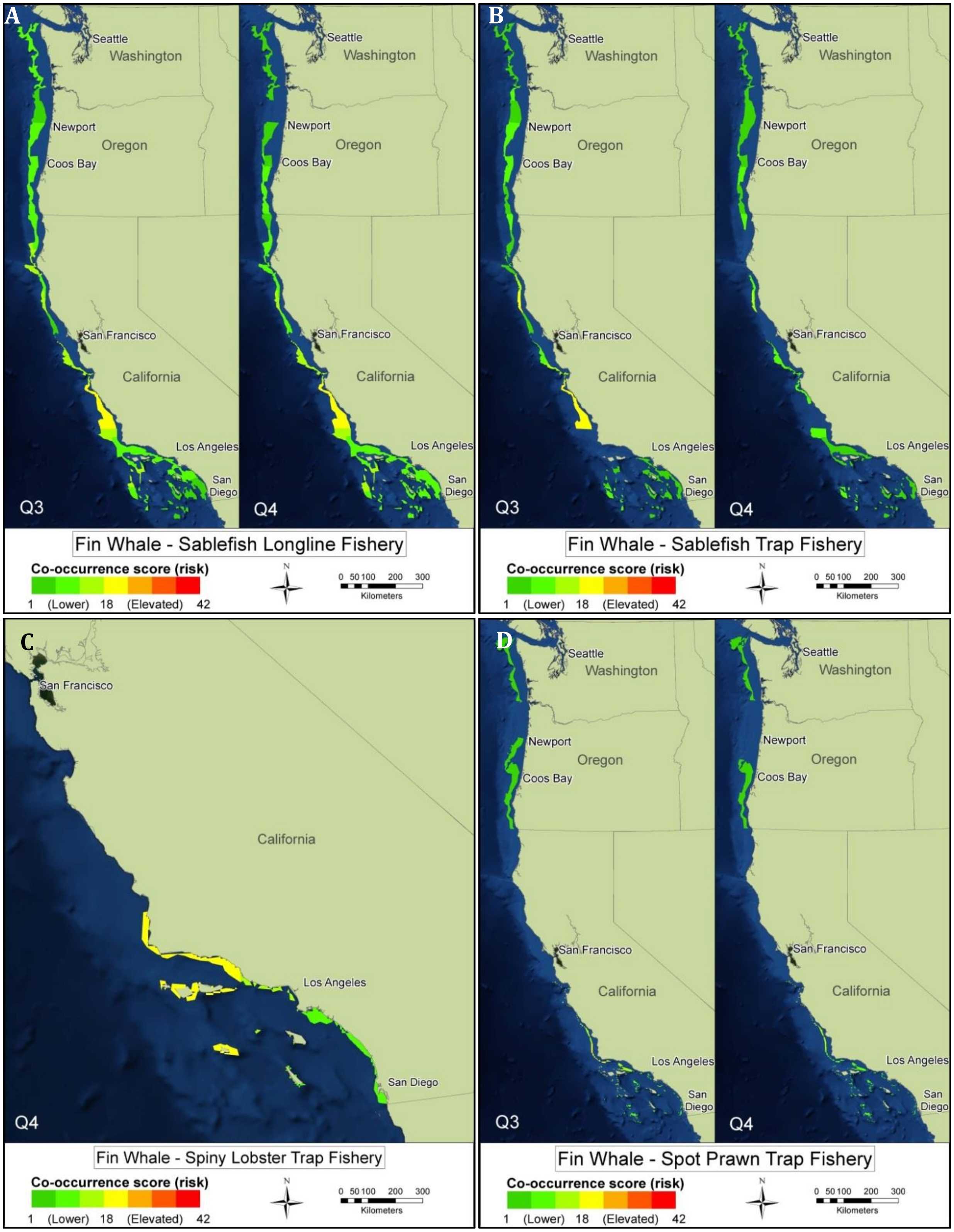


Figure 40. Co-occurrence of the multi-year average fin whale density and: A. sablefish longline, B. sablefish trap, C. spiny lobster trap, and D. spot prawn trap effort, shown for Quarter Three and Four.

Humpback whales

According to the co-occurrence model, when all fixed gear fisheries are combined, the highest co-occurrence scores for humpback whales are in coastal waters off San Francisco, California in Quarter Four (co-occurrence scores of 35 to 42). The risk area aligns well with the predicted highest summer/fall densities of humpback whales in the nearshore waters between Monterey and Point Arena, California (Figure 33). There was also a stretch of higher risk (scores of 20 to 30) in coastal waters from Eureka, California to Newport, Oregon during Quarter Four (Figure 41). There were mid-range co-occurrence scores in the nearshore and offshore waters from Santa Barbara through Newport, Oregon for humpback whales in Quarter Three.

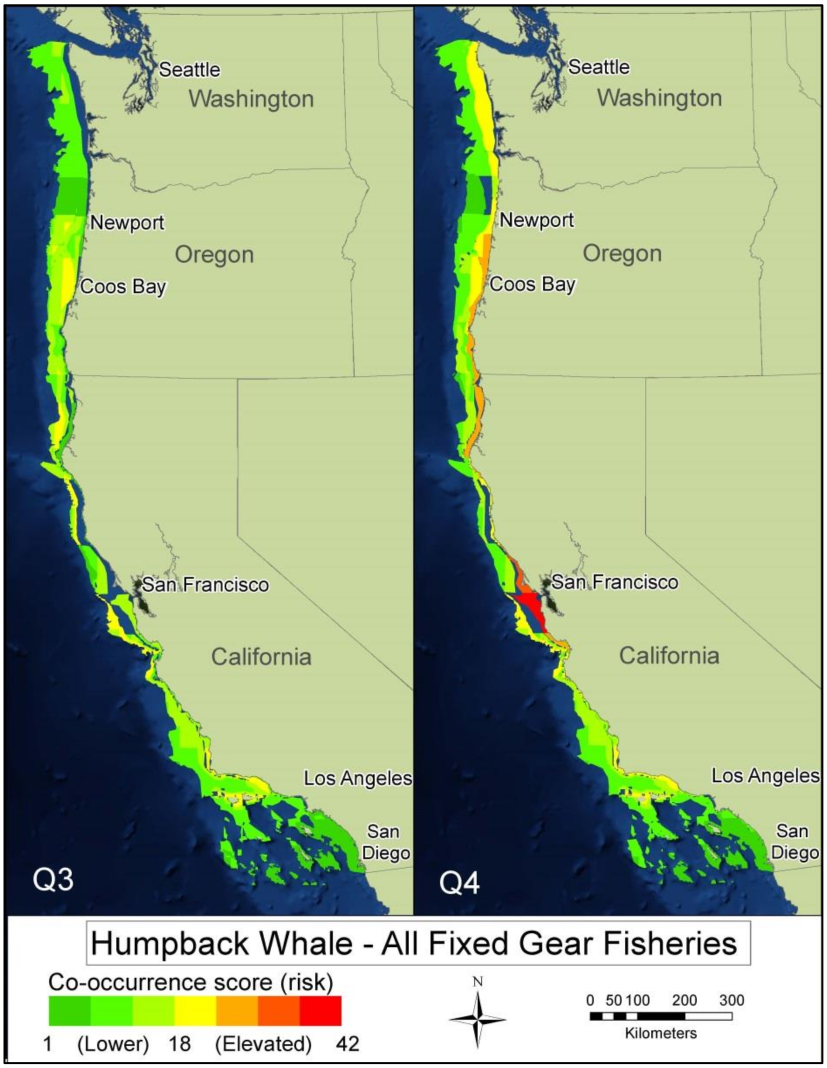


Figure 41. Co-occurrence of the multi-year average humpback whale density and fishing effort for all 11 fisheries shown for Quarter Three and Four.

With respect to individual fisheries, the Dungeness crab fishery resulted in the highest risk for humpback whales near San Francisco in Quarter Four (Table 7). The co-occurrence score of 42 was a result of a humpback whale density score of 7 multiplied with a fishery effort score of 6. Humpback whales had a stretch of higher risk area with the Dungeness crab fishery in coastal waters between San Francisco, California and Newport, Oregon and mid-range co-occurrence scores, 18 to 24, north of Newport through coastal Washington in Quarter Four (Figure 41). There have been six confirmed entanglements of humpback whales in Dungeness crab trap gear (NMFS entanglement database 1982-2012; Saez *et al.*, in prep).

The next highest co-occurrences scores were from the rock crab trap fishery near Santa Barbara (score of 24), then sablefish longline, sablefish trap, and spot prawn trap fisheries near Monterey (score of 21) (Figures 42 and 43). There have been two confirmed entanglements of a humpback whale in spot prawn trap gear and one confirmed entanglement in sablefish trap gear (NMFS entanglement database 1982-2012; Saez *et al*., in prep).

Table 7. Entanglement risk for humpback whales, by fishery, ranked by peak co-occurrence score and location of risk.

Rank	Fishery name	Peak score	Quarter	Area
1	Dungeness crab	42	Q4	San Francisco and Bodega Bay
2	Rock crab trap	24	Q3, Q4	Santa Barbara
3	Sablefish longline	21	Q3, Q4	Monterey to San Francisco
3	Sablefish trap	21	Q3	Monterey (Coos Bay and BB)
3	Spot prawn trap	21	Q3, Q4	Monterey
6	California halibut/white seabass set gillnet	20	Q3	Santa Barbara
6	Hagfish trap	20	Q3, Q4	Coos Bay
6	Spiny lobster	20	Q4	Santa Barbara
9	Coonstripe shrimp trap	15	Q3	Crescent City
9	Pacific halibut longline	15	Q3	Coos Bay
11	California nearshore live finfish trap	14	Q3	Monterey

