Final Report

Baleen Whale Tagging in Support of Marine Mammal Monitoring Across Multiple Navy Training Areas Covering the Years 2014, 2015, and 2016

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A blue whale (*Balaenoptera musculus*) raises its flukes at the start of a foraging dive in Southern California, 2016. Photograph taken by Craig Hayslip under National Marine Fisheries Service Permit 14856 issued to Dr. Bruce Mate.

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14. ABSTRACT
This report details the results of three years (2014-2016) of tracking data for blue and fin whales (Balaenoptera musculus and B. physalus, respecitvely) tagged in southern California waters, as well as one season of tracking data for humpback whales (Megaptera novaeangliae) tagged off the Oregon coast. The resulting tracks and dive behavior data provide valuable information regarding the timing, distribution, and behavior of these species within Navy training ranges in the eastern Pacific and NMFS-identified Biologically Important Areas (BIAs) for blue whales, and allow for the examination of baleen whale movements in relation to oceanographic conditions. The biopsy samples collected provided sex determination for tagged whales and individual identifications, as well as stock structure information

Tagging occurred off the coast of southern and central California in the months from July to September. Three types of tags were used: Location-Only (LO) tags, providing long-term tracking information via the Argos satellite system, Dive Monitoring (DM) tags, providing intermediate duration Argos tracking and dive behavior (duration, depth, number of feeding lunges per dive), and Advanced Dive Behavior (ADB) tags, providing short-term, fine-scale dive profile information and Global Positioning System (GPS)-quality locations. Twenty-four blue whales (20 LO tags, 4 ADB tags) and six fin whales (3 LO, 3 ADB) were tagged in 2014. Twenty-two blue whales (18 LO, 4 ADB), and 11 fin whales (9 LO, 2 ADB) were tagged in 2015. Nineteen blue whales (11 LO tags, 8 DM tags) and 14 fin whales (5 LO tags, 9 DM tags), were tagged in 2016. In addition, one blue/fin whale hybrid (LO), and one Bryde's whale (LO) were tagged in

2015. Two humpback whales were tagged with DM tags off Newport, Oregon, in 2016. Locations were received from all but four tags (2 blue, 2 fin), with tracking periods ranging from 0.6 to 283.8 days (d). Average tracking duration for non-ADB tags was 76.8 d (standard deviation [SD] = 62.3 d) for blue whales and 55.9 d (SD = 54.0 d) for fin whales, for the 3 years combined.

Both blue and fin whales were quite widespread in their tracked distribution, with locations over the three years extending from the northern tip of Vancouver Island, British Columbia, to very close to the equator for blue whales, and from Haida Gwaii, British Columbia, to the northern coast of Baja California for fin whales. Differences existed between years, however, for both species, in sizes of home ranges (HRs) and core areas (CAs), in latitudinal extent of movements, in total distance traveled, and in whales' use of Navy training ranges and NMFS-identified BIAs for blue whales. Blue whales were distributed farther north, traveled significantly longer distances, and had significantly larger HRs and CAs in 2014 than in either 2015 or 2016. Fin whales were distributed farther north in 2015 and 2016 than in 2014, but had significantly larger HRs and CAs in 2015 than either 2014 or 2016. Distances traveled by fin whales were significantly longer in 2015 than in 2016, but were of intermediate lengths in 2014.

Blue whales had locations in the Southern California Range Complex (SOCAL), Point Mugu Range Complex (PT MUGU), and the Northwest Training and Testing Study Area (NWTT) in all three tagging years, but locations in Warning Area 237 (W237) of the Northwest Training Range Complex (NWTRC) occurred in 2014 only. Blue whales were not found in the Gulf of Alaska (GOA) training range in any year. PT MUGU was the most heavily-used Navy training range by blue whales for the three years of study combined, both in terms of total numbers of whales having locations there (50 of 63 tracked whales), residence time (overall mean of 26.2 d), and overlapping HRs and CAs. SOCAL was also used by a high number of blue whales (37 of 63 tracked whales) and was the most heavily used range in terms of whale numbers in 2014. The NWTT was used by a small number of blue whales (9 of 63) over the three-year study, but those that were located there spent an average of 23.2 d in the area, resulting in more extensive overlap of HRs and CAs with this range than with SOCAL. An equal proportion (17 percent) of tracked blue whales was located in NWTT in both 2014 and 2016. Only one of 63 tracked blue whales had locations in area W237 of the NWTT, spending 19.5 d in the area in 2014. Seasonality in the Navy training ranges was very similar between tagging years, with locations occurring predominantly in the summer and fall (July through November in SOCAL and PT MUGU, August through November in NWTT, September through November in W237).

