Assessment of Entanglement Risk: A Vertical Line Co-occurrence Model of Large Whales and the Commercial Fixed Gear Dungeness Crab (*Cancer magister*) Fishery Off the U.S. West Coast

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A thesis
submitted in partial fulfillment of the
requirements for the degree of

Master of Marine Affairs

University of Washington
2018

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Program Authorized to Offer Degree:
School of Marine and Environmental Affairs

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ABSTRACT

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Since 2014, reports of whale entanglements have spiked along the U.S. West Coast from an average of 10 confirmed cases per year to up to 71 reported entanglements in 2016. The commercial fixed gear Dungeness crab (*Cancer magister*) fishery has been the most identifiable gear in confirmed whale entanglements. The continued high number of reported whale entanglements has warranted fishery managers, fishermen, and other stakeholders to look into solutions to reducing the number of entangled whales; however, a better understanding of where and why these entanglement rates have spiked is needed. Previous efforts by National Marine Fisheries Service (NMFS) to understand entanglement risk designed a co-occurrence model to assess entanglement risk along the West Coast by overlaying landings data with species-specific whale density and distribution patterns to produce relative co-occurrence scores as an indicator for risk. The purpose of this study was to create a vertical line co-occurrence model between large whales and the commercial Dungeness crab fishery; as NMFS indicated in their previous model, that the use of gear density instead of the number of pounds landed to represent fishing effort provides a better understanding of high entanglement risk areas. This research provides a comparison to previous co-occurrence modeling efforts, highlights the areas and months of high entanglement risk, and compares risk areas over several time periods. The vertical line co-occurrence models piloted in this study created a new understanding of areas of entanglement risk for large whales in recent years to aid future efforts by NMFS and fishery managers to mitigate large whale entanglements.

Keywords: whale entanglement; risk assessment; vertical line co-occurrence model; baleen whales; Dungeness crab; U.S. West Coast

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CHAPTER 1: INTRODUCTION

The West Coast of the U.S. is home to a diverse range of ecologically and economically important species (Estes et al. 2006, Moffitt and Cajas-Cano 2014). Large baleen whales act as sentinels of ocean health and essential actors in the marine food web (ALWTRT 2010). While the ecological roles of large whales are significant, their cultural and economic value for coastal communities are just as noteworthy with a total expenditure by whale watchers in 2008 reaching nearly $640 million in West Coast states (O'Connor et al. 2009, Jenkins and Romanzo 1998). Fisheries are just as valuable as the characteristic marine megafauna along with West Coast, with the Dungeness crab (*Cancer magister)* fishery bringing in revenues of over $169 million in 2014 (PSMFC 2014).

COMMERCIAL DUNGENESS CRAB FISHERY OVERVIEW

Dungeness crab is caught throughout the West Coast of North America, from the northernmost part of Washington state to the southern part of its range in Baja California (Saez et al. 2013). Traps targeting Dungeness crab are fished individually with a circular steel frame three to four feet in diameter attached to a single vertical line with one or two buoys at the end (Saez et al. 2013, Goblirsch and Theberge 2008). One fisherman may fish 30 to 100 traps in a row along a depth contour, usually between 3 and 80 fathoms; adult Dungeness crabs can be found as deep as 2,000 feet (333 fathoms / 610 meters)[1] (Saez et al. 2013, Goblirsch and Theberge 2008, Table 1). Typical spacing is 15 pots per mile, varying from 10 to 25 pots per mile and left to soak unattended for one to seven days (Saez et al. 2013, Goblirsch and Theberge 2008).

The commercial Dungeness crab fishery is state managed by the California Department of Fish and Wildlife (CDFW), Oregon Department of Fish and Wildlife (ODFW), and Washington Department of Fish and Wildlife (WDFW); with federal oversight regarding the

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[1] ODFW website with commercial fishing regulations https://www.dfw.state.or.us/MRP/shellfish/regulations.asp

implementation of requirements outlined in the Marine Mammal Protection Act (MMPA), the Magnuson-Stevens Fishery Conservation and Management Act (MSA), and the Endangered Species Act (ESA). These state agencies cooperate in the management of the fishery under the Pacific States Marine Fisheries Commission Dungeness Crab Tri-State Committee. The states manage the fishery with limited entry permits, trap limits, and other regulations specific to each state (Calambokidis et al. 2015, Saez et al. 2013). The federal role is one of oversight and implementation of MMPA, MSA, and ESA requirements by National Marine Fisheries Service (NMFS).

Interactions between large whales and fisheries, including bycatch in fisheries, poses a significant threat to not only the specific West Coast populations affected but also West Coast ecosystems, economies, and the people who rely on them both culturally and economically. Increasing rates of entanglement and scarring of large whales is cause for alarm and could result in consequences for the fishery responsible as all marine mammal species are protected in the U.S., many of the populations of large whales are listed as threatened or endangered (Read et al. 2006). These human-whale interactions with fishing gear along the U.S. West Coast are an issue of concern because of the impacts these interactions have on stocks and populations of whales as well as the fishing industry and economy (Saez et al. 2013).

REGULATIONS AND MANAGEMENT

The conservation and management of marine ecosystems and resources falls under the jurisdiction of the National Oceanic and Atmospheric Administration. NOAA’s National Marine Fisheries Service is the agency responsible for protecting species under three U.S. laws; the Magnuson-Stevens Fishery Conservation and Management Act (MSA), the Marine Mammal Protection Act (MMPA), and the Endangered Species Act (ESA) (Shallin Busch et al. 2016).

Under the MSA, NMFS is required to reduce or minimize capture and subsequent discard of non-target species, including marine mammals.

All marine mammals on shore or in U.S. waters are protected by the MMPA, a national policy created in response to significant declines in some species of marine mammals in response to human activities and interactions. The Marine Mammal Protection Act of 1972, as amended in 1994, states that NMFS is mandated to conserve marine mammals and to assess the stock status of all marine mammal species within the U.S. Exclusive Economic Zone (EEZ) to maintain Optimal Sustainable Populations (OSP) (NMFS 2014). In addition, NMFS is required to reduce bycatch, protect habitats, and a variety of other activities such as banning the harassment of marine mammals. NMFS is authorized to allow commercial fisheries to "take" marine mammals subject to registration and reporting requirements as long as the incidental takes do not exceed the potential biological removal levels (PBR). Potential biological removal is "the maximum number of animals, not including natural mortalities, that may be removed from a marine mammal stock while allowing that stock to reach or maintain its optimum sustainable population" (MMPA 1972). Based on the incidental "take" estimates attributed to fisheries, NMFS categorizes commercial fisheries into one of three categories according to their level of impact on a population (i.e., frequent (Category I), occasional (Category II), or rare/none (Category III)) (NMFS 2014). NMFS may develop take reduction plans for Category I fisheries imposing stricter and financially taxing regulations on fishermen to reduce the number of "take" incidents. Importantly, this authority, under Section 118, does not apply to species listed as threatened or endangered under the ESA.

The purpose of the ESA is to protect and recover imperiled species and the ecosystems upon which they depend (Shallin Busch et al. 2016). The ESA protects endangered and threatened species and their habitats by prohibiting the "take" of listed species (NMFS 2014, Shallin Busch et al. 2016). ESA requires Section 7 consultations with fishery managers when managing ESA listed species and may authorize incidental takes of marine mammals under the strict requirements of Section 10 (ESA 1973). Under these three laws, NMFS is mandated to address the spike in the number of entangled whales to ensure levels of optimal sustainable populations are attained and to ensure thriving and sustainable fisheries.

Current whale stock assessment reports, reporting minimum population estimates of large whales, conducted by NMFS under the MMPA, have identified the following species as being at risk for entanglement in fixed gear fisheries: non-Endangered Species Act listed Eastern North Pacific gray whale (*Eschrichtius robustus)* (18,017 animals), the ESA-listed endangered Eastern North Pacific stock of blue whales (*Balaenoptera musculus)* (1,551 animals), the ESA-listed endangered North Pacific stock of fin whales (*Balaenoptera physalus*) (2,598 animals), the ESA-listed as endangered Washington, Oregon, and California stock of sperm whales (751 animals), and the ESA-listed populations of humpback whales (*Megaptera novaeangliae)* part of the Washington, Oregon, and California stock under the MMPA (1,876 animals) (NMFS 2014, Santora et al. 2018, Species Stock Assessments can be found on the NMFS website[2]).

WEST COAST ENTANGLEMENT

Beginning in 2014, the U.S. West Coast has faced a growing amount of pressure to mitigate whale bycatch as human-whale interactions were observed to have increased based on the number of whales becoming entangled in fishing gear each year (NMFS 2017, NMFS 2018, Saez et al. 2013). NMFS has closely monitored large whale entanglement since the early 1980s (NMFS 2014, Shallin Busch et al. 2016). Between 2000 and 2017 a total of 365 whales have been reported entangled: 179 humpback whales, 116 gray whales, 8 blue whales, 6 fin whales, 2

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[2] Current stock assessments https://www.fisheries.noaa.gov/national/marine-mammal-protection/marine-mammal-stock-assessment-reports-species-stock

minke whales, 2 sperm whales, 2 killer whales, and 50 unidentified species (Saez et al. 2017). These numbers represent the total of confirmed and unconfirmed reports. While these totals are thought to be an under representation of the actual number of entangled whales, this study designates if the numbers are confirmed or (unconfirmed) reports of entangled whales. Recent shifts in the number of large whale entanglements has increased from an average of less than 10 confirmed cases per year between 2000 - 2012 off the West Coast with gear from U.S. fisheries to 32 reported entanglement cases in 2014, 62 in 2015, 71 in 2016, and 41 in 2017 (NMFS 2017, NMFS 2018). These numbers are the highest annual total for the West Coast of the U.S. since NMFS started keeping records in 1982 (NMFS 2017). This increase may be attributed to a number of dynamic factors, including: changes in whale abundance and distribution, changes in prey and fish availability, increased public reporting, delays in the opening of fishing seasons, changes in environmental conditions, shifting patterns in fishing, and changing patterns of other human activities (NMFS 2018, Wells et al. 2017).

Since 2008, NMFS has ramped up efforts to improve public awareness and reporting of entangled whales (Lawson 2018). This improved reporting may account for some portion of the increase in reports in recent years. Since 2015, the issue of whale entanglement has captured the public eye with the dramatic increase in the number of reports spiking to up to 71 in 2016, compared to the long-term average (NMFS 2017, NMFS 2018).

The coast-wide bloom of the toxic diatom *Pseudo-nitzschia* spp. in the spring of 2015 “resulted in the largest recorded outbreak of the neurotoxin, domoic acid, along the North American West Coast. Elevated toxins were measured in numerous stranded marine mammals and resulted in geographically extensive and prolonged closures of razor clam, rock crab, and Dungeness crab fisheries” (McCabe et al. 2016). Delays in the opening of the Dungeness crab fishery increased fishing pressure later in the season in 2015. The higher fishing pressure in the spring, when efforts would normally be dwindling, coupled with large whale species migrating through Dungeness crab fishing areas could have increased the risk of whales becoming entangled.

Increased sea surface temperatures among other unusual ecosystem conditions observed in recent years highlight the impacts of ocean variability on coastal marine communities, including large whales, and may influence whale and forage fish abundance and distribution (Wells et al. 2017). Studies suggest that in recent years there has been a shoreward shift in the distribution of baleen whales which may contribute to the increased number of reports of entangled whales (Wells et al. 2017). Not only does this shoreward shift in whales put them in greater proximity to fixed gear fishery grounds but also closer to the public eye, which coupled with public outreach efforts by NMFS could have resulted in increased reporting (Wells et al. 2017, Santora et al. 2018).

DUNGENESS CRAB FISHERIES AND ENTANGLEMENT

The fishery facing the most pressure from the increase in these reported interactions is the Dungeness crab fishery along Washington, Oregon, and California. The Dungeness crab fishing gear from these states has been recognized as the most identified gear to entangle large whale species. For example, in 2016, 29 of the 48 confirmed entanglement cases (71 reports total) were identified as associated with specific fisheries or gear type; 75% of that was identified as Dungeness crab fishing gear (NFMS 2017, NMFS 2018). While 29 of the 48 confirmed entanglement cases can be attributed to a specific fishery or gear type, the remaining 39.6% of gear was unidentifiable and not assigned to a particular fishery. The Dungeness crab fishery can be acknowledged as causing entanglements but the large percentage of unidentifiable fishing gear remains of high concern to NMFS (NMFS 2017, NMFS 2018). The Washington, Oregon, and California commercial Dungeness crab fisheries are classified as Category II under the MMPA, based on its interactions with humpback whales and Eastern North Pacific gray whales (NMFS 2014, ESA 1973). There is significant pressure on these fisheries to reduce entanglements to avoid increased regulations, management, and oversight that comes with a change from a Category II fishery to a Category I fishery.

This increase in the number of entangled whales in fishing gear has prompted National Marine Fisheries Service to work with the CDFW, ODFW, WDFW, commercial and recreational fishermen, general public, and non-governmental organizations to find ways to reduce the number of entanglements. NMFS has proposed several methods to reduce entanglements, including:

- improving the reporting of whale entanglements;
- expanding the number of permitted organizations to respond to entangled whales;
- collaborating with relevant agencies in the private and public sector to develop ways to "minimize entanglements in the California crab fishery, including refining a 'best practices guide' for fishermen that can be used coast-wide" (NMFS 2017, NMFS 2018);
- working with the West Coast states and stakeholders to form priorities for future evaluation of entanglement risk in different fisheries and fishing gear;
- furthering our understanding of how environmental conditions affect potential whale entanglements;
- and, providing "scientific expertise on all known or suspected sources of entanglements, exploring when, where, and how entanglements are occurring, and evaluating the available information on entanglements to determine the impacts on humpback whale populations" (NMFS 2017, NMFS 2018).

The number of whale entanglement reports spiked in 2014, either due to a better system of reporting or an increase in the number of entangled whales. Prior to this spike, which led to the increased entanglement avoidance efforts listed above, there was one analytical tool developed by NMFS to understand whale entanglement risk. NMFS developed the West Coast co-occurrence model for commercial fixed gear fisheries and large whales to assess the potential entanglement risk associated with various fixed gear fisheries relative to their co-occurrence with individual large whale species. This model Saez et al. (2013) developed was for years 2004 – 2008 and quantifies the relative risk of entanglement, focusing on fisheries using gear that has been confirmed or is suspected of being capable of entangling whales. This original co-occurrence model focused on eleven fixed gear commercial trap fisheries off of California, Oregon, and Washington. Saez et al. (2013) highlighted that future co-occurrence modeling efforts to develop vertical line models for each commercial fixed gear fishery might aid in the identification of elevated risk areas and associated time periods for large whales and commercial fixed gear fisheries.

Upon review of the literature, few vertical line models have been published and even fewer vertical line co-occurrence models are available for large whale species. The two most notable efforts to understand vertical line co-occurrence are: 1) the efforts of the Atlantic Large Whale Take Reduction Team (ALWTRT) and 2) the study in Monterey Bay done by the consulting firm Point Blue (ALWTRT 2010, Jahncke et al. 2018). The ALWTRT created a vertical line co-occurrence for endangered whale species along the East Coast of the U.S (IEC 2014, ALWTRT 2010). The other study was done by the conservation science consulting firm Point Blue, NOAA, and National Marine Sanctuaries on the co-occurrence of large whales and crab pots in Monterey Bay by collecting multi-disciplinary data from ship-based surveys (Jahncke et al. 2018). It is acknowledged that the lack of a current vertical line fishery model as a measure of effort is a gap in understanding the co-occurrence between large whales and fixed gear along the U.S. West Coast (NMFS 2017, NMFS 2018, Saez et al. 2013, Jahncke et al.

2018). In such models, risk areas are assessed by a measure of co-occurrence which refers to those areas with the highest whale density and number of traps over a given period.

A better measurement of fishing effort, and therefore a better understanding of co-occurrence, could be calculated by understanding vertical line density as a more direct way to compare overlapping whale and gear densities rather than extrapolating effort from the number of pounds landed by port (Saez et al. 2013). The purpose of this study was to develop a vertical line model. This research developed a vertical line model for the commercial Dungeness crab fixed gear fishery as a pilot to better understand the overlap of large whales and fixed gear along the West Coast. Specifically, this study spatially and temporally identified areas of high risk of entanglement by the number of traps in the water in a given month and the density of whales in that area at a given time.

This study is part of broader set of research and actions by NMFS with the goal to reduce entanglements (NMFS 2017, NMFS 2018). Whale entanglement is a major issue for fisheries management and conservation agencies in many parts of the world and has a high public profile for coastal species (Johnson et al. 2005, Moore 2014). The high monetary cost and risk to personnel of disentanglement efforts coupled with a low success rate, i.e., a total of 30 successful disentanglements were completed from 204 reported entanglements between 2014 - 2017, would argue for the perspective that effective preventative measures are strongly preferred over whale rescues (Harcourt et al. 2014, Viezbicke 2018).

This research builds upon work of Saez et al. (2013) and investigates how the large whale entanglement risk associated with the commercial fixed gear Dungeness crab fishery identified by Saez et al. (2013) from 2004 - 2008 changes, if at all, with the use of vertical line density as the proxy for fishing effort instead of the number of pounds landed by port. This research a) adds updated fishing information from recent years when whale entanglement reports have been increasing, and, b) develops a commercial fixed gear Dungeness crab fishery vertical line model along the West Coast of the U.S. This study developed four vertical line fishing models for overlay with whale density and distribution data to create sixteen vertical line co-occurrence models for comparison. The four vertical line fishery models include an:

1. All States Fishery Model from the 2013/2014 – 2016/2017 fishing seasons in CA/OR/WA
2. Washington and Oregon Only Fishery Model:
    a. from the 2008/2009 – 2011/2012 and 2012/2013 – 2015/2016 fishing seasons
    b. and compared this with an Oregon Logbook Fishery Model from the 2008/2009 – 2011/2012 and 2012/2013 – 2015/2016 fishing season
3. and, California Only Fishery Model from the 2013/2014 – 2016/2017 fishing season.

Exploring these different models will provide additional analysis to be used by NMFS to improve their understanding of entanglement risk relative to the entire West Coast and for the individual states. The differences in the models along with updated fishery effort data might aid in the identification of elevated risk areas and associated time periods of large whales and the commercial fixed gear Dungeness crab fishery to better understand and possibly mitigate large whale entanglements in the future.

CHAPTER 2: DEVELOPMENT OF THE VERTICAL LINE CO-OCCURRENCE MODEL

The vertical line fishery effort models were developed to quantify the distribution and seasonality of the commercial fixed gear Dungeness crab fishery. As a preface, the original co-occurrence model developed by Saez et al. (2013) is briefly described to provide a background for model development and to highlight the differences between it and the vertical line models created in this study. Section 1 details the materials and methods for the four vertical line co-occurrence models created for this study. This section is followed by details on how the models were created including data processing and integration into the models. Lastly, data validation, limitations, and assumptions were described. The results for the fishery models and a brief discussion concludes Section 1. Section 2 details the development of the whale density models created for overlay with the fishery models including results for each species and a brief discussion of the results. The vertical line co-occurrence model development including limitations and assumptions can be found in Section 3. The results and discussion for all of the vertical line co-occurrence models can be found in Chapter 3.

ORIGINAL CO-OCCURRENCE FISHERY MODEL REVIEW

The original co-occurrence model by Saez et al. (2013) included 11 fixed gear commercial fisheries. Their fishery models for each species quantified relative risk by combining port-based fishery effort data obtained through the Pacific Fisheries Information Network (PacFIN) from each state fishery and the predicted density and distribution of large whales (Saez et al. 2013). The model combined potential fishing areas from operational fishing depths in each state with port-based commercial landings, in pounds, to map regional patterns of relative fishing effort in Washington, Oregon, and California (Saez et al. 2013). This co-occurrence model used landings as a proxy for effort (i.e., greater number of pounds landed equals higher level of effort) and scored the relative fishery efforts on a scale of 1 to 7 (Saez et al. 2013). The creation of the whale density models in the original co-occurrence model and the development of the co-occurrence scores were similar to the methods used in this study and are described in Section 2 and Section 3.

SECTION 1: VERTICAL LINE MODEL DEVELOPMENT

VERTICAL LINE MODEL DEVELOPMENT

The four fishery models developed in this study analyzed the number of vertical lines of the commercial fixed gear Dungeness crab fishery along the West Coast of the U.S. Four fishery models were developed to quantify effort and understand the spatial and temporal distribution of the Dungeness crab commercial fixed gear fishery along the U.S. West Coast. The geographic range of the models extends from the border of Washington State to the southern border of California and includes all Pacific waters within the operational fishing depth limit for the Dungeness crab fishery in U.S. state waters. Four fishery models were created to highlight the changes in fishing effort over time, for comparison between states, and for comparison of fishing effort along entire West Coast with the individual states.

1. The model including data from Washington, Oregon, and California used landings data from PacFIN for years 2013/2014 to 2016/2017 for months December to July. These data were used to describe the distribution of fishing effort in this analysis, called the All States Fishery Model.
2. The model specific to the Washington and Oregon commercial Dungeness crab fishery used landings data from PacFIN and was developed for two timeframes for month December to August. The two timeframes included data from the 2008/2009 fishing season to the 2011/2012 season and from the 2012/2013 to 2015/2016 fishing season, as the trap limits for these states were put in place much earlier than California. These ranges were used to describe the distribution of fishing effort in the analysis, called the Washington and Oregon Only Fishery Model.
3. Because California only implemented a trap limit program in 2013, a California specific model using landings data from PacFIN for years 2013/2014 to 2016/2017 was developed for months November to July. This range was used to describe the distribution of fishing effort in this analysis, called the California Only Fishery Model.
4. The ODFW provided the logbook data for 2008/2009 fishing season to the 2011/2012 season and from 2012/2013 to 2015/2016 for months of December to August for

comparison with Oregon landings data used in the All States Fishery Model and the Washington and Oregon Fishery Model. This range was used to describe the distribution of fishing effort in this analysis, called the Oregon Logbook Fishery Model.

SUMMARY OF METHODS

The model incorporates data on fishing activity from 2008/2009 to 2016/2017 for Oregon and Washington and from 2013/2014 to 2016/2017 for California. A summary of the methods used to assign the number of vertical lines to a location for each state by month was calculated through the following steps:

1. A permitted commercial Dungeness crab fisherman made a landing and that landing was recorded in the PacFIN database or in an ODFW logbook.
2. The trap limit for that fisherman was identified from her/his permit.
3. All traps on the permit were assumed active in the location listed in the database if a landing was made.
4. Traps were assigned to the location listed from the PacFIN database. However, the location data are different for each state:
    a) Washington list landings in state designated catch areas (Table 1, Table 3, Figure 2),
    b) Oregon lists landings in the port where they are landed (Table 1, Table 3, Figure 3),
    c) and, California lists landings in 10 x 10 statistical nautical mile blocks and large offshore areas (Table 1, Table 4, Figure 5 – 7).
5. The locations listed from the ODFW logbook data are defined by latitude and depth (Table 1, Table 3, Figure 4).
6. Catch areas were created from potential fishing areas from operational fishing depths different to each state, along with the way each state records the landing location, details can be found below and in Table 1.

7. The trap limit listed for the permit holder who made a landing was assigned to a catch area based on landing location.
8. Traps were summed by month for each catch area, every time a fisherman made a landing the trap limit was recorded for that month to represent the potential maximum number of traps in the water to indicate fishing effort, to serve to protect fisherman identity, and to smooth variability by fishing season and changes in regulation.
9. A fisherman that made more than one landing in the same location was not tallied twice and it was assumed that the gear in the water did not change.
10. Traps were split equally among catch areas for fishermen that made landings in more than one catch area in a given month, except Grays Harbor in Washington (details in Table 1).
11. Lastly, trap totals per month and catch areas were divided by that catch areas potential fishing area in km^2.

DATA PROCESSING, INTEGRATION, AND VALIDATION

DATA SOURCE

The fishery models that derived fishing effort from landings data were obtained through the PacFIN database. The PacFIN database includes landing data from each fish ticket, data for each landing included fishery, species, gear type, date of landing, trap tier (number of traps allowed), landed weight of species in pounds, vessel registration information, port of landing, and location of landing. Trap limit, from the permit information on each landing a permit holder made, was used as a direct measure of effort (i.e., landing made in a specific catch area identified from the location on a fish ticket means X number of traps in that catch area, number of traps from trap tier on permit) to represent the maximum potential fishing effort, or the maximum number of traps in the water in a given catch area. Before each state adopted a trap tier system with limits, there was no official count of the number of traps deployed each season. Each state has adopted a trap limit program with different rules and regulations. Each permit holder is assigned a trap tier, a tier indicates the number of traps that permit holder is allowed to fish each season. The trap tiers for each state are defined in Table 1 (Saez et al. 2014, Goblirsch and Theberge 2008, PSMFC 2014). ODFW provided monthly summaries of total traps fished by fishing area, the same as the created catch areas, for years 2008 - 2016 from commercial Dungeness crab logbooks, these data were used for the Oregon Logbook Fishery Model. The number of traps provided by the ODFW for the data in the Oregon Logbook Fishery Model uses 32% of the logbook data to represent the entire Dungeness crab fleet and only uses logs that had complete information including depth, location, and pots per string.

ODFW provided monthly summaries of total traps fished by fishing area, the same as the created catch areas, for years 2008 -2016 from commercial Dungeness crab logbooks, these data were used for the Oregon Logbook Fishery Model. The number of traps provided by the ODFW for the data in the Oregon Logbook Fishery Model uses 32% of the logbook data to represent the entire Dungeness crab fleet and only uses logs that had complete information including depth, location, and pots per string.

For all data, the total number of traps per catch area were summarized by month and then averaged over three different four-year time periods specific to each model, the timeframes used for each fishery model are found in Table 1.

TIMEFRAMES INCLUDED

The months included in the models represent months open to commercial fishing for all states included in the model, fishing season for each state is listed in Table 1. Due to the use of three different four-year timeframes to summarize fishing effort by month, management changes in trap limit implementation may not be captured. The different timeframes for the models reflects fishing effort during the only four-year timeframe when each state had implemented a trap limit system, 2013/2014 fishing season to the 2016/2017 fishing season for the California Only Fishery Model and the All States Fishery Model. The different timeframes for the other two models describe the distribution of fishing effort over two timeframes, the 2008/2009 fishing season to the 2011/2012 season and from the 2012/2013 fishing season to 2015/2016 season, to assess how risk may have changed, as these states adopted a trap tier system before California.

CATCH AREAS

Catch area is the term used in this study to define fishing areas for each state. Saez et al. (2013) used port-based landings as a proxy for effort in each port complex, or a grouping of ports with in a defined area, created by PacFIN. Fishery managers from each state provided a range of depths considered to be the operational fishing depth for the Dungeness crab fixed gear fishery (PSMFC 2014, Table 1). These values are based on the maximum and minimum operational fishing depth commonly used and referenced by fishermen's anecdotal information and logbook data in each state (Table 1, Goblirsch and Theberge 2008, PSMFC 2014, Saez et al. 2013). This method of defining operational fishing areas was used by Saez et al. (2013) adapted from habitat suitability modeling (NCCOS 2005). Potential fishing areas were mapped for the entire U.S West Coast using the common operational fishing depths as eastern and western boundaries (Table 1, Goblirsch and Theberge 2008, PSMFC 2014, Saez et. al 2013). Fixed gear fisheries common operational fishing and catch areas are defined in Table 1.

This research created catch areas for each state. This method of reporting traps to a specific location differs from the original co-occurrence model which used port complexes to report landings (see Appendix A for a list of the port complexes for comparison with the catch areas created in this model, including: Table 1, Tables 3 – 4, Figures 1 – 7). The method used to create catch areas captures more refined areas for reporting trap density and distribution. The location of landings is reported differently for each state and is detailed in Table 1, 3, and 4 and visually represented in Figures 1 through 8. Landings are reported to a single state defined area for Washington, a port for Oregon landings data, a latitudinally defined by PacFIN port complexes divided by depth contour line of 30 fathoms for Oregon logbook information, and to a single 10 x 10 nautical mile block or a large offshore block for California PacFIN data.

Catch areas in Washington state were created from the WDFW state catch areas (Table 1, Table 3, and Figure 2). State defined areas were then mapped with the operational fishing depth for the Washington Dungeness crab fishery to create the catch areas used in the fishery models. The northern and southern boundaries of the state defined catch area are used as the northern and southern boundaries for the Washington state catch areas. The eastern and western boundaries for each catch area were defined by the maximum and minimum operation fishing depths. Catch areas were named by the state defined catch area numerical and alphabetical code.

Oregon logbook data defined catch areas into areas by depth and latitude (Table 1, Table 3, Figure 1, Figures 3 – 4). The northern and southern boundaries of the Oregon logbook data were defined by latitude are used as the northern and southern boundaries for all Oregon state catch areas. The eastern and western boundaries for the catch areas were defined by the maximum and minimum operation fishing depths and then each catch area was split into shallow catch areas (30 fathoms or less) and deep catch areas (30 fathoms and deeper), a total of 10 catch areas. The names given to the catch areas by the ODFW logbook reporting system were retained.

These fishing area boundaries were used for the Oregon landings data but combined the shallow and deep depths at the 30 fathom contour line for ease of comparison, a total of 5 catch areas (Table 1, Table 3, Figure 4). Oregon landings data recorded location by port landed, to assign these data to a catch area, any port that fell with in the northern and southern boundaries of an Oregon logbook catch area was included in that catch area. This method was used to coincide with the methods used by the Saez et al. 2013 co-occurrence model, PacFIN database, and ODFW commercial Dungeness crab logbook data (Tables 1, Table 3, Figures 3 - 4).

California landings data are reported in 10 x 10 statistical nautical miles blocks, medium blocks along the western edge of the 10 x 10 blocks, and large offshore catch areas for California in which vessels fish in a common area and extend all the way to the coast, see Figure 5 for geographic representation of the CDFW 10 x 10 nautical mile statistical block system, medium blocks, and large offshore reporting blocks. The northern and southern boundaries of the California catch areas were defined by latitude of the 10 x 10 nautical mile block closest to the coast (Figure 1, Figures 5 – 7). The eastern and western boundaries for the catch areas were defined by the maximum and minimum operation fishing depths (Table 1). California catch areas were named by taking each 10 x 10 block closest to the coast and adding a 1 in front of the three digit number, for example block 126 became catch area 1126 (Figure 5 – 7, Table 4). All landings made in blocks in the same latitude line as the block closest to the coast to the block farthest to the west were included in the catch area defined by the block closest to the coast, e.g. blocks 126 – 131 were included in catch area 1126 (Table 4, Figure 7). Every landing made in the line of blocks defined by the latitude of the block closest to the coast were included in the catch area defined by the block closest to the coast, e.g., the maximum number of traps on the permit holder that made a landing in blocks 126 – 131 were included in catch area 1126 (Figure 7). Every landing made in the large offshore blocks was divided by the number of 10 x 10 nautical mile blocks closest to the coast defining the eastern boundary of the large offshore areas and the traps assigned evenly, e.g., there are seven 10 x 10 nautical miles blocks along the coast between the northern and southern border of large offshore block 1041 (Table 4, Figure 7). Medium blocks on the western edge of the 10 x 10 nautical miles blocks were split in the same method as the large offshore blocks, e.g., one third of traps in block 139 were included in catch area 1126 (Table 4, Figure 7).

Figure 6 is a geographic representation of blocks used by the CDFW and PacFIN overlapped with the catch areas created from the 10 x 10 nautical mile blocks closest to the coast as northern and southern boundaries extending out to the California Dungeness crab commercial operational fishing depth (50 fathoms) (also see Table 1 and Table 4). A visual representation of all the catch areas included in the catch areas and the methods of how catch area 1126 was created can be found in Figure 7 (see Table 1, Table 4, Figures 5 - 8 and details above). The creation of these catch areas for the purpose of this vertical line model was an attempt to refine the scale to get a better understanding of fishing effort compared to the larger port complexes of the original co-occurrence model.

Overlap in catch areas, similar to the issue with the large offshore blocks and the 10 x 10 blocks of California, occurred in Washington and Oregon. Washington catch area 61 includes the southernmost catch area of Washington state and the entire Oregon coast (Figures 1 – 4). To account for the trap overlap in these areas, traps data reported in catch area 61 for the Washington state landings data were divided equally among 6 catch areas, 61_60D and all the Oregon catch areas, CLO, TLA, NPA, CBA, BRA for the All State Fishery Model and the Washington and Oregon Only Fishery Model (Figures 1 – 3, Table 3). To account for the trap overlap between the Washington and Oregon logbook catch areas, traps data reported in catch area 61 for the Washington state landings data were divided equally among the 10 Oregon Logbook Fishery Model catch areas (deep and shallow catch areas CLO, TLA, NPA, CBA, BRA) (Figures 1 – 2, Figure 4, Table 3).

In order to preserve identity and fishermen confidentiality, as required by the MSA, the number of fish tickets associated with each catch area follows the "rule of three." The "rule of three" states that all landings must be represented as three or more fishermen during that month in the specific catch area, in the case that the landings from the catch area with 3 or less fishermen were grouped with the nearest catch area to ensure anonymity. Blocks south of Point Conception in California were not considered in the analysis as they were so few and spatially separated and none of the landings followed this rule.

SPECIAL CONSIDERATIONS

This approach assumes that all habitats in the catch areas are suitable for Dungeness crab and may represent effort in areas that are not necessarily fished. Yearly management changes altering trap limit implementation are not reflected. Marine protected areas prohibiting the deployment of traps were taken into account. Marine protected areas for Oregon and California were taken into account for each catch area to reflect the operational fishing area in km^2. Therefore, areas closed to trap fisheries were excluded from catch areas (Figure 7). Marine protected areas for Oregon and California can be accessed on the ODFW[3] and CDFW[4] websites. Some parts of Washington state coastal waters in Washington state defined catch areas are closed during parts of the Dungeness crab fishing season with changing regulations on a yearly basis. These closures due to management regulations and tribal agreements were not taken into account because of their yearly temporal and spatial changes. Future fishery models of this nature and co-occurrence models might take these into account to better understand trap density for this state for both the commercial, recreational, and tribal fishery. The fishery models developed do not reflect vertical lines in the water from derelict fishing gear, although this gear has been identified as capable of entangling whales (Hall et al. 2000, Uhlmann and Broadhurst 2015).

INTEGRATION OF DATA

To illustrate patterns of fishing effort, Dungeness crab fixed gear commercial fishery effort and patterns for the U.S. West Coast were modeled by combining catch area-based fishery

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[3] ODFW details on marine reserves can be found at http://oregonmarinereserves.com/reserves/

[4] CDFW details on marine reserves can be found at https://www.wildlife.ca.gov/Conservation/Marine/MPAs

landing data listed from the location on the fish ticket with number of traps on the permit in depth-defined potential fishing catch areas.

Each fishery model integrated the trap limit information on the fish ticket with the catch area in Washington, Oregon, and California. The maximum number of traps assigned to a permit holder that made a landing in a location, different for each state and defined above, were assigned to a catch area for each month of the Dungeness crab fishing season for that state. Traps were assigned equally over the entire catch area. The trap density was calculated by dividing the monthly trap totals for each catch area by the total area (in km^2) of that catch area. Summarized monthly trap densities were averaged over a four-year time period, fishery model dependent, to get the average trap density for that month over a four year time period. The four fishery models (detailed above) classified the trap density for each model and indexed them into a broad-ranging scale from 1-to-7 using the Jenks Natural Breaks Method, with 1 representing low trap density and 7 representing high trap density for that fishery model (Table 5). The Natural Breaks method as defined by the ESRI GIS dictionary, the same method used to index the fishery and co-occurrence model and used by Saez et al. (2013), "is 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 ArcGIS 2018). ArcGIS Pro was used for the spatial analysis and map output.

OREGON LOGBOOK AND CALIFORNIA MODELING METHODS: COMPARISON AND VALIDATION

Because ODFW collects landings data as well as logbook data, a comparison was made between the Oregon logbook report put out by ODFW that summarizes the total number of traps fished by fishing area from commercial trap logs for the 2014 – 2015 fishing season by month with the Oregon commercial landings data calculated from PacFIN. This comparison was done to validate the way this model assigned traps to catch areas. The traps numbers reported in column 3 of Table 2 are the estimates derived from the ODFW commercial Dungeness crab fishery logbook data. The logbook data identifies the owner, vessel, and pot limit just as this study does to sum the maximum number of traps a vessel is allowed to fish per catch area (personal communication with Justin Ainsworth, ODFW, 2017). Similar to the fishery models these estimates do not take into account a change in the number of traps fished throughout a season or any gear loss. The ODFW logbook numbers represent 32% of the pounds landed throughout the 2014/2015 commercial Dungeness crab fishing season to represent the entire fishery. The second column of Table 2 is a summary of all traps reported in the PacFIN landing data for Oregon state waters (i.e., all catch areas but do not include Washington state fishermen landings reported in catch area 61_60D included in the fishery models. The Oregon logbook data reported by the ODFW and the trap totals this study calculated for the Oregon landings data are similar. Any small discrepancies may be attributed to logbook data using 32% of landings to summarize the entirety of the fishing fleet while this study looks at all landings made throughout a season.

A visual comparison of modeled fishing areas into catch areas with all PacFIN defined blocks that reported landings in the PacFIN database in December 2014 is displayed in Figure 8. The model and the landings data show the same general distribution of effort with concentrations nearshore, with the exception of the large offshore blocks. It should be noted that reporting of landings is through fish dealers and processors, typically not the fishermen themselves. This method of reporting may be questionable regarding location accuracy of the location reported on the landing/fish ticket receipts. The issue of this should be noted especially for California as many landings were reported to be outside of operational fishing depths or in large offshore blocks which encompass large areas from the coast to the EEZ line.

MODEL ASSUMPTIONS AND LIMITATIONS

Commercial fishery landings data, as well as logbook data, were used to represent effort in the vertical line co-occurrence models and there are several issues with using the landings data to understand trap placement and fishing effort. The vertical line co-occurrence models created for this study makes the following assumptions and highlights a few limitations:

1. The vertical line co-occurrence level is proportional to entanglement risk. The greater the fishing effort and a higher density of whales present in an area yields a higher vertical line co-occurrence score and therefore a greater risk of entanglement.
2. Fishing effort from PacFIN landings data was calculated by summing the total number of traps per catch area in a given month. This sum was calculated by the trap limit assigned to a permit holder that made a landing in any given month. The trap limit on the permit was assigned to the catch area the fishermen reported the landing. Therefore, the numbers calculated for each catch area represent the maximum number of traps that could have been deployed in that catch area per month. If a fisherman made a landing in more than one catch area the number of traps were divided equally between the catch areas, except in the case of Grays Harbor in Washington which has a trap limit of 200 traps in that area per fisherman (for more details see Table 1, personal communication with Carol Hendry, WDFW, 2017).
3. The fishing effort for the Oregon Logbook Fishery Model using the Oregon logbook data was already totaled by catch area per month and was not tallied in any way and assumed the numbers were tallied correctly by the ODFW.
4. This information gleaned from the landings data is a measure of effort under the general assumption that the landing area reported is accurate. Since only one location can be reported on an individual fish ticket, that location might not be the most accurate

representation of where the traps were set as fish dealers and processors report the location where the majority of the fishing occurred according to the permit holder who made the landing.

5. This model assumes that the fishermen did not fish in more than one catch area and only reported one catch area on the fish ticket when the landing was made in port. The information from the landings data may be misleading if the fishermen set traps in multiple catch areas but only reported one location on the fish ticket when the landing was made.
6. Anytime whales and gear are present, regardless of density, some entanglement risk is present.
7. The large whale species included in this model, gray, humpback, blue, and fin whale, are considered equally likely to become entangled.
8. The model does not account for the loss of any gear during the season or if the fishermen only fished a portion of the traps assigned on their permit.
9. Future efforts should exclude unsuitable habitats and substrate where commercial Dungeness crab fishing does not occur as this was not considered in the development of the fishery models.
10. This model does not include recreational or tribal fishery landings data. The fishery models and the vertical line co-occurrence scores only reflect the efforts made by the commercial Dungeness crab fishing fleet and may not reflect true risk of entanglement by the number of vertical lines in the water.

Table 1. Dungeness crab fishery characterization for Washington, Oregon, and California landings data and Oregon logbook data including state defined catch areas, notes on catch areas, years, season start and end dates for each state with notes, operational fishing depths, trap tier system, and other pertinent notes for assigning traps to catch areas.

State Information	**WA Landings Data**	**OR Landings Data**	**CA Landings Data**	**OR Logbook Data**
State Defined Catch Areas	58B 59A1 59A2 59B 60A1 60A2 60B 60C 61_60D (rule of 3)	CLO TLA NPA CBA BRA	California reports landings data in 10 x 10 nautical mile blocks, see Table 3 for full details on catch areas[1]	CLO_Deep CLO_Shallow TLA_Deep TLA_Shallow NPA_Deep NPA_Shallow CBA_Deep CBA_Shallow BRA_Deep BRA_Shallow
Areas Notes	Catch areas defined in Table 3	Catch areas defined in Table 3	Catch areas defined in Table 3[5]	Catch areas defined in Figure 4
Years	2008 - 2017	2008 - 2017	2013 - 2017	2008 - 2016
Season	December - August	December - August	November - July	December-August
Fishing Season Notes	The southern catch areas of Washington state open in December while the Northern catch areas open in January, opening dates vary.	December 1 - August 15	November 15 - June 30 from the northern border of block 407 to Point Conception December 1 - July 15 from the southern border of block 401 to the California border	December 1 - August 15
Depth (fathoms)	5 - 60 fm (up to 75 fm or more)	5 - 60 fm (up to 100 fm or more)	10 - 50 fm	5 - 60 fm
Trap Tiers	500, 300	500, 300, 200	500, 450, 400, 350, 300, 250, 175	500, 300, 200

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[5] Full details and information on the block codes for California can be found at https://pacfin.psmfc.org/ and https://www.wildlife.ca.gov

Table 2. Comparison between the 2014/2015 ODFW logbook Report and a summary of the number of traps along the Oregon coast calculated from the PacFIN landings data used in the fishery models (data gathered from personal communication with Justin Ainsworth, ODFW, 2017).