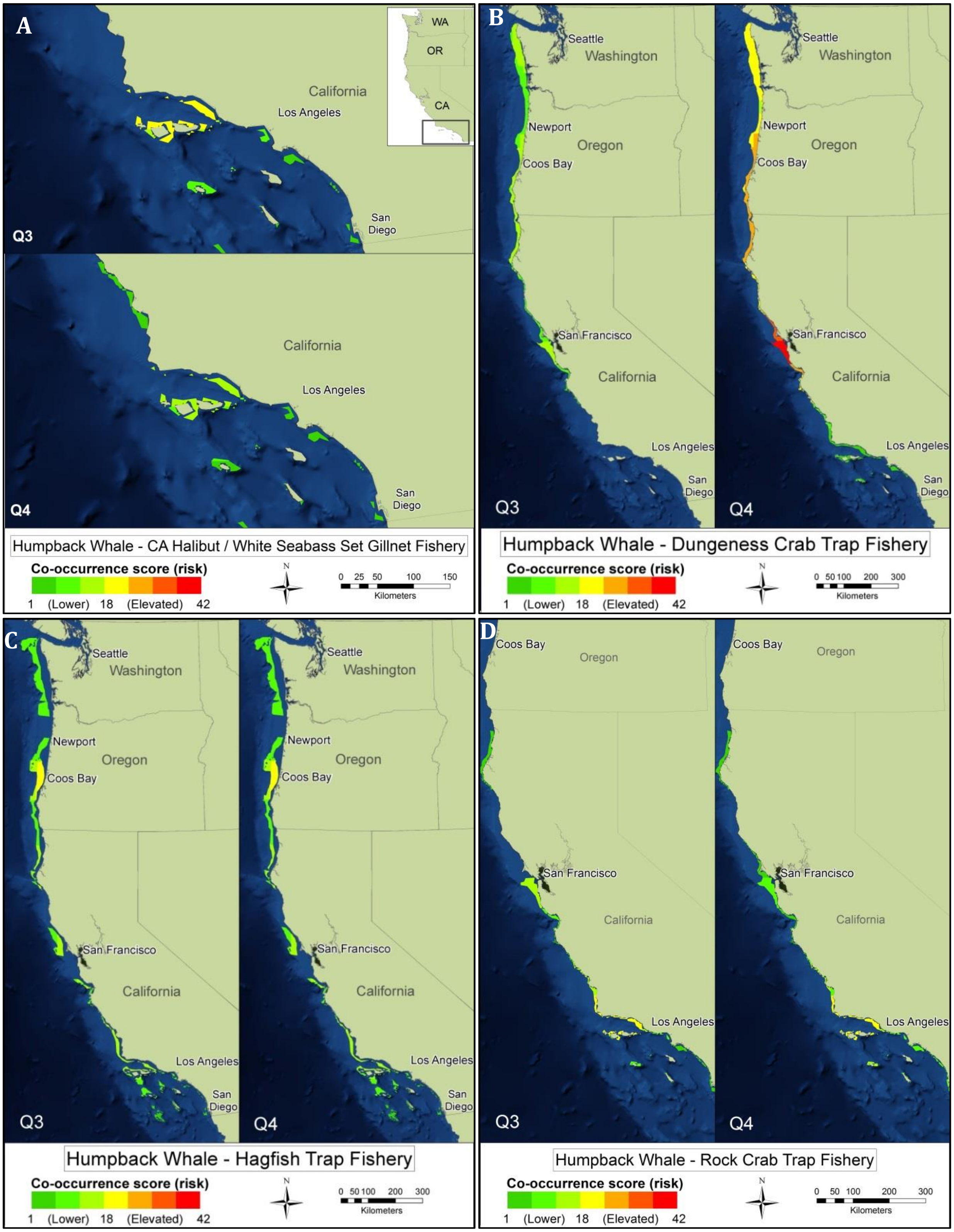


Figure 42. **Co-occurrence of the multi-year average humpback whale density and: A. California halibut/white seabass set gillnet, B. Dungeness crab trap, C. hagfish trap, and D. rock crab trap effort, shown for Quarter Three and Four.**

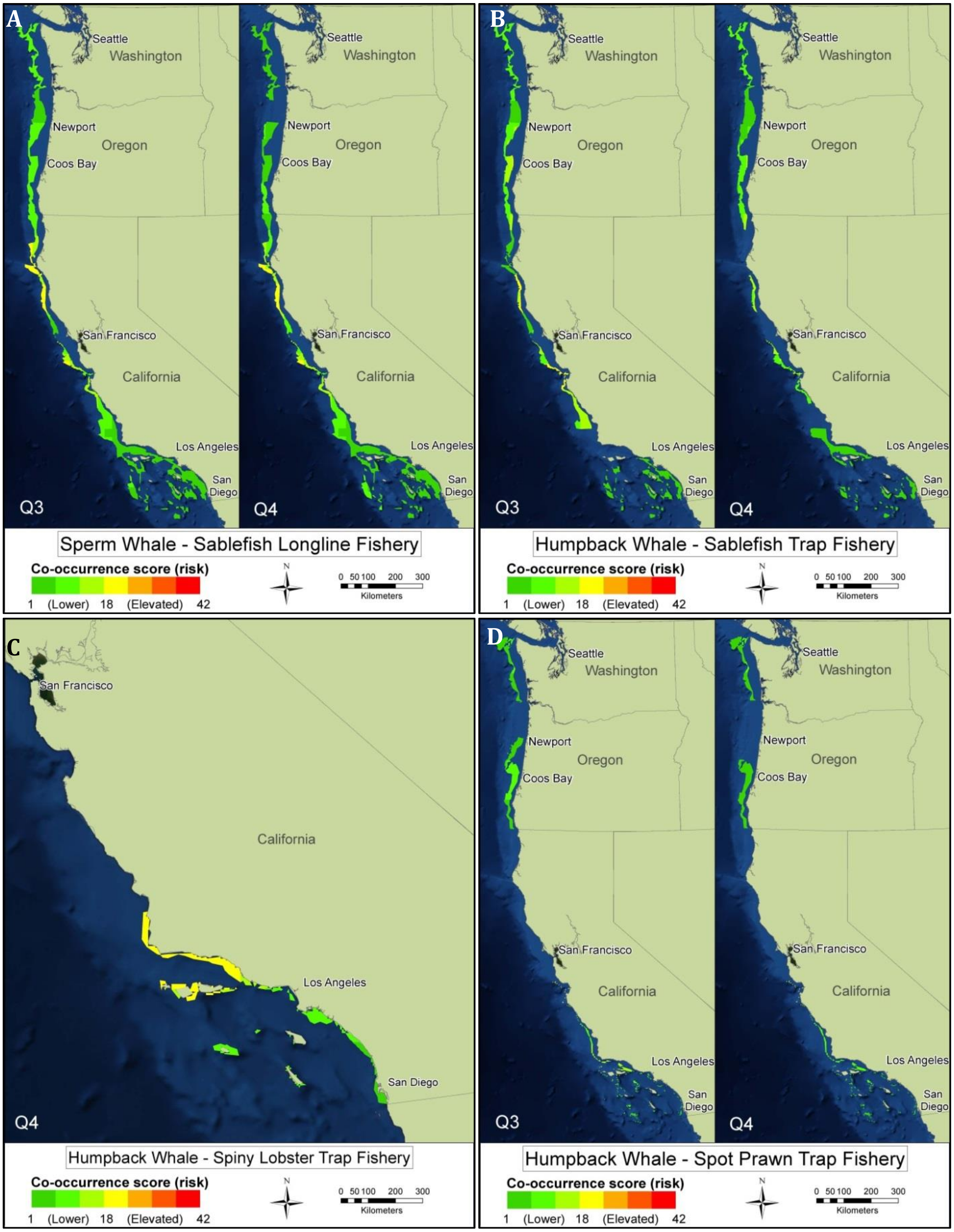


Figure 43. Co-occurrence of the multi-year average humpback whale density and: A. sablefish longline, B. sablefish trap, C. spiny lobster trap, and D. spot prawn trap effort, shown for Quarter Three and Four.

Sperm whales

According to the co-occurrence model, when all fixed gear fisheries are combined, the area of highest risk for sperm whales was offshore Fort Bragg in Quarter Three and northern California (Bodega Bay, Fort Bragg, and Eureka) during Quarters Four (co-occurrence scores of 28 and 30) (Figure 44). The risk areas align with the predicted highest summer/fall densities of sperm whales in the offshore waters approximately 50 km from shore, between Point Conception and Eureka, California (Figure 33). There were additional areas of higher risk along the coast of San Francisco through Crescent City in Quarter Four. The entanglement risk in Quarters Three and Four was lower throughout most of southern California, Oregon and Washington. Sperm whales had mid-range co-occurrence scores in the area from Morro Bay through southern Oregon in Quarter Three and Quarter Four.

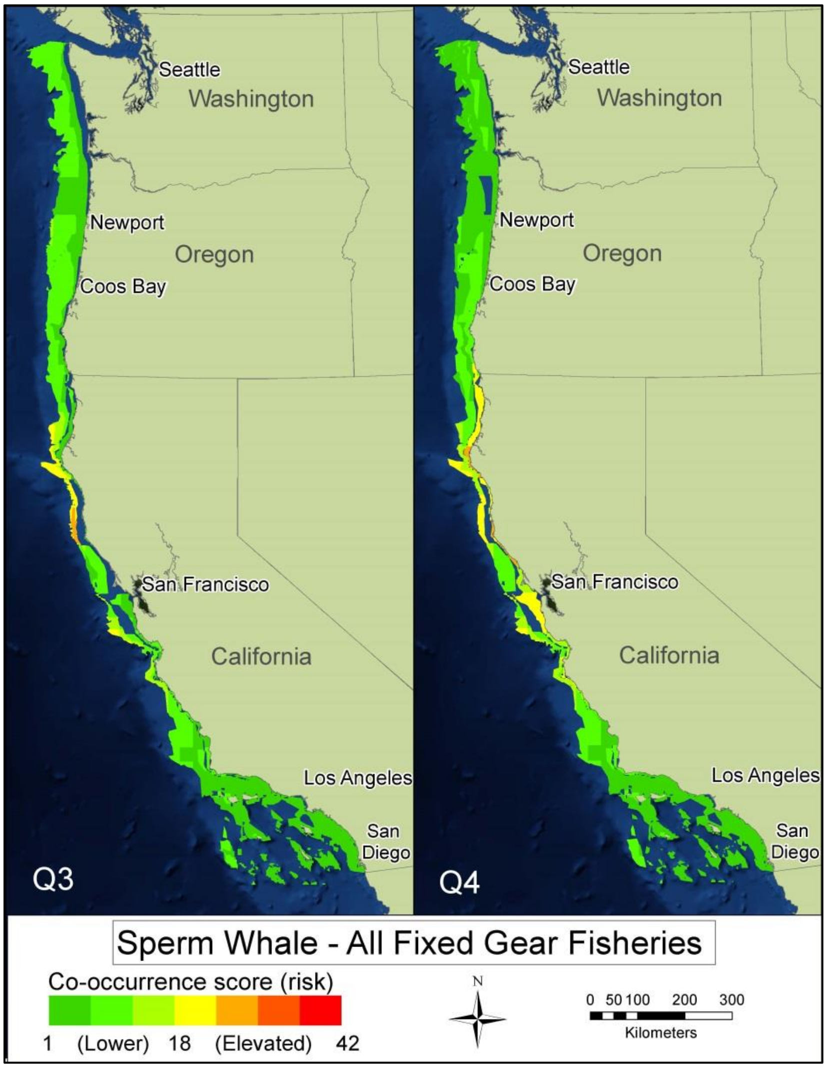


Figure 44. Co-occurrence of the multi-year average sperm whale density and fishing effort for all 11 fisheries shown for Quarter Three and Four.

With respect to individual fisheries, the Dungeness crab fishery resulted in the highest risk for sperm whales in Quarter Four between Monterey and Crescent City, California (Table 8). The co-occurrence score of 30 was a result of a sperm whale density score of 6 multiplied with a fishery effort score of 5. Sperm whales had an area of higher risk with the Dungeness crab fishery between Monterey and Crescent City, California in Quarter Four (Figure 45).

The next highest entanglement risk for sperm whales was the sablefish trap fishery with a co-occurrence score of 28 in Quarter Three near Fort Bragg, California. Sablefish longline, another relatively deep-setting fishery, had a co-occurrence score of 24 with sperm whales in Quarter Three.

Table 8. Entanglement risk for sperm whales, by fishery, ranked by peak co-occurrence score and location of risk.