Fin whales had locations in the PT MUGU and NWTRC ranges in all three years, but locations in SOCAL occurred only in 2014 and 2015, and in area W237 in 2015 and 2016 only. The GOA training range had no fin whale locations in any of the three years. PT MUGU was the most heavily used Navy training range for fin whales in all three tagging years, in terms of number of whales having locations there as well as HRs and CAs occurring there. SOCAL was the second most heavily used training range in terms of number of fin whales as well as HR and CA overlap in 2014, but the NWTT area was the second most heavily used range in 2015. No fin whales tagged in 2016 had locations in SOCAL, and only one fin whale crossed through the NWTT in 2016. Two whales had locations in area W237 of the NWTT in 2015, and one in 2016, but the latter only passed through the area briefly on its way further north. Fin whale use of NWTT and W237 occurred primarily in late summer and fall, whereas fin whales could be found in PT MUGU in summer, fall, and winter, and in SOCAL in all seasons.

Of the 43 biopsy-sampled blue whales, 18 were determined to be females and 25 were males. There were no significant differences in mtDNA haplotype frequencies between the tagged blue whales from 2014–2016 and the reference database for the eastern North Pacific. Of the 20 samples collected from whales that were identified in the field to be fin whales, one was found to be a Bryde's whale (Balaenoptera brydei/edeni) and one was found to be a blue/fin hybrid. Of the 18 biopsy-sampled fin whales, 10 were females and 8 were males.To investigate population structure, we compared the mtDNA haplotype frequencies of the 18 tagged fin whales to a reference dataset of 397 samples. Despite the small sample sizes for these comparisons, the haplotype frequencies of the tagged fin whales from all years showed significant differences from several of the other strata, including California/Oregon/Washington and the Gulf of California, but not the Southern California Bight. Three humpback whales were biopsy-sampled, two were determined to be male and one was female. Both of the mtDNA haplotypes resolved in the tagged humpback whales have been identified previously in North Pacific humpback whales.

15. SUBJECT TERMS

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Executive Summary

Oregon State University's Marine Mammal Institute (OSU) conducted a three-year (2014, 2015, and 2016) tagging and tracking study on eastern North Pacific blue whales (*Balaenoptera musculus*) and fin whales (*Balaenoptera physalus*) to determine their movement patterns, occurrence, and residence times within United States (U.S.) Navy training and testing areas along the U.S. West Coast. This work was performed in support of the Navy's efforts to meet regulatory requirements for monitoring under the Endangered Species Act and the Marine Mammal Protection Act. Tagging occurred off the coast of southern and central California in the months from July to September. Three types of tags were used: Location-Only (LO) tags, providing long-term tracking information via the Argos satellite system, Dive Monitoring (DM) tags, providing intermediate duration Argos tracking and dive behavior (duration, depth, number of feeding lunges per dive), and Advanced Dive Behavior (ADB) tags, providing short-term, fine-scale dive profile information and Global Positioning System (GPS)-quality locations. This report presents detailed results from the 2016 tagging as well as interannual comparisons for both blue and fin whales between 2014, 2015, and 2016. Detailed results from the 2014 and 2015 tagging years can be found in OSU's final reports submitted in 2015 and 2016 (Mate et al. 2015, Mate et al. 2016).