Month	Fishery Model Landings Data (total traps per month)	ODFW Logbook Report (total traps per month)
December	102800	103700
January	100800	100600
February	78000	78000
March	63800	64000
April	34900	35100
May	36550	29100
June	25600	25600
July	19800	19800
August	15700	15700

Figure 1. West Coast geographic context of catch areas as defined in this study for Washington, Oregon, and California. Western boundary is the state operational fishing depth (Table 2).

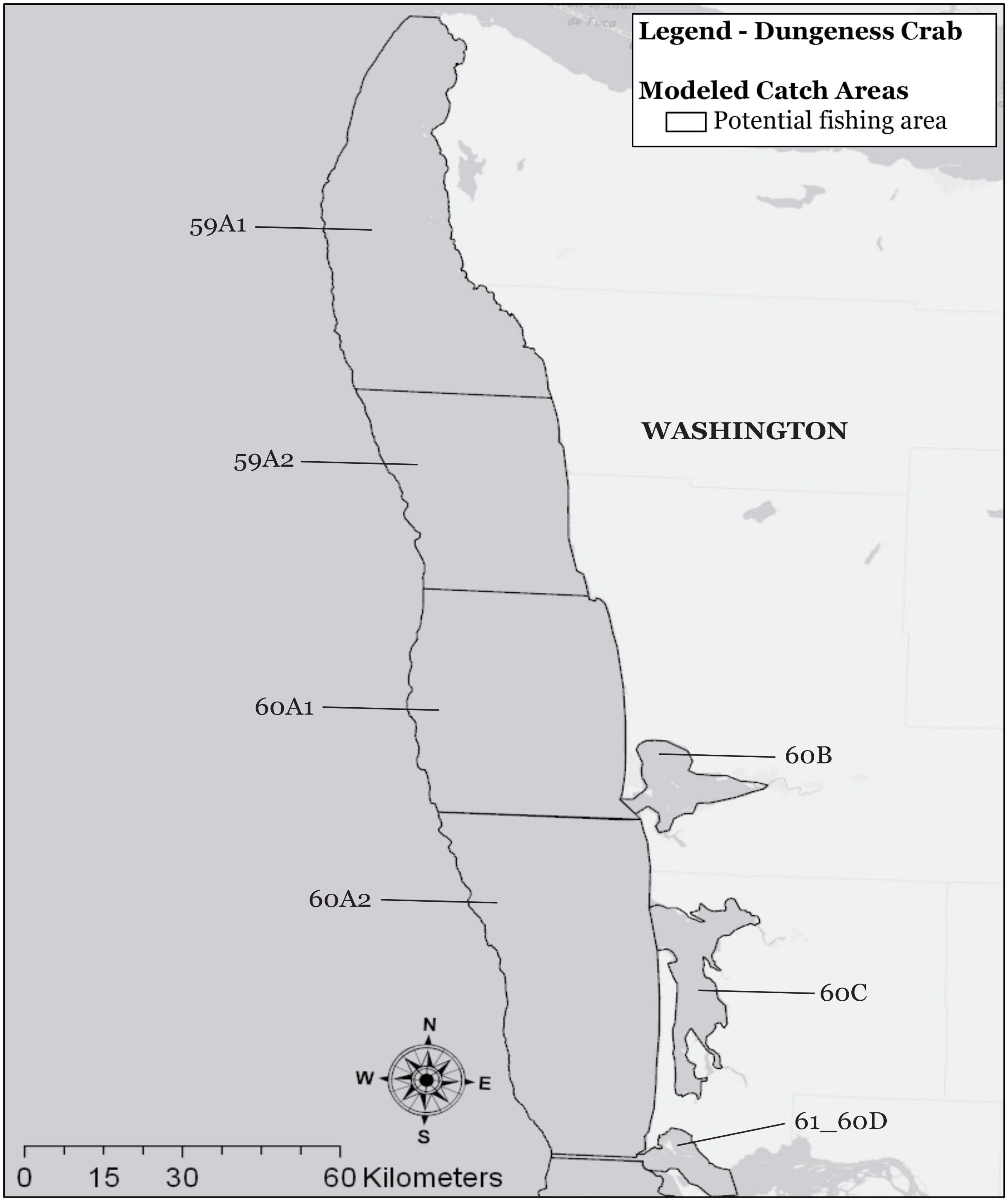

Figure 2. Washington state geographic representation of catch areas as defined by the PacFIN database and the WDFW. Western boundary is the Washington state operational fishing depth (out to 60 fm). Catch areas are as follows (major port): 59A1 Cape Flattery to Destruction Island, 59A2 Destruction Island to Point Grenville, 60A1 Point Grenville to Point Chehalis, 60A2 Point Chehalis to Columbia River, 60B Grays Harbor, 60C Willapa Harbor, 61 Oregon Coast, 60D Columbia Estuary.

Figure 3. Geographic representation of catch areas as defined by the individual state reporting database, Oregon Department of Fish and Wildlife. Western boundary is the operational fishing depth for Dungeness crab fishery for Oregon (5 fm – 60 fm). Catch areas are as follows (major port): CLO Latitude 46 – 46.25 (Astoria, Gearhart/Seaside), TLA Latitude 45 – 46 (Nehalem, Garibaldi, Pacific City), NPA Latitude 44 - 45 (Depoe Bay, Waldport, Newport, Florence), CBA Latitude 43 - 44 (Winchester Bay, Coos Bay, Bandon), BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings).

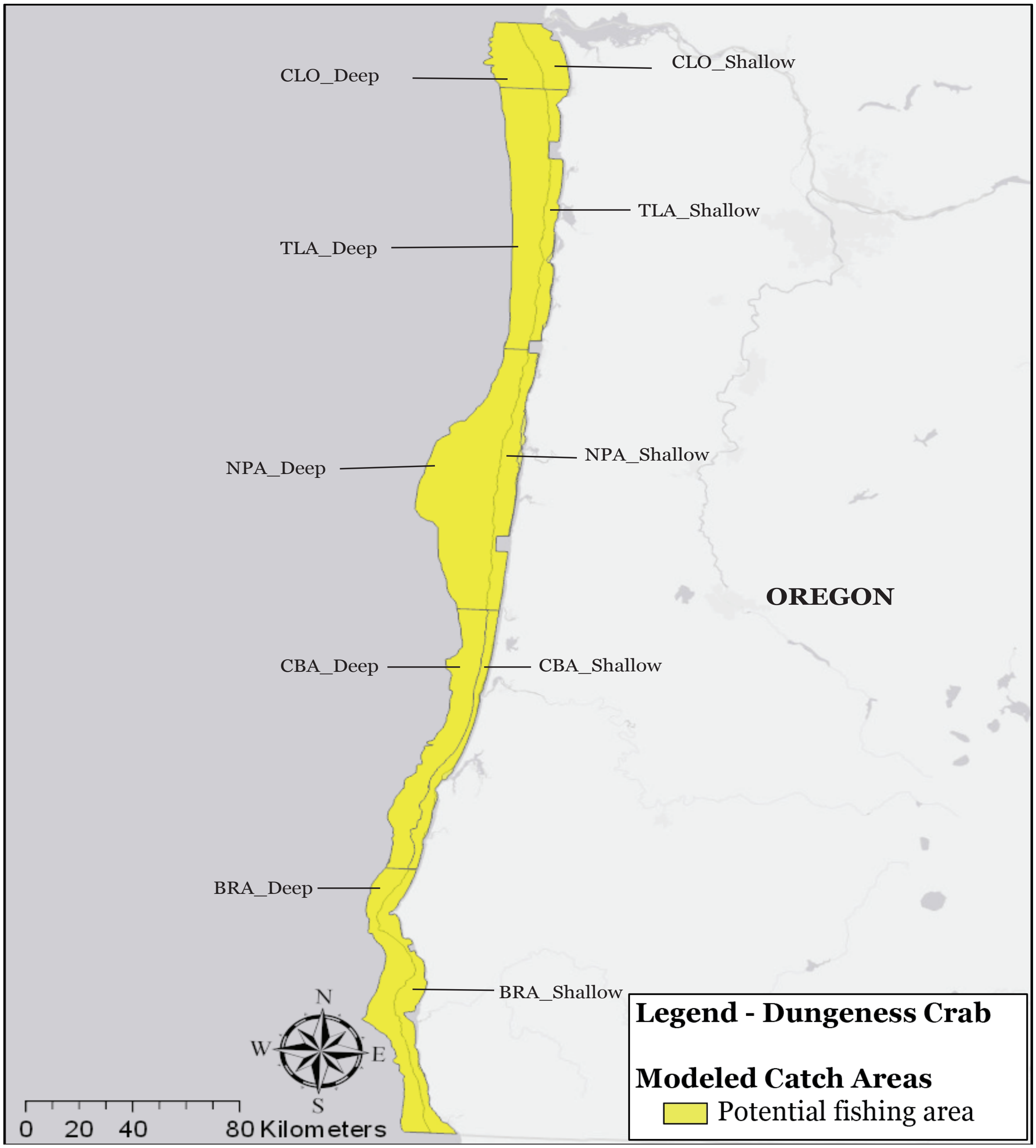

Figure 4. Geographic representation of Oregon port complex regions as defined by the PacFIN database broken down into deep and shallow depths as defined by the OR DFW referred to as Oregon catch areas. Western and Eastern boundaries are the Oregon commercial Dungeness crab operational fishing depths. Port complexes are as follows: CLO_Deep (Astoria at depths greater than 30 fathoms), CLO_Shallow (Astoria at depths less than 30 fathoms), TLA_Deep (Tillamook at depths greater than 30 fathoms), TLA_Shallow (Tillamook at depths less than 30 fathoms), NPA_Deep (Newport at depths greater than 30 fathoms), NPA_Shallow (Newport at depths less than 30 fathoms), CBA_Deep (Coos Bay at depths greater than 30 fathoms), CBA_Shallow (Coos Bay at depths less than 30 fathoms), BRA_Deep (Brookings at depths greater than 30 fathoms), BRA_Shallow (Brookings at depths less than 30 fathoms).

Table 3. Catch area codes and geographic range for Washington and Oregon.

Catch Area	Geographic Range	Major Ports
59A1	East of the 220° true line, west of a line from Cape Flattery to Borilla point, and north of 47°40' 30"N. Latitude (Destruction Island) exclusive of coastal waters (0 - 3 miles) north of a line projected true west from Cape Alava out to 60 fm	Not relevant
59A2	East of the 220° true line, south of 47°40'30". Latitude (Destruction Island), and north of a line projected true west from Point Grenville out to 60 fm	Not relevant
60A1	North of a line projected true West from Point Chehalis at latitude 46°53' 18" N and South of a line projected true West from Point Grenville exclusive of Grays Harbor out to 60 fm	Not relevant
60A2	North of a line projected true West form Washington-Oregon boundary in the Columbia River and South of a line projected true West from Point Chehalis at latitude 46°53' 18" N exclusive of Columbia River estuary and Willapa Bay out to 60 fm	Not relevant
60B	Grays Harbor East of a line projected form the outermost end of the North jetty to the outermost end of the South jetty out to 60 fm	Not relevant
60C	Saltwater areas of Willapa Bay East of a line from Leadbetter Point to Cape Shoalwater Lighthouse out to 60 fm	Not relevant
61_60 D	North of latitude 46°25" N and South of Area 60A, exclusive of the Columbia River estuary, note that the WDFW include all of Oregon waters in this catch area but for the purpose of this study this was cut off at the Northern most Oregon catch area (CLO) and then all landings made were divided equally among this catch area and all Oregon catch areas out to 60 fm	Not relevant
CLO	Oregon side of the Columbia River to the southern border of Clatsop County Latitude 46° – 46.25° out to 60 fm	Astoria, Gearhart, Seaside
TLA	Coastal border of Tillamook County, Oregon Latitude 45° – 46° (Nehalem, Garibaldi, Pacific City) out to 60 fm.	Tillamook, Nehalem, Garibaldi, Pacific City
NPA	Coastal border of Lincoln County, Oregon Latitude 44° - 45° out to 60 fm	Newport, Depoe Bay, Waldport, Florence
CBA	Coastal border of Lane, Douglas, and Coos Counties, Oregon Latitude 43° - 44° out to 60 fm	Coos Bay, Winchester Bay, Bandon
BRA	Includes the waters from Coastal border of Curry County, Oregon to the Oregon/California border Latitude 42° - 43° out to 60 fm	Brookings, Port Orford, Gold Beach

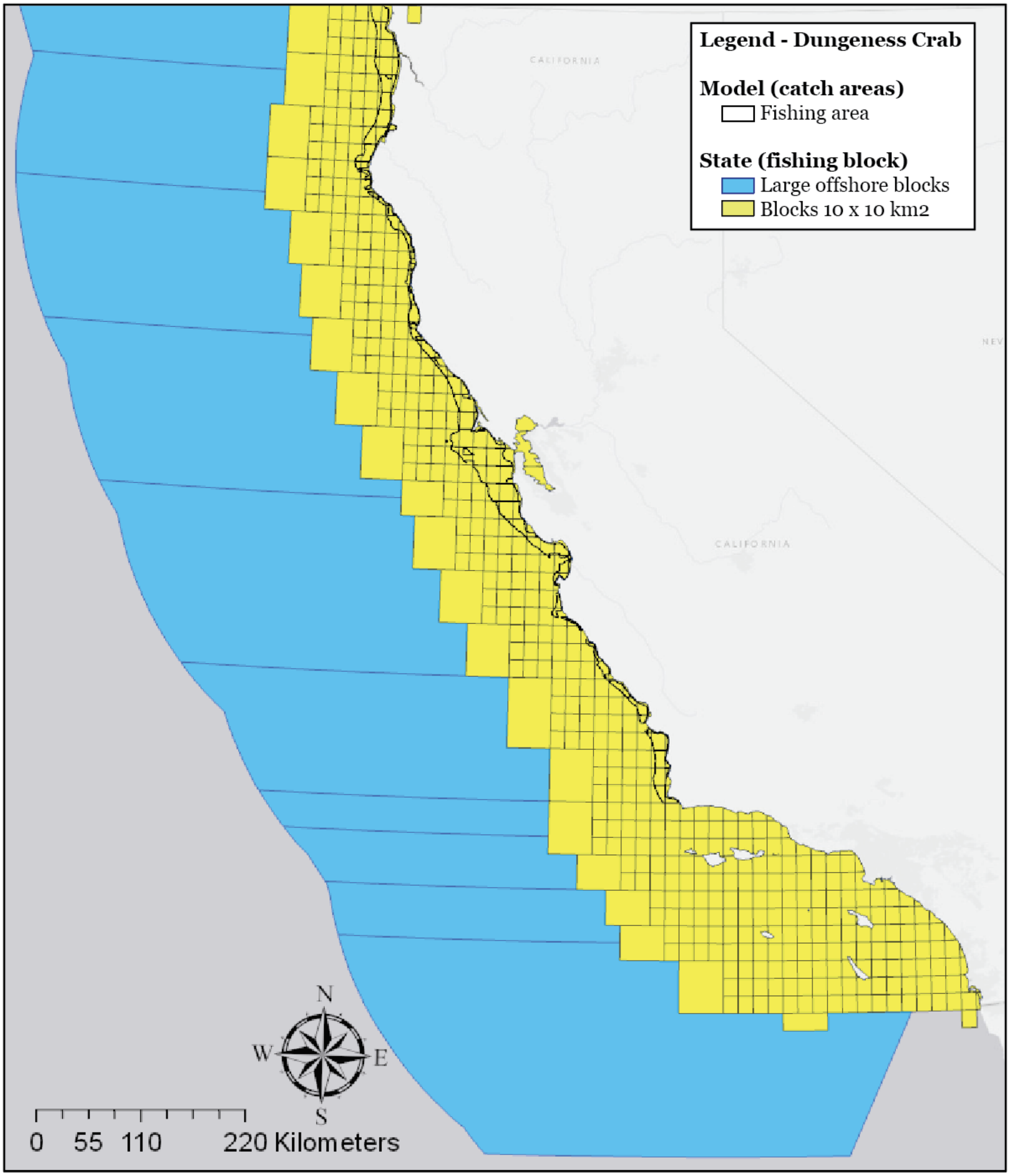

Figure 5. Geographic representation of the CDFW 10x10 nautical mile statistical block system in yellow and the large offshore reporting blocks which extend from the coastline out to the EEZ in blue. Catch areas for the fishery models are reported in black outline.

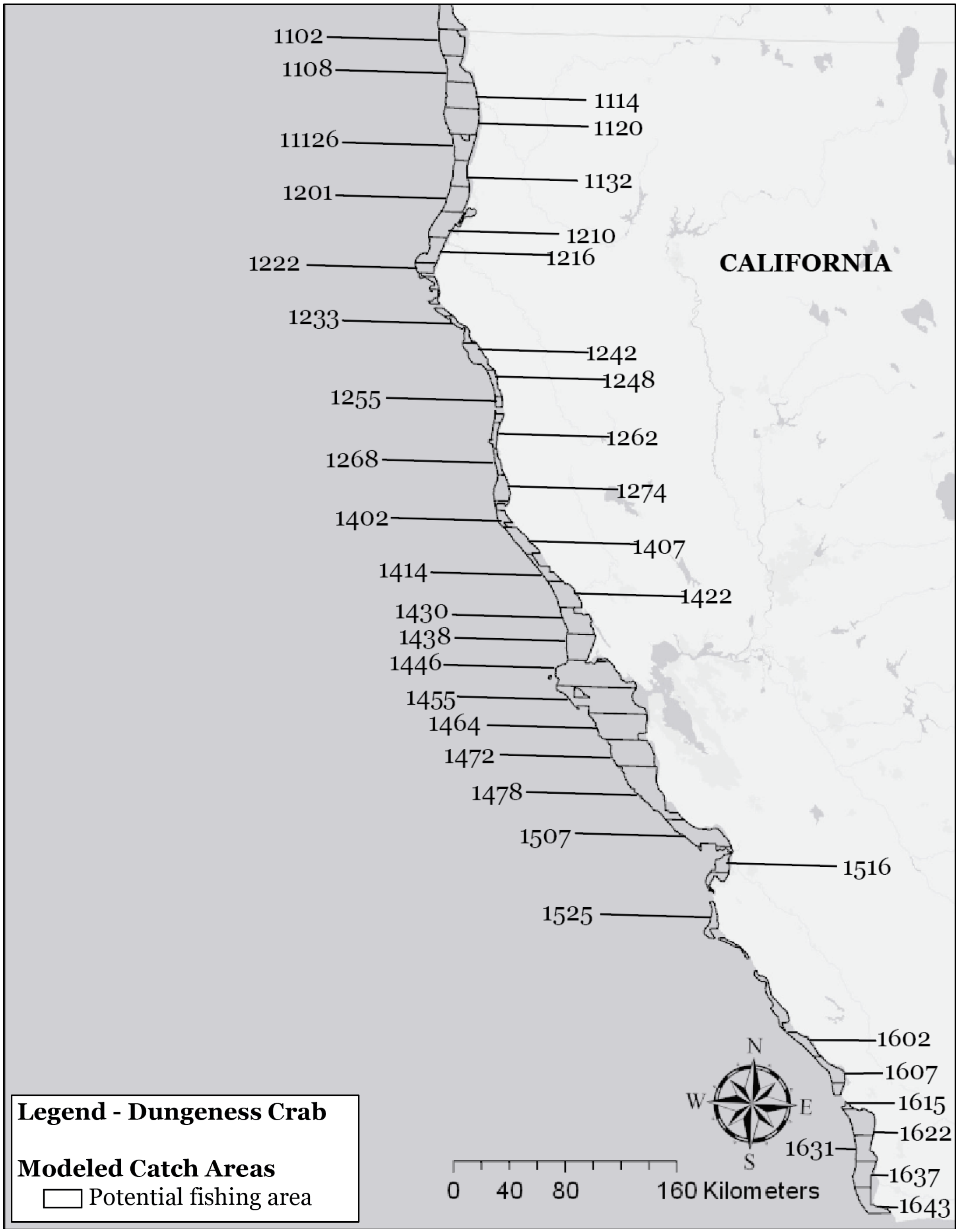

Figure 6. Geographic representation of catch areas created as defined by the California Department of Fish and Wildlife block code reporting. Western boundary is the operational fishing depth for Dungeness crab fishery in California (10 fm – 50 fm). Catch areas are outlined in Table 1 and Table 4.

Table 4: Catch area codes and geographic range for California.

Catch Area	Geographic Range	Details of Blocks Areas include in Catch Area
1102	Northern to Southern boundary of block 102 out to 50 fm	Blocks 102 - 106, one third of traps in block 138, and one fourth of large offshore block 1042.
1108	Northern to Southern boundary of block 108 out to 50 fm	Blocks 107 - 112, one third of traps in block 138 and one fourth of large offshore block 1042
1114	Northern to Southern boundary of block 114 out to 50 fm	Blocks 114 - 119, one third of traps in block 138 and one fourth of large offshore block 1042
1120	Northern to Southern boundary of block 120 out to 50 fm	Blocks 120 - 125, one third of traps in block 139 and one fourth of large offshore block 1042
1126	Northern to Southern boundary of block 126 out to 50 fm	Blocks 126 - 131, one third of traps in block 139 and one seventh of large offshore block 1041
1132	Northern to Southern boundary of block 132 out to 50 fm	Blocks 132 - 137, one third of traps in block 139 and one seventh of large offshore block 1041
1201	Northern to Southern boundary of block 201 out to 50 fm	Blocks 201 - 207, one third of traps in block 240 and one seventh of large offshore block 1041
1210	Northern to Southern boundary of block 210 out to 50 fm	Blocks 208 - 215, one third of traps in block 240 and one seventh of large offshore block 1041
1216	Northern to Southern boundary of block 216 out to 50 fm	Blocks 216 - 221, one third of traps in block 240 and one seventh of large offshore block 1041
1222	Northern to Southern boundary of block 222, 227 out to 50 fm	Blocks 222 - 232, two thirds of traps in block 241 and two sevenths of large offshore block 1041
1233	Northern to Southern boundary of block 233 out to 50 fm	Blocks 233 - 239, one third of traps in block 241 and one eighth of large offshore block 1040
1242	Northern to Southern boundary of block 242 out to 50 fm	Blocks 242 - 247, one third of traps in block 280 and one eighth of large offshore block 1040
1248	Northern to Southern boundary of block 248 out to 50 fm	Blocks 248 - 254, one third of traps in block 280 and one eighth of large offshore block 1040
1255	Northern to Southern boundary of block 255 out to 50 fm	Blocks 255 - 261, one third of traps in block 280 and one eighth of large offshore block 1040
1262	Northern to Southern boundary of block 262 out to 50 fm	Blocks 262 - 267, one third of traps in block 281 and one eighth of large offshore block 1040
1268	Northern to Southern boundary of block 268 out to 50 fm	Blocks 268 - 273, one third of traps in block 281 and one eighth of large offshore block 1040
1274	Northern to Southern boundary of block 274 out to 50 fm	Blocks 274 - 279, one third of traps in block 281 and one eighth of large offshore block 1040
1402	Northern to Southern boundary of block 401 out to 50 fm	Blocks 401 - 406, one third of traps in block 484 and one eighth of large offshore block 1040
1407	Northern to Southern boundary of block 407 out to 50 fm	Blocks 407 - 413, one third of traps in block 484 and one ninth of large offshore block 1038
1414	Northern to Southern boundary of block 414 out to 50 fm	Blocks 414 - 421, one third of traps in block 484 and one ninth of large offshore block 1038

1422	Northern to Southern boundary of block 422 out to 50 fm	Blocks 422 - 428, one third of traps in block 485 and one ninth of large offshore block 1038
1430	Northern to Southern boundary of block 430 out to 50 fm	Blocks 430 - 437, one third of traps in block 485 and one ninth of large offshore block 1038
1438	Northern to Southern boundary of block 438 out to 50 fm	Blocks 438 - 445, one third of traps in block 485 and one ninth of large offshore block 1038
1446	Northern to Southern boundary of block 446 out to 50 fm	Blocks 446 - 453, one third of traps in block 486 and one ninth of large offshore block 1038
1455	Northern to Southern boundary of block 455 out to 50 fm	Blocks 455 - 462, one third of traps in block 486 and one ninth of large offshore block 1038
1464	Northern to Southern boundary of block 462 out to 50 fm	Blocks 464 - 471, one third of traps in block 486 and one ninth of large offshore block 1038
1472	Northern to Southern boundary of block 472 out to 50 fm	Blocks 472 - 477, one half of traps in block 487 and one ninth of large offshore block 1038
1478	Northern to Southern boundary of block 478 out to 50 fm	Blocks 478 - 506, one half of traps in block 487, one third of the traps in block 545 and two tenths of large offshore block 1037
1507	Northern to Southern boundary of block 507 out to 50 fm	Blocks 507 - 515, one third of traps in block 545 and one tenth of large offshore block 1037
1516	Northern to Southern boundary of block 516 out to 50 fm	Blocks 516 - 524, one third of traps in block 545 and one tenth of large offshore block 1037
1525	Northern to Southern boundary of block 525, 526, 532, 538, 547, 553, and 560 out to 50 fm	Blocks 525 - 544, 546 and 547 - 568 and six tenths of large offshore block 1037
1602	Northern to Southern boundary of block 602 out to 50 fm	Blocks 601 - 606, one fourth of traps in block 649 and one seventh of large offshore block 1036
1607	Northern to Southern boundary of block 614 and 615 out to 50 fm	Blocks 607 - 613, one fourth of traps in block 649 and one seventh of large offshore block 1036
1615	Northern to Southern boundary of block 622 out to 50 fm	Blocks 614 - 621, one fourth of traps in block 649 and one seventh of large offshore block 1036
1622	Northern to Southern boundary of block 631 out to 50 fm	Blocks 622 - 630, one fourth of traps in block 649 and one seventh of large offshore block 1036
1631	Northern to Southern boundary of block 637 out to 50 fm	Blocks 631 - 636, one third of traps in block 680 and one seventh of large offshore block 1036
1637	Northern to Southern boundary of block 638 out to 50 fm	Blocks 637 - 642, one third of traps in block 680 and one seventh of large offshore block 1036
1643	Northern to Southern boundary of block 643 out to 50 fm	Blocks 643 - 648, one third of traps in block 680 and one seventh of large offshore block 1036

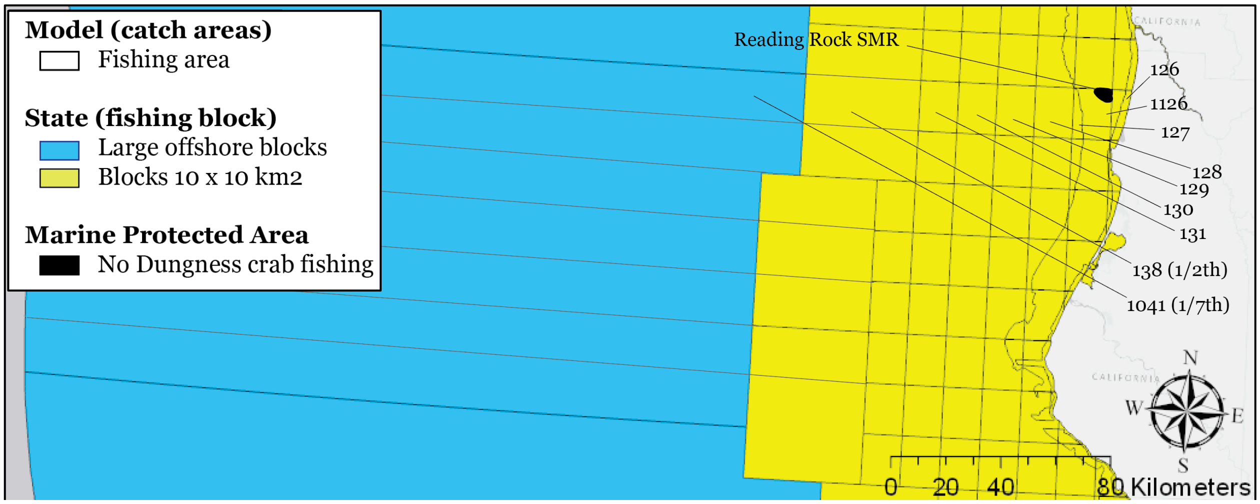

Figure 7. Visual representation of the designation of California catch areas, example of catch area 1126, represented with a thicker black outline, including all the 10 x 10 nautical mile blocks and the breakdown of the large offshore blocks. 10 x 10 nautical mile blocks 126 – 131 in yellow, one third of block 138 in yellow, and one seventh of block 1041, in blue, are included in catch area 1126 with exclusion of the Reading Rock State Marine Reserve, which does not allow trap fisheries, therefore this area is excluded and represented in black.

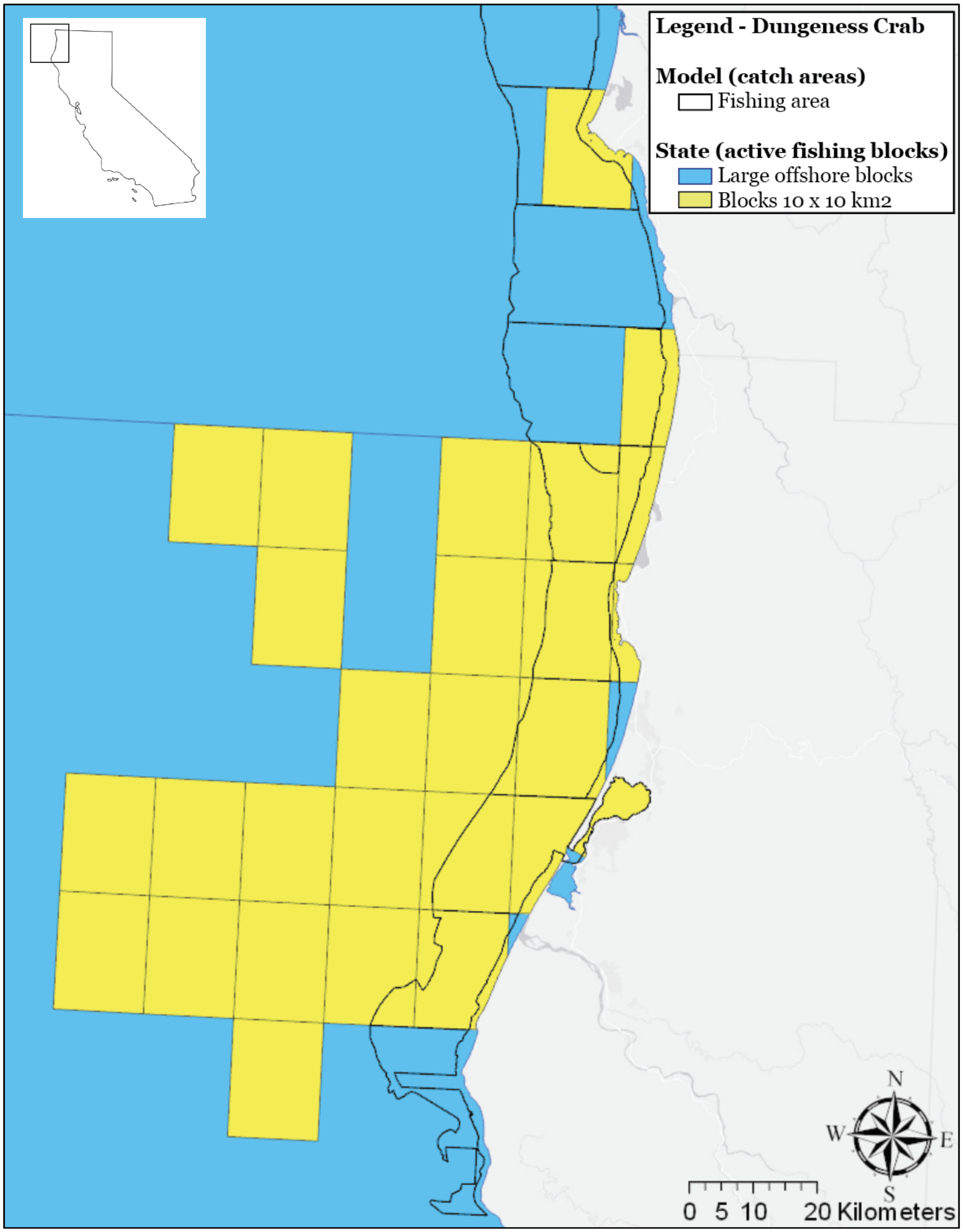

Figure 8. Comparison of modeled fishing areas (catch areas) with CDFW fishing 10 x 10 nautical mile block, and large offshore area, data for December 2014. Large offshore blocks that reported a landing in December in light blue (blocks identified here are blocks 1042 and 1041). Yellow blocks indicate that commercial landings were recorded in that 10 x 10 nautical mile block during December. The black outlined areas indicate active catch areas in the fishery model during that month of the year (December).

Table 5: Scaled values of traps density per km^2 used for each of the fishery models using the Natural breaks method in ArcGIS.

All States 2013/2014 - 2016/2017 (traps per km^2)	**WA and OR Only** 2008/2009 - 2015/2016 (Traps per km^2)	**CA Only** 2013/2014 - 2016/2017 (Traps per km^2)	**OR Logbook** 2008/2009 - 2015/2016 (Traps per km^2)
1 (≤ 2.96)	1 (≤ 2.37)	1 (≤ 3.36)	1 (≤ 3.48)
2 (≤ 6.16)	2 (≤ 5.19)	2 (≤ 6.95)	2 (≤ 7.79)
3 (≤ 10.11)	3 (≤ 8.78)	3 (≤ 10.25)	3 (≤ 14.40)
4 (≤ 14.41)	4 (≤ 12.83)	4 (≤ 14.46)	4 (≤ 22.47)
5 (≤ 19.37)	5 (≤ 17.20)	5 (≤ 20.36)	5 (≤ 29.86)
6 (≤ 25.10)	6 (≤ 24.64)	6 (≤ 28.70)	6 (≤ 39.15)
7 (≤ 38.56)	7 (≤ 32.40)	7 (≤ 38.56)	7 (≤ 44.03)

SECTION 2: VERTICAL LINE FISHERY MODEL RESULTS AND DISCUSSION

Section 2 reports the results for all of the vertical line fishery models developed to quantify the distribution and seasonality of the commercial fixed gear Dungeness crab fishery. The results will be reported in the following order: All State Fishery Model (Figures 9 – 11), Washington and Oregon Only Fishery Model (Figures 12 – 13), California Only Fishery Model (Figure 14), and then the Oregon Logbook Fishery Model (Figures 15 – 17). Following the results of the Oregon Logbook Fishery Model are the results calculated using a different trap density scale (see results in Figures 18 – 20 and the explanation for comparison in the sub-section titled Oregon Logbook Fishery Model Discussion). Following the results for each model in Figures 9 – 17 are sub-sections discussing each model. The sub-sections summarizing the results and a brief discussion for each fishery model are presented in the same order as the results. The Washington and Oregon Fishery Model Discussion sub-section provides additional comparison between the number of traps deployed in each state (Figure 21). The Oregon Logbook Fishery Model sub-section highlights the difference in the number of traps reported in the deep catch areas versus the shallow catch areas in Table 6.

FISHERY MODEL RESULTS

ALL STATES FISHERY MODEL – WEST COAST

Average Trap Density (traps/km^2) 2013/2014–2016/2017

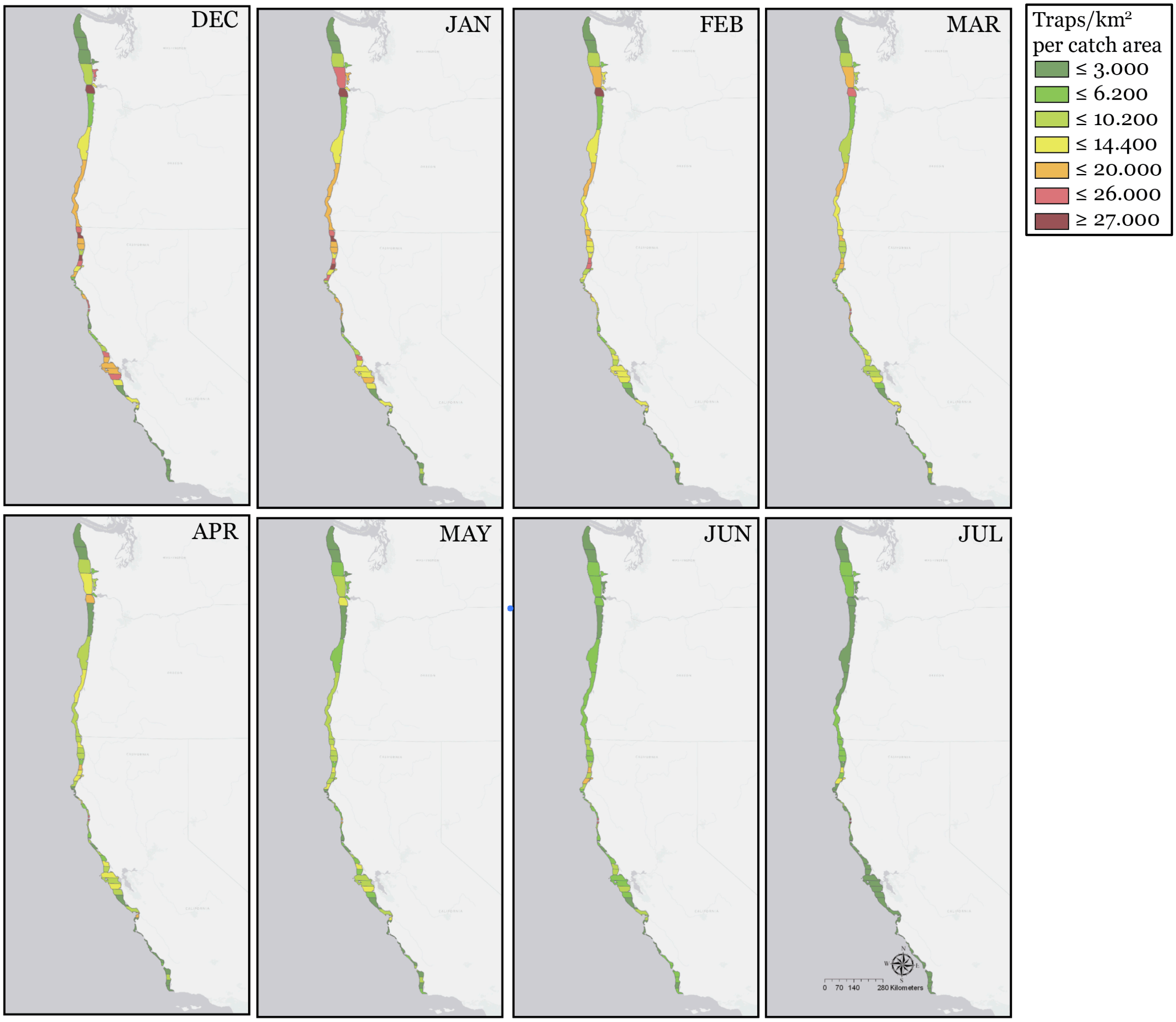

Figure 9. Dungeness crab trap fishery monthly average trap density per catch area per km2, indicated by the green to red colored bands, from 2013/2014 season to 2016/2017 season shown per catch area and by month of the year. Fishing area within a catch area is defined by operational fishing depth range. The density values are not unique to each state and were modeled after all catch area densities for all states and have been scaled, per reported catch area from each states dataset per km2, from 1-to-7 corresponding to the green to red color range, with green representing the lowest density (1) and red representing the highest density (7).