Rank	Fishery name	Peak score	Quarter	Area
1	Dungeness crab	30	Q4	Monterey to Crescent City
2	Sablefish trap	28	Q3	Fort Bragg
3	Sablefish longline	24	Q3	Eureka
4	Spot prawn trap	15	Q3, Q4	Monterey
4	Hagfish trap	15	Q3, Q4	Eureka
6	Rock crab trap	12	Q3	Santa Barbara
7	California nearshore live finfish trap	10	Q3	Monterey
8	Coonstripe shrimp trap	9	Q3	Crescent City
9	California halibut/white seabass set gillnet	8	Q3	Santa Barbara
9	Spiny lobster	8	Q4	Santa Barbara
11	Pacific halibut longline	6	Q3	Oregon and Washington

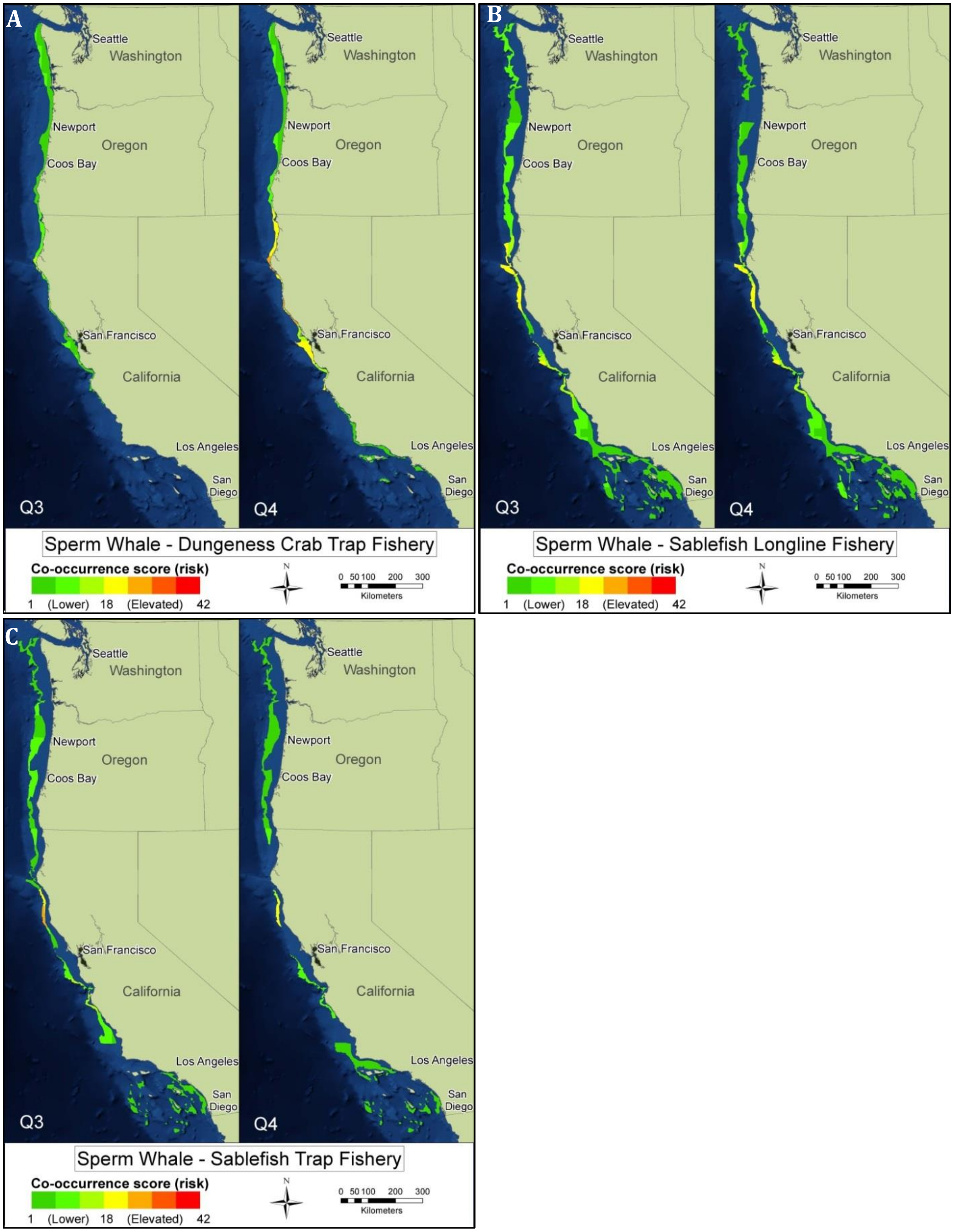


Figure 45. Co-occurrence of the multi-year average sperm whale density and: A. Dungeness crab trap, B. sablefish longline, and C. sablefish trap effort, shown for Quarter Three and Four.

3.2.2 Winter/Spring co-occurrence model results

Gray whales

Entanglement risk for gray whales with fixed gear commercial fisheries was present throughout the U.S. west coast during their annual migration in the months of December to June. The highest co-occurrence scores for gray whales looking at all fisheries combined were in the coastal waters from Eureka, California through the Oregon border and in coastal Washington with co-occurrence scores of 42 in January, and coastal Washington in May (Figure 46). The nearshore waters off of San Francisco had higher risk co-occurrence scores in January and March, along with Santa Barbara and Los Angeles in March, with all of these areas having co-occurrence scores of 20. Entanglement risk areas are consistent with the higher predicted densities of migrating gray whales in January, April, and May (DeAngelis *et al.*, in prep; Figure 34). The highest average monthly density, approximately 1 whale per km^2, occurs near San Diego when the Northbound Phases (A and B) overlap in April. The modeled fishing effort was averaged over a three month quarter; therefore, only the gray whale density per month fluctuated creating changes in monthly co-occurrence scores and entanglement risk. Full page maps of all co-occurrence model results can be found in Appendix F.

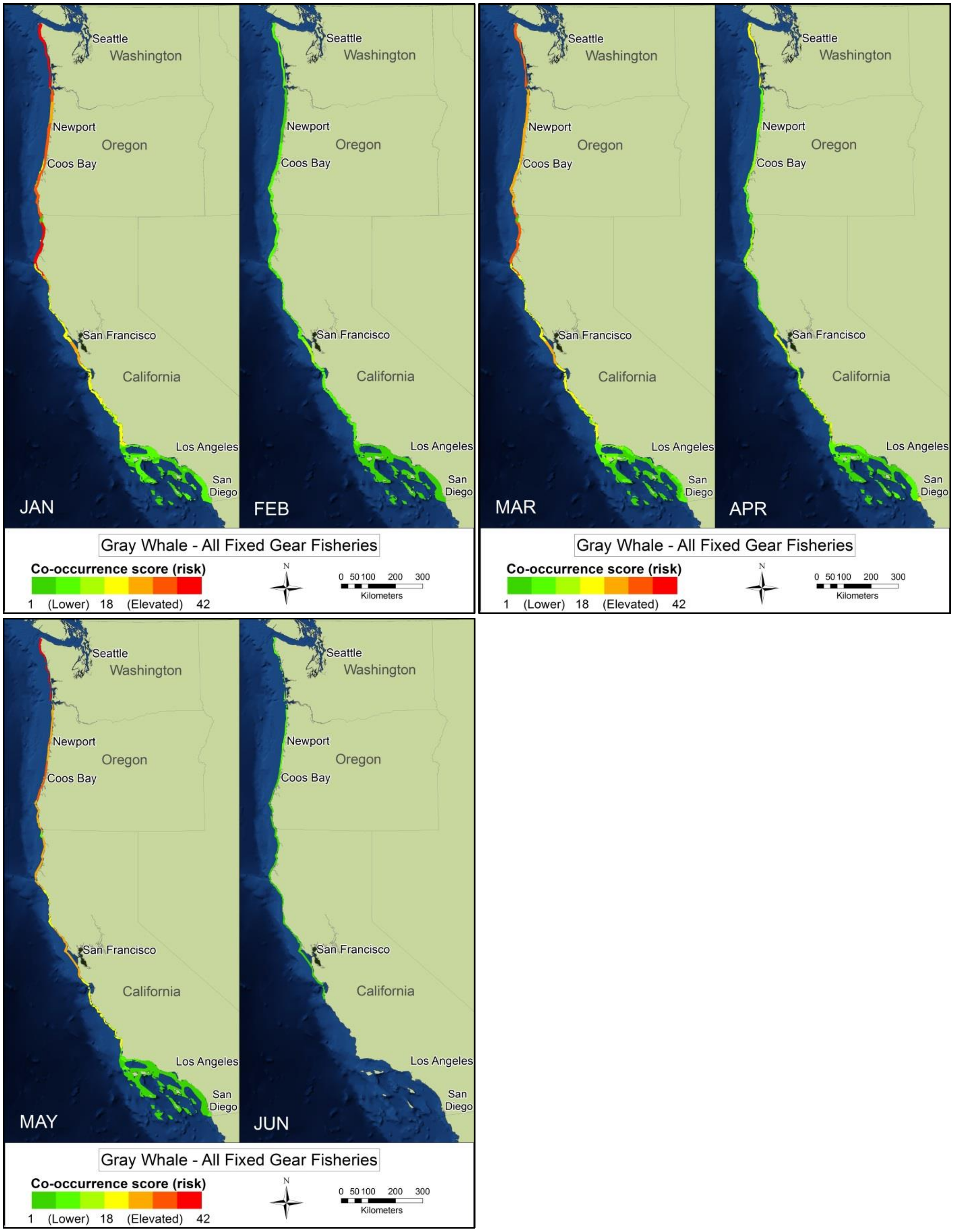


Figure 46. Co-occurrence of gray whale monthly density and fishing effort for all 11 fisheries shown for Quarter One and Two. December risk can be found in Appendix F.

With respect to individual fisheries, the Dungeness crab trap fishery had the highest co-occurrence score for gray whales, 42, along coastal Washington in January and May (Figure 47), followed by the rock crab trap fishery north of Santa Barbara in April (Figure 48) and hagfish trap fishery off Cape Mendocino, California in May, with co-occurrence scores of 28 (Figure 49). The Dungeness crab trap fishery had entanglement risk throughout most of the coastline, from Point Conception, California through Washington from January through June. All fixed gear fisheries in the co-occurrence model had a peak score of at least 18 during at least one month (Table 9).

There has been multiple gray whale entanglements where Dungeness crab or set gillnet gear has been confirmed as the entangling source (NMFS entanglement database 1982-2012; Saez *et al.*, in prep)

Table 9. Entanglement risk for gray whales, by fishery, ranked by peak co-occurrence score and location of risk.

Rank	**Fishery name**	**Peak score**	**Month**	**Area**
1	Dungeness crab	42	January, May	Cape Mendocino through Crescent City, coastal Washington
2	Hagfish trap	28	May	Central Oregon
2	Rock crab trap	28	April	Santa Barbara
4	California halibut/white seabass set gillnet	21	April	Santa Barbara
4	California nearshore live finfish trap	21	April	San Diego
4	Coonstripe shrimp trap	21	May	Crescent City
4	Pacific halibut longline	21	May	Northern Oregon
4	Sablefish longline	21	May	Monterey
4	Sablefish trap	21	May	Monterey
10	Spiny lobster	18	January, March	Santa Barbara
10	Spot prawn trap	18	January, March	Monterey