Twenty-four blue whales (20 LO tags, 4 ADB tags) and six fin whales (3 LO, 3 ADB) were tagged in 2014. Twenty-two blue whales (18 LO, 4 ADB), and 11 fin whales (9 LO, 2 ADB) were tagged in 2015. Nineteen blue whales (11 LO tags, 8 DM tags) and 14 fin whales (5 LO tags, 9 DM tags), were tagged in 2016. In addition, one blue/fin whale hybrid (LO), and one Bryde's whale (LO) were tagged in 2015. Two humpback whales were tagged with DM tags off Newport, Oregon, in 2016. Locations were received from all but four tags (2 blue, 2 fin), with tracking periods ranging from 0.6 to 283.8 days (d). Average tracking duration for non-ADB tags was 76.8 d (standard deviation [SD] = 62.3 d) for blue whales and 55.9 d (SD = 54.0 d) for fin whales, for the 3 years combined.

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Of the six blue whale BIAs that overlap Navy training ranges, the Santa Barbara Channel and San Miguel Island BIA appeared to be the most important area to blue whales, in terms of number of whales using the area, time spent there (with a maximum residency of 63.3 d), and number of overlapping CAs within the area. There were differences in BIA use between years, however, with the San Diego and the Santa Monica Bay to Long Beach BIAs being the most heavily used in 2014, whereas the Santa Barbara Channel and San Miguel Island and the Point Conception/Arguello BIAs being the most heavily used in 2015 and 2016. The remaining two BIAs, San Nicolas Island and Tanner/Cortez Banks, were used only minimally by blue whales in all three years, with residencies ranging from <0.1 to 1.7 d for Tanner/Cortez Bank, and 0.1 to 0.3 d for San Nicolas Island. Blue whale occurrence in BIAs was similar between years, taking place in summer and fall (July to November).

Fin whales had locations in the PT MUGU and NWTRC ranges in all three years, but locations in SOCAL occurred only in 2014 and 2015, and in area W237 in 2015 and 2016 only. The GOA training range had no fin whale locations in any of the three years. PT MUGU was the most heavily used Navy training range for fin whales in all three tagging years, in terms of number of whales having locations there as well as HRs and CAs occurring there. SOCAL was the second most heavily used training range in terms of number of fin whales as well as HR and CA overlap in 2014, but the NWTT area was the second most heavily used range in 2015. No fin whales tagged in 2016 had locations in SOCAL, and only one fin whale crossed through the NWTT in 2016. Two whales had locations in area W237 of the NWTT in 2015, and one in 2016, but the latter only passed through the area briefly on its way further north. Fin whale use of NWTT and W237 occurred primarily in late summer and fall, whereas fin whales could be found in PT MUGU in summer, fall, and winter, and in SOCAL in all seasons.

ADB-tagged blue whales were tracked for a median of 22.4 d, and seven of eight tags were recovered for data download. Each tag recorded more than 1,300 dives. The numbers of GPS locations recorded by the tags were highly variable, ranging from 185 to 2,539. The wide range in the number of recorded GPS locations was likely due to tags using different versions of the Fastloc® GPS software as well as to variations in placement on the whales. Tagged blue whales made deeper dives during the day when most foraging activity also occurred. The whales generally fed in relatively small (median 2.6 square kilometers) areas for time periods ranging from less than 1 to 20.5 h (median = 7.1 h). Foraging bout analysis indicated that the duration of a bout was correlated to the number of feeding lunges made per dive during the bout, suggesting the whales quickly left less productive prey patches.

Five ADB-tagged fin whales were tracked for a median of 14.4 d, and three of the tags were recovered for data download. The shorter tracking duration compared to ADB-tagged blue whales was due to the tags being shed by the whales more rapidly. The three recovered tags recorded a median of 1,188 dives and 228 GPS locations. Diel variability in dive depths and feeding behavior similar to blue whales was recorded by the tags. The general behavior of ADB-tagged fin whales was similar to what was recorded for blue whales, although they generally used different parts of the southern California waters.

In 2016, DM tags were attached to eight blue whales and nine fin whales, staying attached for medians of 61.7 and 28.7 days and providing summaries for medians of 2,294 and 1,670 dives per whale, respectively. Feeding effort of DM-tagged blue whales was generally focused in a few localized, highly productive regions, with feeding also occurring in more diffuse offshore areas. DM-tagged fin whales recorded relatively consistent feeding effort across their central California tracking range except one whale that travelled north to the Hecate Strait and fed there for the remainder of its tracking period. In general, tagged blue whales were more likely to feed in localized areas, while tagged fin whales fed across broad areas.