ALL STATES FISHERY MODEL – WASHINGTON and OREGON

Average Trap Density (traps/km^2) 2013/2014–2016/2017

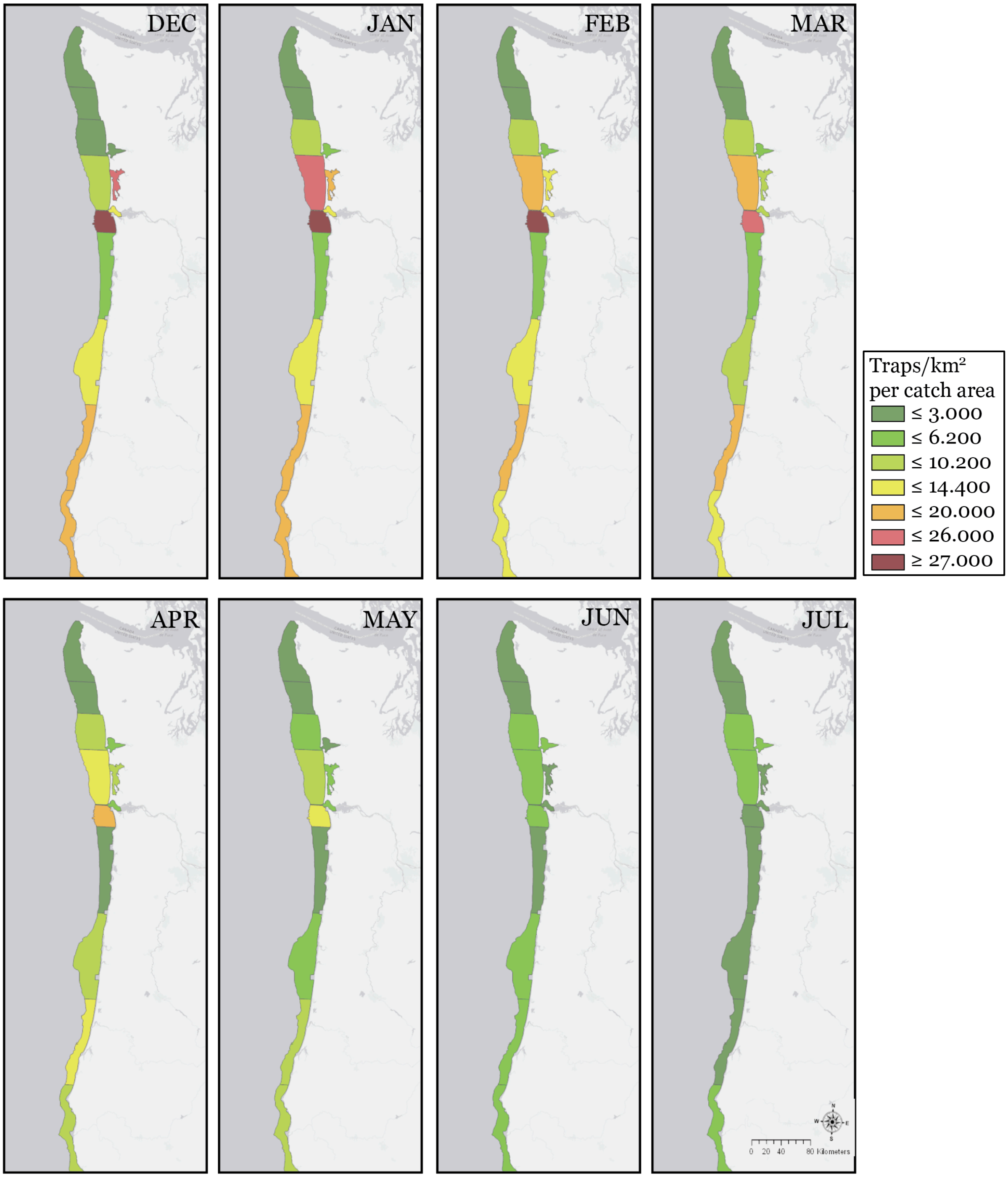

Figure 10. Dungeness crab trap fishery monthly average trap density per catch area per km2, indicated by the green to red colored bands, from 2013/2014 season to 2016/2017 season shown per catch area and by month of the year. Fishing area within a catch area is defined by operational fishing depth range. The density values are not unique to each state and were modeled after all catch area densities for all states.

ALL STATES FISHERY MODEL – WASHINGTON and OREGON

Average Trap Density (traps/km^2) 2013/2014–2016/2017

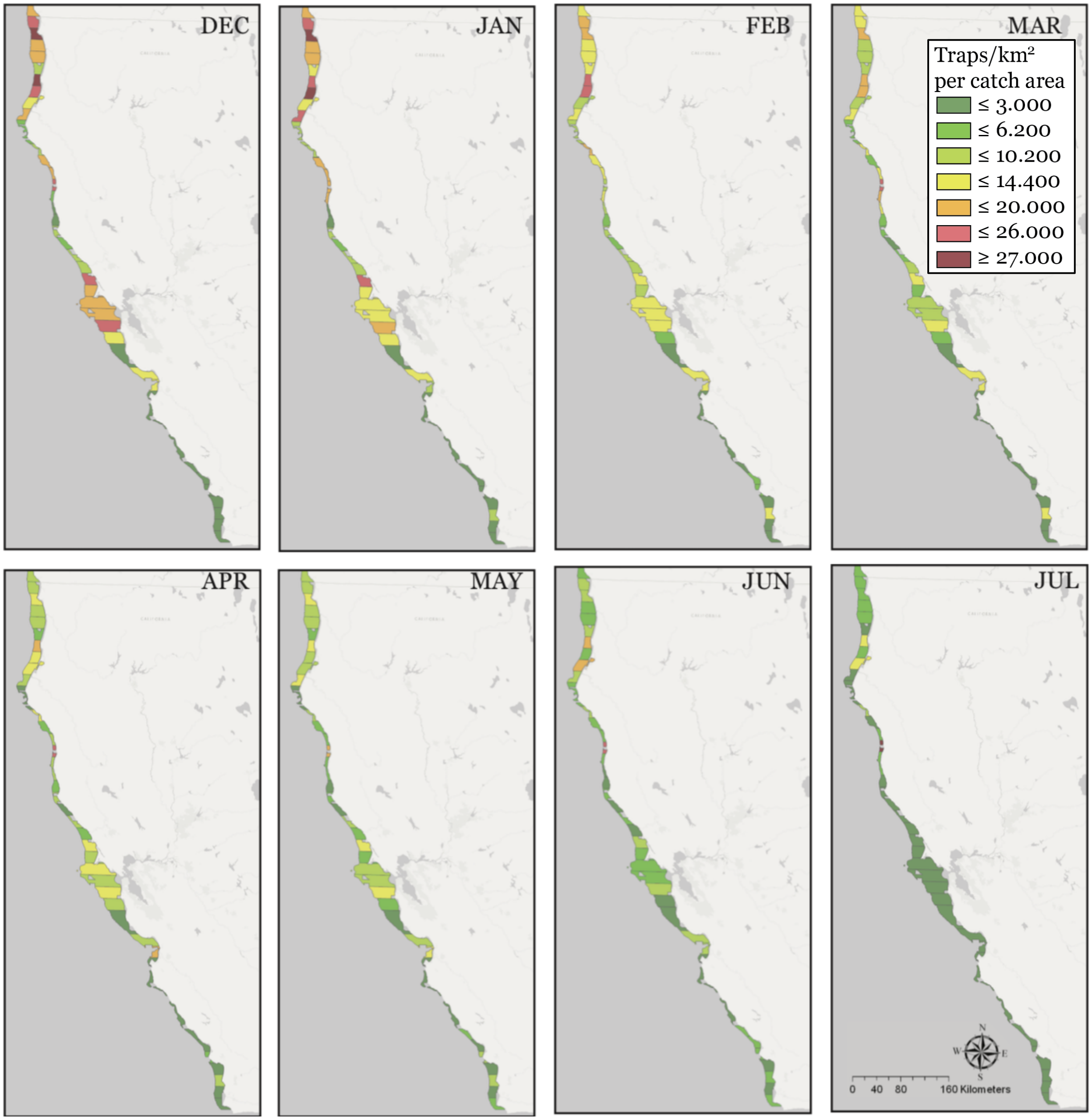

Figure 11. Dungeness crab trap fishery monthly average trap density per catch area per km2, indicated by the green to red colored bands, from 2013/2014 season to 2016/2017 season shown per catch area and by month of the year. Fishing area within a catch area is defined by operational fishing depth range. The density values are not unique to each state and were modeled after all catch area densities for all states.

WASHINGTON AND OREGON ONLY FISHERY MODEL

Average Trap Density (traps/km^2) 2008/2009–2011/2012 and 2012/2013–2015/2016

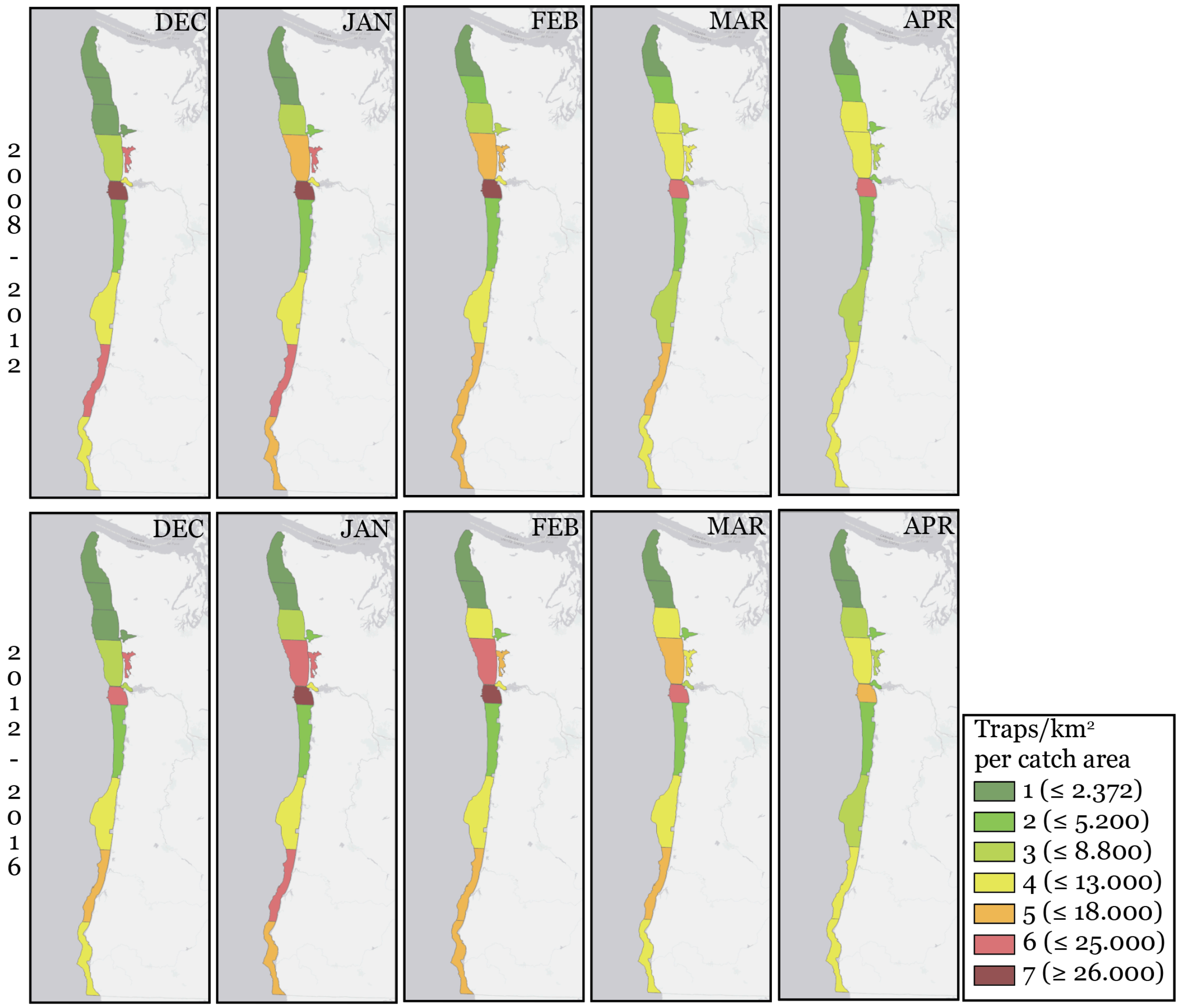

Figure 12. Washington and Oregon specific trap density model. Dungeness crab trap fishery monthly average trap density per catch area per km2, indicated by the green to red colored bands, from 2008/2009 - 2011/2012 and the 2012/2013 - 2015/2016 season shown per catch area, month, and years. Catch areas are defined by operational fishing depth range for Oregon and Washington (5 fm - 60 fm). The density values are unique to Oregon and Washington permit holders and landings data specific catch area densities for these two states have been scaled, per reported catch area from the Oregon and Washington datasets per km2, from 1-to-7 corresponding to the green to red color range, with green representing the lowest density (1) and red representing the highest density (7). Months December to April.

WASHINGTON AND OREGON ONLY FISHERY MODEL

Average Trap Density (traps/km^2) 2008/2009–2011/2012 and 2012/2013–2015/2016

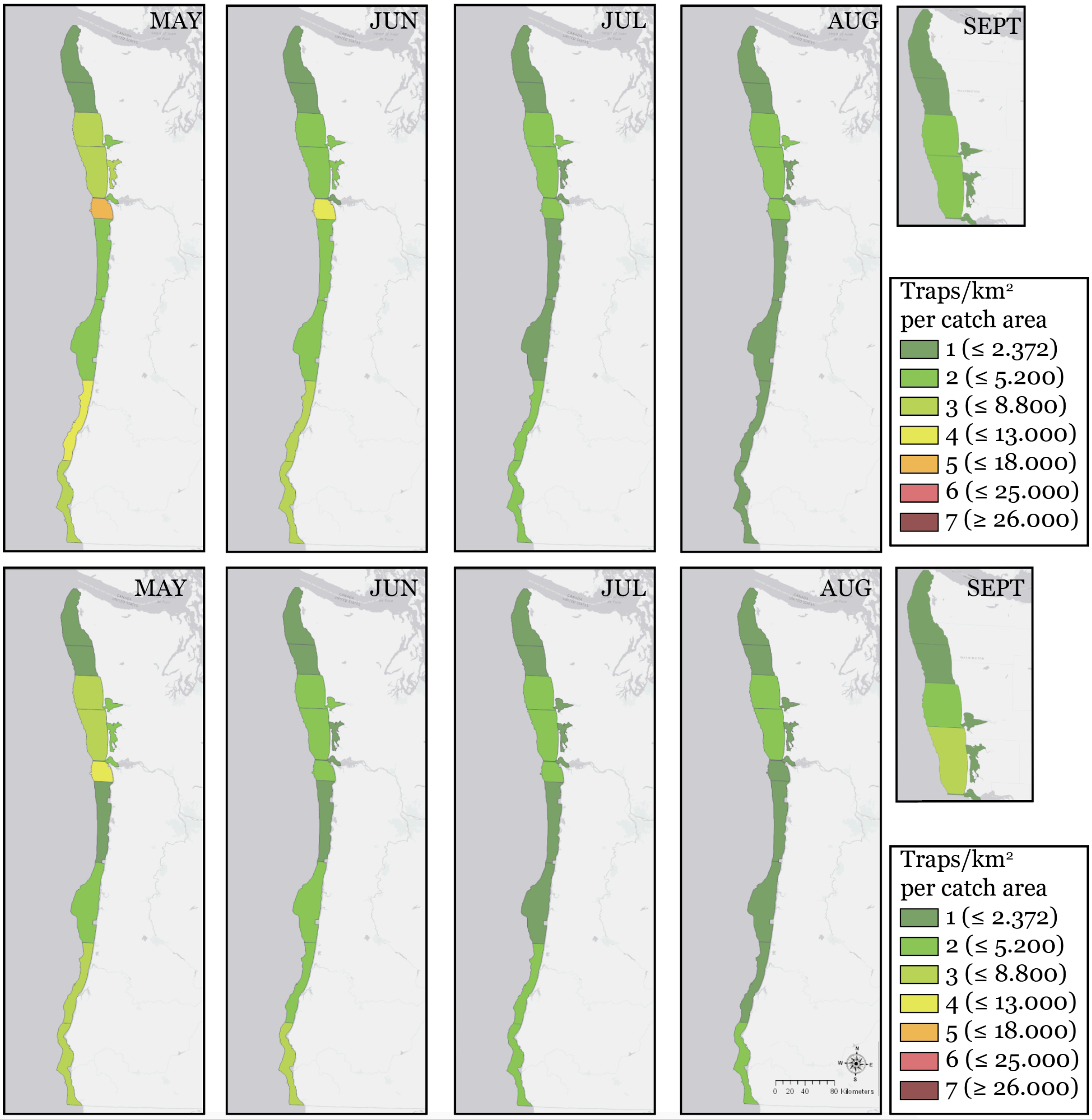

Figure 13. Washington and Oregon specific trap density model. Dungeness crab trap fishery monthly average trap density per catch area per km2, indicated by the green to red colored bands, from 2008/2009 - 2011/2012 and the 2012/2013 - 2015/2016 season shown per catch area, month, and years. Catch areas are defined by operational fishing depth range for Oregon and Washington (5 fm - 60 fm). The density values are unique to Oregon and Washington permit holders and landings data specific catch area densities for these two states have been scaled, per reported catch area from the Oregon and Washington datasets per km2, from 1-to-7 corresponding to the green to red color range, with green representing the lowest density (1) and red representing the highest density (7). Months May to August.

CALIFORNIA ONLY FISHERY MODEL

Average Trap Density (traps/km^2) 2013/2014–2016/2017

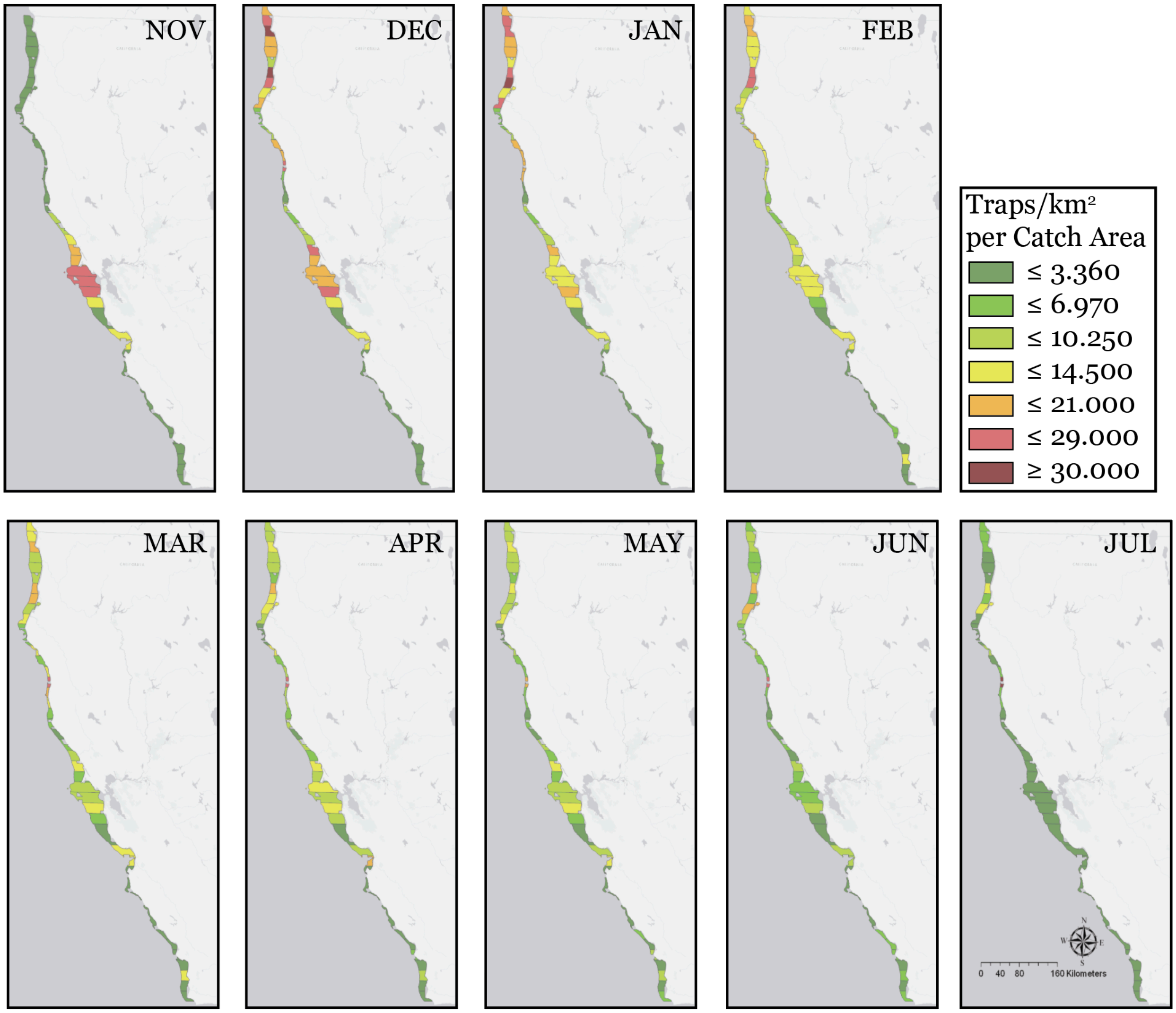

Figure 14. California specific trap density model. Dungeness crab trap fishery monthly average trap density per catch area per km^2, indicated by the green to red colored bands, from 2013/2014 season to 2016/2017 season shown per catch area and by month of the year. Catch areas are defined by operational fishing depth range for California (10 fm - 50 fm). The density values are unique to California permit holders and landings data specific catch area densities have been scaled, per reported catch area from the California dataset per km2, from 1-to-7 corresponding to the green to red color range, with green representing the lowest density (1) and red representing the highest density (7).

OREGON LOGBOOK FISHERY MODEL

Average Trap Density (traps/km^2) 2008/2009–2011/2012 and 2012/2013–2015/2016

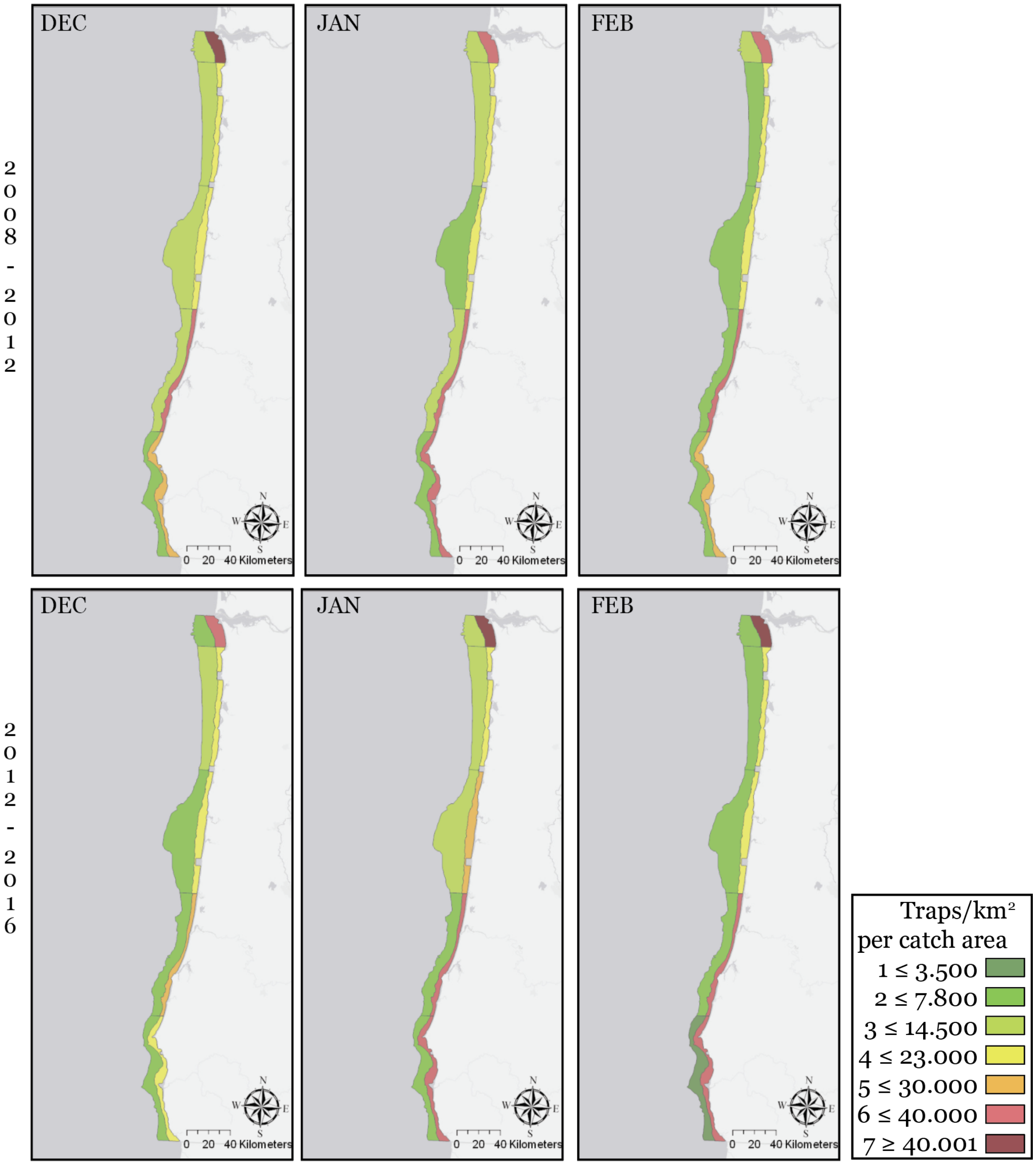

Figure 15. Oregon logbook specific trap density model. Dungeness crab trap fishery monthly average trap density per catch area per km2, indicated by the green to red colored bands, from 2008/2009 - 2011/2012 and the 2012/2013 - 2015/2016 season shown per catch area, month, and years. Catch areas are defined by operational fishing depth range for Oregon (5 fm - 60 fm). The density values are unique to Oregon logbook data, specific catch area densities for this state have been scaled, per reported catch area from Oregon logbook dataset per km2, from 1-to-7 corresponding to the green to red color range, with green representing the lowest density (1) and red representing the highest density (7). Months December - February.

OREGON LOGBOOK FISHERY MODEL

Average Trap Density (traps/km^2) 2008/2009–2011/2012 and 2012/2013–2015/2016

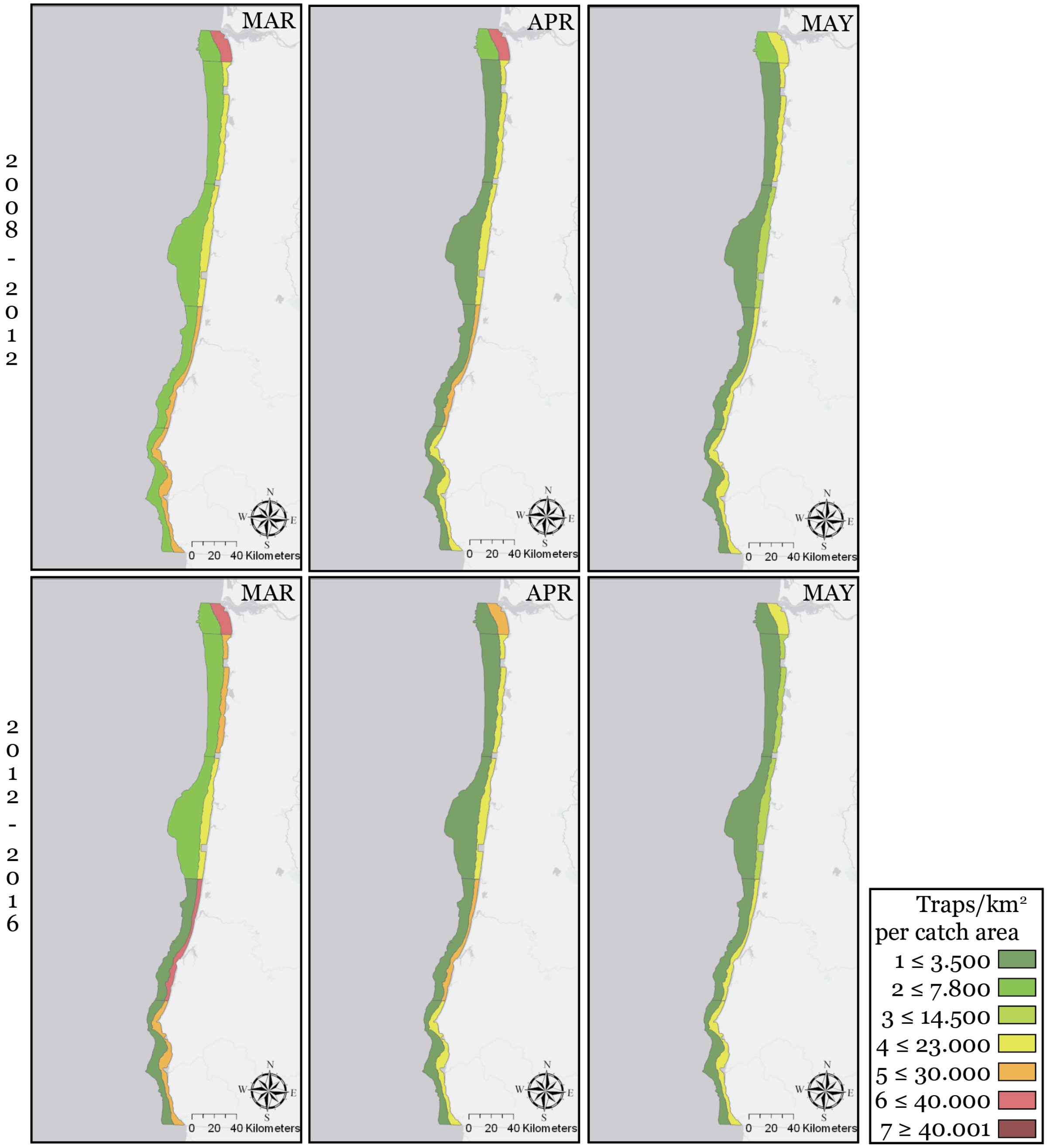

Figure 16. Oregon logbook specific trap density model. Dungeness crab trap fishery monthly average trap density per catch area per km2, indicated by the green to red colored bands, from 2008/2009 - 2011/2012 and the 2012/2013 - 2015/2016 season shown per catch area, month, and years. Catch areas are defined by operational fishing depth range for Oregon (5 fm - 60 fm). The density values are unique to Oregon logbook data, specific catch area densities for this state have been scaled, per reported catch area from Oregon logbook dataset per km2, from 1-to-7 corresponding to the green to red color range, with green representing the lowest density (1) and red representing the highest density (7). Months March - May.

OREGON LOGBOOK FISHERY MODEL

Average Trap Density (traps/km^2) 2008/2009–2011/2012 and 2012/2013–2015/2016

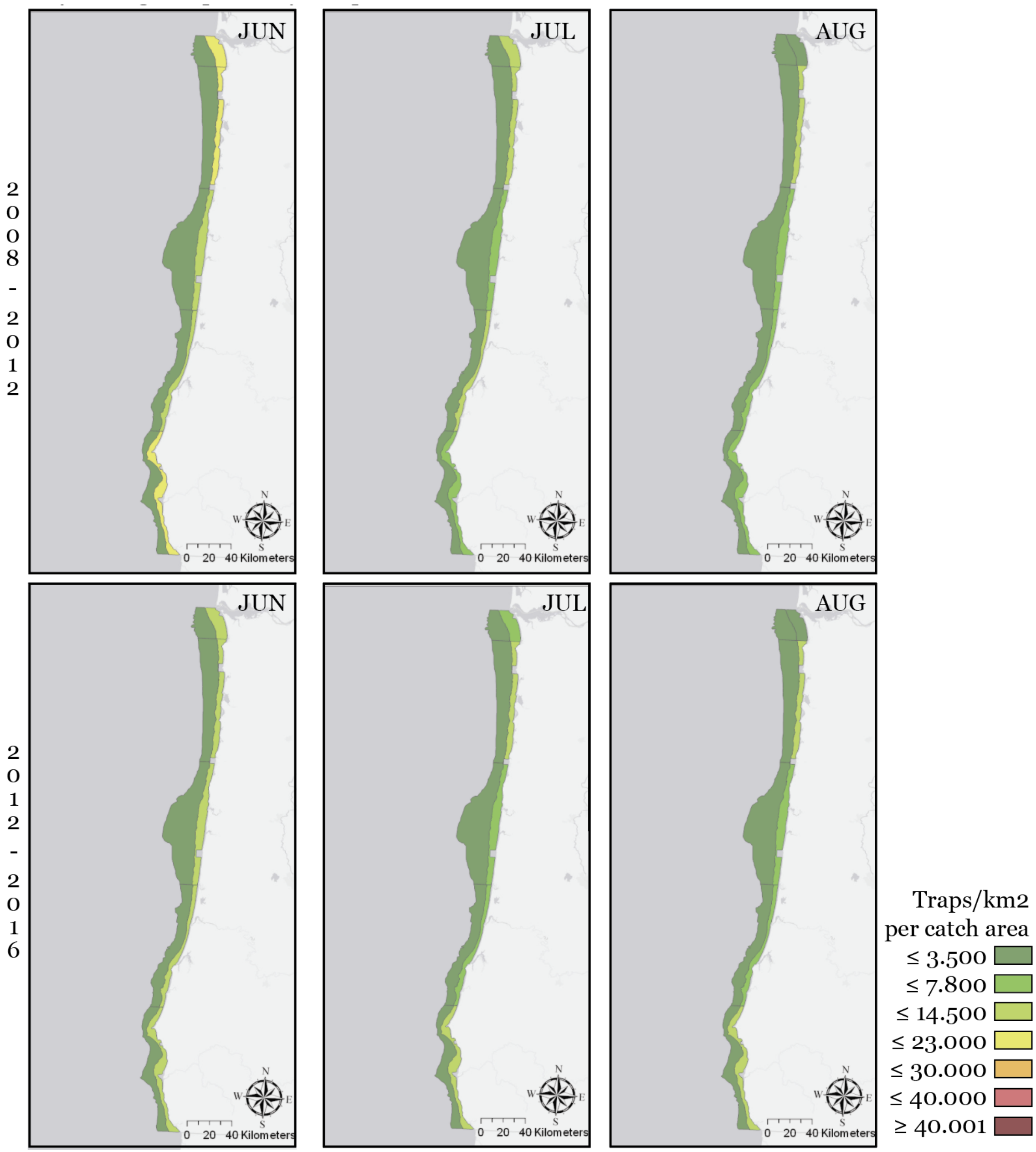

Figure 17. Oregon logbook specific trap density model. Dungeness crab trap fishery monthly average trap density per catch area per km2, indicated by the green to red colored bands, from 2008/2009 - 2011/2012 and the 2012/2013 - 2015/2016 season shown per catch area, month, and years. Catch areas are defined by operational fishing depth range for Oregon (5 fm - 60 fm). The density values are unique to Oregon logbook data, specific catch area densities for this state have been scaled, per reported catch area from Oregon logbook dataset per km2, from 1-to-7 corresponding to the green to red color range, with green representing the lowest density (1) and red representing the highest density (7). Months June - August.

OREGON LOGBOOK FISHERY MODEL COMPARISON WITH ALL STATES

Average Trap Density (traps/km^2) 2008/2009–2011/2012 and 2012/2013–2015/2016

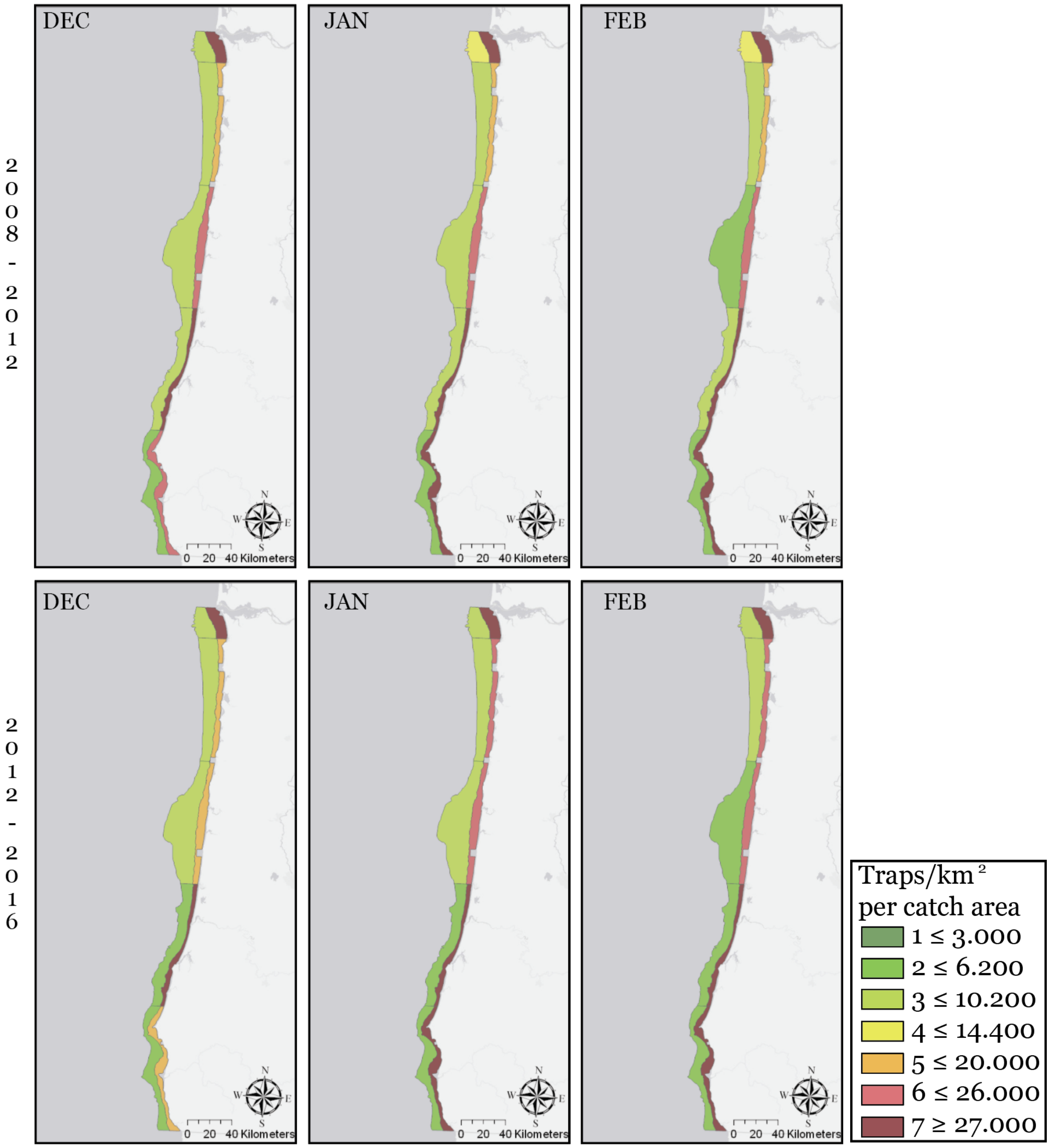

Figure 18. Oregon logbook specific trap density model. Dungeness crab trap fishery monthly average trap density per catch area per km2, indicated by the green to red colored bands, from 2008/2009 - 2011/2012 and the 2012/2013 - 2015/2016 season shown per catch area, month, and years. Catch areas are defined by operational fishing depth range for Oregon (5 fm - 60 fm). The density values are not unique to Oregon logbook data, specific catch area densities for this fishery model have been scaled, per reported catch area from the All State Fishery Model and respective dataset per km^2, from 1-to-7 corresponding to the green to red color range, with green representing the lowest density (1) and red representing the highest density (7) for comparison. Months December - February.

OREGON LOGBOOK FISHERY MODEL COMPARISON WITH ALL STATES INDEX

Average Trap Density (traps/km^2) 2008/2009–2011/2012 and 2012/2013–2015/2016

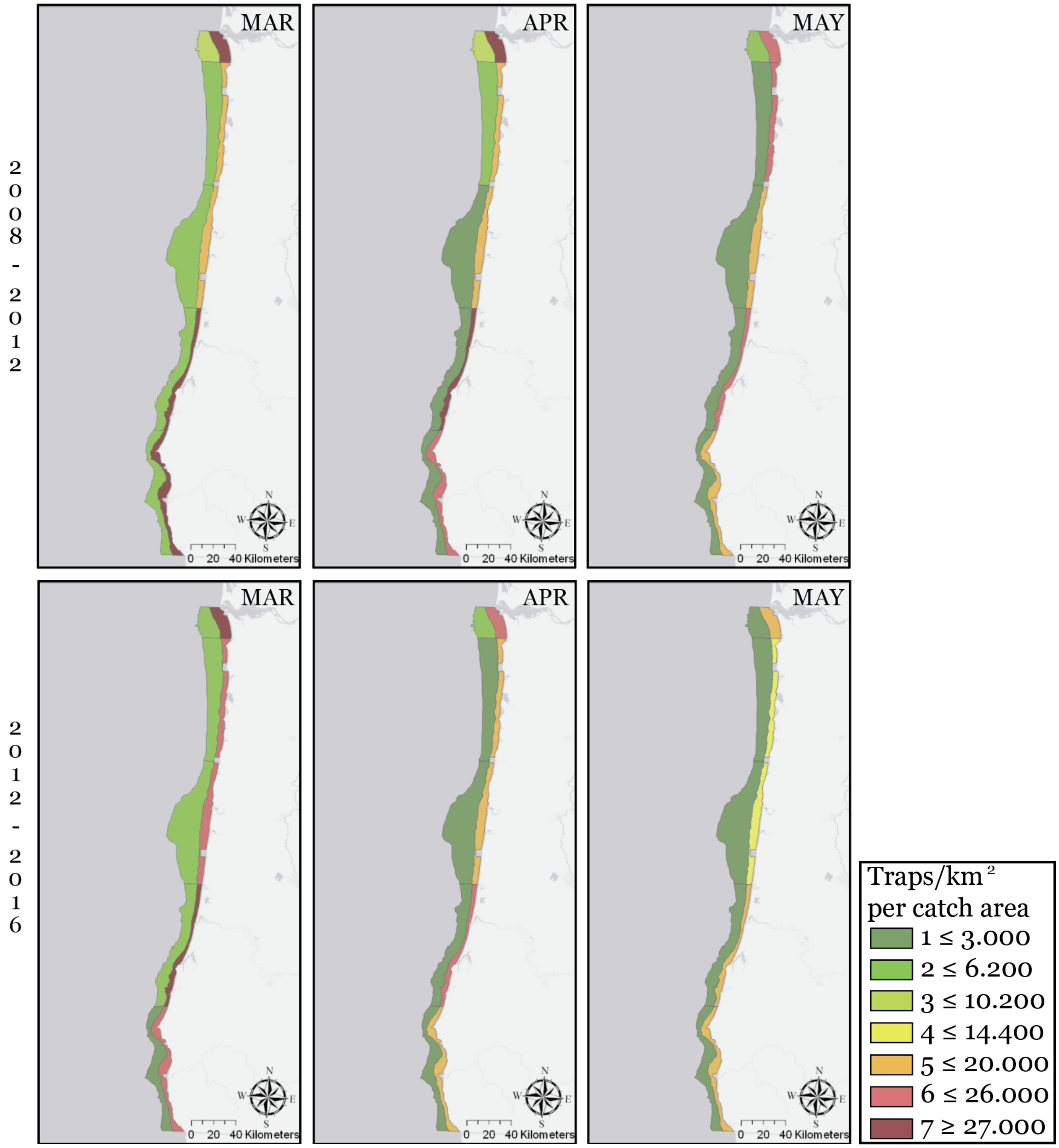

Figure 19. Oregon logbook specific trap density model. Dungeness crab trap fishery monthly average trap density per catch area per km2, indicated by the green to red colored bands, from 2008/2009 - 2011/2012 and the 2012/2013 - 2015/2016 season shown per catch area, month, and years. Catch areas are defined by operational fishing depth range for Oregon (5 fm - 60 fm). The density values are not unique to Oregon logbook data, specific catch area densities for this fishery model have been scaled, per reported catch area from the All State Fishery Model and respective dataset per km^2, from 1-to-7 corresponding to the green to red color range, with green representing the lowest density (1) and red representing the highest density (7) for comparison. Months March - May.