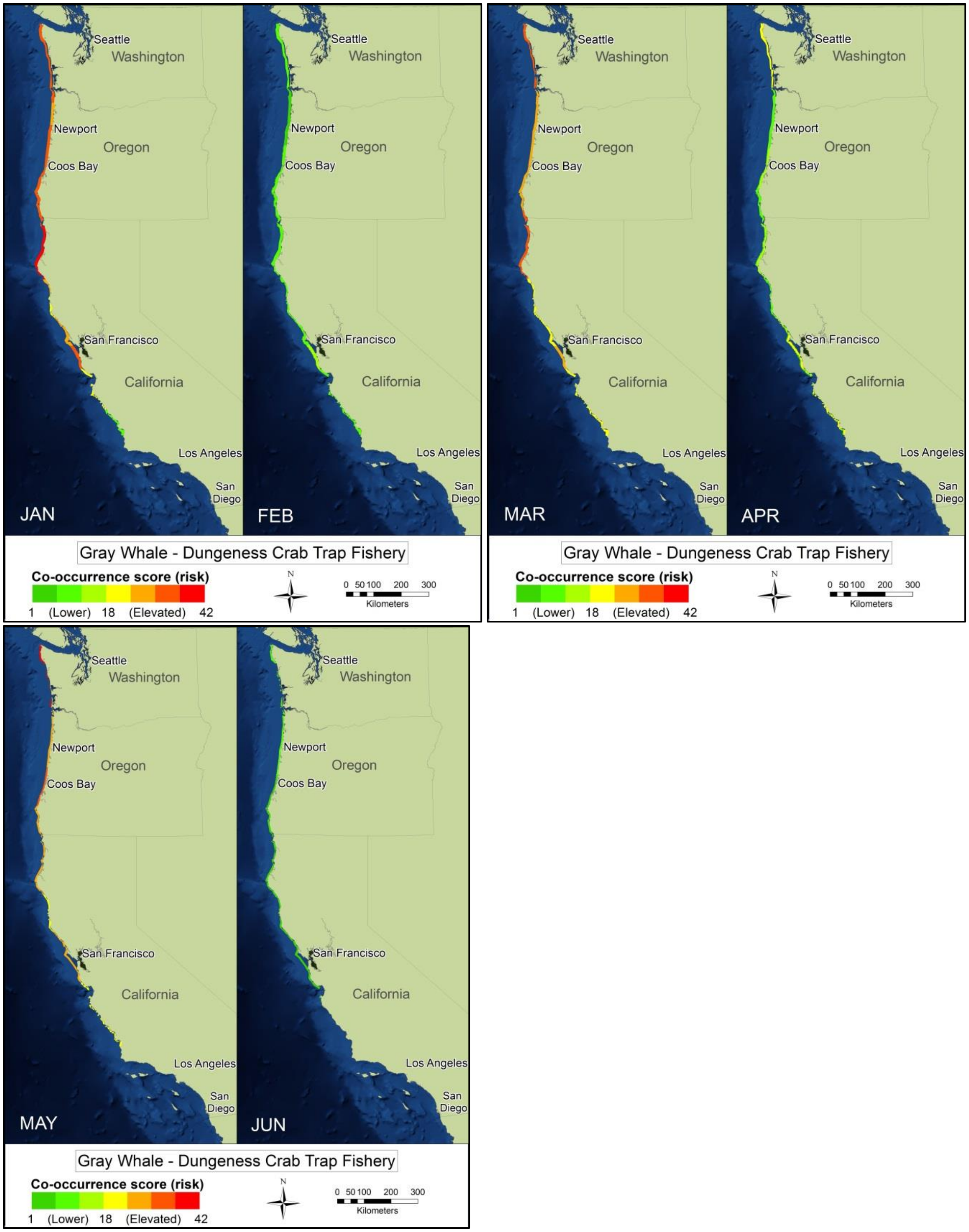


Figure 47. Co-occurrence of gray whale migration and Dungeness crab trap effort, shown monthly from January to June. December map can be found in Appendix F.

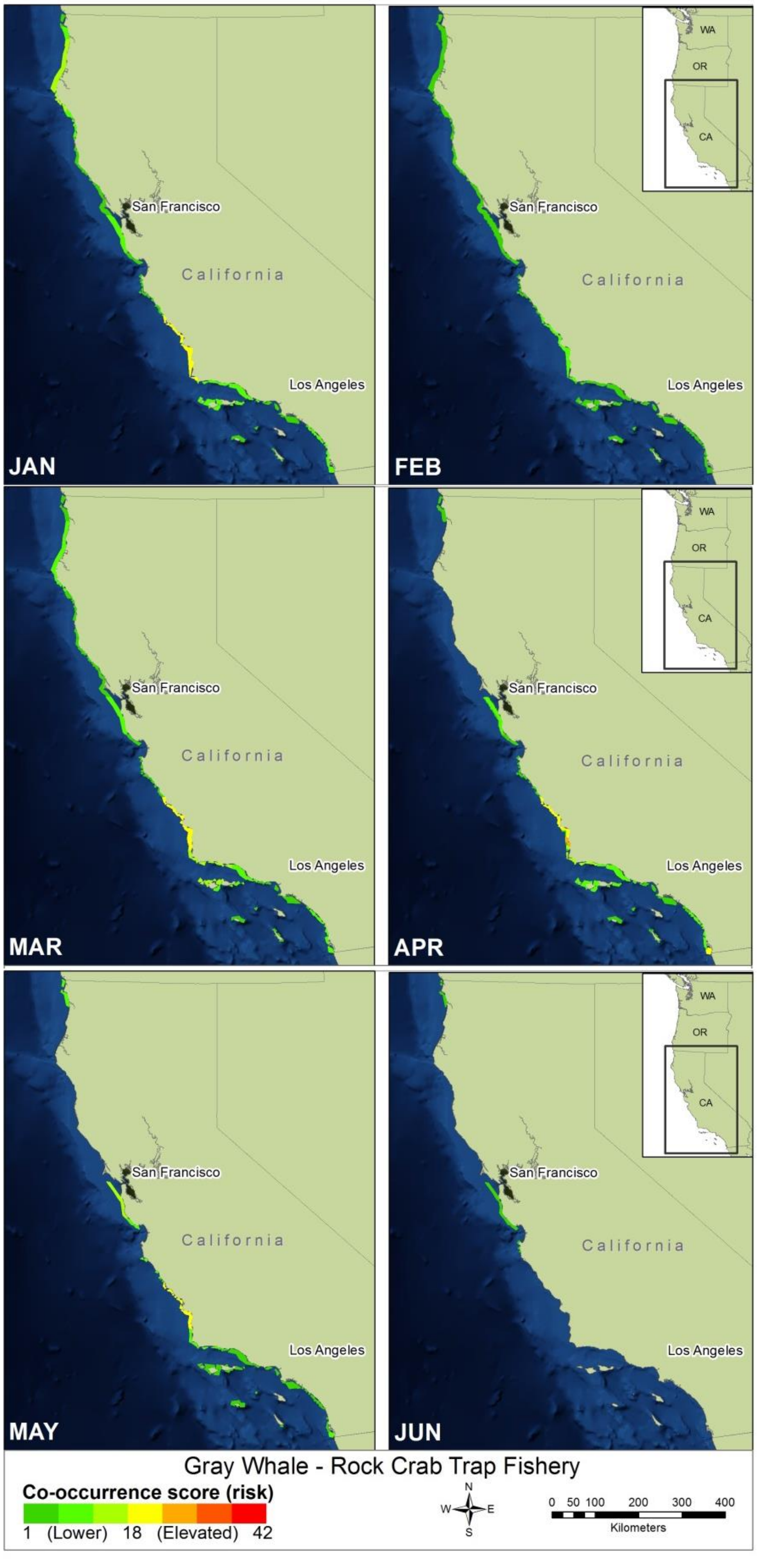


Figure 48. Co-occurrence of gray whale migration and rock crab trap effort, shown monthly from January to June. December map can be found in Appendix F.

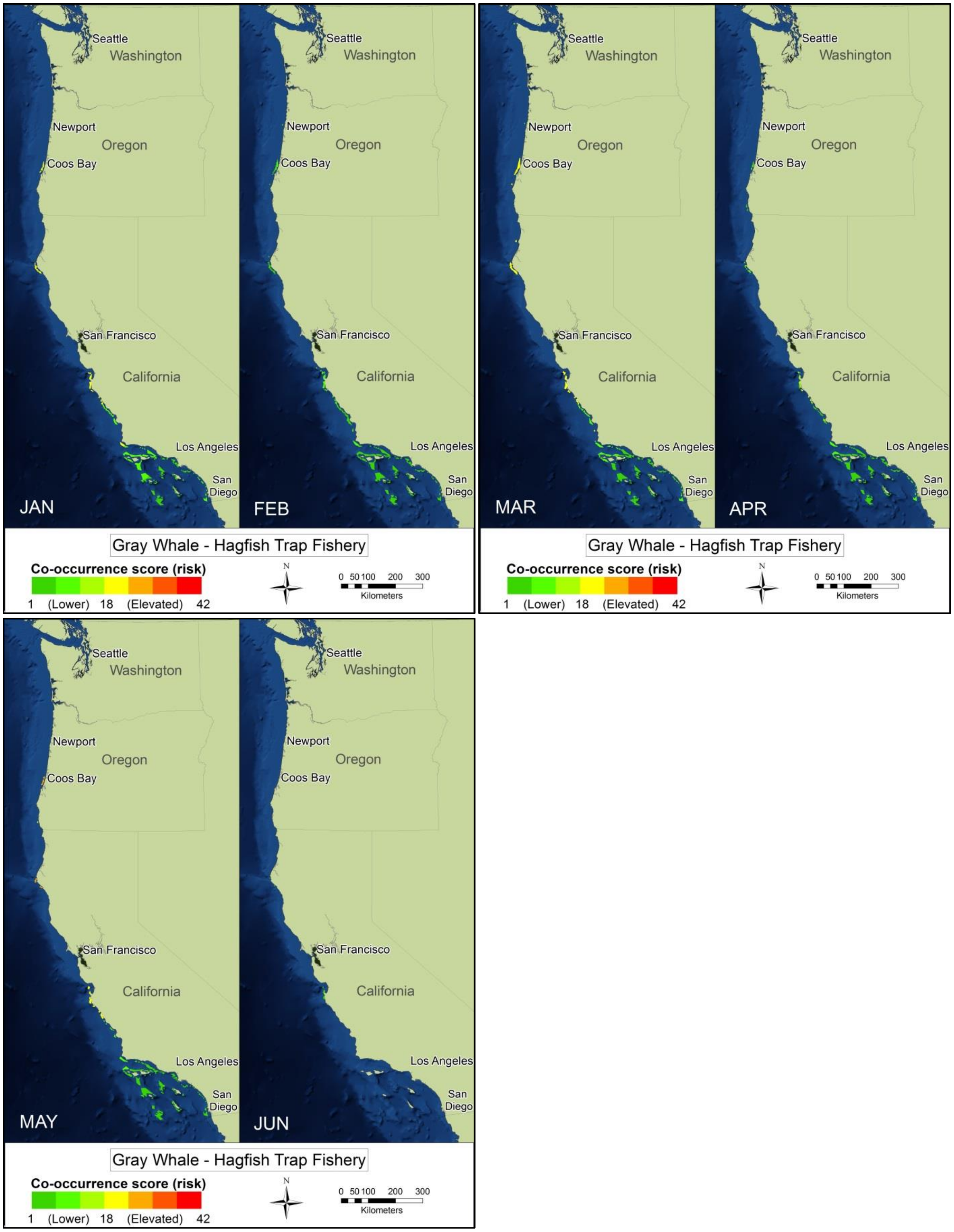


Figure 49. Co-occurrence of gray whale migration and hagfish trap effort, shown monthly from January to June. December map can be found in Appendix F.

Gray whale area intersect comparison

Each fishery's modeled fishing area was intersected with the 3 gray whale migration corridors to determine the percent area overlap of each fishery's potential fishing area with the migration corridor as a comparison with the co-occurrence scores as a qualitative indicator of entanglement risk. The fishery with the highest area intersect was the spiny lobster trap fishery, with 100% of the fishing area falling within the southbound migration corridor (Figure 50). Therefore, regardless of exactly where the fishing effort occurs within the fishing area, it occurs within in the migratory path of gray whales. The California halibut/white sea bass set gillnet fishery had the second highest intersection with a 90% overlap of the potential fishing area with the southbound migration corridor. The California nearshore live finfish trap and rock crab trap fisheries had over 80% overlap, while the coonstripe shrimp trap and Dungeness crab trap fisheries had over 50% overlap. Hagfish trap, Pacific halibut longline, sablefish longline, sablefish trap, and spot prawn trap fisheries had less than 20% overlap with the southbound migration corridor. Percent intersect with the migration corridors decreased for fisheries with the northbound phases since northbound whales travel closer to shore. It is important to remember that these analyses are based only on the potential fishing area as defined above. It is possible that actual intersection between some of these fisheries and the gray whale migratory corridor could be significantly different based on the actual areas that are fished.