Of the whales tagged with either ADB or DM tags, male whales of both species (n = 4 from 2014 to 2016) made long, clock-wise circuits of southern California waters with little feeding, while female tracks were generally more clustered and reported more feeding behavior. This suggests that there may be a reproductive or courtship aspect that influences the behavior of male whales of both species while using southern California waters in summer.

Two DM tags were deployed on humpback whales off Oregon in 2016, staying attached for 7.3 and 18.9 days and providing summaries for 563 and 1,032 dives, respectively. The two DM-tagged humpback whales behaved very differently, with one showing little evidence of diel variability in its diving behavior and the other showing a strong diel difference in both dive depths and the number of lunges recorded. This difference may have been related to the first whale's move from Oregon to northern California.

This project also sought to identify ecological relationships that help explain the spatial and temporal movement patterns by tracked blue and fin whales in the eastern North Pacific from bathymetric and satellite-determined measurements. For this purpose, we applied state-space models (SSM) to regularize the tracks, improve location estimates, and classify movement behavior. We then used the SSM data to put whale distribution in a biogeographic context and to characterize the influence of oceanographic and climatic events on the distribution and movement behavior of the tracked whales. Blue whales covered a large but interannually variable geographic extent (20 to 44 degrees of longitude and 26 to 44 degrees of latitude). From a biogeographic perspective, the majority of the SSM locations for blue whales occurred in the California Current Province (CCAL) and in the North Equatorial Countercurrent Province, with a small proportion occurring in adjacent provinces (including the Pacific Equatorial

Divergence Province and the Gulf of California Province). The SSM provided a behavioral classification for each location, and we interpreted area-restricted searching (ARS) within CCAL as foraging activity. The proportion of locations classified as ARS in CCAL was lower in 2014 and 2015 (11.2 percent and 18.4 percent of locations, respectively), while it was very high in 2016 (51 percent). Blue whale ARS activity went from very low in 2014 (11 percent), as animals spent most of their time transiting in offshore waters, to very high in 2016 (51 percent), as animals spent most of their time foraging. The little ARS activity in 2014 occurred in the warmest sea surface temperature (SST) recorded during the study (mean = 22.9 degrees Celsius [°C]), compared to the more predominant ARS activity that was recorded in cooler waters in 2015 (mean = 19.1°C) and even more so in 2016 (mean = 16.3°C). Correspondingly, chlorophyll-*a* concentration (CHL) in the areas where ARS activity took place steadily increased from 2014 (mean = 0.70 milligrams per cubic meter [mg m^{-3}]) through 2015 (mean = 0.71 mg m^{-3}) and 2016 (mean = 1.72 mg m^{-3}). During 2016, ARS activity took place in shallower waters (mean = 644.1 meters [m]), near the shelf break (mean = 13.3 kilometers [km]), and closer to shore (mean = 33.5 km) than in the previous years. These interannual differences were likely in response to the strongly anomalous oceanographic conditions that occurred during the study, including warm anomalies associated with the marine heat wave of 2013–2015 and with the 2015–2016 El Niño event, and cold anomalies associated with the 2016–2017 La Niña event. These perturbations likely had an impact on the abundance, distribution, species composition, and nutritional value of the euphausiids upon which blue whales forage.