OREGON LOGBOOK FISHERY MODEL COMPARISON WITH ALL STATE INDEX

Average Trap Density (traps/km^2) 2008/2009–2011/2012 and 2012/2013–2015/2016

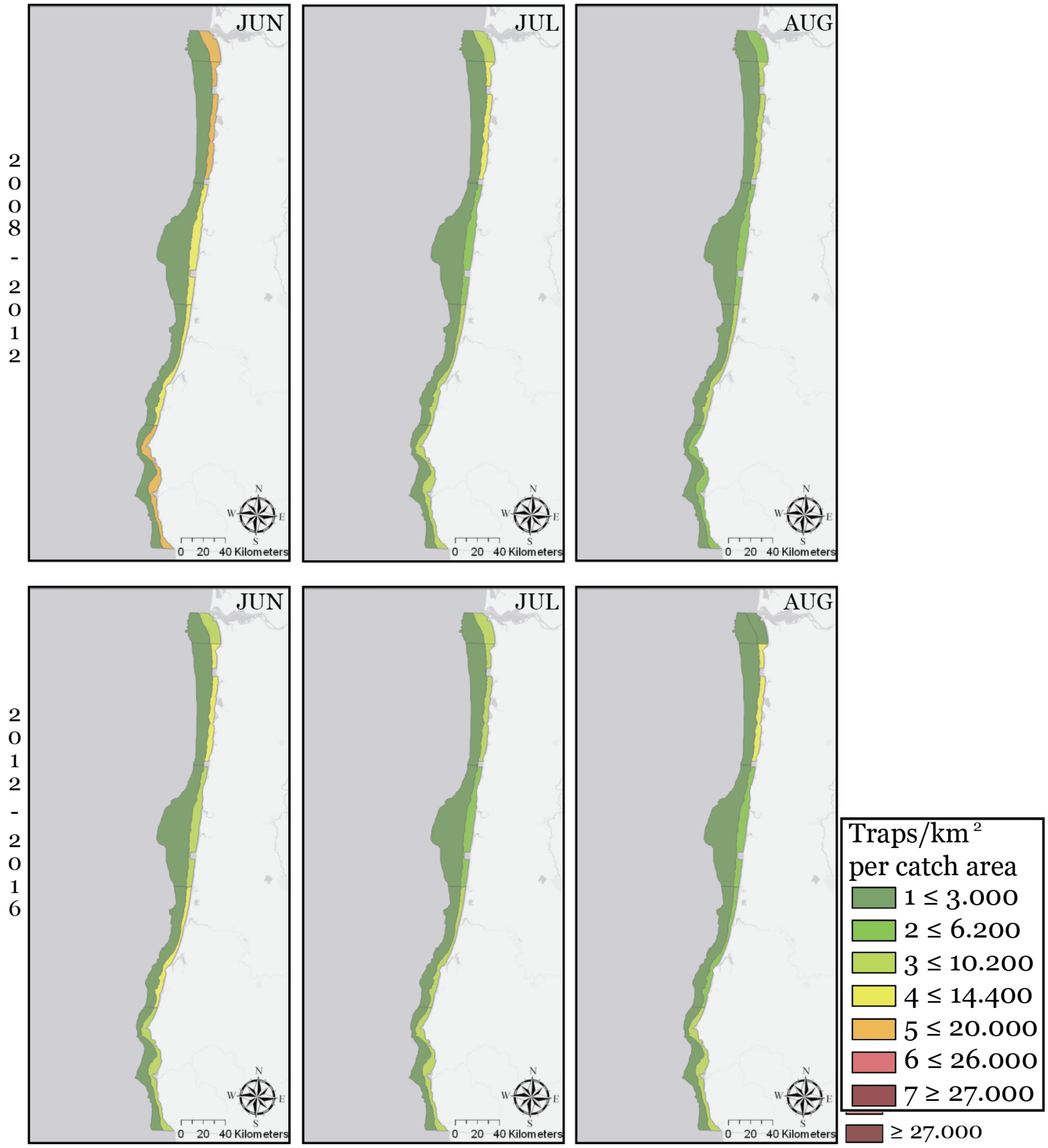

Figure 20. Oregon logbook specific trap density model. Dungeness crab trap fishery monthly average trap density per catch area per km2, indicated by the green to red colored bands, from 2008/2009 - 2011/2012 and the 2012/2013 - 2015/2016 season shown per catch area, month, and years. Catch areas are defined by operational fishing depth range for Oregon (5 fm - 60 fm). The density values are not unique to Oregon logbook data, specific catch area densities for this fishery model have been scaled, per reported catch area from the All State Fishery Model and respective dataset per km^2, from 1-to-7 corresponding to the green to red color range, with green representing the lowest density (1) and red representing the highest density (7) for comparison. Months June - August.

FISHERY MODEL DISCUSSIONS

ALL STATES FISHERY MODEL DISCUSSION

The All States Fishery Model looked at the distribution of fishery effort by month (December to July) averaged between 2013 to 2017 (Figures 9, 10, 11). The greatest amount of fishing effort, highest trap density, occurred in the southern Washington to the northernmost Oregon catch areas, southernmost Oregon catch area to just south of Eureka, and the San Francisco Bay area. When compared with the fishery model developed by Saez et al. (2013), the most obvious difference between the two models in this updated study shows fishing effort in more specific areas compared to the broad port complexes of the 2004 to 2008 Dungeness crab fishery model, see the Appendix A for figures from Saez et al. (2013) original co-occurrence model results. Quarter one of the original fishery model that used pounds of Dungeness crab landed as a proxy for effort indicates that high relative fishing effort occurs from the northernmost part of Washington to just south of Eureka. These differences may be from the presentation of data or a change in the distribution of fishing effort.

WASHINGTON and OREGON FISHERY MODEL DISCUSSION

The Washington and Oregon Only Fishery Model looked at the distribution of fishery effort from two four-year timeframes between the 2008/2009 fishing season to the 2011/2012 fishing season and between the 2012/2013 and 2015/2016 fishing season in the months December to August (Figures 12 and 13). The highest level of trap density occurred in the southern Washington catch areas during January and February with a greater effort from 2012 – 2016 in that area. The northernmost Oregon catch area (CLO) shows the greatest amount of effort from December to April with a higher trap density in this catch area in the timeframe between 2008 – 2012 compared to 2012 – 2016. This might indicate that fishing effort changed from the southern areas of Oregon in 2008 – 2012 to a greater effort in the Southern Washington areas in 2012 – 2016. This model shows that there is relatively low fishing effort from May to August throughout both states. The fishery model created by Saez et al. (2013) indicates that the greatest fishing effort in Washington and Oregon occurs throughout the entire coast in Quarter 1 (January – March) and Quarter 4 (October – November). These differences in effort between this model and the original model in Washington state may be due to the differences between the catch areas created for this model and the port complexes used in the previous model as the original co-occurrence model presents landings data for all Washington state and does not break it up into catch areas. Additionally, Washington state catch areas have the largest areas (in km^2) which could lower the trap density and may present as areas with reduced fishing effort. However, when comparing the total number of traps in Washington and Oregon, Oregon has an overall higher number of traps deployed than Washington state (Figure 21). The number of traps deployed by Washington state commercially licensed fishermen in all catch areas, except catch areas 61 from the Columbia River to the southern border of Oregon, significantly less than the overall number of traps deployed by Oregon commercial fishermen in Oregon catch areas.

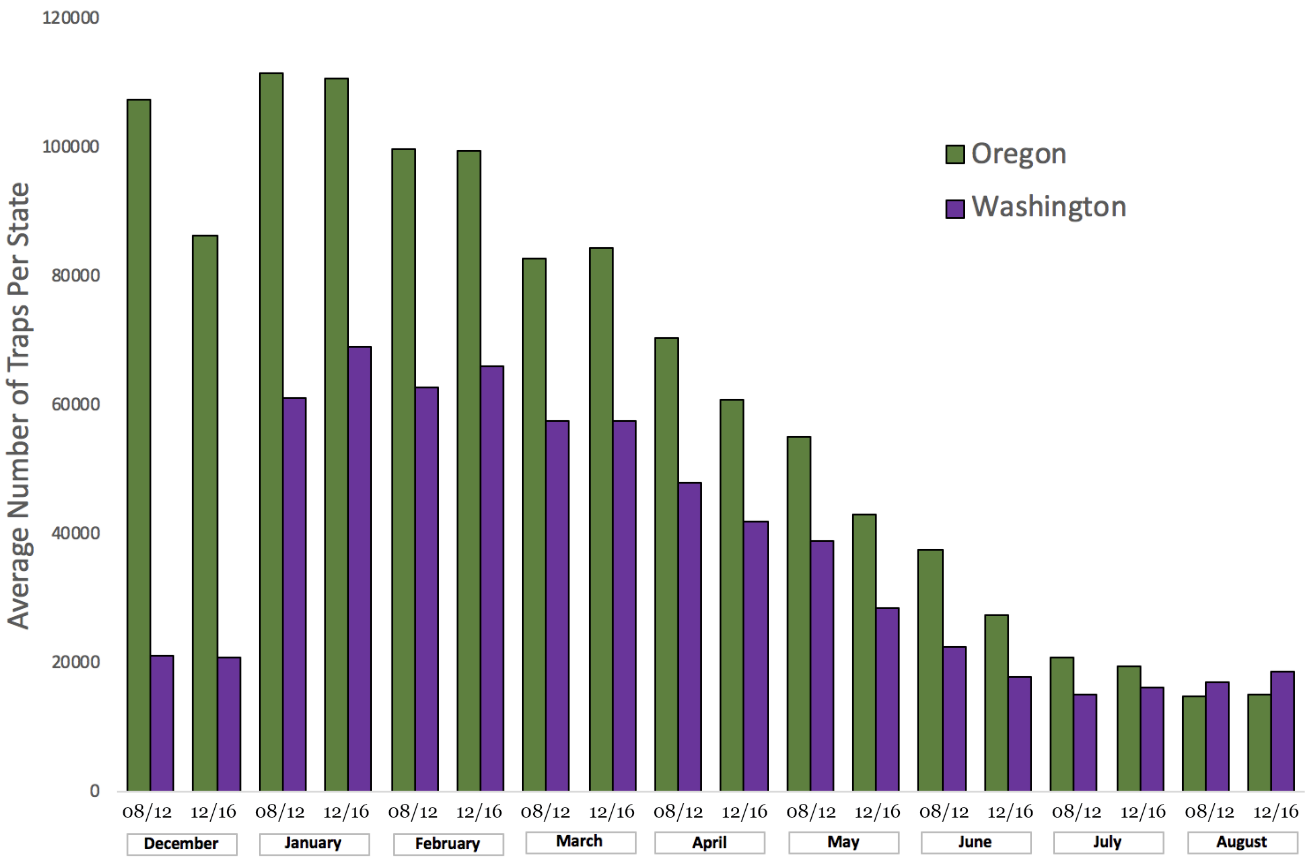

Figure 21. Average number of traps per state (Oregon and Washington only, not including catch area 61_60D) comparing the average number of traps per year averaged over the two timeframes, 2008 - 2012 and 2012 - 2016 fishing season.

CALIFRONIA ONLY FISHERY MODEL DISCUSSION

The California Only Fishery Model looked at the distribution of fishery effort from the four-year average between 2013 to 2017 from December to July (Figure 14). The highest trap density occurred in the catch area from the California border to Fort Bragg from December to February and from Bodega Bay to the southern area of San Francisco Bay during the months of November and December. This model shows that there is a relatively low amount of effort in the Monterey Bay area for all months. When compared with the original co-occurrence model fishery effort, the biggest difference between the two models in this updated study shows the fishing effort in more specific catch areas. However, a comparison between the fishery model efforts shows that both models report similar results of areas with high and low fishing efforts.

OREGON LOGBOOK FISHERY MODEL DISCUSSION

The Oregon Logbook Fishery Model looked at the distribution of fishery effort in Oregon from the two four-year timeframes, between the 2008/2009 to 2011/2012 fishing seasons and between 2012/2013 to 2015/2016 seasons, years average by months December to August (Figures 15, 16, 17). The highest trap density occurred in the shallow catch areas of CLO, CBA, and BRA during December to April. The data (Table 6, Table 25) show that the use of the logbook data gives a more detailed understanding of the use of catch areas along the Oregon coast, a greater proportion of traps are deployed per month at depths of 30 of less compared to the catch areas deeper counterpart. This indicates that the Washington and Oregon Only Fishery Model, which uses landings data instead of logbook data, does not capture that the greatest trap density (higher fishing effort) occurs in the shallower parts of the Oregon catch areas, depths of 30 fathoms or less. This difference in effort of this model compared to the All States Fishery Model and the Washington and Oregon Only Fishery Model highlights the value of logbook data, and the more detailed the data reported in regard to the refined catch areas by depth yields a better understanding of trap density and distribution.

The stark differences between the data from the Oregon Logbook Fishery Model and the Washington and Oregon Only Fishery Model should be noted. The scaled numbers for the Oregon Logbook Fishery Model report trap density numbers outside of the range of values calculated for the Washington and Oregon Only Fishery Model (Table 5, Figures 18 - 20) as higher total trap numbers and trap densities were found in the shallower catch areas. While these numbers were calculated from the Oregon logbook data using the Jenks Natural Breaks Method, future modeling efforts should consider calculating a scale for the Oregon Logbook Fishery Model that fits the Washington and Oregon Fishery Model or the All States Fishery Model for a better comparison between the results from the Oregon logbook data and the Oregon landings data. A universal scale for all model results would provide a better understanding of co-occurrence and where the greatest risk occurs relative to the whole West Coast and not the individual state. For comparison, and example of this can be found in Figures 18 – 20, these figures demonstrate how the Oregon Logbook Fishery Model results change when the scaled trap density numbers from the All State Fishery Model are applied to the Oregon logbook data.

Table 6. Average number of traps per catch area per month, numbers reported per month were averaged over two timeframes, the 2008/2009 – 2011/2012 and the 2012/2013 – 2015/2016 fishing season from the Oregon logbook data from ODFW (personal communication with Justin Ainsworth, ODFW, 2017).

Yearly Averaged Traps per Month	**CLO Shallow**	**CLO Deep**	**TLA Shallow**	**TLA Deep**	**NPA Shallow**	**NPA Deep**	**CBA Shallow**	**CBA Deep**	**BRA Shallow**	**BRA Deep**
JAN 08 - 12	10522	5326	9265	12631	13460	16966	15133	10197	18881	5205
FEB 08 - 12	10216	4945	9416	10884	13717	12684	13874	7216	16794	5109
MAR 08 - 12	10493	3540	9046	7732	10290	8630	11487	4993	15992	3997
APR 08 - 12	9787	3207	9135	4769	10742	5875	11031	2958	12442	2558
MAY 08 - 12	6562	2244	9660	2991	9156	3310	8617	1801	10484	1535
JUN 08 - 12	5323	326	8457	867	6509	1637	5272	612	7927	122
JUL 08 - 12	2876	307	4921	671	3775	353	3828	388	4134	440
AUG 08 - 12	1010	261	4595	459	2229	305	3109	554	2662	132
DEC 08 - 12	13907	4083	8666	12321	14230	17745	16463	9741	13788	4092
JAN 12 - 16	12991	4237	10331	12153	15947	17658	14881	6256	19464	5047
FEB 12 - 16	13459	3777	10108	10332	13525	12892	14664	5844	18314	3555
MAR 12 - 16	11623	2607	11854	7929	12997	986	13435	3808	13516	271
APR 12 - 16	8063	1770	9411	3509	11163	6503	9953	2041	10753	1598
MAY 12 - 16	5673	420	6376	1703	7699	3082	7467	1007	9321	1710
JUN 12 - 16	2959	320	4895	986	5976	2018	5229	407	5131	646
JUL 12 - 16	2049	81	4044	452	3875	1031	2795	657	4890	655
AUG 12 - 16	909	123	5812	861	2596	1843	2100	974	4562	123
DEC 12 - 16	11108	3255	8406	11255	11520	14641	11777	5892	10830	3823

SECTION 3: DEVELOPMENT OF THE WHALE DENSITY MODEL

Four species of large whale were used in this study, gray, humpback, blue, and fin whales. These four species have been identified as being at risk for entanglement in fixed gear fisheries along the West Coast. These species were used in the Saez el al. (2013) co-occurrence model and have seen an increase in entanglement numbers since 2014 (NMFS 2017). Two data sources, DeAngelis et al. (2011) and Becker et al. (2016), were used to report predicted whale density and distribution to be used in the vertical line co-occurrence model. Section 3 describes the methods used for gray whale density model and then describes the methods used for all other species, Tables 7 – 8 report the scaled index for each species. This is followed by a description of some limitations fo the data used to development the whale density models. Lastly, the results are reported for the whale density models for each species in Figures 22 – 23.

GRAY WHALE

With the exception of southern California, gray whales migrate annually from Baja California, Mexico to Artic feeding grounds within 10 kilometers of the coast (Saez et al. 2013, DeAngelis et al. 2011). DeAngelis et al. (2011) created the gray whale migration model to quantifying migration patterns and densities of gray whales along the West Coast of the U.S. for all phases of the gray whale migration: Southbound, Northbound Phase A, and Northbound Phase B. Migration corridors were created based on a distance from shore for each phase and split into geographic segments representing 24 hour travel distance of the gray whale migration. Total daily density values[6] for each geographic segment were averaged over one month time periods to get monthly density values in whales per km^2 and then those numbers were run through the Jenks Natural Breaks method and given an index score from 1-to-7, with 7 being the peak monthly whale density (Table 7, Figure 22).

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[6] Details on the gray whale migration model can be found at www.cetsound.gov or DeAngelis et al. 2011

HUMPBACK, BLUE, FIN WHALE

Becker et al. (2012) used data from 6 systematic ship-based cetacean and ecosystem assessment surveys conducted in the summer and fall of 1991 – 2008 to build habitat based density models for multiple species, including humpback, fin, and blue whales. These models were used to predict cetacean densities from habitat variables and were smoothed and averaged to produce a composite grid that represents the estimate of average cetacean density and distribution for each species. An index score of whale density for each species was created based on the estimated whale density using the Jenks Natural Breaks method and given a score value ranging from 1-to-7 (Table 8). The multi-year average whale density maps for humpback, fin, and blue whales from the Becker et al. (2012) data can be found in Figure 23.

WHALE DENSITY MODEL LIMITATIONS

This study identified two limitations to the whale density data. First, the data for humpback, blue, and fin whales does not include densities from January to June because they only represent a summer and fall estimates. Because the greatest amount of fishing effort for all states occurs in the beginning of the year future efforts should involve the incorporation of winter and spring whale densities to better understand co-occurrence and entanglement risk. Second, whale density scores are different and therefore comparison between all species was not possible.

Table 7. Scaled values of whale density per km^2 used for the gray whale density model using the Natural breaks method in ArcGIS.

Gray Whale Density (whales per km2)
1 (≤ 0.0191)
2 (≤ 0.0383)
3 (≤ 0.0805)
4 (≤ 0.1457)
5 (≤ 0.2798)
6 (≤ 0.4064)
7 (≥ 0.4065)

Table 8. Scaled values of whale density per km^2 used for the humpback, fin, and blue whale density model using the Natural breaks method in ArcGIS.

Humpback Whale Density (whales per km^2)	Fin Whale Density (whales per km^2)	Blue Whale Density (whales per km^2)
1 (≤ 0.0011)	1 (≤ 0.001690)	1 (≤ 0.00086)
2 (≤ 0.0034)	2 (≤ 0.003039)	2 (≤ 0.0034)
3 (≤ 0.0064)	3 (≤ 0.004855)	3 (≤ 0.0064)
4 (≤ 0.0102)	4 (≤ 0.006826)	4 (≤ 0.0102)
5 (≤ 0.0151)	5 (≤ 0.008849)	5 (≤ 0.0151)
6 (≤ 0.0212)	6 (≤ 0.011020)	6 (≤ 0.0212)
7 (≥ 0.0379)	7 (≥ 0.013622)	7 (≥ 0.0379)

WHALE DENSITY MODEL RESULTS

GRAY WHALE

Density Scores (whales/km^2)

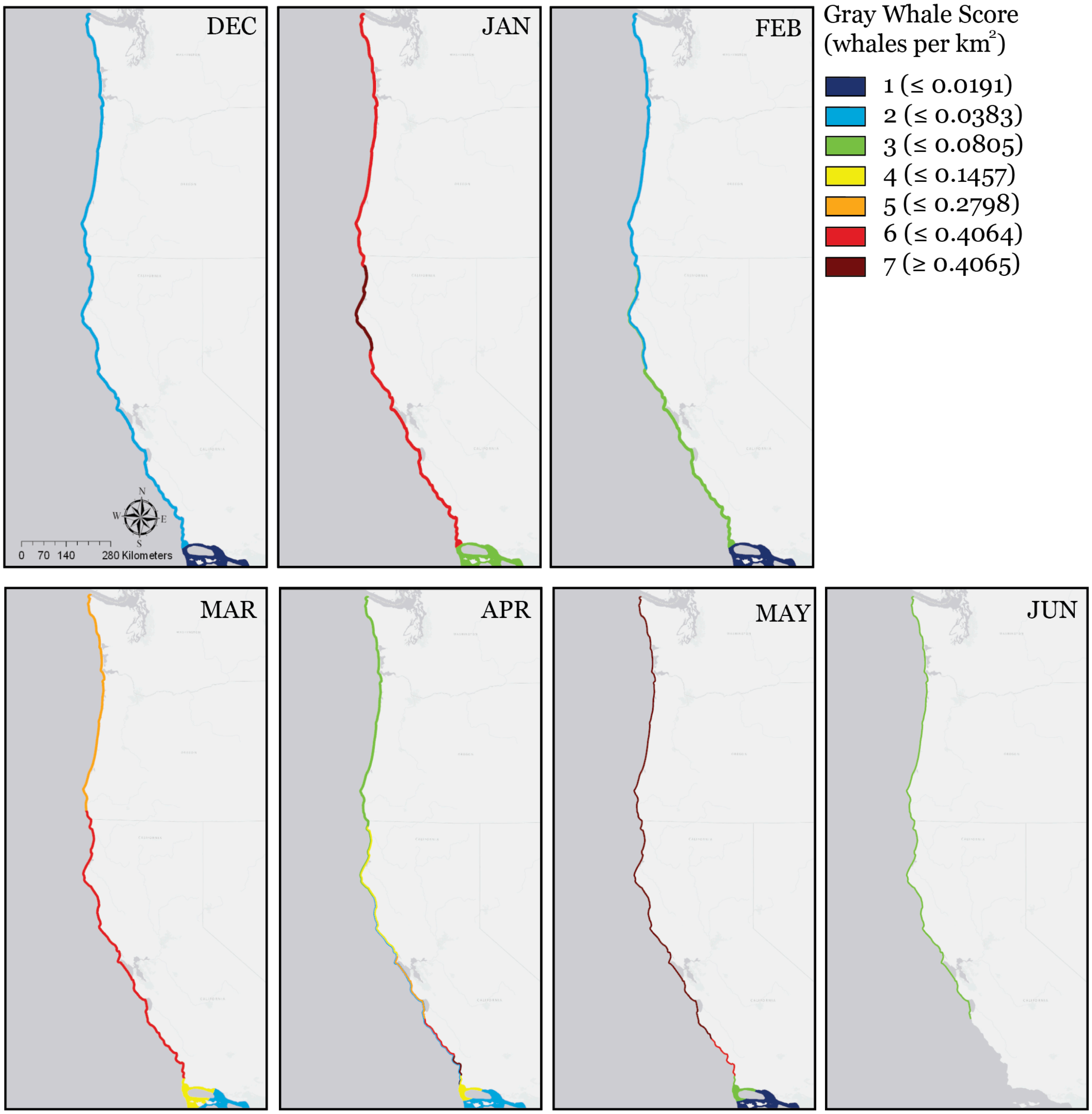

Figure 22. Gray whale migration model maps showing average whale density per month. The monthly density values, per km2, have been scaled from 1-to-7 corresponding to the blue to red color range, with blue representing the lowest density (1) and red representing the highest density (7) for that species.

HUMPBACK, BLUE, FIN WHALE

Density Score (whales/km^2)

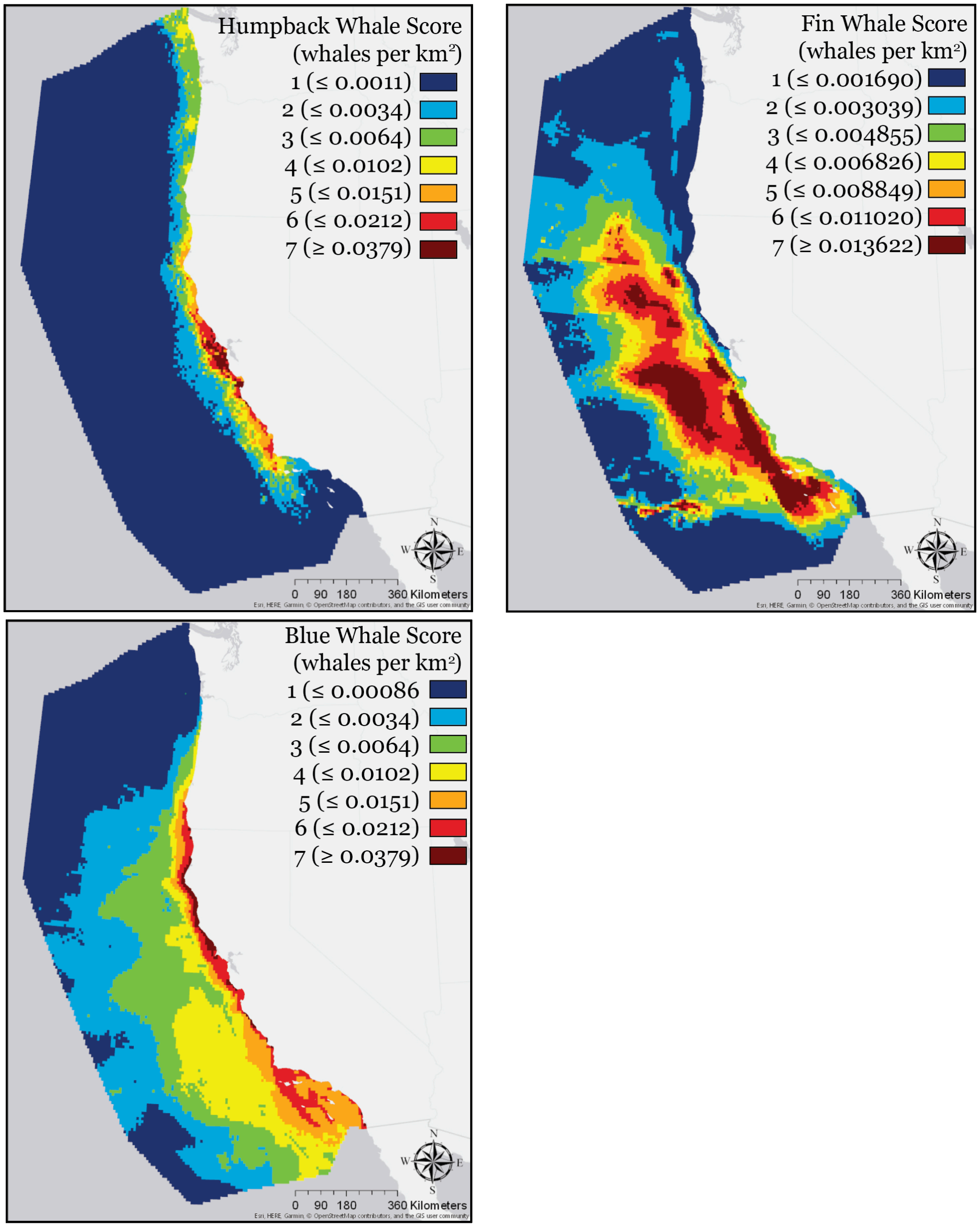

Figure 23. Multi-year average whale density maps for blue, fin, and humpback whales from July to November (recreated using data from Becker et al., 2012). The density values unique to each species have been scaled, per reported block from the dataset per km2, from 1-to-7 corresponding to the blue to 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 and were run through the Jenks Natural Breaks method.

SECTION 4: VERTICAL LINE CO-OCCURRENCE MODEL DEVELOPMENT

Fishery effort, represented by trap density, was modeled along with whale density models for gray, humpback, blue, and fin whales. The predicted density of large whales was overlaid with fishery effort assess areas of vertical line co-occurrence (Figure 24). These locations identified in the vertical line co-occurrence models highlight risk areas where whales are more likely to become entangled, as the presence of commercial Dungeness crab fishery gear and whales may result in higher risk if a linear relationship is to be assumed.

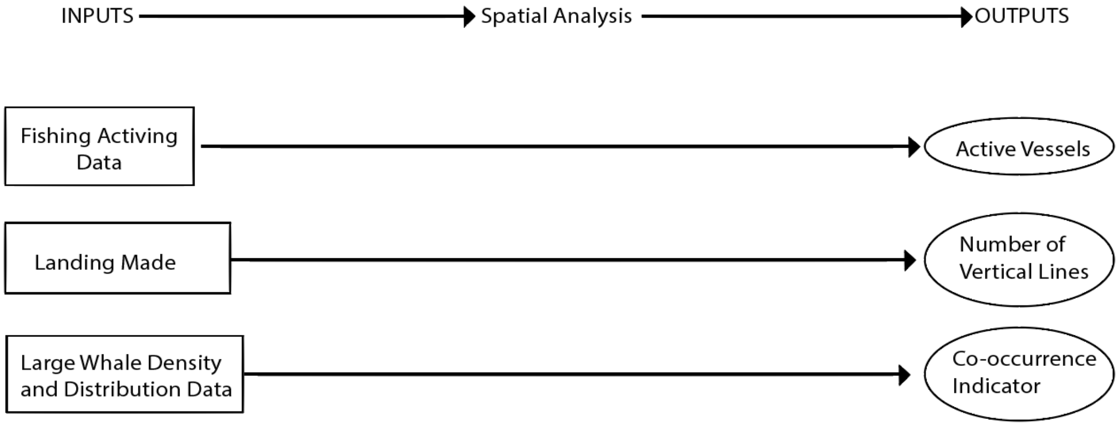

Figure 24. Conceptual model of the vertical line co-occurrence model.

The combined data created co-occurrence scores to identify the level of risk calculated using two different methods, based on the monthly data available for the whale density models and the corresponding fishing season. Vertical line co-occurrence scores for each month calculated using the fishery models were multiplied by the monthly densities for gray whales from DeAngelis et al. (2011). Humpback, blue, and fin whale predicted whale densities reported for summer and fall months were multiplied with the commercial fishing effort for each month of the year corresponding fishery data were available (Becker et al. 2012). Due to the nature of the data collected for humpback, blue, and fin whales, from the ship-based surveys the only months available for vertical line co-occurrence score calculation was for months July to December. Gray whale density data was provided for months December to June, more closely matching up with data from the Dungeness crab fishing season, and thus all vertical line co-occurrence models include months December to June for gray whales.

As noted in Table 5 and Tables 7 – 8, the whale density data and trap density data were both indexed and scaled between 1 to 7 using the Jenks Natural Breaks Method. These numbers were multiplied to create co-occurrence scores between 1 and 49, with one being the lowest level of risk and 49 the highest (Table 9). This method of risk calculation was adapted from Saez et al. (2013) co-occurrence model and from another study which calculated the co-distribution of minke whales (*Balaenoptera acutorostrata*) and creels along the northern waters of Scotland (Northridge et al. 2010).

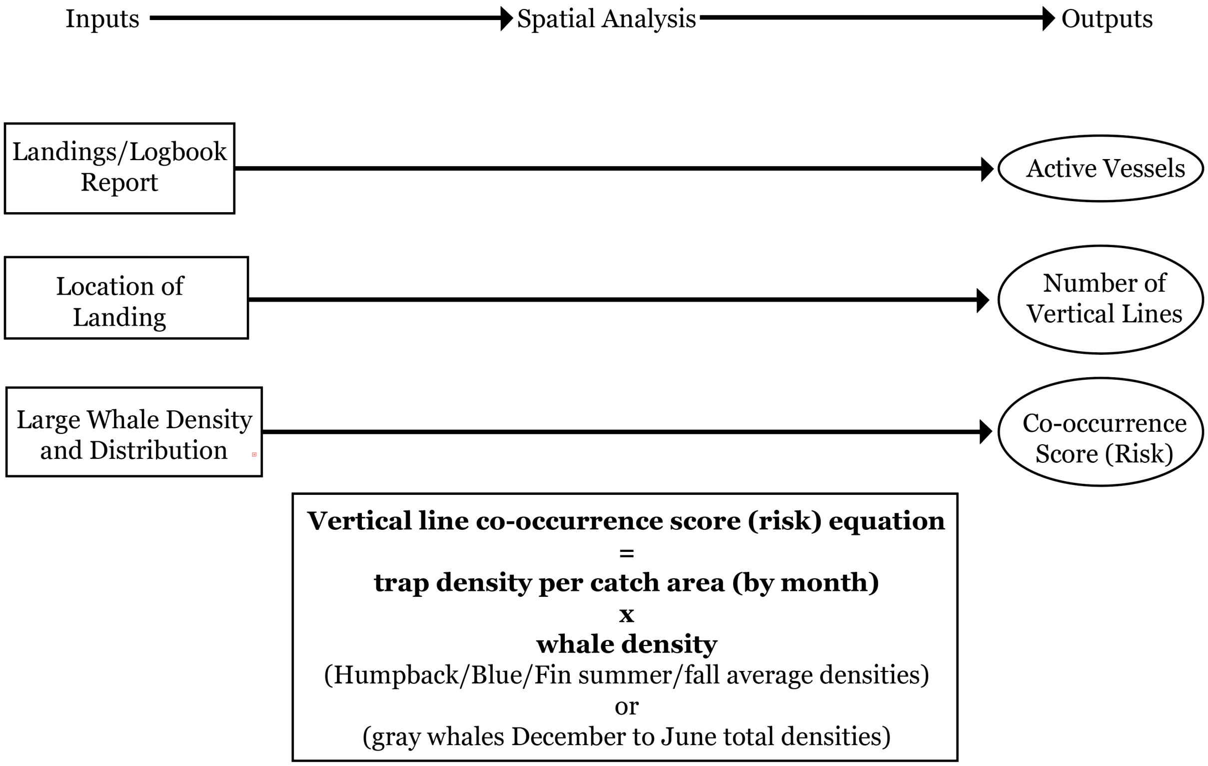

Figure 4. Conceptual model of the vertical line co-occurrence model and vertical line co-occurrence score (risk) equation.

The same co-occurrence scores (risk) used in the Saez et al. 2013 co-occurrence model were used for the vertical line co-occurrence models for ease of comparison; they defined elevated risk areas with scores above 24 and lower risk areas with scores below 18. Terminology used in the results section for this research identifies classes 1 and 2 as low risk (scores 1 - 10), 3 to 5 as moderate risk (scores 11 - 29), and 6 and 7 as high risk (scores 30 - 49) (Table 9).

Table 9. Scaled index for gray, blue, fin, and humpback whale co-occurrence scores to assess risk.

Co-occurrence Score Class	*Lower Boundary*	*Upper Boundary*
1 - low	1	5
2 - low	6	10
3 - moderate	11	17
4 - moderate	18	24
5 - moderate	25	29
6 - high	30	41
7 - high	42	49

OVERVIEW OF VERTICAL LINE CO-OCCURRENCE MODEL RESULTS and DISCUSSION

The results reported for all species and fishery models include an overview of risk, the peak co-occurrence scores for each month, and the areas of high risk (scores 30 - 49). In addition, the vertical line co-occurrence model results are compared to the original model results between the vertical line co-occurrence models developed using the All States Fishery Model and each large whale species to better understand how the spatial, temporal, and methods quantifying fishing effort differ. The vertical line co-occurrence models for the Washington and Oregon Only Fishery Model report overview of risk, the peak scores for each month, the areas of high risk, and how fishing effort has changed between the two timeframes investigated in this study, 2008 - 2012 and 2012 - 2016. The vertical line co-occurrence models created using the California Only Fishery Model report overview of risk, peak scores by month, and areas of high risk. Each vertical line co-occurrence model includes a brief discussion on the results.

VERTICAL LINE CO-OCCURRENCE MODEL RESULTS LIMITATIONS

General limitations of the vertical line co-occurrence models include the following:

1. The results and discussion for each vertical line co-occurrence model identify general trends and can be interpreted differently if more information on species or fishery effort

is known. For example, if fishing effort distribution changes throughout the season, not all traps are utilized, or if a species is more likely to become entangled based on behavior, these can affect interpretations.

2. Results may be limited due to the timeframes used, as the whale data extends beyond the restrictions of the months used and the presence of whales may not conform to this timeframe. For example, the models for blue, humpback, and fin whales are compromised because the time period when these species are known to be present based on the data and the season for the Dungeness crab fishery does not cover the exact same timeframes. The application of model results for the month of December, given variability of whale presence, is suitable considering the distribution whale species can change in any given year for a variety of dynamic factors.
3. Validation for this model is difficult because many whale entanglements go undetected (Heyning and Lewis 1990, Saez et al. 2013).
4. Differences highlighted between timeframes and models could be due to a change in fishing effort or differences in the nature of the model development. The original co-occurrence model should be recreated using their similar methods using landings, from 2008 - 2017, as a proxy for effort in port complexes to better understand if the majority of the difference between the two models can be attributed to a change in the fishery effort over time or the fundamental difference of representation of effort, pounds landed as a proxy for effort or the number of vertical lines in the water.
5. It should be noted that effort in some smaller catch areas due to the exclusion of area (in km^2) from marine protected area report scores of greater risk of co-occurrence, as smaller area yields greater trap numbers. Future efforts to understand the true co-occurrence

during the higher risk months should be further investigated with observational studies or the limitations of this model outlined in Chapter 2 should be incorporated.

OTHER CONSIDERATIONS

The comparisons between the vertical line co-occurrence models using the Oregon Logbook Fishery Model and the Washington and Oregon Only Fishery Model should be viewed with further considerations. The catch areas defined by WDFW and the operational fishing depths for Washington State yielded the largest catch area relative to any other state. The five catch areas of Oregon used in the All State Fishery Model and the Washington and Oregon Only Fishery Model were broken up into 10 catch areas. The catch areas were divided by the 30 fathom depth line for the Oregon Logbook Fishery Model as the ODFW logbook data reports trap numbers for each catch area as fished in waters greater than or less than 30 fathoms. Additionally, Washington state landings data reports that there are fewer traps deployed each month, except for August, in Washington state coastal waters compared to Oregon (Figure 21). These two factors combined produce lower trap density (traps per km^2) numbers compared to the Oregon Logbook Fishery Model, which has smaller catch areas. Therefore, an overall lower trap density was produced, and thus, a lower trap density scale was calculated using the Jenks Natural Breaks method. Furthermore, Oregon logbook data reports that a greater percent of traps are reported in less than 30 fathoms for each catch area, the shallow catch areas (Table 6, Table 10, Figure 25). This greater proportion of traps in the shallow catch areas in the Oregon Logbook Fishery Model along with the smaller catch areas, separated by the 30 fathom depth line, produce larger trap densities than in any other model. Therefore, an indexed scale with larger values was produced using the Jenks Natural Break Method (see Table 5).

Table 10 highlights that a greater percentage of traps are set in the shallow catch areas compared to their deeper counterparts in the Oregon Logbook Fishery Model. The distribution of traps from the beginning of the season in December to the end of the season shows a shoreward shift in the percentage of traps set. A greater percentage of traps in the shallower areas as the season progresses in an interesting nuance missed by the Washington and Oregon Only Fishery Model. When comparing the distribution of traps between the two timeframes, a greater percentage of overall traps were set in the shallow catch areas in the 2012/2013 – 2015/2016 season compared to the 2008/2009 – 2011/2012 fishing season.

Table 10. Percent of the average number of traps per catch area per month in less than 30 fathoms, numbers reported per month were averaged over two timeframes, the 2008/2009 – 2011/2012 fishing seasons and the 2012/2013 – 2015/2016 fishing season from the Oregon logbook data from ODFW.