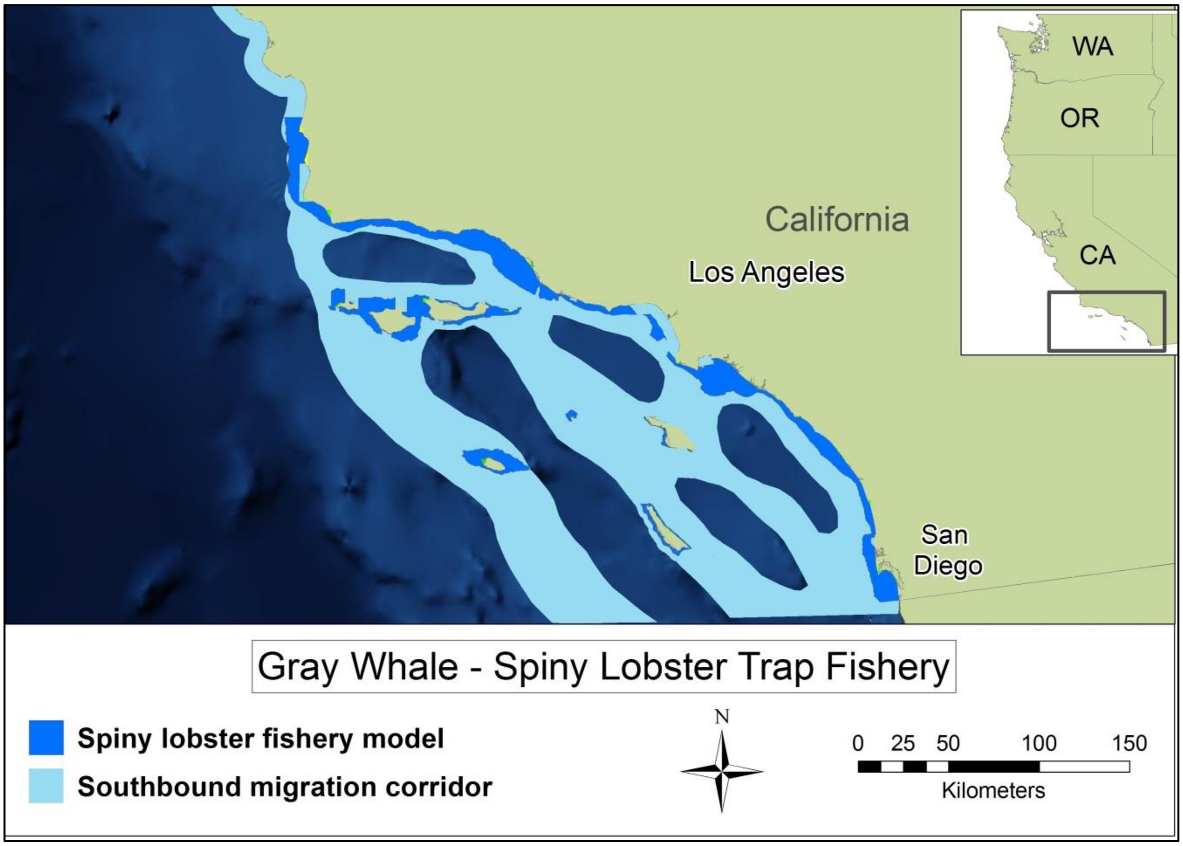


Figure 50. Example map to show the percent overlap of modeled fishery area (spiny lobster in darker blue) with the gray whale migrations corridor (southbound in light blue). Spiny lobster modeled fishing area occurs 100% within the southbound migration corridor.

3.3 Comparison of co-occurrence model with confirmed entanglements

There were eight documented humpback entanglements from 2000 to 2012 where the fishery identification was confirmed and the gear set location is known (Table 10). In addition, there were multiple gray whale entanglements from 2000 to 2012 where the fishery identification was confirmed but the gear set location was only identified to the state level (Table 11). These records were compared with the co-occurrence model results to check for preliminary indications of consistency.

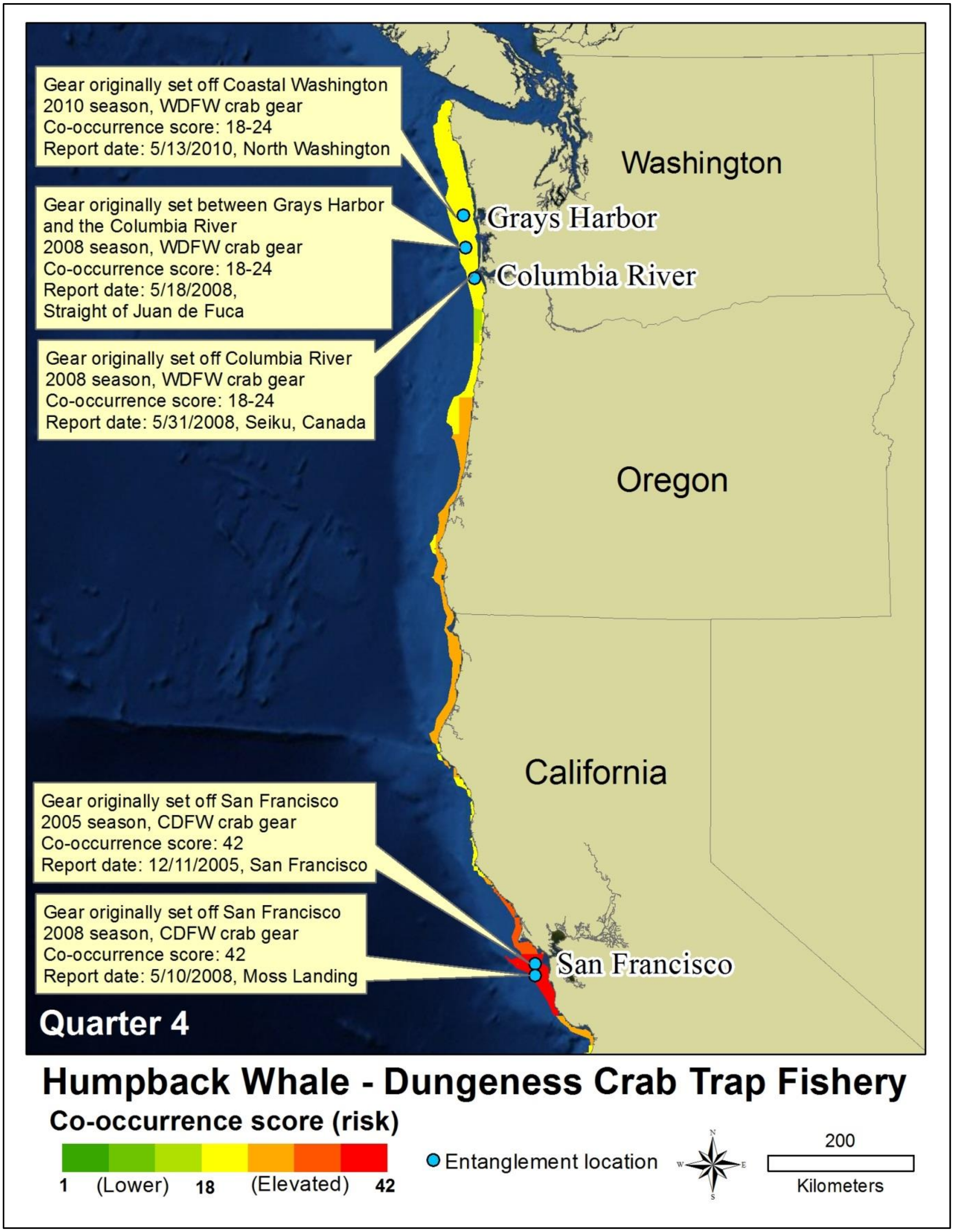
Table 10. Entanglement records for humpback whales off the U.S. west coast and western Canada where the commercial fishery and gear set location are known, along with the co-occurrence score at gear set location.

Whale species	Fishery	Sighting date	Sighting location	Gear location	Score
Humpback	Spot prawn	9/24/2005	Moss Landing, CA	Moss Landing, CA	18-21 (Q3)
Humpback	Dungeness crab	12/11/2005	Offshore San Francisco, CA	Offshore San Francisco, CA	42 (Q4)
Humpback	Sablefish trap	9/3/2006	Monterey, CA	Monterey, CA	18-21
Humpback	Dungeness crab	5/10/2008	Moss Landing, CA	Offshore San Francisco	28 (Q4)
Humpback	Dungeness crab	5/18/2008	Torfino, BC	Between Grays Harbor and Columbia River, WA	18-24 (Q4)
Humpback	Dungeness crab	5/31/2008	Torfino, BC	Mouth of Columbia River and Willapa Bay, WA	18-24 (Q4)
Humpback	Dungeness crab	5/13/2010	Destruction Islands, WA	Coastal Washington	18-24 (Q4)
Humpback	Dungeness crab	8/31/2010	Coos Bay, OR	Oregon and Washington	12-16 (Q3) 18-30 (Q4)

Table 11. Entanglement records of gray whales off the U.S. west coast where the commercial fishery and state where the gear was set are known, along with the co-occurrence score in state gear set location.

Whale species	Fishery	State	Sighting date	Sighting location	Score
Gray (SB)	Dungeness crab	California	1/31/2003	Morro Bay, CA	24-42
Gray (SB)	Dungeness crab	Washington	2/21/2005	Depoe Bay, OR	36 (January) 7 (February)
Gray (NB)	Dungeness crab	Oregon	5/14/2006	Lakeside, OR	28-35
Gray (NB)	Dungeness crab	Washington	5/27/2006	Quinault, WA	42
Gray (NB)	Dungeness crab	California	5/8/2012	Humboldt, CA	28
Gray (NB)	Dungeness crab	California and Oregon	5/13/2012	Dillon Beach, Bodega Bay, CA	28
Gray (NB)	Dungeness crab	Oregon	5/19/2012	Gold Beach, OR	28-35

* (NB) = northbound migration whale; (SB) = southbound migrating whale



Gear originally set off Coastal Washington
2010 season, WDFW crab gear
Co-occurrence score: 18-24
Report date: 5/13/2010, North Washington

Gear originally set between Grays Harbor and the Columbia River
2008 season, WDFW crab gear
Co-occurrence score: 18-24
Report date: 5/18/2008,
Straight of Juan de Fuca

Gear originally set off Columbia River
2008 season, WDFW crab gear
Co-occurrence score: 18-24
Report date: 5/31/2008, Seiku, Canada

Gear originally set off San Francisco
2005 season, CDFW crab gear
Co-occurrence score: 42
Report date: 12/11/2005, San Francisco

Gear originally set off San Francisco
2008 season, CDFW crab gear
Co-occurrence score: 42
Report date: 5/10/2008, Moss Landing

Figure 51. **Comparison of confirmed entanglement reports with co-occurrence model results: humpback whale and Dungeness crab trap fishery. A blue dot indicates where an entanglement occurred. Callout text gives information regarding the entanglement including: gear set location, fishery, associated co-occurrence score, date reported, and where the whale was sighted. More maps overlaying confirmed entanglements with co-occurrence results can be found in Appendix F.**

The locations of entanglements were in areas of higher co-occurrence scores relative to surrounding areas for the whale species/fishery combination, ranging from 18 to 42 (Table 10 and 11; Figure 51; Appendix F). These findings support preliminary justification for the modeling methodology to predict areas of higher entanglement risk. Combinations of time/area/fishery effort/whale density that produced mid-range and higher (18+) co-occurrence scores can be considered places of “elevated” risk, coded as yellow, orange, and red on the co-occurrence maps. Areas in the co-occurrence model shaded green can be considered places of lower entanglement risk, although entanglements may still occur in these areas whenever at least one whale and some fishing gear are in the same location.