The geographic extent covered by the fin whales was smaller than that of the blue whales (10 to 16 degrees of longitude and 12 to 22 degrees of latitude), but it also displayed marked interannually variability. Also, while blue whales migrated in late fall and winter from CCAL to lower-latitude provinces, fin whales moved northward and remained in CCAL or visited the Alaska Downwelling Coastal Province. Interannual differences in fin whale behavior in CCAL suggested very low foraging success in 2015 (11 percent ARS activity), relative to the other two years (19 percent in 2014 and 35 percent in 2016). In contrast, blue whale foraging success in 2015 (during El Niño) was higher than in 2014 (during the heat wave). Examination of SST and CHL values where ARS activity occurred provided clues for this interspecific difference in foraging success: while in 2015 blue whales foraged in areas with lower SST and higher CHL than in 2014, fin whales occurred in areas with warmer SST (mean = 18.5 and 16.7°C, respectively) and lower CHL levels (mean = 0.48 and 1.13 mg m^{-3}, respectively) in the two years. In contrast, in 2016, the two species foraged in habitats with cooler SST and elevated CHL (during La Niña), and both had the highest levels of ARS. These results suggest that the anomalous warm events of 2014 and 2015 had different impacts on blue and fin whales. Being found generally further inshore in most of CCAL, blue whales appeared to have fared better than fin whales during the 2015–2016 El Niño event, likely because they were able to take advantage of the elevated biological productivity provided by several locations along the coast where upwelling remained despite the otherwise unfavorable conditions prevalent further offshore. Thus, despite partial spatial and environmental overlap, fin and blue whales have distinct ecological optima that likely reflect different prey resource utilization in much of their range. With the 2014 shift to a warm phase of the Pacific Decadal Oscillation, in the next decade, we might expect blue and fin whale range and movement patterns in CCAL to change, given that the prey types they forage on (euphausiids and pelagic schooling fish, respectively) respond strongly to decadal variability.

The short tracking period and the small geographic extent (0.6 degrees of longitude by 4 degrees of latitude) covered by the two humpback whales tagged off Oregon in 2016 prevented us from drawing robust ecological inferences. Generally, however, compared to blue and fin whales, humpback whale habitat off Oregon and northern California on average occurred in areas characterized by downwelling (-3.8e-07 m second^{-1}), colder SST (13.4°C), and much higher CHL levels (6.78 mg m^{-3}). The two humpback whales were found in much shallower depth (143.2 m), over seafloor with very gentle slope (7.69 m km^{-1}), and closer to shore (27.5 km).

Tissue samples collected from the tagged blue, fin, and humpback whales in 2014, 2015, and 2016, were used for 'deoxyribonucleic acid (DNA) profiling,' including sex identification, sequencing of mitochondrial DNA (mtDNA) control region haplotypes, and genotyping of up to 17 microsatellite loci. The DNA profiles were used to confirm species identification and individual identity and to investigate population structure using published information on mtDNA haplotype frequencies or unpublished referenced databases developed through collaborative agreements.

For all years combined, the 43 samples of blue whales were represented by unique multi-locus genotypes with an average probability of identity of 6.8×10^{-16} (i.e., there was a very low probability of a match by chance). Of the 43 individuals, 18 were females and 25 were males. Of the 13 mtDNA haplotypes resolved in the tagged blue whales from 2014–2016, 9 matched to the 16 haplotypes represented in reference database from the eastern North Pacific (n = 76 individuals), resulting in a total of 20 haplotypes for this stock. There was no evidence of differences in haplotype frequencies of the tagged blue whales in comparison to the reference database from the eastern North Pacific. Although this comparison provided reasonable confidence that the two samples do not represent distinct stocks, we cannot discount the potential for more subtle spatial heterogeneity or fine-scale population structure in this geographic region. Our analysis of stock structure was also limited by the absence of samples from other putative stocks in the North Pacific, particularly the western North Pacific stock.

Of the 20 samples collected from whales and identified in the field to be fin whales, one was found to be a Bryde's whale (*Balaenoptera brydei/edeni*) and one was found to be a blue/fin hybrid. In collaboration with researchers from Cascadia Research Collective, we used the DNA profile of the hybrid to confirm a match with a previously reported hybrid individual, first sampled off California on 22 September 2004, providing an 11-year record of genotype recapture.

All of the 18 tagged fin whales were represented by unique multi-locus genotypes, with an average probability of identity of 8.8×10^{-21} (i.e., there was a very low probability of a match by chance). Of the 18 individuals, 10 were females and 8 were males. To investigate population structure, we compared the mtDNA haplotype frequencies of the 18 tagged fin whales to a reference dataset of 397 samples. Despite the small sample sizes for these comparisons, the haplotype frequencies of the tagged fin whales from all years showed significant differences from several of the other strata, including California/Oregon/Washington and the Gulf of

California, but not the Southern California Bight. However, we note that the location of tagging/sampling of fin whales shifted to the north in 2016. Sample sizes were not sufficient for an analysis of any differences due to this change in location.