Percentage of traps in less than 30 fathoms per catch area averaged yearly	CLO Shallow	TLA Shallow	NPA Shallow	CBA Shallow	BRA Shallow
JAN_08_12	66.4%	42.3%	44.2%	59.7%	78.4%
FEB_08_12	67.4%	46.4%	52.0%	65.8%	76.7%
MAR_08_12	74.8%	53.9%	54.4%	69.7%	80.0%
APR_08_12	75.3%	65.7%	64.6%	78.9%	82.9%
MAY_08_12	74.5%	76.4%	73.5%	82.7%	87.2%
JUN_08_12	94.2%	90.7%	79.9%	89.6%	86.6%
JUL_08_12	90.4%	88.0%	91.5%	90.8%	90.4%
AUG_08_12	79.5%	90.9%	88.0%	84.9%	95.3%
DEC_08_12	77.3%	41.3%	44.5%	62.8%	77.1%
JAN_12_16	75.4%	45.9%	47.5%	70.4%	79.4%
FEB_12_16	78.1%	49.5%	51.2%	71.5%	83.7%
MAR_12_16	81.7%	59.9%	56.9%	77.9%	83.3%
APR_12_16	82.0%	72.8%	63.2%	83.0%	87.1%
MAY_12_16	93.1%	78.9%	71.4%	88.1%	84.5%
JUN_12_16	90.2%	83.2%	74.8%	92.8%	88.8%
JUL_12_16	96.2%	89.9%	79.0%	81.0%	88.2%
AUG_12_16	88.1%	87.1%	58.5%	68.3%	97.4%
DEC_12_16	77.3%	42.8%	44.0%	66.7%	73.9%
Average	81.2%	67.0%	63.3%	76.9%	84.5%
Standard Deviation	8.7%	18.7%	14.9%	10.0%	6.2%

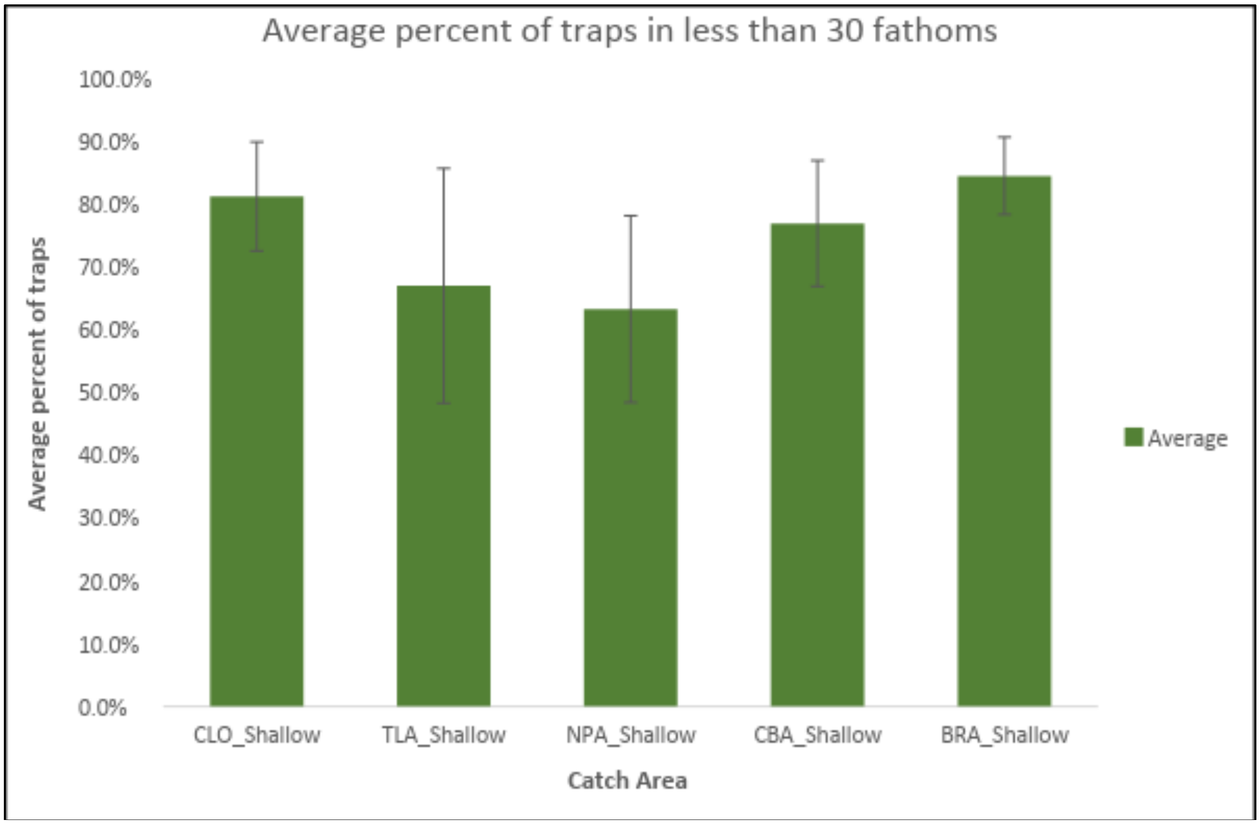

Figure 25. Percent of the average number of traps per catch area for all months and years in less than 30 fathoms in Oregon, numbers reported per month were averaged over two timeframes, the 2008/2009 – 2011/2012 fishing seasons and the 2012/2013 – 2015/2016 fishing season, percent of average number of traps in less than 30 fathoms for each catch area were averaged (+/- SD), data from the Oregon logbook data from ODFW.

The risk scores reported in the vertical line co-occurrence models using the Oregon logbook data should be considered with this context. When looking at the numbers in regard to the vertical line co-occurrence model using the Oregon Logbook Fishery Model, it should be noted that when these numbers were scaled to trap density values using the trap density scale calculated using the All State Fishery Model data there were more high risk areas identified in Oregon (Figures 15 – 20). For comparison see Table 11 and Table 12, in these tables the Oregon logbook data were scaled using the index for the All States Fishery Model (Table 5), then the vertical line co-occurrence scores were calculated monthly using the gray whale density models for comparison with Table 14 and Table 15.

Table 11. Entanglement risk for gray whales in Oregon ranked by peak vertical line co-occurrence score and location of risk when modeled from years averaged 2008/2009 – 2011/2012 for months December to June for the Oregon Logbook Fishery Model, with fishery model data scaled using the All States Fishery Model index. *means there is no difference in peak score co-occurrence scores in that month with Table 14 but may have differences in scores in other catch areas.

Months	Peak Score	General Area	Specific Areas
December	14	CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), CBA Latitude 43° - 44° (Winchester Bay, Coos Bay, Bandon), in waters less than 30 fathoms	CLO_Shallow, CBA_Shallow
January*	42	All of the Oregon Coast, in waters less than 30 fathoms	CLO_Shallow, TLA_Shallow, NPA_Shallow, CBA_Shallow, BRA_Shallow
February*	14	CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), CBA Latitude 43° - 44° (Winchester Bay, Coos Bay, Bandon), BRA Latitude 42 - 43 (Port Orford, Gold Beach, Brookings), in waters less than 30 fathoms	CLO_Shallow, CBA_Shallow, BRA_Shallow
March*	36	CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), CBA Latitude 43° - 44° (Winchester Bay, Coos Bay, Bandon), BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings), in waters less than 30 fathoms	CLO_Shallow, CBA_Shallow, BRA_Shallow
April*	21	CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), in waters less than 30 fathoms	CLO_Shallow
May*	42	CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), NPA Latitude 45° - 46° (Newport, Depoe Bay, Waldport, Florence), CBA Latitude 43° - 44° (Winchester Bay, Coos Bay, Bandon), BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings), in waters less than 30 fathoms	CLO_Shallow, NPA_Shallow, CBA_Shallow, BRA_Shallow
June*	15	CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), TLA Latitude 46° - 45° (Nehalem, Garibaldi, Pacific City), BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings), in waters less than 30 fathoms	CLO_Shallow, TLA_Shallow, BRA_Shallow

Table 12. Entanglement risk for gray whales in Oregon ranked by peak vertical line co-occurrence score and location of risk when modeled from years averaged 2012/2013 – 2015/2016 for months December to June for the Oregon Logbook Fishery Model, with fishery model data scaled using the All States Fishery Model index. *means there is a difference in peak co-occurrence scores in that month with Table 15

Months	Peak Score	General Area	Specific Areas
December*	14	CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), CBA Latitude 43° - 44° (Winchester Bay, Coos Bay, Bandon), in waters less than 30 fathoms	CLO_Shallow, CBA_Shallow
January*	42	All of the Oregon Coast, in waters less than 30 fathoms	CLO_Shallow, TLA_Shallow, NPA_Shallow, CBA_Shallow, BRA_Shallow
February*	14	CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), CBA Latitude 43° - 44° (Winchester Bay, Coos Bay, Bandon), BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings), in waters less than 30 fathoms	CLO_Shallow, CBA_Shallow, BRA_Shallow
March*	42	All of the Oregon Coast, in waters less than 30 fathoms	CLO_Shallow, TLA_Shallow, NPA_Shallow, CBA_Shallow, BRA_Shallow
April*	21	CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), CBA Latitude 43° - 44° (Winchester Bay, Coos Bay, Bandon), in waters less than 30 fathoms	CLO_Shallow, CBA_Shallow
May*	35	CLO Latitude 46°– 46.25° (Astoria, Gearhart/Seaside), CBA Latitude 43° - 44° (Winchester Bay, Coos Bay, Bandon), BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings), in waters less than 30 fathoms	CLO_Shallow, CBA_Shallow, BRA_Shallow
June*	12	TLA Latitude 45° - 46° (Nehalem, Garibaldi, Pacific City), CBA Latitude 43° - 44° (Winchester Bay, Coos Bay, Bandon)	TLA_Shallow, CBA_Shallow

Another consideration when understanding the vertical line co-occurrence efforts in this study is the total area (km^2) for catch area 1255 in California from north of Westport, California to north of Fort Bragg and the relative number of traps set in this specific area. This catch area contains the smallest amount of fishable area according to the operational fishing depths. The small area (km^2) of this catch area yields high trap densities from this factor alone. However, when looking at the landings data reported only in the 10 x 10 nautical mile block 255, the block closest to the coast, shows much larger trap numbers reported compared to surrounding blocks. To illustrate this, the total number of traps summed in July during the 2014/2015 season was 3425 (44.5% of the maximum number of traps deployed in all of California), 2015/2016 season 3462.5 (10.2% of the maximum number of traps that could be deployed in all of California), and 2016/2017 season 2000 (14.4% of the maximum number of trap that could be deployed in the water). There numbers are the number of traps reported in block 255 alone, do not include traps aggregated in 10 x 10 blocks in the same latitude boundaries as block 255 to make up the catch areas 1255, and do not include the portion of the traps attributed to this catch areas from the large offshore block 1040 (see Figures 5 – 6, Table 4 for details on block 255 relative to catch area 1255).

These staggering numbers from this 10 x 10 block at the end of the season ,when trap densities should be winding down, could stem from a number of reasons and therefore producing higher co-occurrence scores:

1) Inaccurate reporting of the catch areas on the fish ticket.
2) A change in fishing effort to this area which would lead to greater co-occurrence.
3) With two larger ports in the catch area and another adjacent to it, it is possible that at the end of the season fishermen aggregate their traps around the port in which they keep their vessel. A similar trend might also apply to the Oregon coast as is shown with the shoreward shift of trap placement throughout the season in the Oregon Logbook Fishery Model.

4) This catch area is on the border of a state marine reserve. The documented spillover effect for marine reserves may be noted by fishermen and fishing efforts might be grouped around these productive areas for this reason, as the high trap density in this block is present throughout the season (Lester et al. 2010).
5) The location of this catch area is at the beginning of a submarine canyon, an ecosystem known to support high levels of biodiversity and may be important to benthic-pelagic ecosystem coupling (Santora et al. 2018). This coupling could lead to an elevated co-occurrence from greater densities of whales and a higher fishing effort, considering that higher trap densities for this block were reported year-round. Furthermore, biologically important areas such as these, as highlighted by Calambokidis et al. (2015), are important for these species of large whale and overlap with elevated risk areas presented in the co-occurrence model (Calambokidis et al. 2015, Santora et al. 2018).

CHAPTER 3: VERTICAL LINE CO-OCCURRENCE MODELS RESULTS AND DISCUSSION

SECTION 1: GRAY WHALES VERTICAL LINE CO-OCCURRENCE MODEL RESULTS

Entanglement risk for gray whales with Dungeness crab commercial fixed gear fishery is present at moderate levels throughout their annual migration from December to June (Figures 26 – 32, Tables 13 – 18). The highest co-occurrence scores were in January, March, and May from coastal waters between Port Chehalis to Seaside, the two southernmost catch areas in Oregon (CBA and BRA) in all models, from the California border to Mendocino, and from Bodega Bay to just north of Half Moon Bay. These scores correlate to the areas of high density for gray whales. The Dungeness crab fishery has a lower trap density south of Monterey in all months and therefore the risk of gray whale entanglement is consistently reported as low to moderate (DeAngelis et al. 2011, Figure 22). According to the vertical line co-occurrence model there is no risk for the catch areas in waters deeper than 30 fathoms because the gray whale migration model used does not show whales traveling in waters greater than 30 fathoms. This does not mean that there is no risk for gray whales in these areas; instead, only that the risk is minimal in these areas as the majority of gray whales travel within 10 kilometers of the coast. Gray whale density from 10 to 47 kilometers off the coast during migration is assumed to be low and was not included in this model (Saez et al. 2013, DeAngelis et al. 2011).

GRAY WHALE in the ALL STATES FISHERY MODEL

CO-OCCURRENCE MODEL RESULTS

Co-occurrence Score (Risk) 2012/2013 – 2016/2017 (December to June)

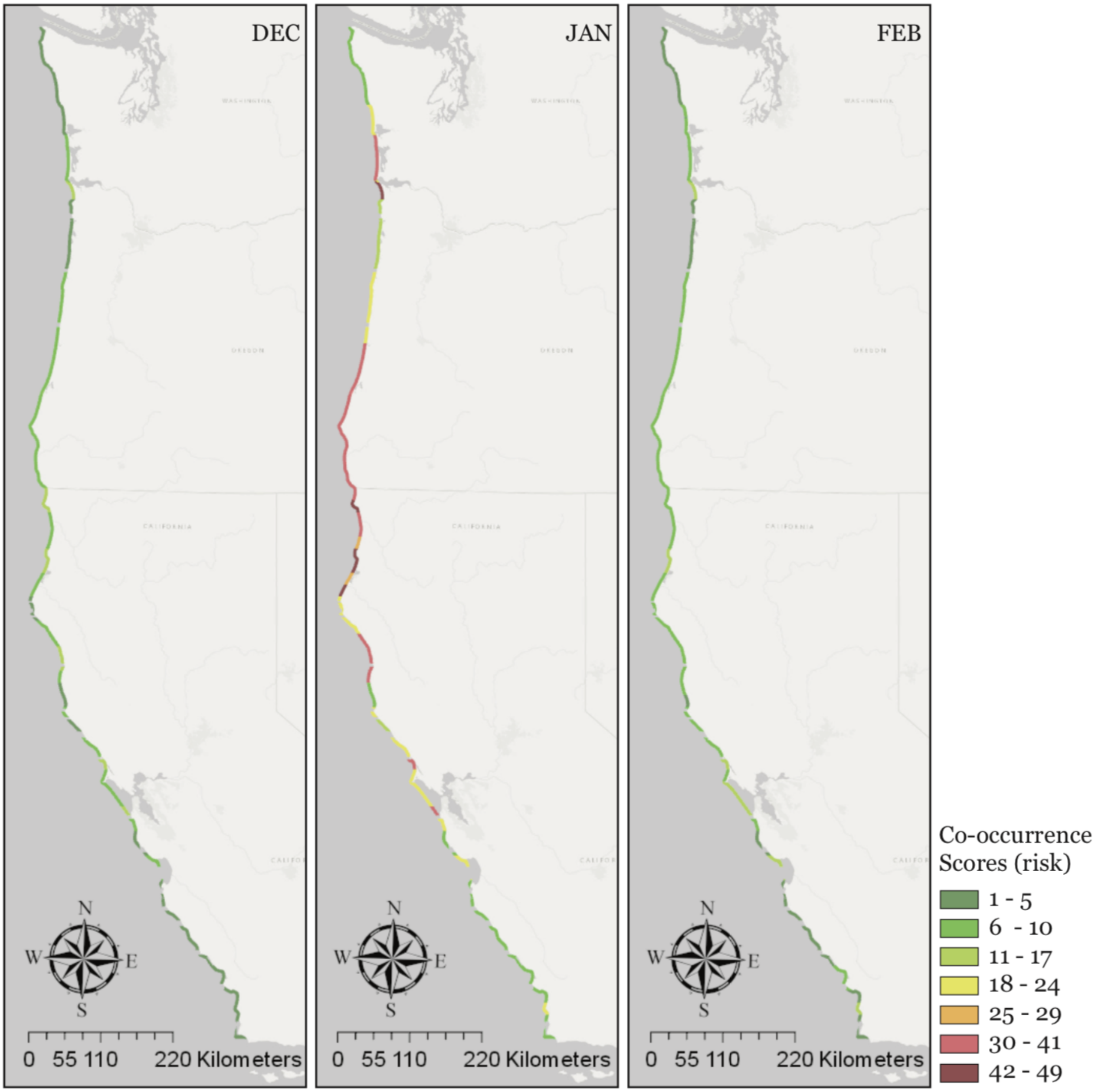

Figure 26. Co-occurrence of gray whale migration and All States Fishery Model for the Dungeness crab trap effort for Washington, Oregon, and California; shown monthly from December to March for years 2013 - 2017. The risk scores from 1-to-49 corresponding to the green to red color range, with green representing the lowest risk (1) and red representing the highest risk (49). Months December to February.

GRAY WHALE in the ALL STATES FISHERY MODEL

CO-OCCURRENCE MODEL RESULTS

Co-occurrence Score (Risk) 2012/2013 – 2016/2017 (December to June)

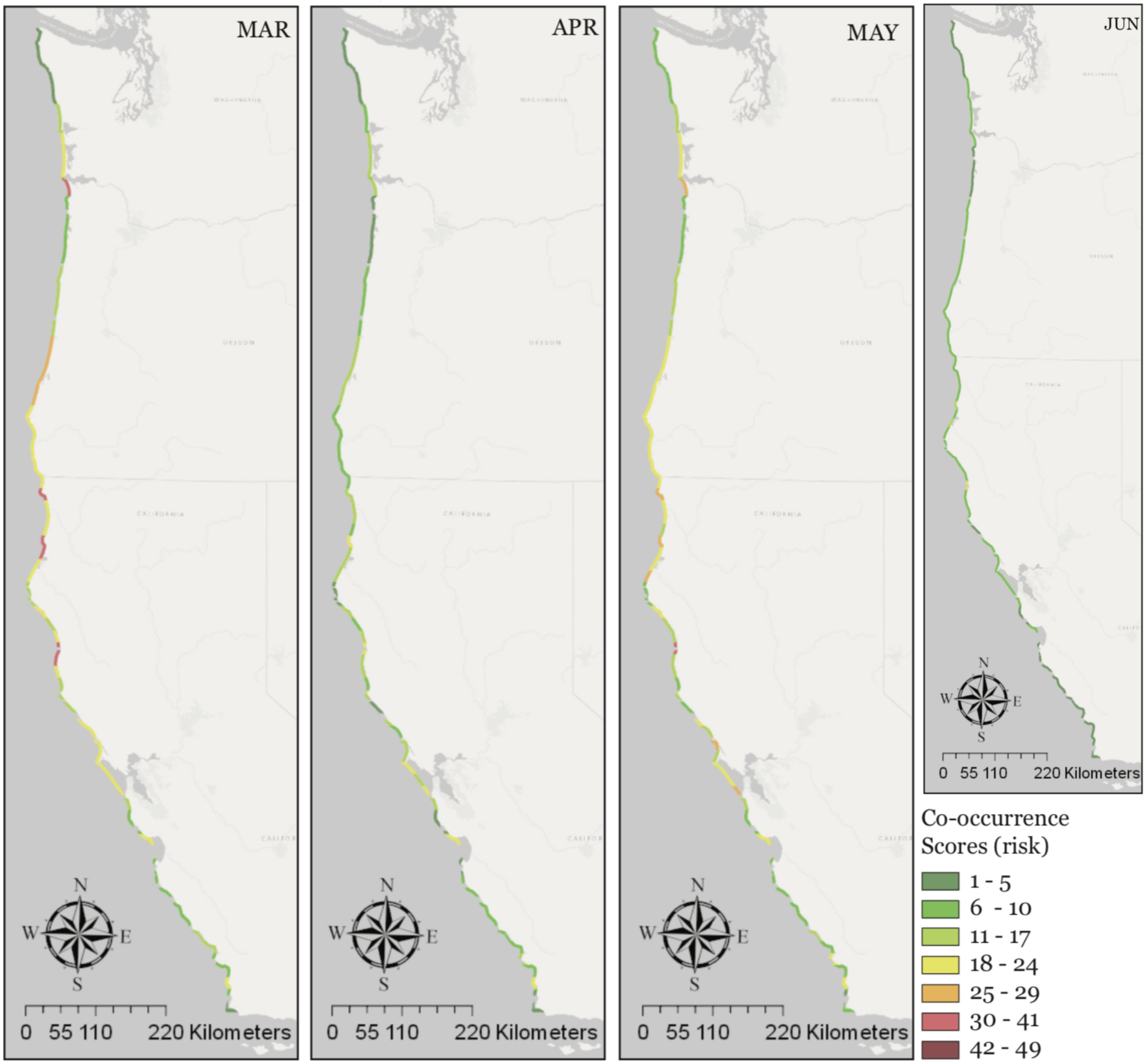

Figure 27. Co-occurrence of gray whale migration and All States Fishery Model for the Dungeness crab trap effort for Washington, Oregon, and California; shown monthly from April to June for years 2013 - 2017. The risk scores from 1-to-49 corresponding to the green to red color range, with green representing the lowest risk (1) and red representing the highest risk (49). Months March to June.

With respect to the All States Fishery Model, the highest co-occurrence score for gray whales (42) occurred in catch areas CLO (latitude 46° – 46.25°) and patches along the northern

California coast to just south of Eureka in January (Figure 26, Figure 27, Table 13). High risk scores between 30 and 36 in January occurred in coastal waters from Port Chehalis to the Columbia River, the two southernmost catch areas in Oregon (CBA and BRA), patches from the California border to Mendocino, and from Bodega Bay to just north of Half Moon Bay (Figure 26, Figure 27, Table 13). March reported fewer high risk scores than January but still high risk levels between 30 and 36 in catch area CLO and patches from the California border to Mendocino (Figure 27). The highest risk score not in January and March occurred in catch area 1255 with a score of 35 in May. According to the vertical line co-occurrence model results, this catch area was consistently reported as an area of high risk. The reader should note that scores in this area are reported as the highest risk could be due to a number of reasons previously mentioned (see the sub-section titled Other Considerations for details in Chapter 2 Section 4). Throughout the rest of the West Coast a majority of the catch areas reported moderate risk levels in May. The Dungeness crab trap fishery showed some risk of gray whale entanglement throughout most of the coastline from Point Conception through Washington from December to June, with December and June having the lowest scores overall (Figure 22, Figures 26 – 27).

The co-occurrence model from Saez et al. 2013 reported that the Dungeness crab fishery between years 2004 to 2008 showed the highest risk for gray whale entanglement occurred in January, March, and May from Cape Mendocino through Crescent City, Bodega Bay to just north of Half Moon Bay, and coastal Washington (Appendix A, Saez et al. 2013). Similarities between the two models highlight that there are areas of high risk in January from the northern California boarder to Mendocino. The original co-occurrence model reported all of coastal Washington to be an area of high risk in January, March, and May (Appendix A, Saez et al. 2013). According to this model, the northernmost part of Washington to Port Chehalis had risk scores lower than 10, indicating that the northern catch areas of Washington calculated low levels of entanglement risk throughout the gray whale migration season with regards to trap density. As noted in previously, the tribal Dungeness crab fishery was not included in any of the models and much of the waters in the northern catch areas of Washington are set with tribal fishing gear in Usual and Accustomed fishing areas. These numbers are not reflected in this model as this model only included data from the commercial Dungeness crab fishery. Another area in which the vertical line co-occurrence model highlights lower levels of risk compared to the original model is coastal Oregon; the original co-occurrence model showed that catch areas CLO, NPA, CBA, and BRA all have high risk scores whereas the vertical line co-occurrence model showed that catch area NPA is not a high risk area, only moderate, with no scores higher than 24. The vertical line co-occurrence model reported that the adjacent areas, north and south, of San Francisco Bay as areas of high risk in January, while the original model reported the San Francisco Bay area and the adjacent areas to the south are areas of high risk (Appendix A, Saez et al. 2013).

The original model reported the San Francisco Bay and the adjacent south area to have overall higher levels of risk in the months of January, March, and May compared with the vertical line co-occurrence model (Appendix A, Saez et al. 2013, Figures 26 – 27, Table 13). The higher risk scores reported in the vertical line co-occurrence model could be due to a change in the fishing pressure, differences in the methods in which fishing effort is quantified, or differences of scale between the catch areas in the vertical line co-occurrence model compared to the port complexes of the original co-occurrence model.

Table 13. Entanglement risk for gray whales ranked by peak co-occurrence score and location of risk when modeled from years averaged 2012/2013 – 2016/2017 for months December to June for the all All States Aodel.

Months	**Peak Score**	**General Area**	**Catch Areas** (with the high risk scores 30 – 49)
December	14	Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), Patches along the Northern California coast	CLO, 1108, 1132
January	42	Port Chehalis to Columbia River, CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), CBA Latitude 43° - 44° (Winchester Bay, Coos Bay, Bandon), BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings)	60A2, CLO, CBA, BRA
January	49*, 42	Patches of high risk areas California border to Mendocino	1102, 1108, 1114, 1120, 1132, 1201, 1216, 1242, 1248, 1255*, 1262
February	14	Latitude 46° – 46.25° (Astoria, Gearhart/Seaside)	CLO
March	36	Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), Patches of high risk areas California border to north of Mendocino	CLO, 1108, 1132,1201, 1255*, 1262
April	25	Monterey Bay	1516
May	35*	North of Westport, California to north of Fort Bragg	1255*
June	18*	North of Westport, California to north of Fort Bragg	1255*

*indicates that these values should be considered with the information mentioned in the overview of this section

GRAY WHALE in the WASHINGTON and OREGON ONLY FISHERY MODEL

CO-OCCURRENCE MODEL RESULTS

Co-occurrence Score (Risk)
2008/2009–2011/2012 and 2012/2013 –2015/2016 (December to February)

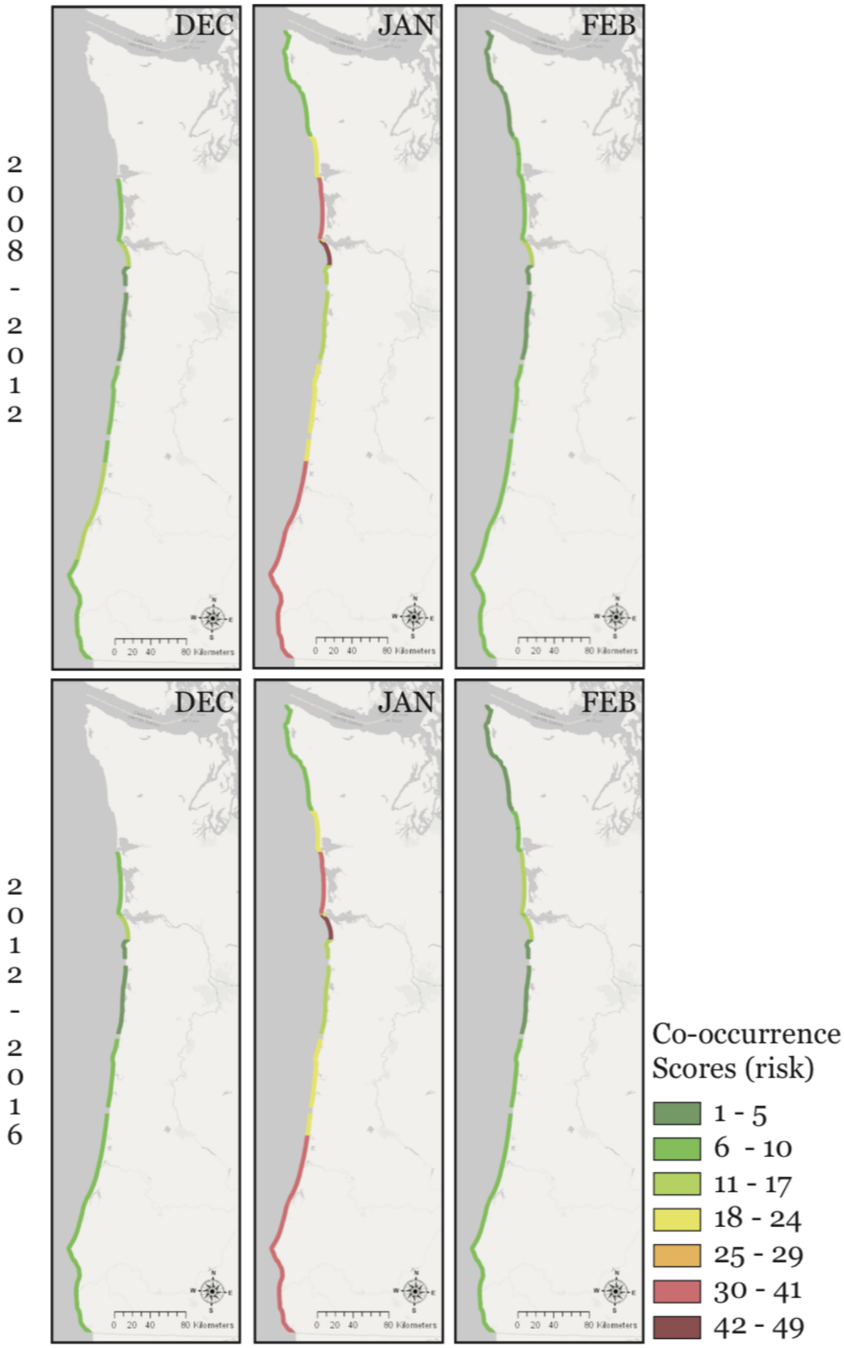

Figure 28. Co-occurrence of gray whale migration and Washington and Oregon Only Fishery Model for the Dungeness crab trap effort for Washington and Oregon; shown monthly from December to February yearly averages from the 2008/2009 - 2011/2012 fishing seasons and the 2012/2013 - 2015/2016 fishing seasons.

GRAY WHALE in the WASHINGTON and OREGON ONLY FISHERY MODEL

CO-OCCURRENCE MODEL RESULTS

Co-occurrence Score (Risk)
2008/2009–2011/2012 and 2012/2013–2015/2016 (March to June)

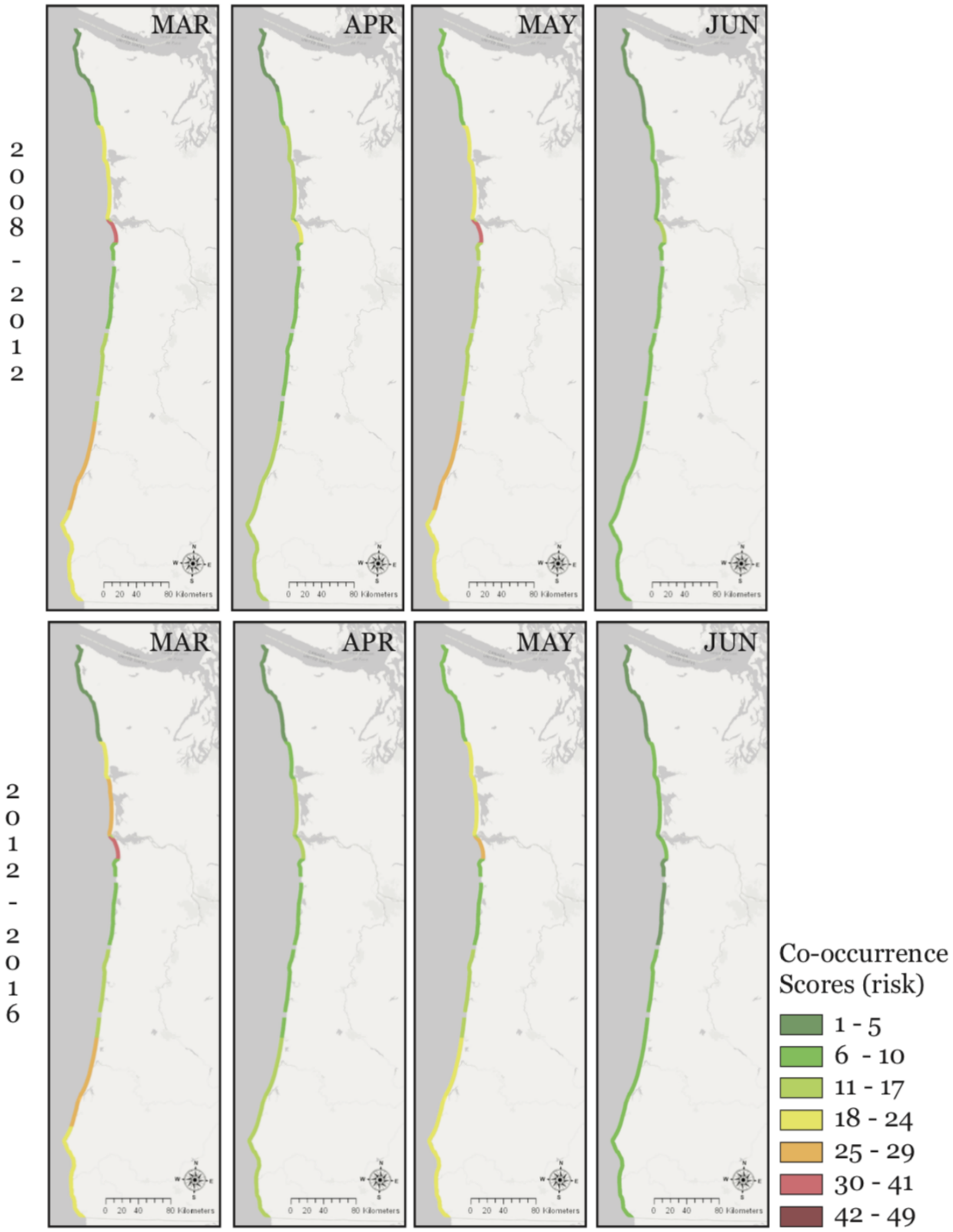

Figure 29. Co-occurrence of gray whale migration and Washington and Oregon Only Fishery Model for the Dungeness crab trap effort for Washington and Oregon; shown monthly from March to June yearly averages from the 2008/2009 - 2011/2012 fishing seasons and the 2012/2013 - 2015/2016 fishing seasons.

With respect to the Washington and Oregon Only Fishery Model, the highest co-occurrence score for gray whales (42) occurred in catch area CLO for both timeframes this vertical line co-occurrence model investigates, 2008 - 2012 and 2012 - 2016 (Figure 28, Figure 29, Table 14, Table 15). CLO had the highest risk in all months and years, except for June in the 2012 – 2016 timeframe, compared to the other catch areas in Oregon and Washington where January, March, and May were the months with the highest risk scores. According to the vertical line co-occurrence model high risk scores between 30 and 36 were found from Port Chehalis to the Columbia River, and the southern Oregon catch areas CBA and BRA in January from 2008 - 2016. Although the risk scores are moderate in March and May from 2008 - 2016, reported greater risk of entanglement in catch area CBA compared to the southern Oregon catch area BRA. The Dungeness crab trap fishery had entanglement risk throughout most of the Oregon and Washington coast for months December to June, with December, February, and June having the lowest scores overall.

Risk remained similar between the two timeframes investigated in this gray whale vertical line co-occurrence model using the Washington and Oregon Only Fishery Model. The main difference of fishing effort between the two timeframes was a greater fishing effort in the 2012 - 2016 timeframe in the southern Washington to southern Oregon catch areas in March, while 2008 - 2012 timeframe reported a greater fishing effort in CLO and CBA when compared with the 2012 – 2016 timeframe.

Table 14. Entanglement risk for gray whales ranked by peak co-occurrence score and location of risk when modeled from years averaged 2008/2009 – 2011/2012 for months December to June for the Washington and Oregon only model.

Months	Peak Score	General Area	Catch Areas
December	14	Latitude 46° – 46.25° (Astoria, Gearhart/Seaside)	CLO
January	42	Port Chehalis to Columbia River, CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), CBA Latitude 43° - 44° (Winchester Bay, Coos Bay, Bandon), BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings)	60A2, CLO, CBA, BRA
February	12	Latitude 46° – 46.25° (Astoria, Gearhart/Seaside)	CLO
March	30	Latitude 46° – 46.25° (Astoria, Gearhart/Seaside)	CLO
April	18	Latitude 46° – 46.25° (Astoria, Gearhart/Seaside)	CLO
May	35	Latitude 46° – 46.25° (Astoria, Gearhart/Seaside)	CLO
June	12	Latitude 46° – 46.25° (Astoria, Gearhart/Seaside)	CLO

Table 15. Entanglement risk for gray whales ranked by peak co-occurrence score and location of risk when modeled from years averaged 2012/2013 – 2015/2016 for months December to June for the Washington and Oregon only model.

Months	Peak Score	General Area	Catch Areas
December	12	Latitude 46° – 46.25° (Astoria, Gearhart/Seaside)	CLO
January	42	Port Chehalis to Columbia River, CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), CBA Latitude 43° - 44° (Winchester Bay, Coos Bay, Bandon), BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings)	60A2, CLO, CBA, BRA
February	14	Latitude 46° – 46.25° (Astoria, Gearhart/Seaside)	CLO
March	30	Latitude 46° – 46.25° (Astoria, Gearhart/Seaside)	CLO
April	15	Latitude 46° – 46.25° (Astoria, Gearhart/Seaside)	CLO
May	28	Latitude 46° – 46.25° (Astoria, Gearhart/Seaside)	CLO
June	9	Latitude 42° - 43° (Port Orford, Gold Beach, Brookings)	BRA

GRAY WHALE in the CALIFRONIA ONLY FISHERY MODEL

CO-OCCURRENCE MODEL RESULTS

Co-occurrence Score (Risk) 2012/2013 – 2016/2017 (December to June)

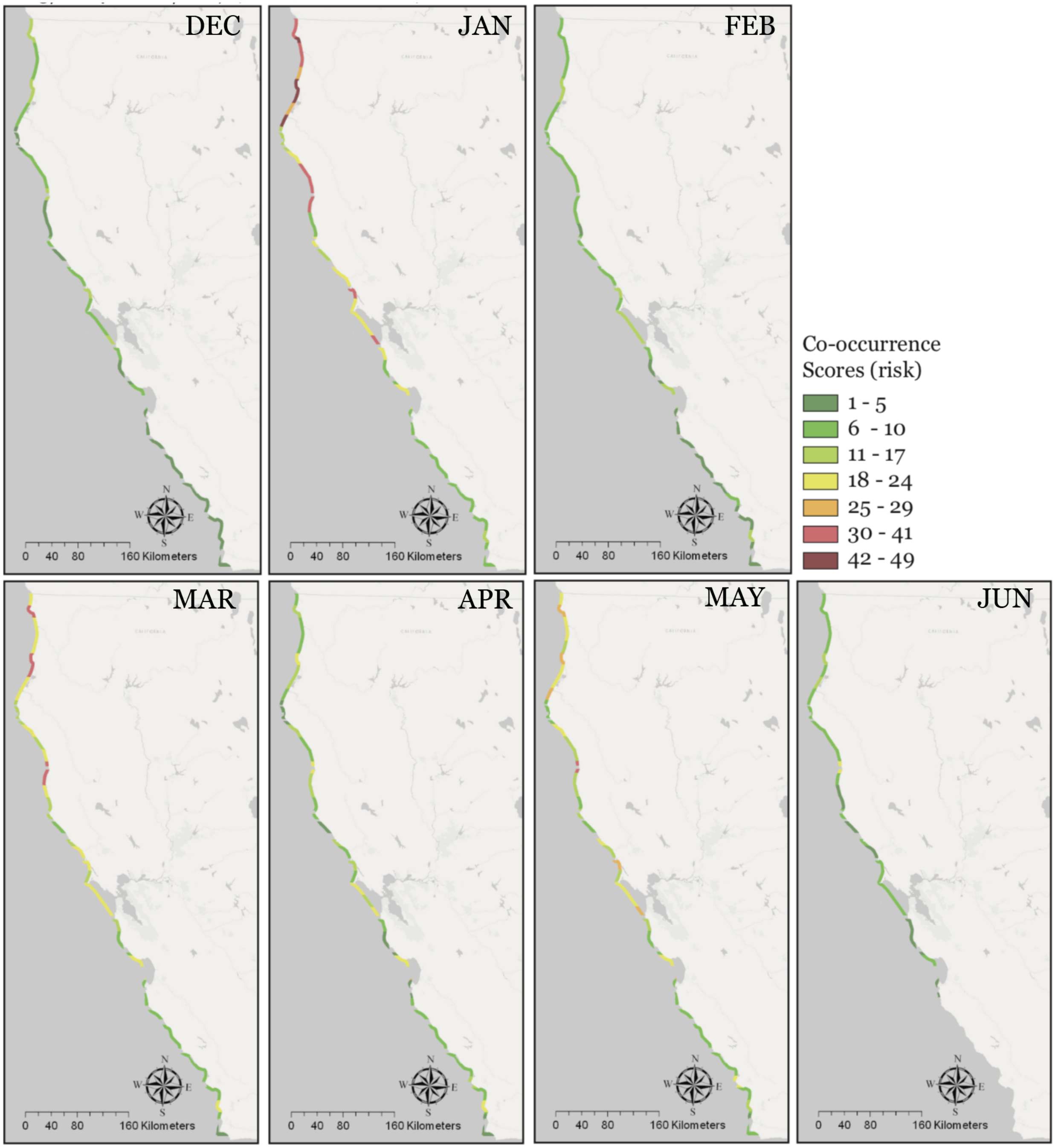

Figure 30. Co-occurrence of gray whale migration and Dungeness crab trap effort, shown monthly for California specific data for months December to June yearly averages from 2013/2014 - 2016/2017 season.