3.4 Discussion

The co-occurrence scores for blue, fin, humpback and sperm whales were lower in summer (Quarter Three) than fall (Quarter Four), primarily driven by the high landings of the Dungeness crab trap fishery, especially surrounding the fishing season opener in the months of November to January depending on the year and location. Entanglement risk was elevated for all four species in the waters near San Francisco in Quarter Four. Co-occurrence scores are not comparable across species due to the scaling of whale density.

Gray whale co-occurrence scores were highest in the months of January, April, and May as the peak of the migrating animals passes through U.S. west coast waters. Entanglement risk was higher in Washington, Oregon, and northern California. The densities predicted by the gray whale model and associated co-occurrence scores are lower in southern California because the density of migrating whales is spread over a larger area since the migration corridors expand to include the offshore islands and a straight path from Santa Barbara to Baja California, Mexico.

While fin, gray, humpback, and sperm whales have all been reported entangled in fishing gear, there has never been a report of an entangled blue whale off the U.S. west coast, which is somewhat contradictory to the co-occurrence results presented in this analysis that suggest some areas of elevated entanglement risks for blue whales are present. However, researchers have noticed scarring on blue whales, indicative of interactions with gear (personal communication with John Calambokidis, Cascadia Research, Research Biologist, August 8, 2012). If we were to predict the area where a blue whale entanglement was most likely, the co-occurrence model results indicate that the areas of highest risk for blue whales are off San Francisco and Eureka through southern Oregon, despite higher whale density in southern California. The highest risk fishery for blue whales, based on this model is the Dungeness crab trap fishery.

Whale morphology and behavior may help explain the differences found between the co-occurrence model and actual entanglement events. The humpback whale’s characteristic large pectoral fins and flukes are the most reported attachment point for entanglements along the U.S. west coast (Saez *et al.*, in prep). Humpback and gray whales have also been observed “playing” in kelp, so their curiosity with fixed lines may also factor into risk. The large size, tapered shape, behavior, and power of blue and fin whales may allow safe passage through a gillnet and less risk of entanglement in trap lines.

The gray whale migration is generally very near to shore, crossing through a variety of anthropogenic threats, including fixed gear fisheries. It is possible that the high number of gray whale entanglement reports may be because they actually get entangled more often than other whales or because these encounters occur closer to human activity and are more often detected. Fixed gear fisheries that operate in deeper waters such as hagfish trap, sablefish longline and trap, and spot prawn trap fisheries have less overlap (<50%) with gray whales as they occur farther offshore than migrating gray whales and subsequently pose generally lower entanglement risk. After passing through Dungeness crab trap fishing grounds, gray whales migrate south through areas of rock crab and spiny lobster trap fisheries and the California halibut/white seabass set gillnet fishery in southern California. During the Northbound Phase gray whales migrate through the same suite of fisheries on their way back up to Alaska. There have been entanglement reports of gray whales in a number of fisheries including: Dungeness crab trap, rock crab, spiny lobster trap, and set gillnet gear (Saez *et al.,* in prep).

The summer distribution of sperm whales is in the deeper waters off the U.S. west coast, therefore co-occurrence and associated entanglement risk with fixed gear fisheries in these areas, such as sablefish longline and trap fisheries (100 to 450 fm), is higher. Historically, sperm whales have only been documented as entangled in drift gillnet gear in offshore waters, specifically the California sword fish/thresher shark drift gillnet fishery (Carretta *et al.,* 2012), which was not included in this co-occurrence model.

3.4.1 Highest risk fisheries as identified by the co-occurrence model

Using the methodology described above, the Dungeness crab fishery had the highest co-occurrence scores and was classified as the highest risk fishery for all whale species considered in this analysis. The highest co-occurrence scores occurred only during Quarter Four for blue, fin, humpback, and sperm whales, and during January and May for gray whales. The Dungeness crab fishery had the highest landings of all fixed gear fisheries considered and therefore was likely to have the highest co-occurrence scores given the fishery model used in this analysis. Given all fisheries were landings were scaled the same, the Dungeness crab trap fishery was the only fishery with scaled fishery landings higher than 5 out of 7. The Dungeness crab fishery also covered most of the coastline from 5 to 60 fathoms (30 to 360 feet) depth operating throughout most of the year with varying effort levels, north of Point Conception, California, although a few landings were reported into Santa Barbara and Los Angeles. There have been multiple confirmed reports of entanglements of large whales in Dungeness crab trap gear on the U. S. west coast.

Other higher risk fisheries are: California halibut/white seabass set gillnet, rock crab trap, sablefish longline, sablefish trap, and spot prawn trap fisheries. The California halibut/white seabass set gillnet fishery operates primarily in southern California, therefore entanglement risk to large whales in the set gillnet fishery is confined to southern California. The set gillnet fishery has elevated risk with blue, fin, gray, and humpback whales. Rock crab trap fishery had elevated entanglement risk for all whale species considered except sperm whales, with the highest risk in the Santa Barbara port complex. The sablefish longline and trap fisheries have elevated risk with all whale species, generally in central and northern California. Spot prawn trap fishery had elevated risk primarily in the Monterey and Santa Barbara port complexes with blue, fin, gray, and humpback whales. There have been confirmed entanglements of gray whales with rock crab traps and set gillnet gear and humpback whales with sablefish trap and spot prawn trap fisheries.

3.4.2 Lowest risk fisheries as identified by the co-occurrence model

There are three fixed gear fisheries in this analysis that had consistently low entanglement risk for most whale species: California nearshore live finfish trap, coonstripe shrimp trap, and Pacific halibut longline. These fisheries are low risk because they have little overlap with whale presence and/or have low fishing effort. There have been no confirmed whale entanglements with these fisheries.

3.5 Model assumptions and limitations

The co-occurrence model includes many assumptions:

1. Entanglement risk is proportional to the level of co-occurrence: the more effort/gear and more whales present in an area, the higher the co-occurrence score and assumed entanglement risk.
2. Landings data are a proxy for effort under the general assumption that the number of pounds landed is directly proportional to fishing effort.
3. Anytime whales and gear are present, regardless of density, some entanglement risk is present.
4. All whale species are equally likely to become entangled.
5. All gear types have equal likelihood of causing an entanglement.

Fishery data limitations

Commercial fishery landing data were used to represent effort in the co-occurrence model. There are a number of reasons why landings may not the best measure of effort and could be misleading. Within a given fishery, the relative average catch per trap fished (catch per effort) could vary significantly depending on the time of year and the location being fished. Additionally, landings are only reflective of successful catch and do not capture effort where gear is set and is unsuccessful. Across different fisheries, comparisons of landings are problematic based on variable weights and expectations for catch per effort for different target species, making it more difficult to compare effort targeted at smaller sized species, such as shrimp, with larger fish, such as halibut. In a similar study, the Atlantic Large Whale Take Reduction Team (ALWTRT) used the density of vertical lines as a metric for measuring fishery effort while modeling co-occurrence with endangered whale species (ALWTRT, 2010). Vertical line density or other measures of fishing gear could be a better metric for entanglement risk since it is a more direct way to compare overlapping whale and gear densities versus extrapolating effort from landings data. Preliminary work has been conducted to estimate vertical line density and the numbers of pots/traps used off the U.S. west coast but was not developed enough to warrant inclusion in this analysis.

Although landing data provide a consistent source of information across all fisheries and states, there were limitations to the use and processing of the data. Landings were averaged over five-year time frames in an effort to capture seasonal patterns. Quarterly averages were useful for capturing inter-annual variability in landings, driven by multiple factors including the health of target stocks, regulatory influences, weather, and the economics of market demand and the costs of going fishing. However, some fishing seasons did not align well with the quarterly aggregation. For example, the Dungeness crab fishery season does not open until mid-November in California and December in Oregon and Washington. Although Dungeness crab fishing effort is only present in the last month and a half of the Quarter, the high effort of the season opener is shown for the entire Quarter.

The fishery model uses data from 2004 to 2008, believed to be representative of the current and future fishery effort; therefore, assessment of relative entanglement risk represented in this analysis should still be applicable for the immediate future. The fishery model time period also aligns with the field station data included the gray whale model and fell within one of the research cruises included in the density surface maps. The fishery model can be modified and the co-occurrence model re-run if regulations change, such as the implementation of marine protected areas under the California Marine Life Protection Act or other factors that can influence the catch level and distribution of any of the fisheries included in this analysis (Appendix F).

Landing data were mapped geographically using potential fishing areas defined by operational depths and assigned to a port complex. This method was used in the absence of fishing effort location data, as this information is not provided for most fisheries. However, not all potential fishing grounds within the operational depth are used by the fishery, as suggested when state logbook data are compared with the model outputs (such as the sablefish longline and trap fisheries in Section 2.0). Bottom substrate or habitat type may be a variable that explains the differences seen between the fishery model and the state landing data. Adding habitat data could further refine potential fishing areas in future models of fixed gear commercial fishing data.

Whale data limitations

Co-occurrence scores and potential entanglement risk for a given year may be markedly different than the results presented here utilizing multi-year average whale densities for blue whales, fin whales, humpback whales, and sperm whales. Future co-occurrence models should consider the time frame of available whale data and could improve temporal resolution and possible accuracy if both the whale data and fishing data cover exactly the same time periods and seasonality. In addition, the whale density scores (1-7) were not comparable across species, limiting any analysis of relative risk of fixed gear fisheries between species.

The exact migration paths of gray whales through southern California and the offshore islands may be further refined with analysis of a recent satellite tagging study conducted during the northbound migration phases. Since the gray whale model originally included daily gray whale density estimates, future co-occurrence models could be modeled on a finer temporal scale if daily, weekly, or monthly fishing effort is available.

Co-occurrence model limitations

The resolution of the co-occurrence model presented in this analysis was limited when the fishery landings and whale densities were scaled, resulting in model outputs of areas of “relative” co-occurrence and entanglement risk. Although it is not possible to measure “actual” entanglement risk with current information, using a gear based metric of effort would provide a more direct analysis of co-occurrence because it would directly compare the density of fishing gear and density of whales. The landing information and whale density data could have been scaled using a different method, but the 1-to-7 scale best fit the distribution of fishery landings data throughout the quarter time frames and 5 year period and was used consistently throughout model development. General trends in entanglement risk have been outlined here; however, co-occurrence scores may be interpreted differently or weighted for emphasis on whale species or risk based on fishing gear configuration if more information about entanglement risk related to these aspects can be described.

Model results may have been biased because the spatial and temporal time frames for the fishing season and available whale data did not match exactly and extended beyond the constraints of the defined Quarters (i.e. the quarters were defined by days in a month and the whale presence may not conform to those days and/or months). As noted earlier, the co-occurrence scores for Quarter Four for blue, fin, humpback, and sperm whales could be overestimated since the time periods where whales are known to be present and Dungeness crab trap fishery, for example, is active and do not cover the same time period. The co-occurrence scores for gray whales in the month of December may also be skewed because the single month representation of whale distribution is compared with a three-month average for fishing effort.

There was one confirmed entanglement report and successful disentanglement of a humpback whale in Dungeness crab gear off San Francisco during the month of December around the time when the number of Dungeness crab traps in the area is highest. Although the humpback whale data input into the model did not include the month of December, the confirmed report indicates that the application of model results for the month of December, especially given variability of whale presence, is appropriate. Thus, this model could be expanded to other months not included in the model input, but the applicability of this model to other months should be further explored. The distribution of any individual whale species may be different in any given year. However, the multi-year average used in the model includes inter-annual variability in a species' distribution, because the model included survey data from multiple years. Caution should be made when directly comparing a single year with an average of multiple years to determine the actual entanglement risk for any given year or fishing season as it may be different depending on how variable the species distribution or fishing effort might be for that year of interest. As a result, the alignment of time periods should be considered for future research and should strive for consistency when comparing the whale data and fishing seasons.