The three humpback whales (two tagged and one tag miss) were represented by unique multi-locus genotypes with an average probability of identity of 6.2×10^{-12} (i.e. there was a very low probability of a match by chance). Two of the three individuals were male and one was female. Both of the mtDNA haplotypes resolved in the tagged humpback whales have been identified previously in North Pacific humpback whales. The sample size was too small for statistical analysis; however, a qualitative comparison with an ocean-basin wide reference dataset of mtDNA haplotypes (n = 1981) suggested a greater stock affinity of these whales with humpback whales feeding from Oregon to southeastern Alaska than to those from central and southern California.

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Acronyms and Abbreviations

°C	degree(s) Celsius
ADB	Advanced Dive Behavior
ALSK	Alaska Downwelling Coastal Province
ARS	area-restricted searching
ASPECT	compass direction of the bottom slope (data variable)
BIA	Biologically Important Area
BLAST	Basic Local Alignment Search Tool
bp	base pair
CA	core area
CAMR	Central American Coastal Province
CCAL	California Current Province
CHL	chlorophyll-*a* (data variable)
cm	centimeter(s)
CRD	Costa Rica Dome
d	day(s)
DEPTH	water depth (data variable)
DISTSHELF	distance from the 200-m isobath/shelf break (data variable)
DISTSHORE	distance from shore (data variable)
DM	dive monitoring
DNA	deoxyribonucleic acid
DPS 6	Distinct Population Segment 6: Central America
EEZ	Exclusive Economic Zone
ERDDAP	Environmental Research Division Data Access Program
g	gram(s)
GOA	Gulf of Alaska Temporary Maritime Activities Area
GPS	Global Positioning System
GUCA	Gulf of California Province
HR	home range
ID	identification
km	kilometer(s)
km^2	square kilometer(s)
LC	location class
LO	location only
m	meter(s)

mg m^{-3}	milligrams per cubic meter
min	minute(s)
mtDNA	mitochondrial deoxyribonucleic acid
Navy	U.S. Navy
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPGO	North Pacific Gyre Oscillation
NPPF	North Pacific Transition Zone Province
NPTG	North Pacific Tropical Gyre Province
NWTRC	Northwest Training Range Complex
NWTT	Northwest Training and Testing Study Area
ONI	Oceanic Niño Index
OSU	Oregon State University Marine Mammal Institute
PCR	Polymerase Chain Reaction
PDO	Pacific Decadal Oscillation
PNEC	North Pacific Equatorial Countercurrent Province
PQED	Pacific Equatorial Divergence Province
PSAE	Pacific Subarctic Gyre-East Province
PT MUGU	Point Mugu Range Complex
R/V	research vessel
s	second(s)
SD	standard deviation
SE	standard error
SLOPE	bottom slope (data variable)
SOCAL	Southern California Range Complex
SPLASH	Structure of Populations, Levels of Abundance, and Status of Humpbacks
SSM	state-space model
SST	sea-surface temperature (data variable)
UTC	Coordinated Universal Time
U.S.	United States
W237	Warning Area 237 of the Northwest Training and Testing Study Area
WEKM	vertical upwelling velocity (data variable)

1. Introduction

Whales of several species in the eastern North Pacific Ocean, including blue (*Balaenoptera musculus*), fin (*Balaenoptera physalus*), and humpback (*Megaptera novaeangliae*) whales, arrive in the productive California Current ecosystem off the West Coast of the United States (U.S.) in summer and fall months (Larkman and Veit 1998, Burtenshaw et al. 2004, Oleson et al. 2007, Dransfield et al. 2014, Irvine et al. 2014, Fleming et al. 2016) to forage on the seasonally abundant aggregations of euphausiids and schooling fish, their primary prey (Schoenherr 1991, Fiedler et al. 1998, Croll et al. 2005). Breeding and offspring rearing takes place in low latitudes in winter and spring, with blue whales migrating the Costa Rica Dome off Central America and to the Gulf of California in Mexico (Bailey et al. 2009), and humpback whales migrating to Mexican and Central American destinations (Calambokidis et al. 2000). In contrast, fin whales do not appear to migrate to low latitudes, remaining year-round in the California Current (Scales et al. 2017).