With respect to the California Only Fishery Model, the highest co-occurrence score for gray whales (42) occurred in scattered catch areas from the California boarder to north of Mendocino in January (Figure 30, Table 16). It should be noted that the highest risk score reported for all of California Only vertical line co-occurrence with gray whales was in catch area 1255 in January with a score of 49. January, March, and May all had areas of high risk, scores between 30 and 36. All months during the gray whale migration along the California coast from the northern border to Point Conception had areas of moderate risk, co-occurrence risk scores between 11 and 29. Catch area 1255 reported to have a high risk area with a score of 35 while the rest of the West Coast reported moderate risk levels in May. December, February, April and June all reported areas of low to moderate risk with the peak score of 14, 12, 25, 18, respectively (Table 16). These results are extremely similar to the results in the vertical line co-occurrence model with gray whales and the All State Fishery Model. This may indicate that while it is interesting to piece apart each state for an individual vertical line co-occurrence between fishing effort and large whales, these numbers do not greatly differ from those reported in all results including the All State Fishery Model which represents effort relative to the entire West Coast.

Table 16. Entanglement risk for gray whales ranked by peak vertical line co-occurrence score and location of risk when modeled from years averaged 2012/2013 – 2016/2017 for months December to June for the California Only Fishery Model.

Months	Peak Score	General Area	Catch Areas
December	14	Patches along the Northern California coast	1108, 1132
January	49*, 42	Patches of high risk areas California border to north of Mendocino	1102, 1108, 1114, 1120, 1132, 1201, 1216, 1242, 1248, 1255*, 1262
January	30	Bodega Bay to Point Reyes, South San Francisco to north of Half Moon Bay	1430, 1464
February	12	Patches of California Border to north of Mendocino, Bodega Bay to north of Half Moon Bay, Monterey Bay	1132, 1201, 1430, 1446, 1455, 1464, 1464, 1464, 1507, 1516
March	30	Patches of California border to north of Mendocino	1108, 1132, 1201, 1255*, 1262, 1262
April	25	Monterey Bay	1516
May	35*	North of Westport, California to north of Fort Bragg	1255*
June	18*	North of Westport, California to north of Fort Bragg	1255*

*indicates that these values should be considered with the information mentioned in the overview of this section

GRAY WHALE in the OREGON LOGBOOK FISHERY MODEL

CO-OCCURRENCE MODEL RESULTS

Co-occurrence Score (Risk)
2008/2009 – 2011/2012 and 2011/2012 – 2015/2016 (December to February)

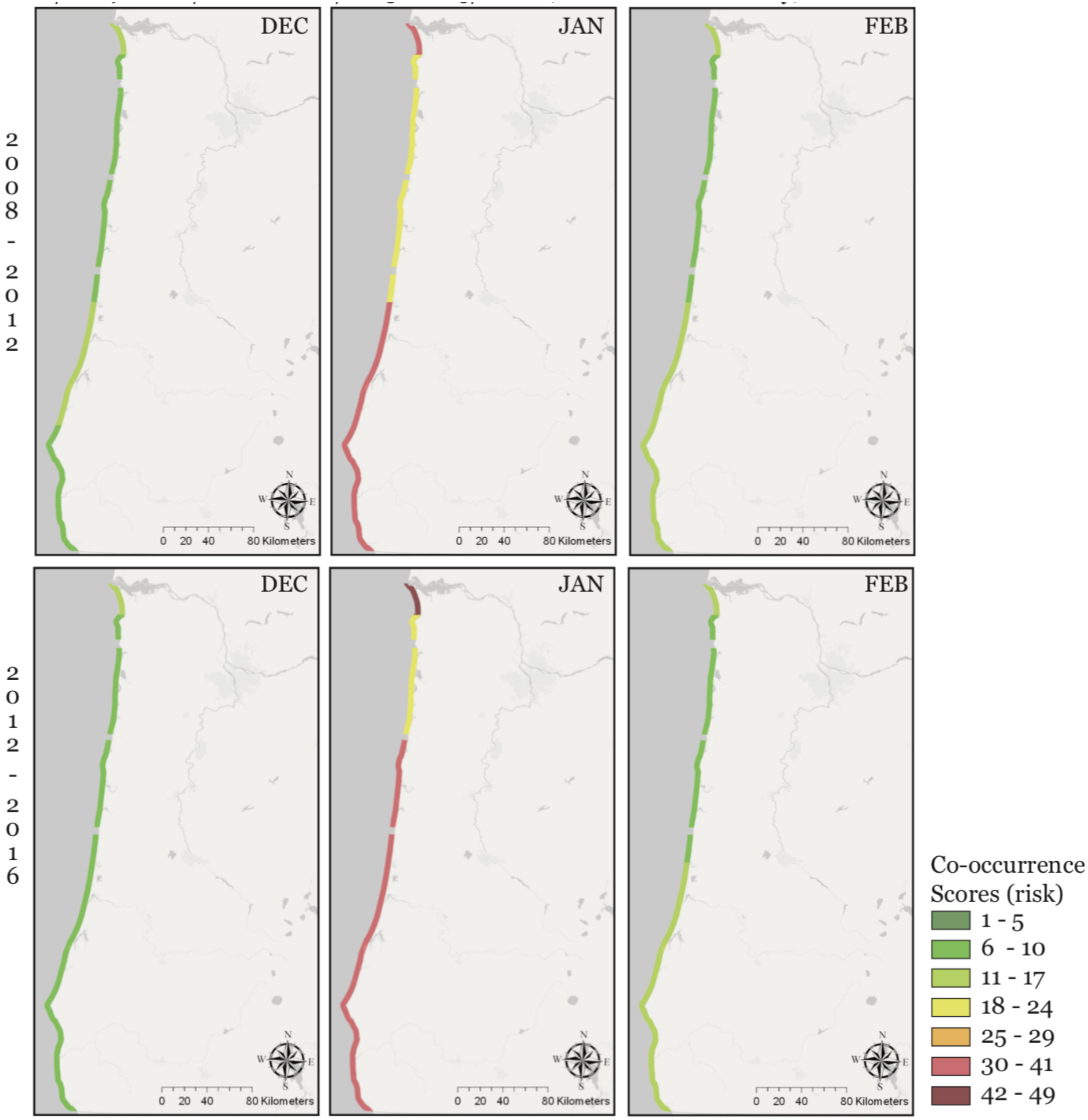

Figure 31. Co-occurrence of gray whale migration and Dungeness crab trap effort, shown monthly for Oregon specific logbook data in December, January, and February yearly averages from 2008/2009 - 2011/2012 seasons and the 2012/2013 - 2015/2016 season.

GRAY WHALE in the OREGON LOGBOOK FISHERY MODEL

CO-OCCURRENCE MODEL RESULTS

Co-occurrence Score (Risk)
2008/2009 – 2011/2012 and 2011/2012 – 2015/2016 (March to June)

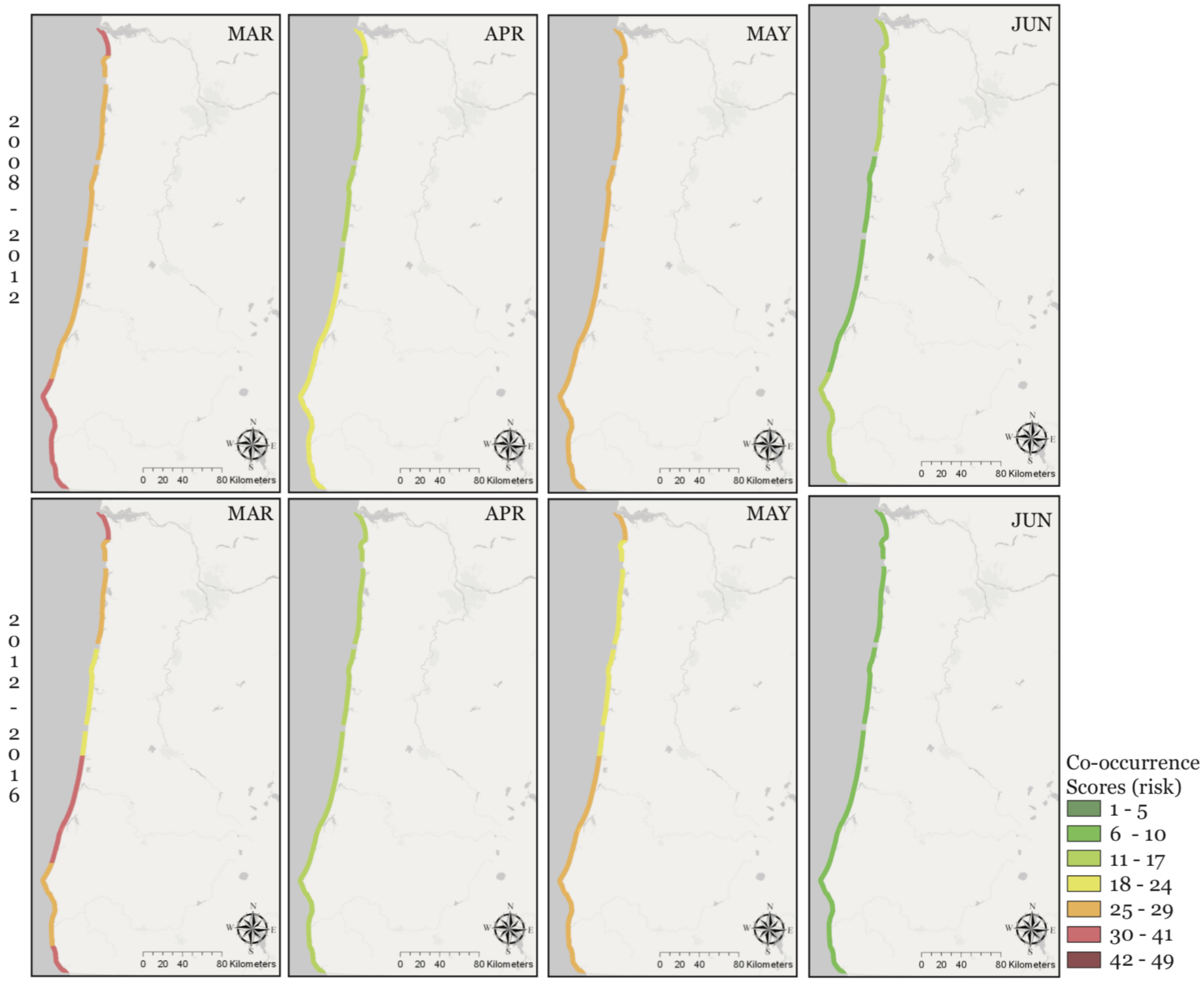

Figure 32. Co-occurrence of gray whale migration and Dungeness crab trap effort, shown monthly for Oregon specific logbook data for months March to June yearly averages from 2008/2009 - 2011/2012 seasons and the 2012/2013 - 2015/2016 season.

With respect to the Oregon Logbook Fishery Model, the highest co-occurrence score for gray whales (42) occurred in catch areas CLO for January averaged for years 2012 - 2016 (Figure 31, Figure 32, Table 17, Table 18). January and March each had areas of high risk in both timeframes. All catch areas along the Oregon coast reported moderate levels of risk from 11 - 29 for the month April, a low score of 18 for years 2008 - 2012 and 15 for years 2012 - 2016;

and May, a high score of 28 in both timeframes. The remaining months (December, February, and June) reported levels of low to moderate risk.

Differences between the two timeframes showed three general trends in the co-occurrence scores for Oregon using the Oregon Logbook Fishery Model and the gray whale density data:

1) the months of January and March reported the highest risk, showed increased co-occurrence scores with more high risk areas in timeframe 2012 - 2016 than 2008 - 2012,
2) there was a minor increase in risk score reported in February for the latter timeframe 2012 - 2016, and,
3) there was a slight decrease in the risk scores in December, April, May, and June.

The increase in the risk scores for January – March could be attributed to the delay in the opening of the Dungeness crab commercial fishing season to January 4th in 2015, as a month delay could have caused fishermen to increase fishing effort to make up for revenues lost causing a greater number of traps to be deployed in January through March. This delay may also account for the decrease in risk in December (i.e., no landings, no traps).

The vertical line co-occurrence model using the Oregon Logbook Fishery Model data (Figure 31, Figure 32, Table 17, Table 18) shows that May had no areas of high risk, unlike the vertical line co-occurrence model using the Washington and Oregon Only Fishery Model data (Figure 28, Figure 29, Table 14, Table 15). However, the risk scores calculated using the Oregon logbook data showed that there is a greater overall risk along the entire Oregon coast with elevated co-occurrence scores in each catch area. When the risk scores were compared between the vertical line co-occurrence models using the Oregon Logbook Fishery Model and the Washington and Oregon Only Fishery Model, the models created using the Oregon logbook data indicate that there is a greater co-occurrence, higher risk scores, in every month, timeframe, and catch area along the Oregon coast; thus, representing an improvement in the model as the Oregon logbook data are more accurate by the nature in which they are reported (Oregon logbook data is reported by the fishermen directly and uses more refined reporting areas as detailed in Chapter 2). Changing environmental conditions that might push prey species into these shallow catch areas could result in even greater risk to gray whales along the Oregon coast according to the Oregon logbook Fishery Model and vertical line co-occurrence model calculated from it.

Table 17. Entanglement risk for gray whales ranked by peak vertical line co-occurrence score and location of risk when modeled from years averaged 2008/2009 – 2011/2012 for months December to June for the Oregon Logbook Fishery Model.

Months	Peak Score	General Area	Specific Areas
December	14	CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), CBA Latitude 43° - 44° (Winchester Bay, Coos Bay, Bandon), in waters less than 30 fathoms	CLO_Shallow, CBA_Shallow
January	36	CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), CBA Latitude 43° - 44° (Winchester Bay, Coos Bay, Bandon), in waters less than 30 fathoms	CLO_Shallow, CBA_Shallow
February	12	CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), CBA Latitude 43° - 44° (Winchester Bay, Coos Bay, Bandon), in waters less than 30 fathoms, BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings), in waters less than 30 fathoms	CLO_Shallow, CBA_Shallow BRA_Shallow
March	36	CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside),BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings), in waters less than 30 fathoms	CLO_Shallow, BRA_Shallow
April	18	CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), in waters less than 30 fathoms	CLO_Shallow
May	28	All of the Oregon Coast, in waters less than 30 fathoms	CLO_Shallow, TLA_Shallow, NPA_Shallow, CBA_Shallow , BRA_Shallow
June	12	CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), TLA Latitude 45° - 46° (Nehalem, Garibaldi, Pacific City), BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings), in waters less than 30 fathoms	CLO_Shallow, TLA_Shallow, BRA_Shallow

Table 18. Entanglement risk for gray whales ranked by peak vertical line co-occurrence score and location of risk when modeled from years averaged 2012/2013 – 2015/2016 for months December to June for the Oregon Logbook Fishery Model.

Months	Peak Score	General Area	Specific Areas
December	12	CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), in waters less than 30 fathoms	CLO_Shallow
January	42	CLO Latitude 46°– 46.25° (Astoria, Gearhart/Seaside), NPA Latitude 46° - 45° (Newport, Depoe Bay, Waldport, Florence), CBA Latitude 43°- 44° (Winchester Bay, Coos Bay, Bandon), BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings), in waters less than 30 fathoms	CLO_Shallow, NPA_Shallow, CBA_Shallow, BRA_Shallow
February	14	CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), in waters less than 30 fathoms	CLO_Shallow
March	30	CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), CBA Latitude 43° - 44° (Winchester Bay, Coos Bay, Bandon), BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings), in waters less than 30 fathoms	CLO_Shallow, CBA_Shallow, BRA_Shallow
April	15	CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), CBA Latitude 43° - 44° (Winchester Bay, Coos Bay, Bandon), in waters less than 30 fathoms	CLO_Shallow, CBA_Shallow
May	28	CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), CBA Latitude 43° - 44° (Winchester Bay, Coos Bay, Bandon), BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings), in waters less than 30 fathoms	CLO_Shallow, CBA_Shallow, BRA_Shallow
June	9	All Oregon Coast, in waters less than 30 fathoms	CLO_Shallow, TLA_Shallow, NPA_Shallow, CBA_Shallow, BRA_Shallow

SECTION 2: HUMPBACK WHALES VERTICAL LINE CO-OCCURRENCE MODEL RESULTS

Overall, elevated entanglement risk for humpback whales with the Dungeness crab commercial fixed gear fishery was present throughout all fishery models using landings data for December in: the northern catch areas of Oregon, from the California border to Fort Bragg, and in the San Francisco Bay area and surrounding waters. The month and area with the highest co-occurrence scores and the largest number of areas with high risk scores were in the month of November from Bodega Bay to just north of Half Moon Bay and correlates to the areas of high density for humpback whales around the San Francisco Bay area (Becker et al. 2012, Becker et al. 2016, Figure 23). While the northern catch areas of Oregon reported high risk scores in December, throughout the rest of the catch areas in Oregon only moderate risk scores occurred in all fishery models. The Dungeness crab fishery had a low fishery effort from Washington state to the southernmost point of Monterey Bay in July and August which is reflected in all the humpback whale vertical line co-occurrence models with scores of low risk reported.

HUMPBACK WHALE in the ALL STATES FISHERY MODEL

CO-OCCURRENCE MODEL RESULTS

Co-occurrence Score (Risk) 2012/2013 – 2016/2017 (December and July)

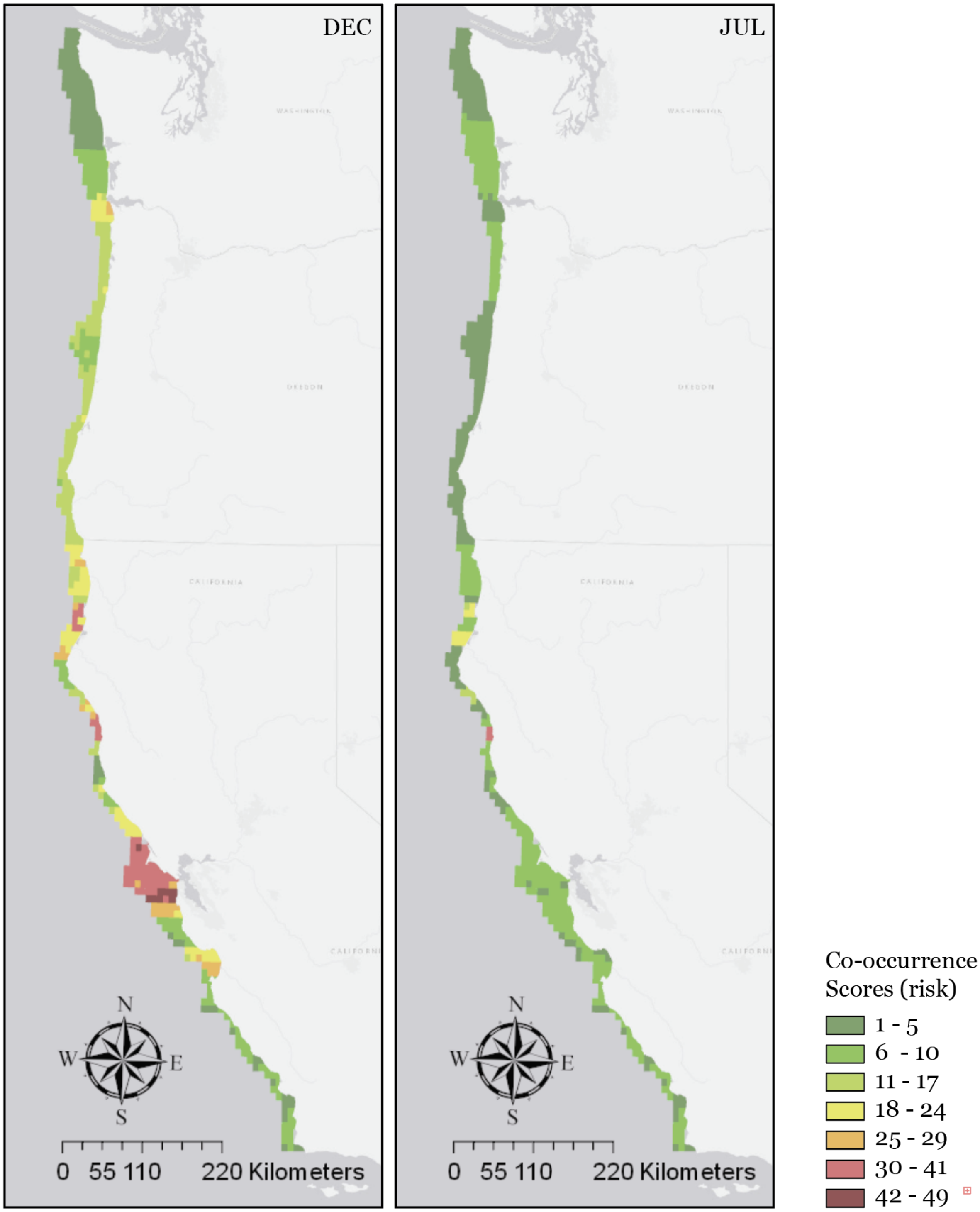

Figure 33. Co-occurrence of the multi-year average humpback whale density and fishing effort for all states in December and July for years 2013 - 2017.

With respect to the All States Fishery Model, the highest co-occurrence score for humpback whales (42) occurred in catch areas from Bodega Bay to north of Half Moon Bay in December (Figure 33, Table 19). Low to moderate levels of risk remained in July from the California border to Fort Bragg, with one high risk area (1255) which extends from Westport, California to Fort Bragg. The low levels of risk in July occurred along the Washington and Oregon coast and from Point Arena to Point Conception.

The results reported in the co-occurrence model from Saez et al. (2013), concurs with the vertical line co-occurrence model results reported using the All State Fishery Model (Appendix A, Figure 33, Table 19). The original co-occurrence model reported that the monthly Dungeness crab fishery co-occurrence scores, average for years 2004 to 2008, showed that the highest risk for humpback whale entanglement in Dungeness crab trap gear occurred in quarter 4 (October to December) from Bodega Bay to the southern end of San Francisco Bay (Appendix A, Saez et al. 2013). However, this model did not identify any northern California areas as high risk in December, only as areas of moderate risk. The original co-occurrence model showed that low risk occurs along the Washington and Oregon coast and from Point Arena to Point Conception in quarter 4 (months October to December), but the vertical line models showed these as areas of moderate risk. These differences could be due to a change in the fishing pressure, differences in the methods in which fishing effort is quantified, or the size of the catch areas used in the vertical line co-occurrence models compared to the port complexes of the original co-occurrence model.

Table 19. Entanglement risk for humpback whales ranked by peak vertical line co-occurrence score and location of risk when modeled from years averaged 2013/2014 – 2016 - 2017 for months December and July for the All States Fishery Model.

Months	Peak Score	General Area	Specific Areas
December	42	Bodega Bay to north of Half Moon Bay	1430, 1438, 1446, 1455, 1464
December	35	Patches of high risk areas California border to north of Fort Bragg	1132, 1201, 1248, 1255*
July	35*	North of Westport, California to north of Fort Bragg	1255*

*indicates that these values should be considered with the information mentioned in the overview of this section

HUMPBACK WHALE in the WASHINGTON and OREGON FISHERY MODEL

CO-OCCURRENCE MODEL RESULTS

Co-occurrence Score (Risk) 2008/2009 – 2011/2012 (December, July, and August)

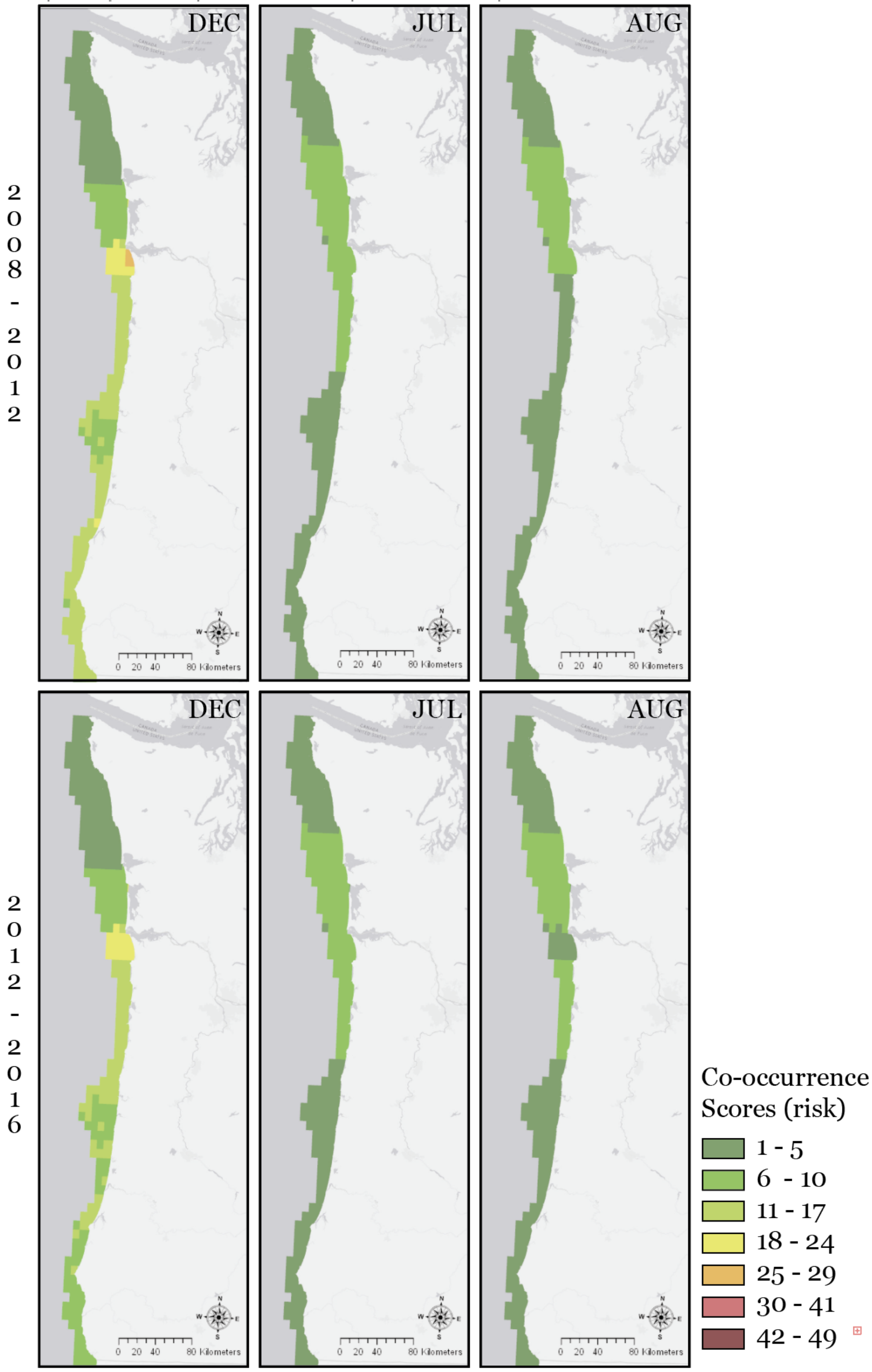

Figure 34. Co-occurrence of the multi-year average humpback whale density and fishing effort for Oregon and Washington specific data in December, July, and August yearly averages from 2008/2009 - 2011/2012 seasons and the 2012/2013 - 2015/2016 season.

With respect to the Washington and Oregon Only Fishery Model, the highest co-occurrence score for humpback whales (28) occurred in December along parts of catch area CLO, from the northern border of Oregon to Seaside when averaged for years 2008 - 2012 (Figure 34, Table 20, Table 21). Throughout the rest of Washington and Oregon in December, this vertical line co-occurrence model reported moderate entanglement risk with a few low risk areas on the west edge of the catch area boarders. Scores remained low with small patches of moderate risk areas from July to September. Between the two timeframes few differences in risk levels were reported, the only significant difference between the two models occurred along the Oregon coast with higher risk scores reported in December throughout the Oregon coast in the 2008 - 2012 timeframe compared to the 2012 - 2016 timeframe.

Table 20. Entanglement risk for humpback whales ranked by peak vertical line co-occurrence score and location of risk when modeled from years averaged 2008/2009 – 2011/2012 for months December, July, August, and September for the Washington and Oregon Only Fishery Model.

Months	Peak Score	General Area	Catch Areas
December	28	Patches in CLO latitude 46° – 46.25° (Astoria, Gearhart/Seaside)	CLO
July	8	Point Grenville to TLA Latitude 45° – 46° (Nehalem, Garibaldi, Pacific City)	60A1, 60A2, CLO, TLA
August	8	Point Grenville to Latitude 46° – 46.25° (Astoria, Gearhart/Seaside)	60A1, 60A2, CLO
September*	8	Port Chehalis to the Columbia River	60A1, 60A2

*indicates that these values are only relevant to Washington state

Table 21 Entanglement risk for humpback whales ranked by peak vertical line co-occurrence score and location of risk when modeled from years averaged 2012/2013 - 2015/2016 for months December, July, August, and September for the Washington and Oregon Only Fishery Model.

Months	Peak Score	General Area	Catch Areas
December	24	Patches of High Risk latitude 46° – 46.25° (Astoria, Gearhart/Seaside)	CLO
July	8	Point Grenville to TLA Latitude 45° – 46° (Nehalem, Garibaldi, Pacific City)	60A1, 60A2, CLO, TLA
August	8	Point Grenville to the Columbia River and TLA Latitude 45° – 46° (Nehalem, Garibaldi, Pacific City)	60A1, 60A2, TLA
September*	12	Port Chehalis to the Columbia River	60A2

*indicates that these values are only relevant to Washington state

HUMPBACK WHALE in the CALIFRONIA ONLY FISHERY MODEL

CO-OCCURRENCE MODEL RESULTS

Co-occurrence Score (Risk) 2012/2013 – 2016/2017 (November, December, and July)

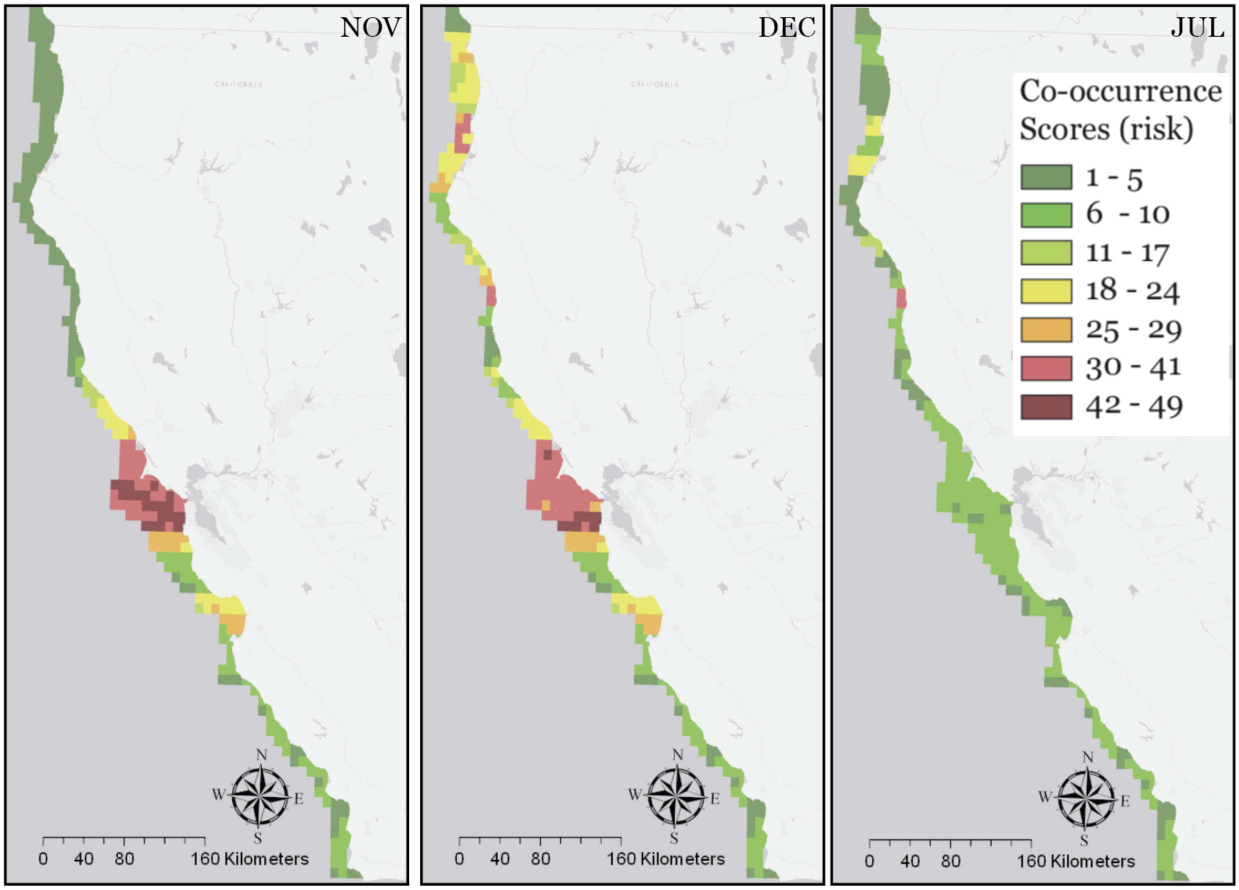

Figure 35. Co-occurrence of the multi-year average humpback whale density and fishing effort for California specific data in November, December, and July yearly averages from 2013/2014 - 2016/2017 fishing season.

With respect to the California Only Fishery Model, the highest co-occurrence score for humpback whales (42) occurred in catch areas from Fort Bragg to Bodega Bay to just north of Half Moon Bay in November and December (Figure 35, Table 22). Catch in area 1255 reported a high risk score (35) in July, the end of the season, when efforts along the coast should have dwindled down.

Table 17. Entanglement risk for humpback whales ranked by peak vertical line co-occurrence score and location of risk when modeled from years averaged 2013/2014 – 2016/2017 for months November, December, and July for the California Only Fishery Model.

Months	Peak Score	General Area	Catch Areas
November	42	Bodega Bay to north of Half Moon Bay	1430, 1438, 1446, 1455, 1464
December	42	Bodega Bay to north of Half Moon Bay	1430, 1438, 1446, 1455, 1464
December	42	Patches of high risk areas California border to north of Fort Bragg	11132, 1201, 1255*
July	35*, 20	North of Westport, California to north of Fort Bragg	1132, 1210, 1255*

*indicates that these values should be considered with the information mentioned in the overview of this section

HUMPBACK WHALE in the OREGON LOGBOOK FISHERY MODEL

CO-OCCURRENCE MODEL RESULTS

Co-occurrence Score (Risk)
2008/2009 – 2011/2012 and 2011/2012 – 2015/2016 (December to June)

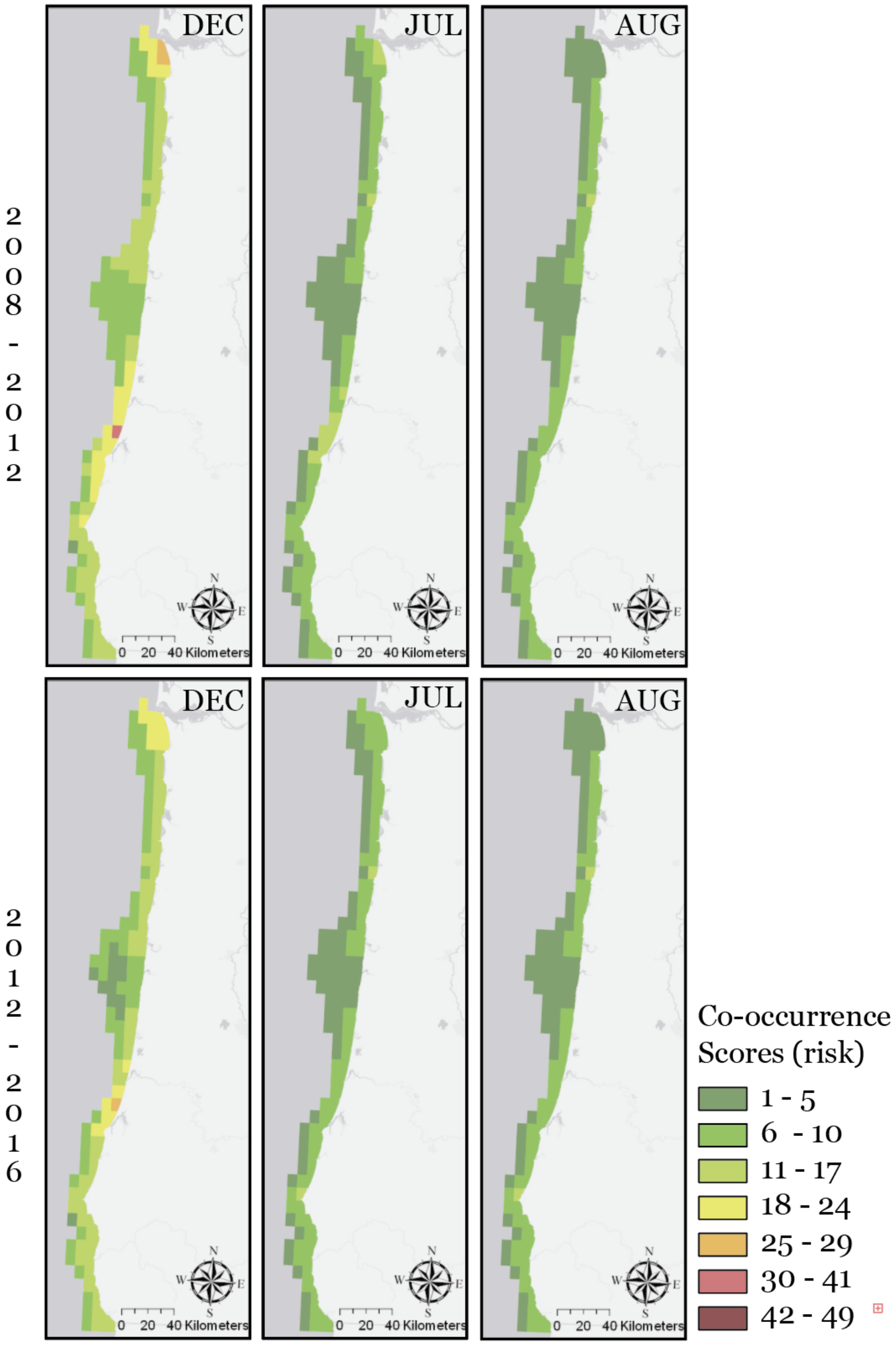

Figure 36. Co-occurrence of the multi-year average humpback whale density and Dungeness crab trap effort for Oregon logbook data in December, July, and August yearly averages from 2008/2009 - 2011/2012 seasons and the 2012/2013 - 2015/2016 season.

With respect to the Oregon Logbook Fishery Model, the highest co-occurrence score for humpback whales (30) occurred in a small portion of the catch area CBA in December in the 2008 - 2012 timeframe (Figure 36, Table 23, Table 24). Moderate scores were reported along the Oregon coast throughout both timeframes in December. Scores did not vary greatly between timeframes in July and August. In general, the difference between the two timeframes showed slightly higher co-occurrence scores in December in the 2008 - 2012 timeframe compared to the 2012 - 2016 timeframe, a trend also shown in the Washington and Oregon Only Fishery Model.

The vertical line co-occurrence model using the Oregon Logbook Fishery Model data (Figure 36, Table 23, Table 24) reported high risk scores and moderate risk scores in catch area CBA in both timeframes. This trend was not captured in the vertical line co-occurrence model using the Washington and Oregon Only Fishery Model data (Figure 34, Table 20, Table 21). The risk scores calculated using the Oregon logbook data showed that there was a greater overall risk along the entire Oregon coast with elevated co-occurrence scores in each catch area. When the risk scores were compared between the vertical line co-occurrence models using the Oregon Logbook Fishery Model and the Washington and Oregon Fishery Model, the vertical line models created using the Oregon logbook data indicated that there was a greater co-occurrence and higher risk, in every month, timeframe, and catch area along the Oregon coast in catch areas less than 30 fathoms. Changing environmental conditions that might push prey species into these shallow catch areas could result in greater risk to humpback whales along the Oregon coast according to the Oregon Logbook Fishery Model and vertical line co-occurrence model calculated from it.

Table 23. Entanglement risk for humpback whales ranked by peak vertical line co-occurrence score and location of risk when modeled from years averaged 2008/2009 – 2011/2012 for months December, July, and August for the Oregon Logbook Fishery Model.

Months	Peak Score	General Area	Specific Areas
December	30	CBA Latitude 43° - 44° (Winchester Bay, Coos Bay, Bandon) in waters less than 30 fathoms	CBA_Shallow
July	15	CBA Latitude 43° - 44° (Winchester Bay, Coos Bay, Bandon) in waters less than 30 fathoms	CBA_Shallow
August	12	TLA Latitude 45° - 46° (Nehalem, Garibaldi, Pacific City) in waters less than 30 fathoms	TLA_Shallow

Table 24. Entanglement risk for gray whales ranked by peak vertical line co-occurrence score and location of risk when modeled from years averaged 2012/2013 - 2015/2016 for months December, July, and August for the Oregon Logbook Fishery Model.

Months	Peak Score	General Area	Specific Areas
December	25	CBA Latitude 43° - 44° (Winchester Bay, Coos Bay, Bandon) in waters less than 30 fathoms	CBA_Shallow
July	12	TLA Latitude 45° - 46° (Nehalem, Garibaldi, Pacific City), BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings) in waters less than 30 fathoms	TLA_Shallow, BRA_Shallow
August	12	TLA Latitude 45° - 46° (Nehalem, Garibaldi, Pacific City), BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings) in waters less than 30 fathoms	TLA_Shallow, BRA_Shallow

SECTION 3: BLUE WHALES VERTICAL LINE CO-OCCURRENCE MODEL RESULTS

According to the vertical line co-occurrence models, the Dungeness crab commercial fishery yielded the highest risk scores for Blue whales in the coastal waters off of Bodega Bay and near the coastal waters of San Francisco in December, with the highest risk score reported, of 36. The southern coastal waters of Oregon consistently showed levels of moderate risk in December. Blue whale densities in the coastal waters of Washington state yielded the lowest numbers; this was reflected in all vertical line co-occurrence models with blue whales, with minor changes in scores, spatially and temporally, driven by fishery effort (Figures 37 – 40, Tables 25 – 30).