The co-occurrence model is limited to fixed gear commercial fisheries in the U.S. The fisheries selected for the model were based on a study of historic whale entanglement reports and the fact that fixed gear is known to entangle large whales. There are other sources of entanglement that were not considered in this analysis such as: commercial fisheries using non-fixed gear, commercial fishing gear from other countries, recreational fisheries, mooring lines, marine debris, and derelict fishing gear. If quantitative data on the density and spatial distribution of these other potential sources of entanglement become available, they should be included in future analyses of large whale entanglement risk.

For any model, it is important to have data to validate the model outputs. However, it is particularly difficult to "ground truth" this model since so many entanglements likely go undetected. Heyning and Lewis' (1990) study of baleen whale entanglements in southern California suggested that most whales killed by offshore fishing gear do not drift far enough to strand on beaches or to be detected floating in the nearshore corridor where most whale watching occurs. Thus, the lack of documented entanglements for any whale species or entanglements associated with any given fishery should not be interpreted that none have occurred.

3.6 Management implications and suggestions

The co-occurrence model developed in this paper and analysis of entanglement reporting history (Saez *et al.*, in prep) identified six areas where there is need for improvement in understanding the risk of U.S. west coast large whale entanglements: 1) research on specific elevated risk time/areas; 2) research that would fill in identified data gaps and reduce limitations to refine future co-occurrence modeling and other efforts to assess entanglement risks associated with fixed gear fisheries; 3) continued gear research; 4) research to understand the mechanisms of large whale entanglements; 5) improving traceability of gear through gear marking; and 6) improve the level of detail reported for each specific entanglement report (particularly the identification of gear).

Specific investigations/research

The co-occurrence model identified elevated risk areas (e.g. potential hot spots) where specific research efforts should be focused to understand and reduce future large whale entanglements in the future.

1. **San Francisco:** November, December, and January - This time/area study of fishing effort and large whale presence would capture an elevated risk area for all whale species included in this study and would address multiple model limitations.
2. **Santa Barbara:** July to December - this time/area study would capture an elevated risk area for multiple whale species with the California halibut/white seabass set gillnet, hagfish trap, rock crab trap, sablefish, spiny lobster trap, and spot prawn trap fisheries.
3. **Washington, Oregon, and northern California**: Areas that overlap with Dungeness crab trap fishery in December and January - focus on a wide area over a short time frame would capture an elevated risk for blue, fin, and humpback whales and further refine the fishery effort model to target areas of higher gear concentrations.
4. **Central California:** Humpback whales in central California with sablefish/spot prawn based on model results and confirmed entanglement.

Filling in data gaps

Outside of the specific time/area research listed above, density modeling of whale distributions off the U.S. west coast in Quarters One and Two (January to June), especially for blue, fin, humpback, and sperm whales, should be conducted. Winter density estimates would allow for a year-round co-occurrence assessment and a more complete understanding of which locations, fisheries, and times of the year have the highest co-occurrence risk for all whale species. Refinement of the gray whale migratory path using recent satellite telemetry data or updated information from land-based and aerial surveys can improve the depiction of migratory paths through southern California and along their entire migration route. Density and distribution estimates for the gray whale Pacific Coast Feeding Group and the Western North Pacific stock not available for this analysis could also be included in the co-occurrence model to assess entanglement risk to these specific populations should they become available. Additional whale research, through satellite tracking, winter surveys or sightings, could lead to more fine-scale modeling of co-occurrence, focused on areas of medium or high co-occurrence scores that have been identified through these initial analyses.

Gear research

Of the 143 large whale entanglements reported along the U.S. west coast from 2000 to 2012, there were 22 (15%) cases where the fishery was identified and confirmed (Saez *et al*., in prep). Inability to identify entangling gear type may lead to the assumption that similar fisheries, in known whale habitats, have the same potential entanglement risk. Should resources become available, research should be conducted to assess the relative entanglement risk between different gear types on the U.S. west coast, with emphasis on risk to specific species of whales, based on their distribution, density, and behavior. Research may also include directed or opportunistic studies of whale behavior when encountering commercial fishing gear, which could influence entanglement risk. This could help address two limiting assumptions of the co-occurrence model developed in this analysis: that all gear types are equally likely to entangle a whale, and all species of whales are equally likely to become entangled. Research on potential gear modifications for the U.S. west coast, including changes in gear configuration, gear and/or materials construction and manufacturing, line tension, etc., could also be conducted while being mindful of avoiding the creation of lost gear and formation of marine debris. Research should also be mindful of costs to the fishermen in terms of gear modification and potential for lost gear. The Atlantic Large Whale Take Reduction Team has conducted research on modifications, such as buoy types, weak links, knot tying locations, line cutters, and line material for gear to help understand and reduce entanglements of large whales on the U.S. east coast. A summary of their research can be found at: http://www.nero.noaa.gov/Protected/whaletrp/research/index.html.

Future research should expand baseline information already conducted on fixed gear fisheries in California, Oregon, and Washington and included in this analysis. For instance, there are multiple sources of entanglements documented within the U.S. west coast and outside the U.S., including non-fixed gear (i.e. drift gillnet), marine debris, other commercial fishing gear types, recreational fisheries, mooring and anchor lines, and wires and cables associated with non-fishery projects. Distributions of the non-fixed gear entanglement sources could be mapped and integrated into the co-occurrence model if data exists.

Research testing the assumption that entanglement risk is proportional to the level of co-occurrence (i.e. the more effort/gear and more whales present in an area, the higher the co-occurrence score and assumed entanglement risk) could further refine future co-occurrence models and improve interpretation of model results. Future co-occurrence modeling of commercial fishing and large whales could incorporate quantification of the amount of active fishing gear (traps/net/hooks) per area as a more direct measure of fishing effort. This would provide a more direct assessment of co-occurrence and risks of whale entanglement with fishing gear compared to the use of landings as a measure of effort currently described in this co-occurrence model. A gear density based co-occurrence model could help assess how changes in the density of active fishing gear in certain areas affects co-occurrence and ultimately entanglement risk.

Currently, under the assumption of a linear relationship between gear/whale density and entanglement risk, any effort at reducing the amount of gear in the water should lead to reduced entanglement risk for large whales. Research could be conducted to test the assumption that reduced gear density equals less entanglement risk. Oregon and Washington have already implemented fishery regulations to reduce the overall number of traps allowed in their commercial Dungeness crab fishery through a trap limit system (CDCTF, 2010). Currently, California has legislation in place for a trap limit system to start in the 2013 fishing season with the goal of reducing the total number of traps off the California coast (CDCTF, 2010). Trap limits are a way to reduce the amount of gear entering the water. Lost gear and marine debris removal efforts are a compliment to the trap limit system as a way to remove the overall amount of material in the ocean that could potentially entangle a marine mammal. There are multiple marine debris removal efforts occurring off the U.S. west coast and some are specifically targeted at lost gear recovery.

Gear marking

A limiting factor in identifying the origin of fishing gear associated with entangled whales is traceability, including gear markings that may be limited or difficult to readily identify during an entanglement. More definitive gear marks, such as buoy tags, trap tags, and color marking schemes specific to a fishery/region/gear part, could increase the percentage of entanglement reports where the gear is correctly identified. Traceability allows for the gear owner to be contacted for information regarding where and when the gear was set, gear configuration (which can help in disentanglement efforts), determining active versus lost gear status, and also returning gear when possible. Gear marking schemes, as researched and implemented as part of the Atlantic Large Whale Take Reduction Plan, have helped NMFS and other stakeholders on the U.S. east coast address management questions of when and where whales encounter commercial fishing gear and which section of the gear entangles whales.

There are already marking requirements for U.S. west coast commercial fisheries. In California, every trap shall be marked with a buoy, and certain trap fisheries are required to mark their buoys with a fishery-specific letter in addition to their license number (i.e. a buoy marked with 00000B would indicate the sablefish fishery in California). The Oregon and Washington Dungeness crab fisheries have a buoy tag system, designed to assist with monitoring their trap limit system. The Washington Indian tribes also have a buoy branding requirement. These tags and buoy marking requirements were useful in identifying fisheries when tags or buoys are included on the gear that are found on entangled whales. These current gear marking requirements should be assessed and evaluated for potential ways to improve marking for identification purposes. More information on gear marking for specific fisheries, including photos of fishing gear, can be found in the Fixed Gear Guide (Appendix A and available at: http://swr.nmfs.noaa.gov/psd/fixed_gear.htm).

Suggestions for future modeling

Future modeling should integrate the suggestions summarized below and any new available whale, fishery, or gear removal data to improve assessment of co-occurrence and the associated entanglement risk for large whales off the U.S. west coast.

Suggestions:

- Align the timeframes of the fishery and whale data

- Vertical line or gear density metric for fishing effort in co-occurrence model
- Bottom substrate/habitat component added to refine fishery effort model
- Include fishery effort for other commercial fisheries
- Re-scaling or weighting landings or whale species depending on management priorities
- Include winter density estimates for blue, fin, humpback and sperm whales, if available
- Include Pacific Coast Feeding Group or Western North Pacific gray whale densities, if available

Models to assess large whale entanglement can always be improved, so NMFS will rely on the input of large whale entanglement reporting as baseline data and address the differences seen between actual reports and co-occurrence model outcome.

Improved reporting

The primary tool for recording information about whale entanglements along the U.S. west coast is through reports received into the whale entanglement hotline operated by NMFS as part of the stranding network or through the U.S. Coast Guard (Saez *et al.*, in prep). A goal for the reporting of whale entanglements is to provide accurate and detailed information on the whale species, location, gear type, and nature of entanglement to the large whale disentanglement network as quickly as possible. Disentanglement efforts, when successful, can save an individual whale's life; however, the underlying cause of whale entanglements still needs to be addressed. The ultimate goal of for each report is to contribute to a greater understanding of which fishery or other source of entanglement is responsible so that effective actions may be taken to reduce entanglements.

Outreach efforts should be continued and target the following:

1. Increase public awareness of whale entanglements.
2. Inform the public on what to look for and how to report and document (including photographs) an entangled whale.
3. Encourage mariners to safely stay with the entangled whale as long as possible until trained help arrives and not attempt to help the whale.
4. Share knowledge of trained response network.
5. Expand the geographic range of observers and reporting parties.
6. Educate observers and reporting parties to better identify gear types and whale species.

Information in this report can be coupled with the fixed gear guide (Appendix A) to begin a more formal educational outreach campaign. Even with expert knowledge, there will always be challenges in assessing the gear involved and complexity of the whale entanglements. Such factors include environmental conditions (e.g. weather, sea state, and time of day) location and direction of the whale, and details related to attachment of the gear to the whale.

4.0 Conclusion

The models presented in this preliminary analysis were created to investigate the risk of large whale entanglement in commercial fixed gear fisheries along California, Oregon, and Washington. The results of this study provide a reference of historic and potentially future areas of entanglement risk for the U.S. west coast large whale species. The model identified areas of elevated risk for where and when large whales are more likely to encounter fixed commercial gear and possibly become entangled. Notably, elevated risk as outlined here does not necessarily equate to certain numbers of whale entanglements, as an entanglement can occur in any area and at any time when a whale and gear are present. The Dungeness crab trap fishery had the highest co-occurrence scores for all whale species included in the model and is considered the highest risk commercial fixed gear fishery off the U.S. west coast for the months of November, December and January. Specific time/area/fishery investigations into elevated entanglement risk areas such as central California and Santa Barbara, coupled with gear research, updated or new modeling approaches, traceability through gear marking, and strengthening outreach, could further improve knowledge of the interactions of large whales with commercial fishing gear.