BLUE WHALE in the ALL STATE FISHERY MODEL

CO-OCCURRENCE MODEL RESULTS

Co-occurrence Score (Risk) 2012/2013 – 2016/2017 (December and July)

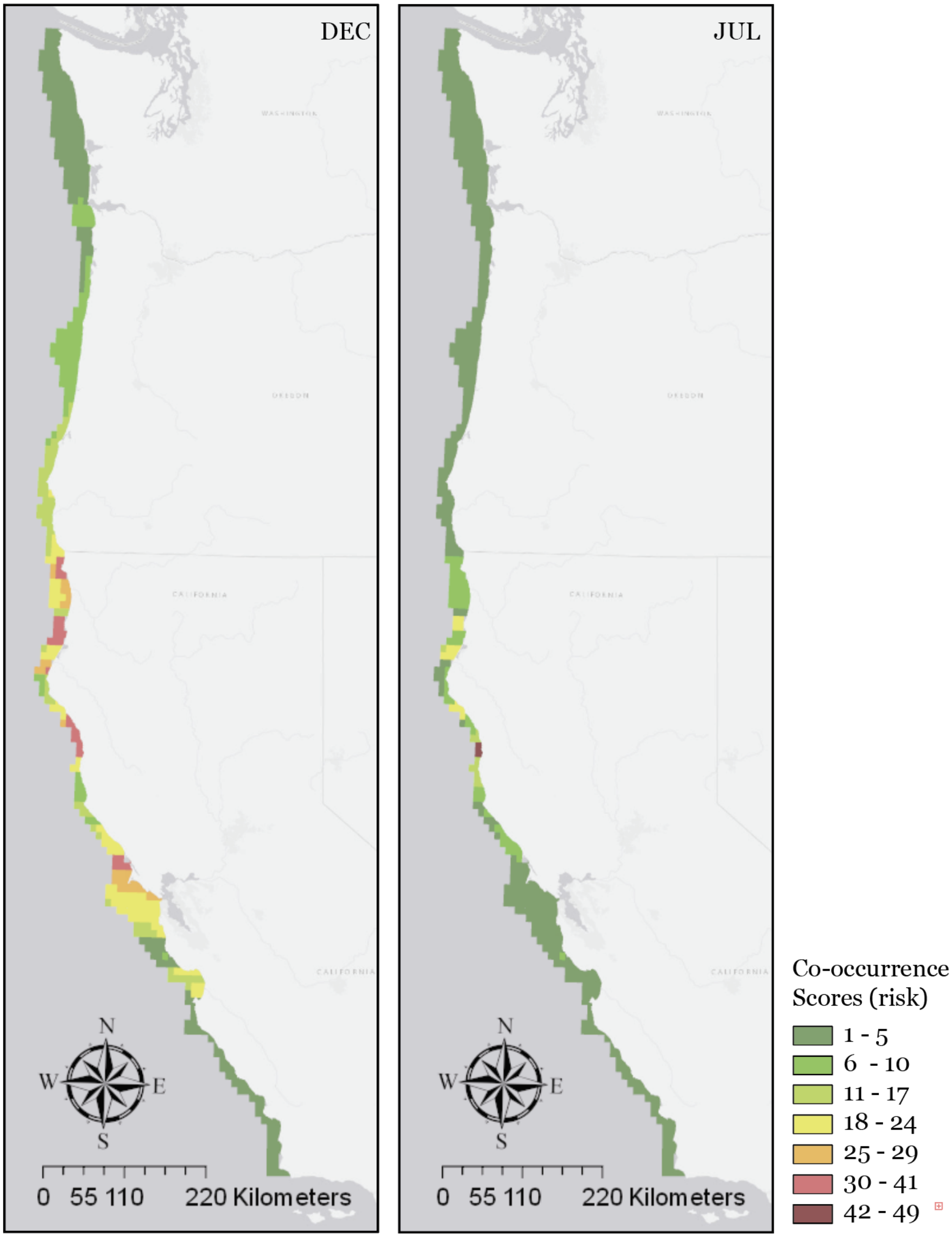

Figure 37. Co-occurrence of the multi-year average blue whale density and fishing effort for all states in December and July for years 2013 - 2017.

With respect to the All States Fishery Model, the highest co-occurrence score for blue whales (36) occurred in a number of catch areas from the California border to north of Fort Bragg and Bodega Bay in December (Figure 37, Table 25). Moderate to high scores occurred from the California border to Monterey Bay during the month of December, with a few low scores. The southern coastal areas of Oregon contained moderate co-occurrence scores in December. Low to moderate levels of risk remained in July from the California border to Fort Bragg, with one high risk area (1255). Low levels of risk in July occurred along the Washington coast.

The co-occurrence model from Saez et al. 2013, which concurred with the vertical line co-occurrence model results using the All State Fishery Model in the following ways, both reported that the Dungeness crab fishery showed the highest risk for humpback whale entanglement in Dungeness crab trap gear occurred in quarter 4 (October to December) from Bodega Bay to the southern end of San Francisco Bay (Appendix A). Further agreement between the two models occurred in the month of December in the southern Oregon catch areas (Appendix A, Saez et al. 2013).

Differences between the two models showed that the original co-occurrence model did not identify any northern California areas as high risk in December, only areas of moderate risk (Appendix A, Saez et al. 2013). The original co-occurrence model showed that low to moderate risk areas occurred along the Washington and Oregon coast and from Point Arena to Point Conception in the month of July (Appendix A, Saez et al. 2013). The vertical line co-occurrence model showed these as areas of similar risk (Figure 37). These differences could have been due to a change in the fishing pressure, differences in the methods in which fishing effort was quantified, or the size of the catch areas in the vertical line co-occurrence model compared to the port complexes of the original co-occurrence model, which uses smaller catch areas and therefore yielded more refined potential risk areas.

Table 25. Entanglement risk for blue whales ranked by peak vertical line co-occurrence score and location of risk when modeled from years averaged 2013/2014 – 2016/2017 for months December and July for the All States Fishery Model.

Months	Peak Score	General Area	Catch Areas
December	36	Bodega Bay	1430
December	36	Patches of high risk areas California border to north of Fort Bragg	1102, 1108, 1132, 1201, 1216, 1242, 1248, 1255*
July	42*	North of Westport, California to north of Fort Bragg	1255*

*indicates that these values should be considered with the information mentioned in the overview of this section

BLUE WHALE in the WASHINGTON and OREGON FISHERY MODEL

CO-OCCURRENCE MODEL RESULTS

Co-occurrence Score (Risk) 2008/2009 – 2011/2012 (December, July, and August)

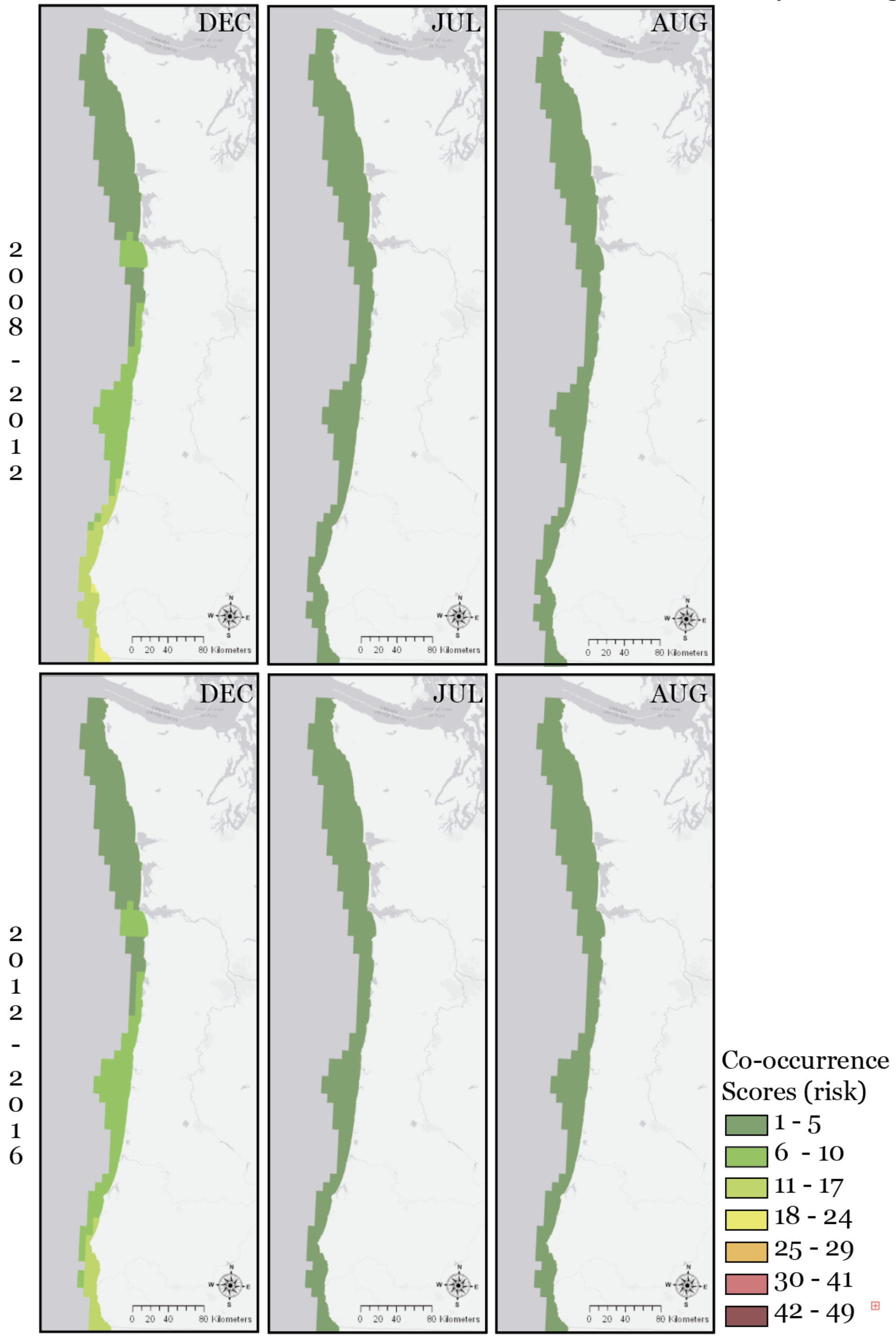

Figure 38. Co-occurrence of the multi-year average blue whale density and fishing effort for Oregon and Washington specific data in December, July, and August yearly averages from 2008/2009 - 2011/2012 seasons and the 2012/2013 - 2015/2016 season.

With respect to the Washington and Oregon Only Fishery Model, the highest co-occurrence score for blue whales (20) occurred in catch area BRA for December in the 2008 - 2012 timeframe (Figure 38, Tables 26 - 27). The model reported moderate levels of risk in catch area CBA during the month of December in both timeframes. No high entanglement risk areas for blue whales occurred throughout the coastal areas of Washington and Oregon in both timeframes.

Differences between the two timeframes showed two general trends in the vertical line co-occurrence model using the Washington and Oregon Only Fishery Model data, risk scores 1) for the month of December averaged over in the 2008 - 2012 timeframe had an overall larger number of, and greater, risk scores than the 2012 - 2016 timeframe in catch areas BRA and CBA, and 2) the scores in July, August, and September (for Washington only) were negligible for the Oregon and Washington coast because blue whale density were reported as the lowest density (Figure 23).

Table 26. Entanglement risk for blue whales ranked by peak vertical line co-occurrence score and location of risk when modeled from years averaged 2008/2009 – 2011/2012 for months December, July, August for the Washington and Oregon Only Fishery Model.

Months	Peak Score	General Area	Catch Areas
December	20	Latitude 42° - 43° (Port Orford, Gold Beach, Brookings)	BRA
July	5	Latitude 42° - 43° (Port Orford, Gold Beach, Brookings)	BRA
August	5	Latitude 42° - 43° (Port Orford, Gold Beach, Brookings)	BRA
September*	2	Port Grenville to the Columbia River	60A1, 60A2

*indicates that these values only apply to Washington state

Table 27. Entanglement risk for blue whales ranked by peak vertical line co-occurrence score and location of risk when modeled from years averaged 2012/2013 - 2015/2016 for months December, July, and August for the Washington and Oregon Only Fishery Model.

Months	Peak Score	General Area	Catch Areas
December	15	Latitude 42° - 43° (Port Orford, Gold Beach, Brookings)	BRA
July	5	Latitude 42° - 43° (Port Orford, Gold Beach, Brookings)	BRA
August	5	Latitude 42° - 43° (Port Orford, Gold Beach, Brookings)	BRA
September*	2	Port Grenville to the Columbia River	60A1, 60A2

*indicates that these values only apply to Washington state

BLUE WHALE in the CALIFRONIA ONLY FISHERY MODEL

CO-OCCURRENCE MODEL RESULTS

Co-occurrence Score (Risk) 2012/2013 – 2016/2017 (November, December, and July)

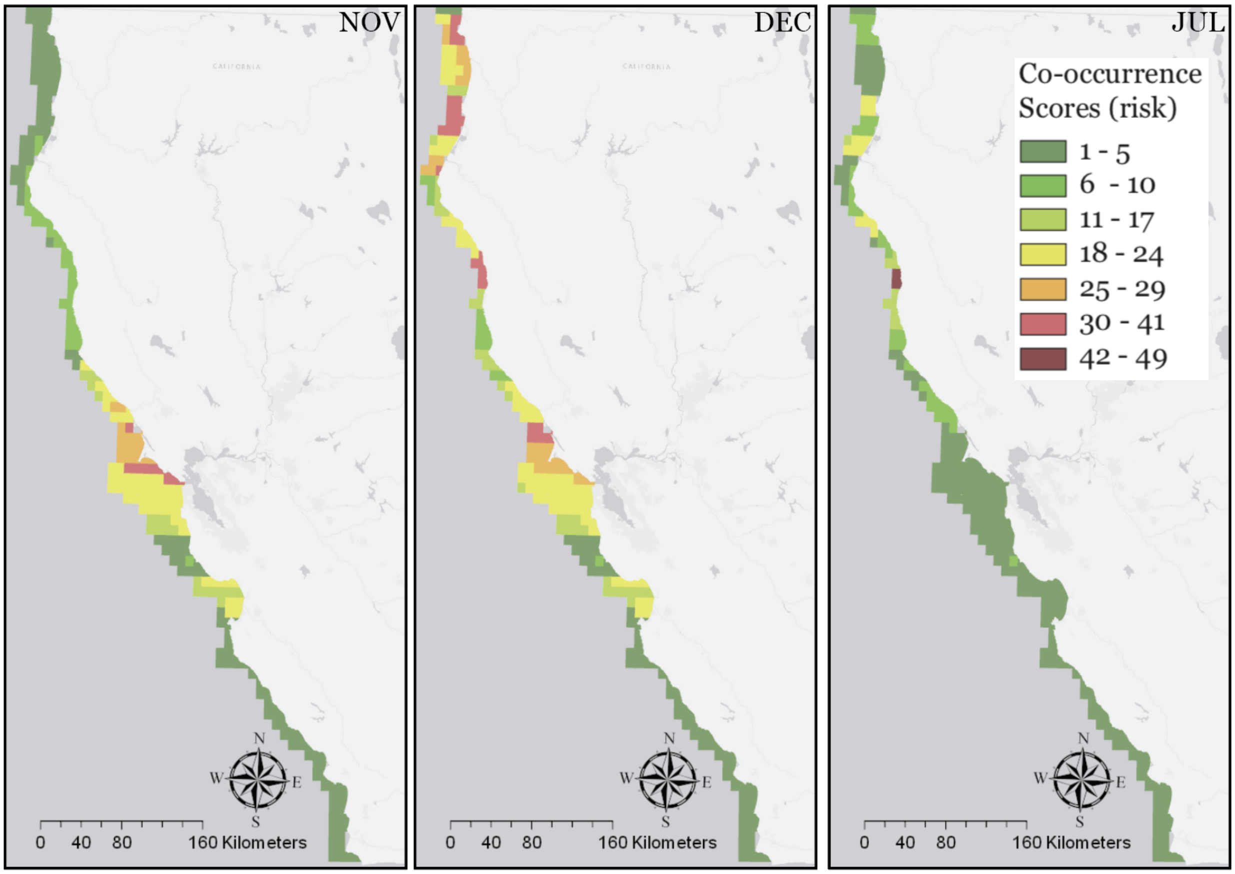

Figure 39. Co-occurrence of the multi-year average blue whale density and fishing effort for California only data in November yearly averages for years 2013 - 2017 for November, December, and July.

With respect to the California Only Fishery Model, the highest co-occurrence score for blue whales (36) occurred in Bodega Bay in December (Figure 39, Table 28). November reported high risk scores in Bodega Bay and moderate score from Bodega Bay to the south end of San Francisco Bay area waters and Monterey Bay. It should be noted that the highest risk score reported for the vertical line co-occurrence using the California Only Fishing Model for blue whales was in catch area 1255 in July with a score of 42. Low scores were reported from the southern end of Monterey Bay to Point Conception for all months, i.e., co-occurrence risk scores less than 5. These results are similar to the results in the vertical line co-occurrence model for blue whales using the All State Fishery Model representing vertical line co-occurrence to the entire West Coast (Figure 37, Table 25, Figure 39, Table 28).

Table 28. Entanglement risk for blue whales ranked by peak vertical line co-occurrence score and location of risk when modeled from years averaged 2013/2014 – 2016/2017 for months November, December, and July for the California Only Fishery Model.

Months	Peak Score	General Area	Catch Areas
November	30	Bodega Bay to Sausalito	1430, 1446
December	36	Patches of high risk areas California border to north of Fort Bragg, and Bodega Bay	1102, 1108, 1132, 1201, 1216, 1248, 1255*
July	42*	North of Westport, California to north of Fort Bragg	1255*

*indicates that these values should be considered with the information mentioned in the overview of this section

BLUE WHALE in the OREGON LOGBOOK FISHERY MODEL

CO-OCCURRENCE MODEL RESULTS

Co-occurrence Score (Risk)

2008/2009 – 2011/2012 and 2011/2012 – 2015/2016 (December to June)

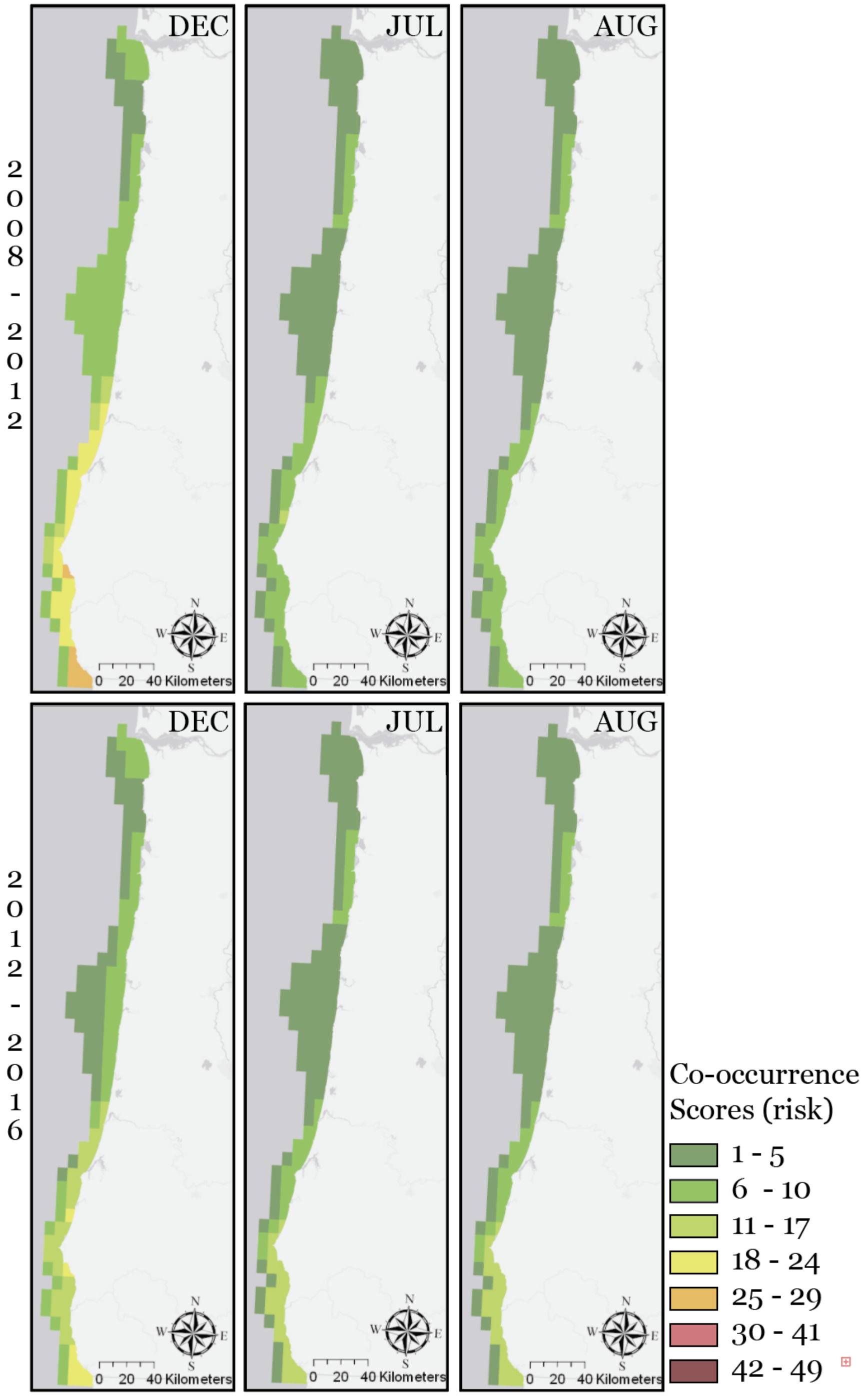

Figure 40. Co-occurrence of the multi-year average blue whale density and Dungeness crab trap effort for Oregon logbook data in December, July, and August yearly averages from 2008/2009 - 2011/2012 seasons and the 2012/2013 - 2015/2016 season.

With respect to the Oregon Logbook Fishery Model, the highest co-occurrence score for blue whales (25) occurred in catch area BRA_Shallow (Figure 40, Table 29, Table 30). There were no high risk scores reported in deep or shallow catch areas in either timeframe. Moderate scores were reported throughout shallow catch areas of CBA and BRA in December in the 2008 - 2012 timeframe, with co-occurrence scores between 12 and 25. There was a reduction in these scores in December in the 2012 - 2016 timeframe, with co-occurrence scores between 10 and 20. The general trend of the blue whale vertical line co-occurrence model using the Washington and Oregon Only Fishery Model indicated that there was greater amount of fishing effort in the 2008 - 2012 timeframe compared to the 2012 - 2016 timeframe. This trend was true for the month of December but flipped for months July and August with an increase in fishing effort in the 2012 - 2016 timeframe. The vertical line co-occurrence model with Oregon logbook data shows that fishing effort occurred primarily in the shallow regions of catch areas CBA and BRA, a trend not shown in any other fishery model.

Table 29. Entanglement risk for blue whales ranked by peak vertical line co-occurrence score and location of risk when modeled from years averaged 2008/2009 – 2011/2012 for months December, July, and August for the Oregon Logbook Fishery Model.

Months	Peak Score	General Area	Specific Areas
December	25	BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings) in waters less than 30 fathoms	BRA_Shallow
July	12	CBA Latitude 43° - 44° (Winchester Bay, Coos Bay, Bandon) in waters less than 30 fathoms	CBA_Shallow
August	10	BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings) in waters less than 30 fathoms	BRA_Shallow

Table 30. Entanglement risk for blue whales ranked by peak vertical line co-occurrence score and location of risk when modeled from years averaged 2012/2013 - 2015/2016 for months December, July, and August for the Oregon Logbook Fishery Model.

Months	Peak Score	General Area	Specific Areas
December	20	CBA Latitude 43° - 44° (Winchester Bay, Coos Bay, Bandon), BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings) in waters less than 30 fathoms	CBA_Shallow, BRA_Shallow
July	15	BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings) in waters less than 30 fathoms	BRA_Shallow
August	15	BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings) in waters less than 30 fathoms	BRA_Shallow

SECTION 4: FIN WHALES in the VERTICAL LINE CO-OCCURRENCE MODEL RESULTS

An assessment of the entanglement risk for fin whales with Dungeness crab commercial fishery yielded consistently lower scores for all the vertical line co-occurrence models in all months with few exceptions. The only high risk scores occurred in the deeper parts of catch areas in the San Francisco Bay area at the opening of the Dungeness crab fishing season. These results are consistent with the whale density model for fin whales with greater density of fin whales in deeper waters along the California coast than any other whale species in this study (Figure 23). Fin whales typically occur in higher densities in shallower water in the central California region only, and do not occur in high numbers along Washington and Oregon (Figure 23). The density and distribution of fin whales in these areas does not overlap with a majority of the potential fishing areas for Dungeness crab.

FIN WHALE in the ALL STATES FISHERY MODEL

CO-OCCURRENCE RESULTS

Co-occurrence Score (Risk) 2012/2013 – 2016/2017 (December and July)

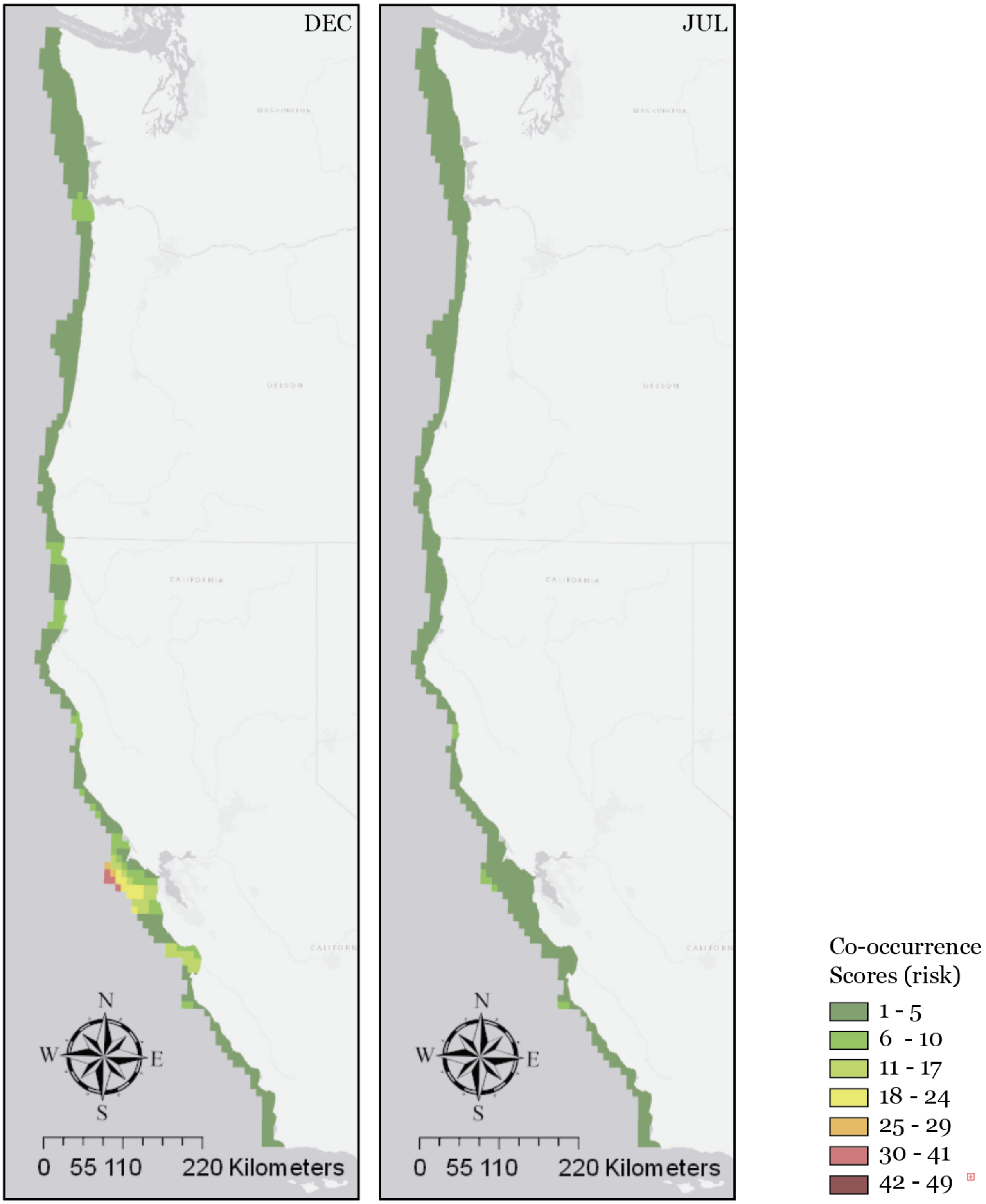

Figure 41. Co-occurrence of the multi-year average fin whale density and fishing effort for all states in December and July for years 2013 - 2017.

With respect to the All States Fishery Model, the highest co-occurrence score for fin whales (30) occurred in the deep areas in the San Francisco Bay area waters in December, specifically the western edge of the catch areas from Point Reyes to north of Half Moon Bay (Figure 41, Table 31). The risk of co-occurrence deceased closer to the coast with moderate scores in these same catch areas between 10 - 25 in December. In July, the coastal waters along the West Coast reported scores less than 7. The co-occurrence model from Saez et al. 2013 showed the highest risk for fin whale entanglement in Dungeness crab fishery occurred in quarter 4 in San Francisco and Monterey Bay with scores of 30 (Appendix A). The vertical line co-occurrence model using the All States Fishery Model yielded similar peak scores in the San Francisco Bay area, but this model did not identify Monterey as an area of elevated risk (Figure 41). These differences could be due to a change in the fishing pressure, differences in the methods in which fishing effort is quantified, or the differences in the size of the catch areas of this study compared to the port complexes of the original co-occurrence model.

Table 31. Entanglement risk for fin whales ranked by peak vertical line co-occurrence score and location of risk when modeled from years averaged 2013/2014 – 2016/2017 for months December and July for the All States Fishery Model.

Months	Peak Score	General Area	Catch Areas
December	30	Western edge of the blocks from Point Reyes to north of Half Moon Bay	1446, 1455
July	7	North of Westport, California to north of Fort Bragg and the central California Coast from the south end of Monterey Bay south to San Simeon	1255*, 1525

*indicates that these values should be considered with the information mentioned in the overview of this section

FIN WHALE in the WASHINGTON and OREGON FISHERY MODEL

CO-OCCURRENCE RESULTS

Co-occurrence Score (Risk) 2008/2009 – 2011/2012 (December, July, and August)

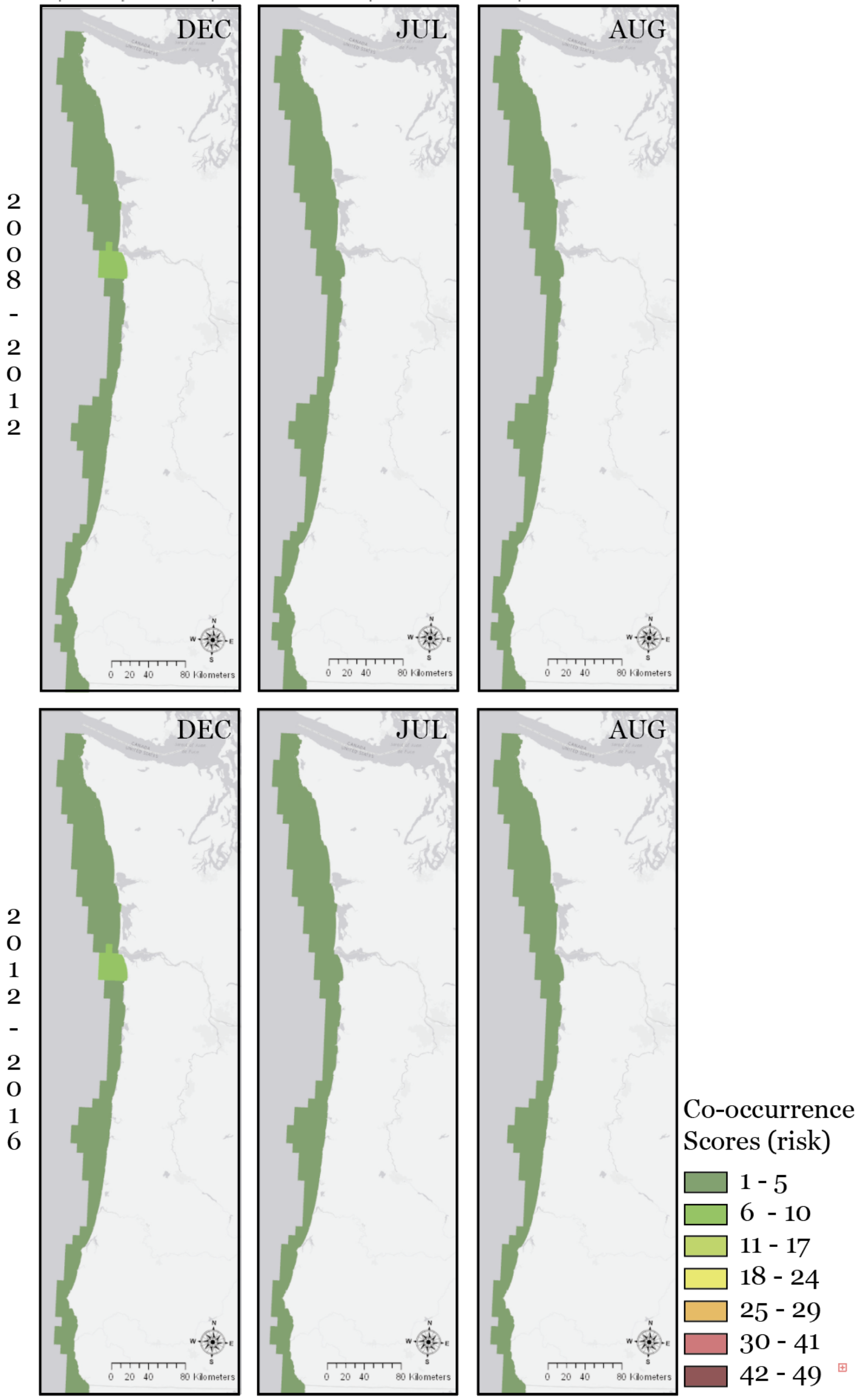

Figure 42. Co-occurrence of the multi-year average fin whale density and fishing effort for Oregon and Washington specific data in December, July, and August yearly averages from 2008/2009 - 2011/2012 seasons and the 2012/2013 - 2015/2016 season.

With respect to the Washington and Oregon Only Fishery Model, the highest co-occurrence score for fin whales (7) occurred in catch area CLO (Figure 42, Table 32). Co-occurrence scores did not go exceed 7 for all months and years. Any variation in scores can be attributed to the fishery as fin whale densities in the coastal waters of Washington and Oregon did not go over a score of 1 (Table 5, Figures 12 - 13, Table 8, Figure 23).

Table 32. Entanglement risk for fin whales ranked by peak vertical line co-occurrence score and location of risk when modeled from years averaged 2008/2009 – 2011/2012 for months December, July, August for the Washington and Oregon Only Fishery Model.

Months	Peak Score	General Area	Catch Areas
December	7	Latitude 46° – 46.25° (Astoria, Gearhart, Seaside)	CLO
July	2	Point Grenville down to TLA Latitude 45° - 46° (Nehalem, Garibaldi, Pacific City)	60A1, 60A2, 61_60D, CLO, TLA
August	2	Point Grenville to CLO Latitude 46° – 46.25° (Astoria, Gearhart, Seaside)	60A1, 60A2, 61_60D, CLO
September*	2	Point Grenville to the Columbia River	60A1, 60A2, 61_60D

*indicates that these values are for Washington state only

Table 33. Entanglement risk for fin whales ranked by peak vertical line co-occurrence score and location of risk when modeled from years averaged 2012/2013 - 2015/2016 for months December, July, and August for the Washington and Oregon Only Fishery Model.

Months	Peak Score	General Area	Catch Areas
December	6	Latitude 46° – 46.25° (Astoria, Gearhart, Seaside)	CLO
July	2	Point Grenville to the southern border of Oregon	60A1, 60^{a}2, 61_60D, CLO, TLA, NPA, CBA, BRA
August	2	Point Grenville to the Columbia River and TLA Latitude 45° - 46° (Nehalem, Garibaldi, Pacific City)	60A1, 60A2, 61_60D, TLA
September*	3	Port Chehalis to the Columbia river	60A2, 61_60D

*indicates that these values are for Washington state only

FIN WHALE in the CALIFORNIA ONLY FISHERY MODEL

CO-OCCURRENCE MODEL RESULTS

Co-occurrence Score (Risk) 2012/2013 – 2016/2017 (November, December, and July)

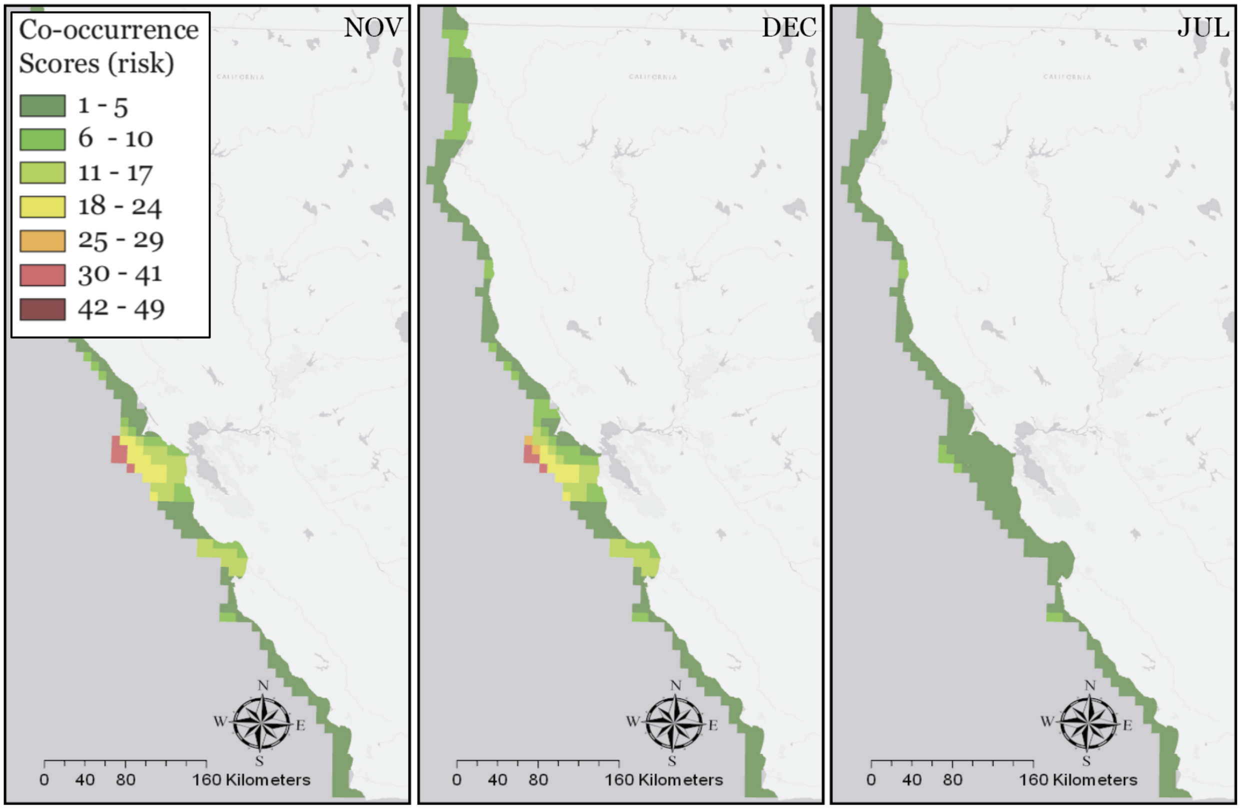

Figure 43. Co-occurrence of the multi-year average fin whale density and fishing effort for California only data in November yearly averages for years 2013 - 2017

With respect to the California Only Fishery Model, the highest co-occurrence score for fin whales (36) occurred in catch areas along the western edge of the catch areas from Point Reyes to north of Half Moon Bay in the month of November (Figure 43, Table 34). The scores of the vertical line co-occurrence model for fin whales using the California Only Fishery Model were similar to those of the scores for the All States Fishery Model in December and July and can be referenced in the sub-section for Fin Whales in the All State Fishery Model (Figure 41 Table 31).

Table 34. Entanglement risk for fin whales ranked by peak vertical line co-occurrence score and location of risk when modeled from years averaged 2013/2014 – 2016/2017 for months November, December, and July for the California Only Fishery Model.

Months	Peak Score	General Area	Catch Areas
November	36	Western edge of the catch areas from Point Reyes to north of Half Moon Bay	1446, 1455
December	30	Western edge of the catch areas from Point Reyes to north of Half Moon Bay	1446, 1455
July	7	North of Westport, California to north of Fort Bragg and the central California Coast from the south end of Monterey Bay south to San Simeon	1255*, 1525

*indicates that these values should be considered with the information mentioned in the overview of this section

FIN WHALE in the OREGON LOGBOOK FISHERY MODEL

CO-OCCURRENCE MODEL RESULTS

Co-occurrence Score (Risk)
2008/2009 – 2011/2012 and 2011/2012 – 2015/2016 (December, July, and August)

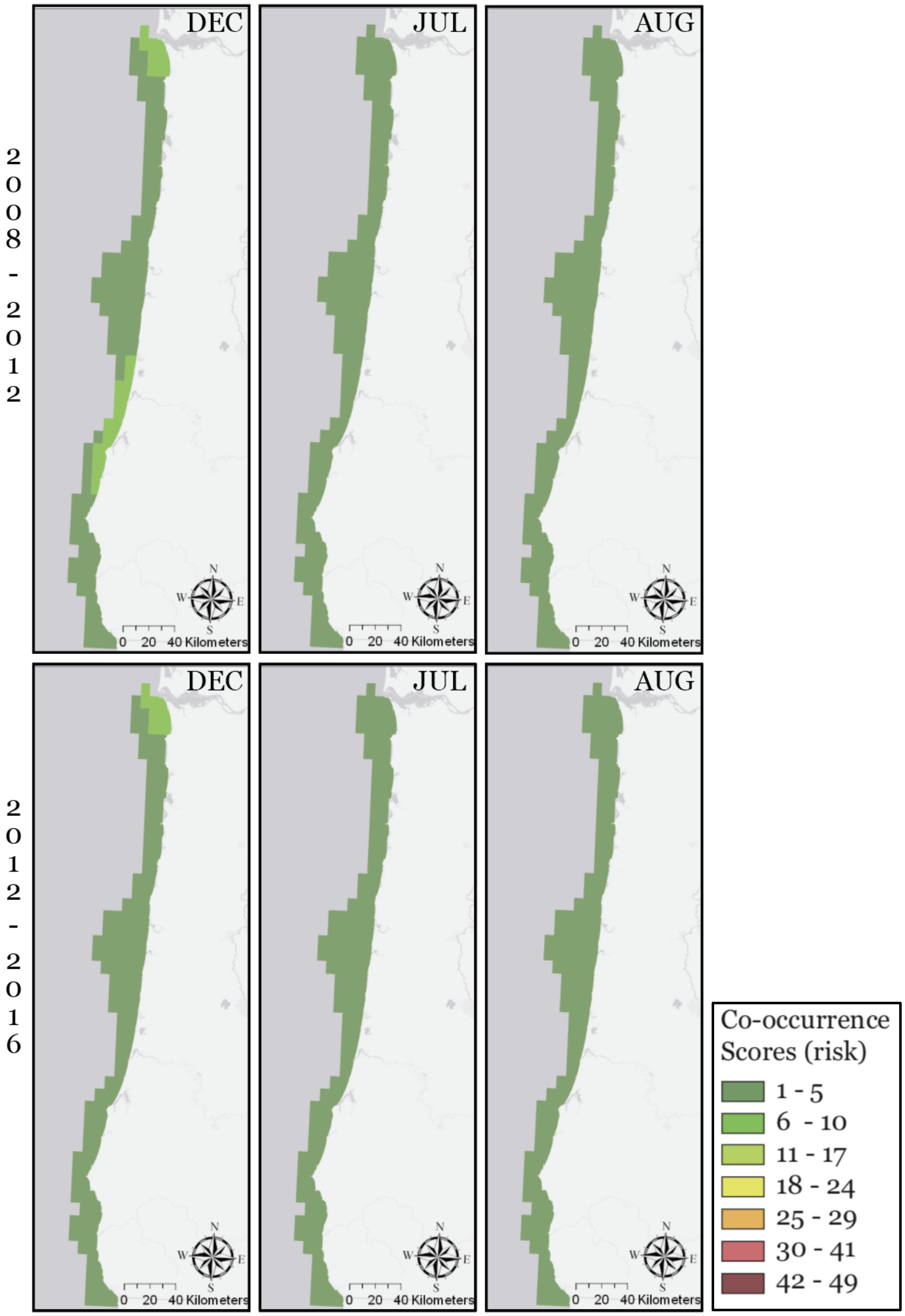

Figure 44. Co-occurrence of the multi-year average fin whale density and Dungeness crab trap effort for Oregon logbook data in December, July, and August yearly averages from 2008/2009 - 2011/2012 seasons and the 2012/2013 - 2015/2016 season.

The vertical line co-occurrence scores for fin whales using the Oregon Logbook Fishery Model did not yield any significant differences between the fin whale vertical line co-occurrence model using the Washington and Oregon Only Fishery Model (Figures 30 – 31, Tables 32 - 33).

Table 35. Entanglement risk for fin whales ranked by peak vertical line co-occurrence score and location of risk when modeled from years averaged 2008/2009 – 2011/2012 for months December, July, and August for the Oregon Logbook Fishery Model.

Months	Peak Score	General Area	Specific Areas
December	7	CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside) in waters less than 30 fathoms	CLO_Shallow
July	3	CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside), TLA Latitude 45° - 46° (Nehalem, Garibaldi, Pacific City), CBA Latitude 43 - 44 (Winchester Bay, Coos Bay, Bandon), BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings) in waters less than 30 fathoms in waters less than 30 fathoms	CLO_Shallow, TLA_Shallow, CBA_Shallow, BRA_Shallow
August	3	TLA Latitude 45° - 46° (Nehalem, Garibaldi, Pacific City) in waters less than 30 fathoms	TLA_Shallow

Table 36. Entanglement risk for fin whales ranked by peak vertical line co-occurrence score and location of risk when modeled from years averaged 2012/2013 - 2015/2016 for months December, July, and August for the Oregon Logbook Fishery Model.

Months	Peak Score	General Area	Specific Areas
December	6	CLO Latitude 46° – 46.25° (Astoria, Gearhart/Seaside) in waters less than 30 fathoms	CLO_Shallow
July	3	TLA Latitude 45° - 46° (Nehalem, Garibaldi, Pacific City), BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings) in waters less than 30 fathoms	TLA_Shallow, BRA_Shallow
August	3	TLA Latitude 45° - 46° (Nehalem, Garibaldi, Pacific City), BRA Latitude 42° - 43° (Port Orford, Gold Beach, Brookings) in waters less than 30 fathoms	TLA_Shallow, BRA_Shallow

CHAPTER 4: RECOMMENDATIONS AND CONCLUSION

The findings from this project are expected to provide additional data and analysis to be used by NMFS, the West Coast state agencies, and other stakeholders to further aid future management or other actions implemented to aid in protection of these species under the MMPA and ESA. These improvements and updated information used in this study hope to aid the understanding fishing effort and dynamics of the Dungeness crab fishery in recent years. This model hopes to ultimately aid in the assessment of fishery management decisions to help mitigate large whale entanglements in the future.

FUTURE CONSIDERATIONS

The vertical line co-occurrence models piloted in this study were created to better understand where the areas of entanglement risk for gray, humpback, blue, and fin whales have occurred and to aid fishery managers in the future. The following points are recommendations to help inform and aide in the development of future vertical line co-occurrence modeling. Further investigation to in a vertical line co-occurrence model should consider:

1. Eliminating the individual state models. The issue of large whale entanglement is a coast-wide issue and while individual state models provide insight into risk from a narrow viewpoint, risk should be considered from a coast-wide perspective provided by the All State Fishery Model and the vertical line co-occurrence results that use it. Because whales migrate along the coast and their protection falls under federal mandate, the issue of entanglement transcends state boundaries. Furthermore, insight into risk of entanglement from fixed gear fisheries should not be specific to each state but relative to the entire coast as much of the confirmed entanglement gear cannot be attributed to a specific fishery let alone state, statistical area, or time.
2. Refining fishery models for each state. State specific data should only be used to gain further understanding into the spatial and temporal distribution of fixed gear fisheries, such as the Oregon Logbook data. Future modeling effort should incorporate Washington logbook data to better understand the density and distribution of the fishery effort there. Additionally, better understanding of fishing effort along the California

coast is needed, whether through: observational studies, implementation of logbook reporting system, or better reporting of areas in general to eliminate the reports of landings in blocks and large offshore catch areas that are not within feasible fishing depths.

3. Improving whale density and distribution data. The addition of winter and spring whale density data should be added. This information is needed to match up with the entire Dungeness crab fishing season to better understand entanglement risk throughout the entire season.
4. Refining the catch areas. Refinement of catch areas to eliminate habitats and substrates not suitable for the Dungeness crab trap fishery as this refinement would provide a more accurate measure of trap density.
5. Adding of Vessel Monitoring System (VMS) data. The addition of this data to the model may help identify areas of co-occurrence with updated fishing information. VMS data records the exactly geographic location of fishing efforts and would be the most accurate method of identifying where vessels have placed their traps.
6. Comparing the methods of the original co-occurrence model in the updated timeframes used in this study. Future efforts should include creating a fishery model using the same methods in the original co-occurrence model to better understand how fishing effort changes and how it has changed in recent years.
7. Using a universal trap density scale. The stark differences between the data from the Oregon Logbook Fishery Model and all other models should be noted. The scaled numbers for the Oregon Logbook Fishing Model report trap density numbers that are outside of the range of values found in the Washington and Oregon Only Fishing Model (see Table 5, Figures 12 – 13, Figures 15 – 17, Figures 18 - 20) for reasons previously

mentioned. While these numbers were calculated from the Oregon Logbook data using the Jenks Natural Breaks Method, future modeling efforts should consider calculating a scale for the Oregon Logbook Fishery Model that fits the All States Fishery Model for a better comparison between Oregon logbook data and the Oregon landings data, and therefore a better understanding of co-occurrence; or Oregon landings data should be replaced by Oregon logbook data in the All State Fishery mode. For comparison and an example of the differences between the representation of the Oregon logbook data Figures 18 – 20 should be referenced as they use the trap density scale from the All State Fishery Model. These figures demonstrate what fishing effort looks like when the scaled trap density numbers from the All State Fishery Model.

MANAGEMENT IMPLICATIONS and SUGGESTIONS

The use of the vertical line co-occurrence model to inform future management decision imposed on the Dungeness crab fishery could be of benefit in reducing whale entanglements in this trap gear. Management solutions are currently being explored by state managers to protect whale populations and to retain the profitable fishery. One such solution is the creation of working groups, which brings together stakeholders and fishery managers, to tackle the issue of large whale entanglements (California Ocean Protection Council, 2017). For example, the California Dungeness Crab Working Group created the Risk Assessment and Mitigation Program (RAMP) to identify circumstances such as whale concentrations, current entanglement numbers, forage fish distribution, ocean conditions, and fishing dynamics to understand entanglement risk levels each year (California Dungeness Crab Fishing Gear Working Group 2017a, California Dungeness Crab Fishing Gear Working Group 2017b). The RAMP program could benefit from the results of the vertical line models to better inform the assessment of risk.

While this is an example in one state along the West Coast, similar solutions have also been explored by Washington and Oregon as well.

While working groups are one pathway of managers to reduce entanglements there are other regulatory and non-regulatory pathways to aid in this issue. A study done by Lebon (2018) reported fifteen regulatory and non-regulatory alternatives to changing the Dungeness crab fishery to reduce entanglements and investigated their merits based on cost, performance, and preference. This study found that devices such as Galvanic Timed Releases (GTRs), inexpensive devices that erode over time when in salt water to keep the lines out of the water column, were the most effective and preferred alternative (Lebon 2018, Salvador et al. 2006). Other alternatives that were favorable in terms of low cost, effectiveness, and preference by fishermen included reducing float length of the trailer line and seafood certification programs; when effectiveness of reducing whale entanglements was weighted as most important this study found that, in addition to GTRs, catch shares and temporary closures scored the highest (Lebon 2018). The least favorable outcomes were changing fishing season length, increasing the number of traps per line, or implementing pingers to deter whales (Lebon 2018). Based on the alternatives suggested by Lebon (2018) and the vertical line co-occurrence model results, implementation of management alternatives like GTRs and temporary closures to areas of high risk identified by this study may be the most effective way to reduce whale entanglements. The West Coast states have taken some measures to better identify gear type and state the gear was deployed. Additional regulations could be implemented in the areas and months of high risk, areas noted below, such as additional markings on traps, buoys, and float lines; while this does not directly reduce whale entanglements it may help managers identify the location of whale entanglements.

As mentioned above, the Oregon logbook data provided more insight into the density and distribution of fishing efforts than landing data from PacFIN and would be of benefit to future modeling efforts to better support management decisions. One such alternative that was not explored by Lebon (2018) was the implementation of logbook reporting for the California Dungeness crab fishery. This study highlighted the issues with the reported location of the landing, recorded by fish dealer and processors and not the fishermen themselves. Implementation of a logbook reporting system in California would aid in future modeling efforts to better understand fishing effort dynamics and would provide insight to managers if any alternative management solutions are implemented.

This vertical line co-occurrence model identifies several elevated risk areas where specific research efforts, as suggested in the future considerations section, or management solutions, as identified above, would be of most benefit. The benefit of these directed efforts to better understand and reduce large whale entanglements in the future should be focused in the following areas:

1. Northern California Coast during December. The models reported consistently high risk scores in this time and area.
2. Fort Bragg and surrounding catch areas in December and July. Focused efforts in this area would benefit the understanding of fishing effort and may address many of the assumptions and limitations of this area; such as, the relatively high number of traps reported in block 255 closest to the coast which has relatively small available fishing area due to location along the coast and less potential fishing area due to restricted trap fishing from the MPA in that area.
3. Coastal Oregon shallow catch areas. This area was identified as high risk in the logbook data with higher risk scores from high trap densities in the shallow parts of this catch area compared to the deep (greater than 30 fathoms) catch area counterpart. Furthermore, because it is an area of high risk and these areas overlap with the Washington state

Dungeness crab trap fishery, a better understanding of trap density and distribution would clarify areas of potential risk for all whale species.

CONCLUSION

The continued high number of reported whale entanglements over the last five years has warranted fishery managers, fishermen, and other stakeholders to look into solutions to reducing the number of entangled whales along the West Coast. Because the Dungeness crab fishery has been the most often identified gear in confirmed whale entanglement cases it has become increasingly under public scrutiny to look for ways to reduce whale entanglements. This model may aid fishery managers to better understand the spatial and temporal distribution of vertical lines in the water in future efforts to reduce whale entanglements.

Acknowledgments

It is with endless gratitude and sincerity that I would like to thank everyone who made this project possible. Thank you to my committee chair, Dr. Dave Fluharty, for the all the guidance, insight, support, expertise, and encouragement given to me over the years. Thank you also to committee member and advisor Dr. Patrick Christie for all the opportunities and guidance he provided over the years. I want to thank Dr. Sam Dover, committee member, who has been an endless source of support over the years; and most importantly, introducing me to the world of large whale entanglement. A big thank you to both my committee member Dan Lawson, who supported me and guided me throughout this process, and, Lauren Saez, who helped enormously and provided an endless source of encouragement; without either of them, or the insight and support they provided through countless emails and meetings, this project would not have happened.

I want to thank Ruth Dover and the Channel Islands Marine and Wildlife Institute (CIMWI) for supporting me in this task, seeing my potential, and sticking with me while providing insight and wisdom. I also want to thank Justin Viezbiecke and Justin Greenman from NOAA's National Marine Fisheries Service, who advocated for this project from the very beginning. Thank you to Traci Lacinto, Christy Juhasz, Heather Reed, Dan Ayres, Corey Niles, Justin Ainsworth, Kelly Corbett, and Troy Buell at the CDFW, ODFW, and WDFW for all your help and patiently answering my endless questions. This work could not have been completed without the support of those at the Pacific States Marine Fisheries Commission who guided me through the data gathering process, Dave Colpo, Brad Stenberg, and Bob Ryznar.

Thank you to my fiancé Brian for all your encouragement, I know preventing me from banging my head against the computer screen was not easy. And lastly, a big thank you to my family for their endless love and support.

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APPENDIX A: Commercial Dungeness crab fishery and co-occurrence model results published by Saez et al. (2013) referenced for comparison with the vertical line fishery and co-occurrence model results.

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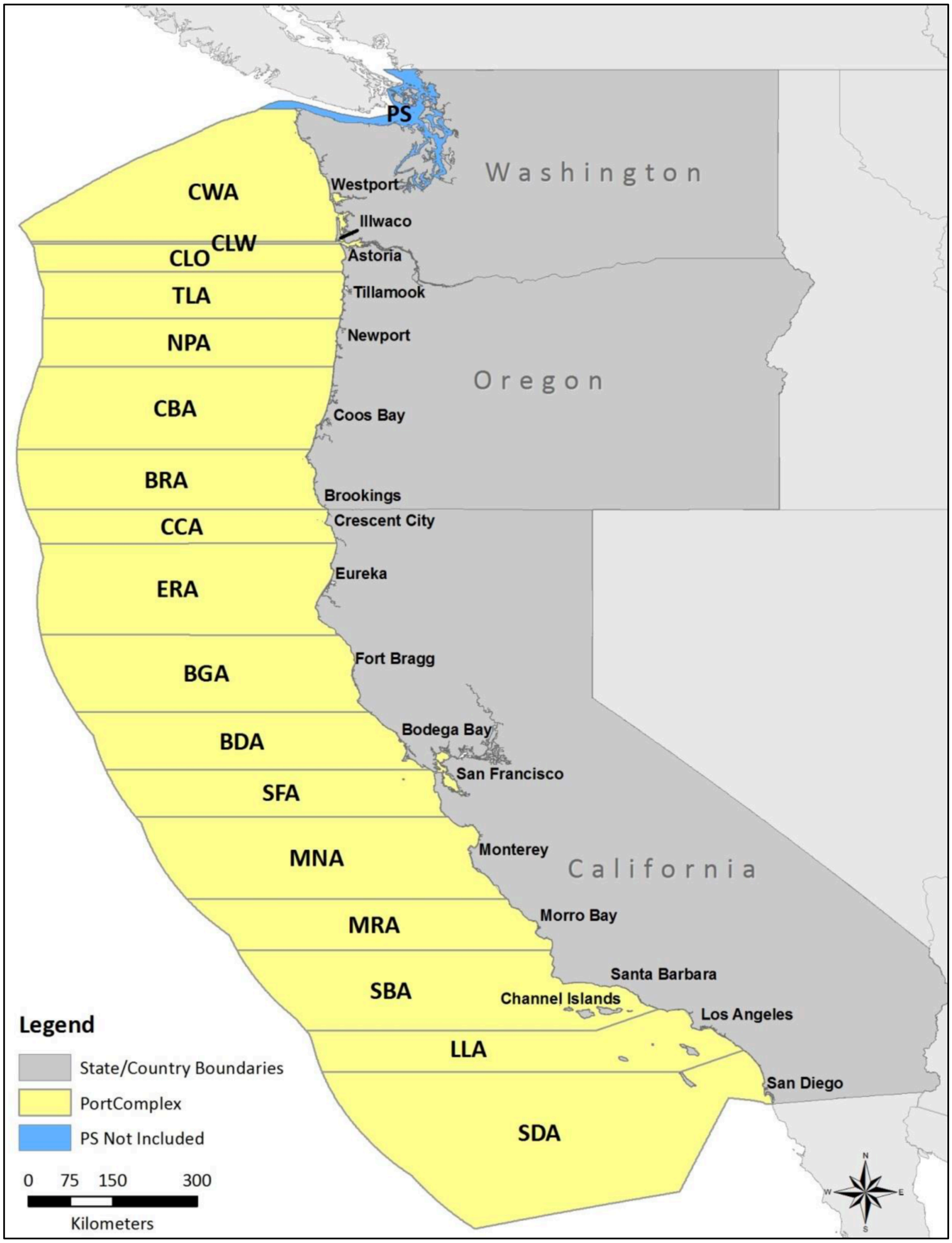

Figure *i*. Geographic representation of port complex regions as defined by the PacFIN database. Western boundary is the United State Exclusive Economic Zone. Port complexes are as follows (major port): PS (Seattle), CWA (Westport), CLW (Illwaco), CLO (Astoria), TLA (Tillamook), NPA (Newport), CBA (Coos 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) (Saez et al. 2013).

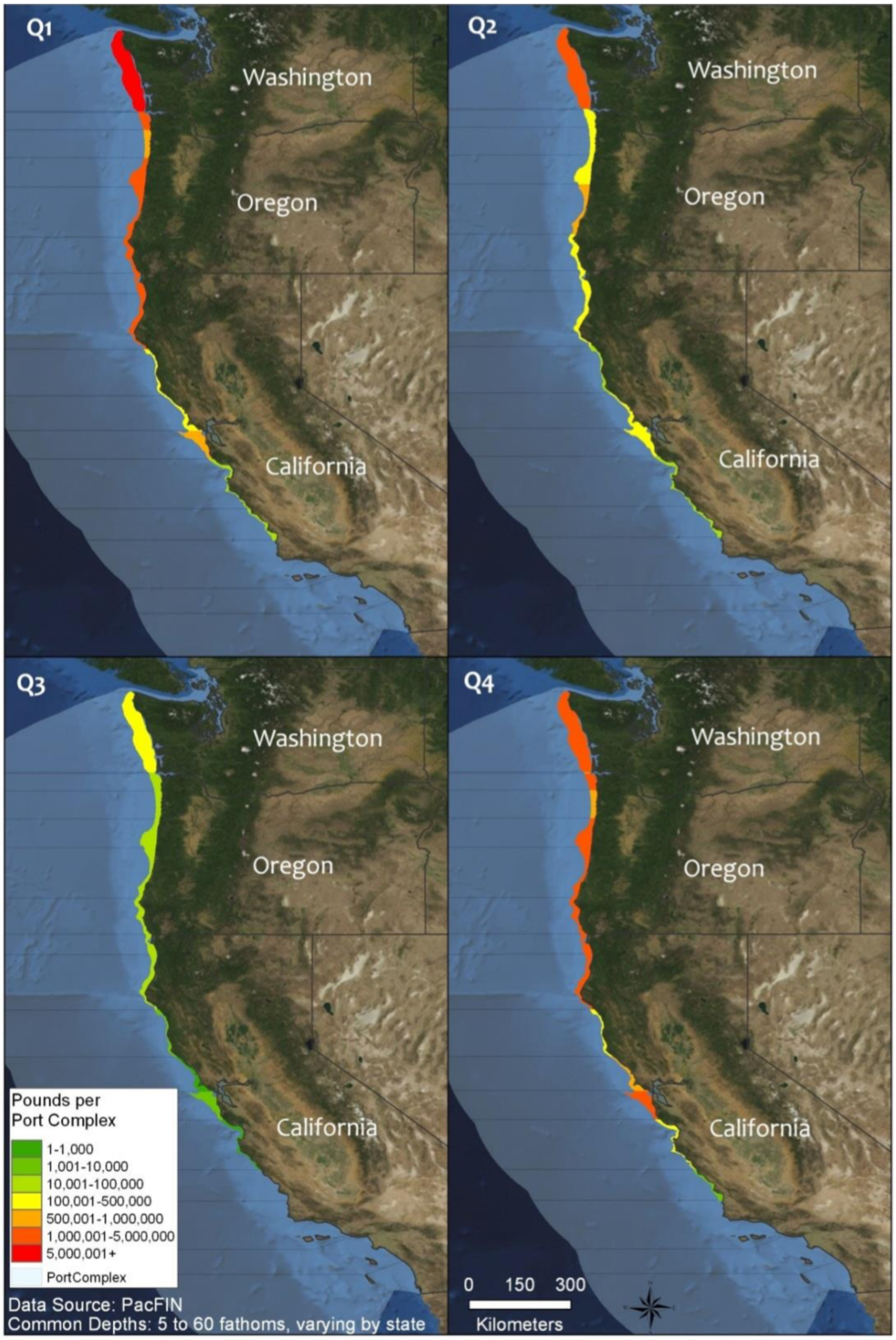

Figure *ii*. Dungeness crab trap fishery yearly average landings, indicated by the green to red colored bands, from 2004 to 2008 are shown per port complex and by quarter of the year. Fishing area within a port complex is defined by operational fishing depth range (Saez et al. 2013).

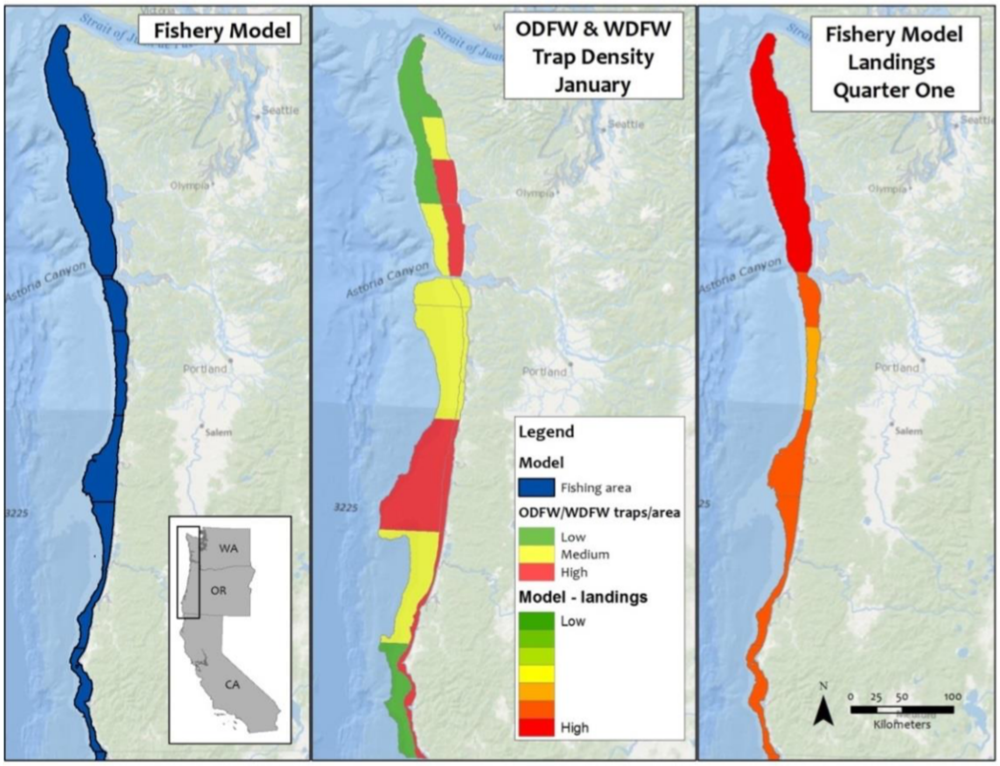

Figure *iii*. Modeled fishing area (2004 - 2008), by port complex, compared to Dungeness crab traps/area, shown on a green to red scale with red representing high traps/area, summarized from ODFW and WDFW commercial logbook data (2009 - 10), and fishery model landings show on a green to red scale with red representing the highest landings (2004 - 2008, Quarter One) (Saez et al. 2013).

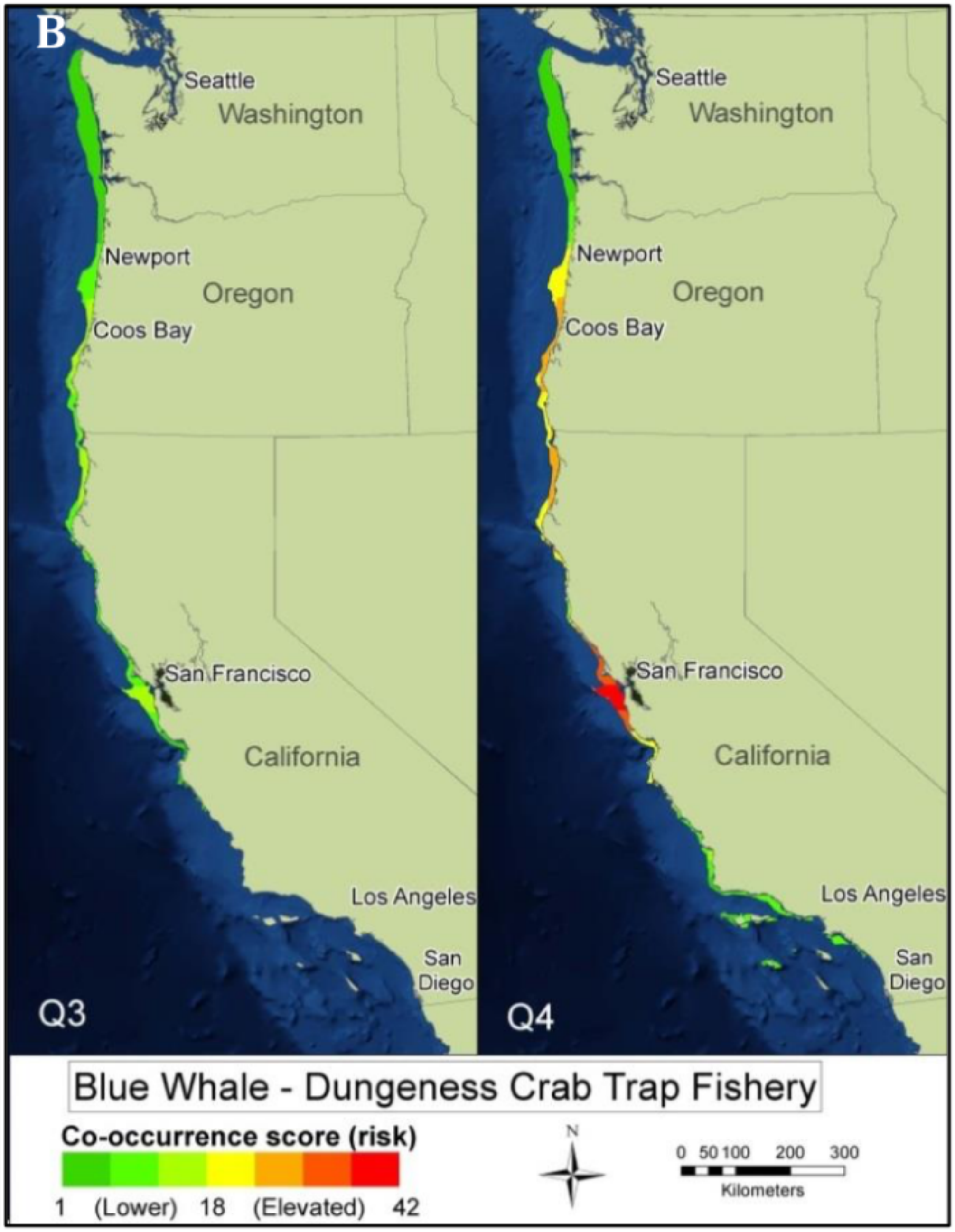

Figure *iv*. Co-occurrence of the multi-year average blue whale density (left) and Dungeness crab trap effort, shown for Quarter Three and Four (Saez et al. 2013).

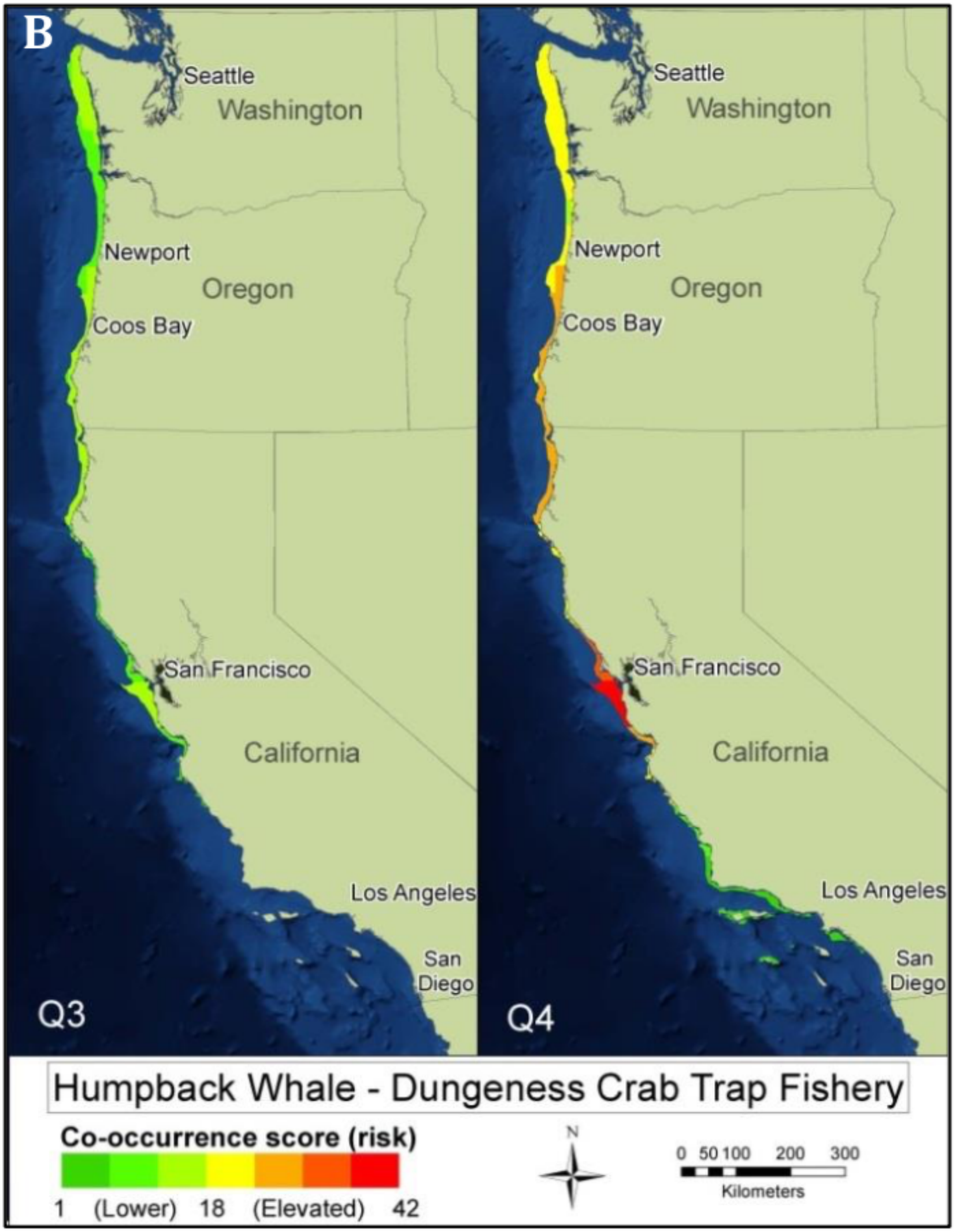

Figure *v*. Co-occurrence of the multi-year average humpback whale density and Dungeness crab trap effort, shown for Quarter Three and Four (Saez et al. 2013).

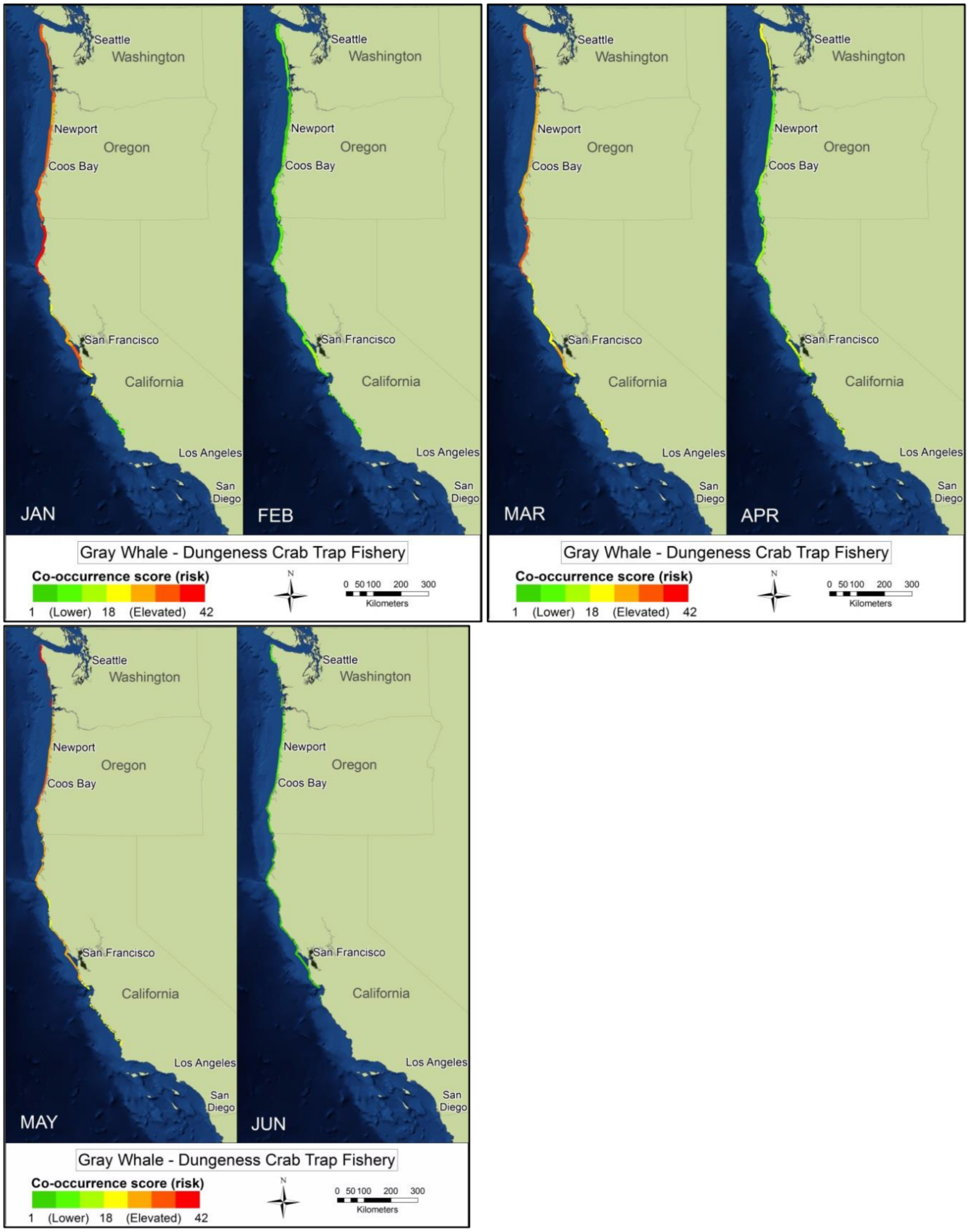

Figure *vi*. Co-occurrence of gray whale migration and Dungeness crab trap effort, shown monthly from January to June (Saez et al. 2013).

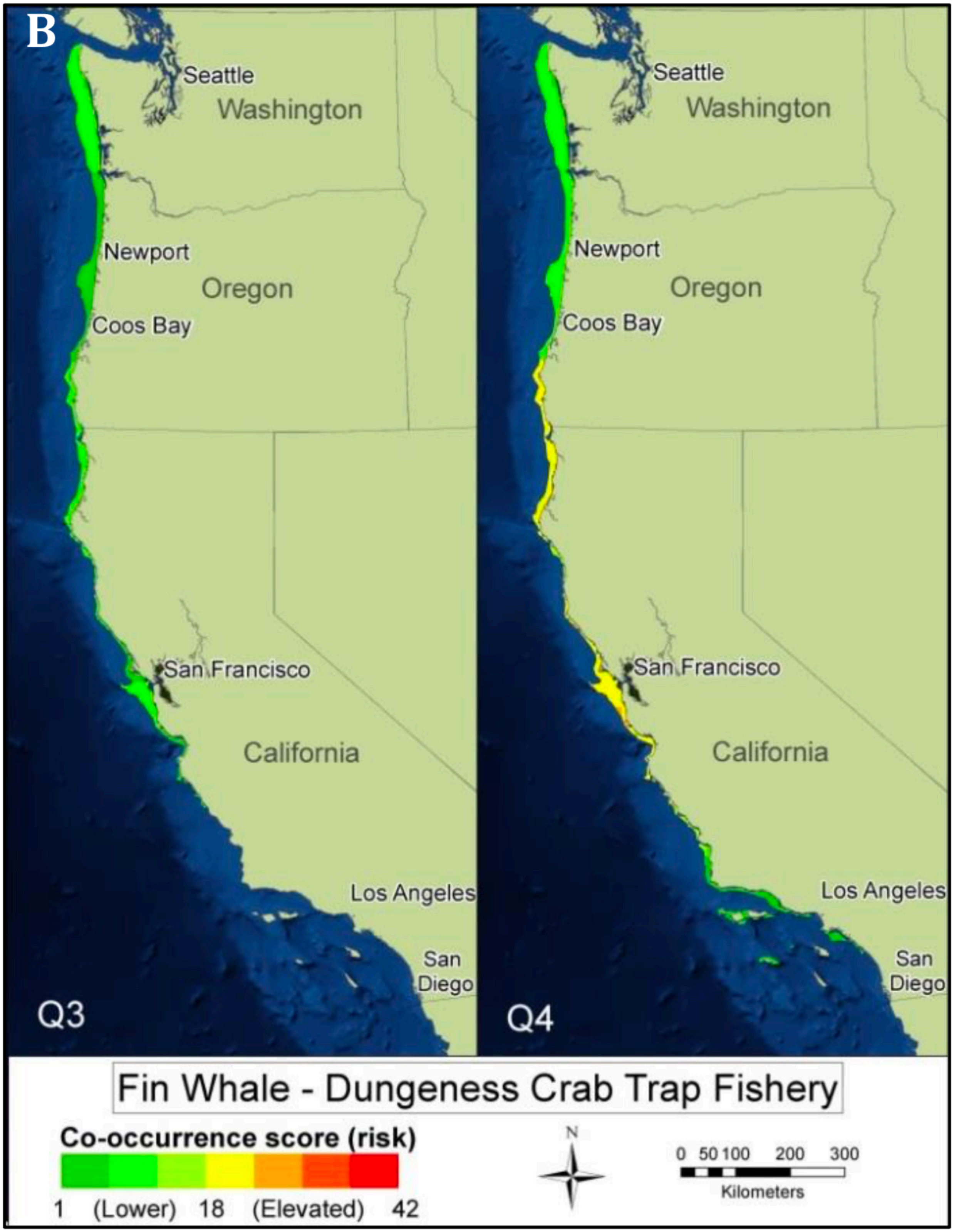

Figure *vii*. Co-occurrence of the multi-year average fin whale density and Dungeness crab trap effort, shown for Quarter Three and Four (Saez et al. 2013).