NMFS plans to use the information from the co-occurrence model results to focus efforts to reduce large whale entanglements. NMFS plans and also encourages other to include efforts for further refinement of co-occurrence models, taking into account gear configuration, specific research and education of fishermen and other mariners who may encounter whales in higher risk times/areas/places/fisheries. NMFS recognizes that entanglement is one of the leading threats to many large whale species, along with ship strikes, anthropogenic noise, and loss of habitat.

References

Atlantic Large Whale Take Reduction Team (ALWTRT). 2010. Atlantic Large Whale Take Reduction Plan Vertical Line Model: Development and Distribution of Baseline Co-occurrence scores. Presented at the Northeast Subgroup Take Reduction Team Meeting. Providence, RI. December 2010.

Barsky, Kristine. Senior Biologist, California Department of Fish and Game, Ventura, CA. January 17, 2012. Personal communication, e-mail fishery characterization.

Barss, W. 1993. Pacific hagfish, *Eptatretus stouti*, and black hagfish, *E. deani*: the Oregon Fishery and Port sampling observations, 1988-92. Marine Fisheries Review.

Becker E.A., K.A. Forney, M.C. Ferguson, J. Barlow, and J.V. Redfern (2012). Predictive modeling of cetacean densities in the California Current Ecosystem based on summer/fall ship surveys in 1991- 2008, NOAA Technical Memorandum NMFS-SWFSC-499. Barsky, Kristine. Senior Biologist, California Department of Fish and Game, Ventura, CA. February 28, 2011. Personal communication, e-mail regarding trap usage in the spiny lobster trap fishery.

Calambokidis, John. Research Biologist, Cascadia Research, Olympia, Washington. August 8, 2012. Personal communication.

California Department of Fish and Game (CDFG). 2001. California's living marine resources: a status report. California Fish and Game Code (FGC).Accessed February 14, 2011. Available at: http://www.leginfo.ca.gov/cgibin/calawquery?codesection=fgc&codebody=&hits=20

California Department of Fish and Game (CDFG). 2010. 2010 Digest of California commercial fishing laws and licensing requirements. Available at: www.dfg.ca.gov. California Department of Fish and Game (CDFG). 2012. Draft regulations, Dungeness crab trap limit program. Available at: http://www.opc.ca.gov/2009/04/dungeness-crab-task-force/

California Dungeness Crab Task Force (CDCTF). 2010. Record of the Proceedings: California Dungeness Crab Task Force. Available at: http://www.opc.ca.gov/webmaster/ftp/project_pages/dctf/Nov2010_ROP_DCTF.pdf

California Seafood Council (CSC). 2011. Hook and Line Facts in Brief. Accessed on March 2, 2011. Available at: http://ca-seafood.ucdavis.edu/facts/hookline.htm

Carretta, J. V., Forney, K. A., Oleson, E., Martien, K., Muto, M. M., Lowry, M. S., Barlow, J., Baker, J., Hanson, B., Lynch, D., Carswell, L., Brownell Jr., R. L., Robbins, J., Mattila, D. K., Ralls, K., and Hill, M. C. 2011. Pacific Regional Stock Assessment Report: National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, California.

Corbett, Kelly. Marine Fisheries Biologist, Oregon Department of Fish and Wildlife. Newport, Oregon April 8, 2010. Personal communication, e-mail regarding spot prawn trap fishery.

Corbett, Kelly. Marine Fisheries Biologist, Oregon Department of Fish and Wildlife. Newport, Oregon April 1, 2011. Personal communication, e-mail regarding Dungeness crab trap depths from logbook.

Corbett, Kelly. Marine Fisheries Biologist, Oregon Department of Fish and Wildlife. Newport, Oregon. November 9, 2011.Personal communications, e-mail regarding characteristics of the Dungeness crab trap fishery.

DeAngelis, M., Saez, L., MacNeil, J., Mate, B., Moore, T., Weller, D., and Perryman, W. 2011. Spatio-temporal modeling of the eastern Pacific gray whale (*Eschrichtius robustus)* migration through California, Oregon, and Washington. No page number *in* Selected papers presented at the 19th Biennial Conference on the Biology of Marine Mammals. November 26 through December 2, 2011. Tampa, FL.

DeAngelis, M., Saez, L., MacNeil, J., Mate, B., Moore, T., Weller, D., and Perryman, W. (unpublished) Spatio-temporal modeling of the eastern Pacific gray whale (*Eschrichtius robustus)* migration through California, Oregon, and Washington. In prep. Data available at www.cetsound.noaa.gov

Goblirsh, G., and Theberge, S. 2003. Long-liners. Oregon Sea Grant.ORESU-G-03-010.

Hipkins, F. W. 1974. NOAA Fishery Facts 7. A trapping system for harvesting sablefish, *Anoplopoma fimbria*. Seattle, Washington.

Heyning J. E. and T. D. Lewis. 1990. Entanglements of baleen whales in fishing gear off southern California. Report to the International Whaling Commission 40: 427-431.

International Pacific Halibut Commission (IPHC). 2010. General biology of Pacific halibut. http://www.iphc.washington.edu/research/biology.html. Accessed on November 22, 2010.

International Whaling Commission. 2011. Report of the Scientific Committee. Journal of Cetacean Research and Management. 12(Suppl.):1-75.

Laake, J., Punt, A., Hobbs, R., Ferguson, M., Rugh, D. and J. Breiwick. 2009. Re-analysis of gray whale southbound migration surveys 1967-2006. U.S. Department of Commerce. NOAA Tech. Memo. NMFS-AFSC-203, 55 p.

Lang, A. R., Weller, D. W., Leduc, R. G., Burdin, A. M., and R. L. Brownell, Jr. 2010. Genetic differentiation between western and eastern (*Eschrichtius robustus*) gray whale populations using microsatellite markers. Paper SC/62/BRG11 presented to the International Whaling Commission, Scientific Committee. 18 p.

McVeigh, B. 2010.Coonstripe shrimp fishery. California Department of Fish and Game. Unpublished.

National Centers for Coastal Ocean Science (NCCOS) 2005. A Biogeographic Assessment of the Channel Islands National Marine Sanctuary: A Review of Boundary Expansion Concepts for NOAA's National Marine Sanctuary Program. Silver Spring, MD. NOAA Technical Memorandum NOS NCCOS 21.

National Marine Fisheries Service (NMFS). 2005. Essential Fish Habitat Final Environmental Impact Statement. Appendix 8.Description of fishing gears used on the United State west coast. December 2005.

National Marine Fisheries Service (NMFS). 2008. Characterization of U.S. West Coast Pot/Trap Fisheries. White paper

National Marine Fisheries Service (NMFS). 2010a. CA Halibut/White Seabass and Other Species Set Gillnet (>3.5 in mesh) Fishery. http://www.nmfs.noaa.gov/pr/pdfs/fisheries/ca_halibut_whiteseabass_other_set_gillnet.pdf. Accessed on October 6, 2010.

National Marine Fisheries Service (NMFS). 2010b. WA/OR/CA Sablefish Pot Fishery. http://www.nmfs.noaa.gov/pr/pdfs/fisheries/wa_or_ca_sablefish_pot.pdf. Accessed October 6, 2010.

National Marine Fisheries Service (NMFS). 2010c. CA Spot Prawn Pot Fishery. http://www.nmfs.noaa.gov/pr/pdfs/fisheries/ca_spot_prawn_pot.pdf. Accessed October 6, 2010.

Northwest Fisheries Science Center (NWFSC). 2010a. Data report and summary analyses of the U.S. west coast non-nearshore fixed gear groundfish fishery. West Coast Groundfish

Observer Program. National Marine Fisheries Service, NWFSC, 2725 Montlake Blvd E., Seattle, WA 98112.

Northwest Fisheries Science Center (NWFSC). 2010b. Pacific coast groundfish limited entry vessel permit history. Accessed on November 17, 2010.

Northwest Fisheries Science Center (NWFSC). 2012. Nearshore fixed gear – fishery resources analysis and monitoring. Accessed February 7, 2012.http://www.nwfsc.noaa.gov/research/divisions/fram/observer/nearshore_gear.cfishery model.

Oregon Administrative Rule (OAR) for Oregon Department of Fish and Wildlife. Division 006.Accessed on February 14, 2011. Available at: http://www.dfw.state.or.us/OARs/06.pdf

Pacific States Marine Fisheries Commission (PSMFC). 2010. PacFIN overview. http://pacfin.psmfc.org/pacfin_pub/overview.php. Accessed on October 6, 2010.

Reed, Heather. Coastal Marine Resources Policy Coordinator, Washington Department of Fish and Wildlife. Montesano, Washington. November 14, 2010. Personal communication, e-mail regarding the Washington coastal Dungeness crab trap fishery.

Robbins, J., and D. Mattila. 2004. Estimating humpback whale (Megaptera *novaeangliae*) entanglement rates on the basis of scar evidence. Report to the Northeast Fisheries Science Center National Marine Fisheries Service. Order number 43EANF030121. May 13, 2004.

Robbins, J., Barlow, J., Burdin, A.M., Calambokidis, J., Gabriele, C., Clapham, P., Ford, J., LeDuc, R., Mattila, D.K., Quinn, T., Rojas-Bracho, L., Straley, J., Urban, J., Wade, P., Weller, D., Witteveen, B.H., Wynne, K. and Yamaguchi, M. 2007. Comparison of humpback whale entanglement across the North Pacific Ocean based on scar evidence. Unpublished report to the Scientific Committee of the International Whaling Commission. Report number SC/59/BC.

Saez, L., D. Lawson, M. DeAngelis, E. Petras, S.Wilkin, C. Fahy, and B. Norberg. In prep. Large whale entanglements off the U.S. West Coast.

Sandilands, D., L. Barrett-Lennard, and A. Phillips. 2009. Grey and humpback whale entanglement. Vancouver Aquarium. Presented at: Humpback Whale Recovery Strategy Technical Workshop. January 12 - 14, 2009. Nanaimo, British Columbia, Canada.

Schumacker, Joe. Marine Resources Scientist, Quinault Department of Fisheries. Taholah, Washington. April 21, 2011. Personal communication regarding tribal commercial fishing.

Sweetnam, Dale. Senior Marine Biologist, California Department of Fish and Game, La Jolla, California. February 14, 2011. Personal communication, e-mail regarding gillnet fisheries.

Tanaka, Travis. Associate Marine Biologist, California Department of Fish and Game. Monterey, California. January 28, 2010. Personal communication, regarding the hagfish trap fishery.

U.S. Federal Register, Volume 76 No. 73912. November 19, 2011. Final rule: List of Fisheries for 2012.

Walk, D., T. Sean, and E. Summers. 2009. Mapping risk of whale entanglement in fishing gear in the northeast gulf of main using GIS. *In*: Proceedings of the 18th Biennial Conference of Marine Mammals. Quebec City, Canada.12-16 October, 2009.

Wargo, Lorna. Marine Fish Biologist, Washington Department of Fish and Wildlife. Montesano, Washington. April 20, 2010.Personal communication, e-mail regarding the hagfish trap and spot prawn trap fisheries in Washington.

Weller, D.W., Klimek, A., Bradford, A. L., Calambokidis, J., Lang, A. R., Gisborne, B., Burdin, A. M., Szaniszlo, W., Urbán, J., Unzueta A. G., Swartz, S., and R. L. Brownell Jr.. 2012.

Movement of gray whales between the western and eastern North Pacific. Endangered Species Research. 18: 193-199.