In 2016 the Oregon State University Marine Mammal Institute (OSU) conducted a third year of tagging operations in support of the U.S. Navy's (Navy) marine mammal monitoring in three areas along the U.S. West Coast: (1) the Southern California Range Complex (SOCAL), which is a portion of the Hawaii-Southern California Training and Testing Study Area, (2) the Point Mugu Range Complex (PT MUGU), and (3) the Northwest Training and Testing Study Area (NWTT), which includes both the Northwest Training Range Complex (NWTRC) and the Warning Area-237 (W237). The focus of these studies is to address key science objectives the Navy has committed to complete as part of regulatory requirements promulgated from the National Marine Fisheries Service (NMFS). In particular, this multi-year project was designed to address the following questions:

1. What are the movement patterns, occurrence, and residence time of blue and fin whales within Navy training and testing areas along the U.S. West Coast as compared to other areas visited by tagged whales outside of Navy training and testing areas?
2. What are the residency time/occupancy patterns of blue whales within NMFS-designated Biologically Important Areas (BIAs) for this species along the U.S. West Coast? (i.e., the areas identified in 2015 by Calambokidis et al. [2015] and referenced in the Navy's Letter of Authorization (LOA) and Environmental Impact Statement [EIS])
3. Are there bathymetric, annual oceanographic conditions (e.g., sea surface temperature, frontal zones, etc.), and/or climatic and ocean variations (e.g., global warming, North Pacific Gyre Oscillation [NPGO], Pacific Decadal Oscillation [PDO], El Niño/La Niña events, etc.) that can help explain blue and fin whale affinity for any identified areas of high residency along the U.S. West Coast?

In order to address these questions, the project's specific objectives for 2016 were as follows:

A. Determine blue and fin whale distribution and habitat use through deployment of long-term location-only (LO) satellite tags to refine understanding of short- and long-term movement patterns and, most importantly, to generate metrics for defining residency times, home ranges (HRs) and core areas (CAs), area-restricted searches (ARS), and migratory timing.

B. Determine blue and fin whale behavior changes over time, by individual and between individuals, over the course of several weeks by deploying intermediate-duration dive monitoring (DM) tags. This new technology incorporates depth and tri-axial accelerometer sensors into the traditional LO-tag design, enabling us to obtain a relative measure of foraging effort and its changes over time via satellite, without the need to recover the tags.

C. Identify ecological relationships that will help explain/predict spatial and temporal movement patterns from bathymetric and satellite-determined measurements like sea surface temperature (SST), frontal zones, phytoplankton chlorophyll-*a* (CHL) concentration, salinity, or current information derived from altimetry.

D. Conduct genetic analyses from tissue samples of tagged blue and fin whales to integrate with the tracking results and further expand their interpretation. These analyses include determination of sex, mitochondrial haplotypic composition, nuclear microsatellite locus composition, individual identification, population structure, and interspecific introgressive hybridization.

Additionally, in 2016 OSU obtained permission from the Navy to deploy DM tags on humpback whales off Newport, Oregon. Humpback whales using this area are thought to be part of the recently designated "Distinct Population Segment 6: Central America" (DPS 6) by NMFS, with an Endangered Species Act conservation status of "Endangered" (DOC-NOAA 2016, DOI-FWS 2016). The distribution range of DPS 6 extends from the feeding ground in waters off California, Oregon, and Washington to the breeding ground off Central America (Bettridge et al. 2015, DOC-NOAA 2016, DOI-FWS 2016); hence, whales from this population are likely to occupy Navy training and testing areas off the U.S. West Coast during the feeding season in summer and fall. Therefore, the questions and objectives described above for blue and fin whales also apply to humpback whales in this report.

This Final Report presents detailed analyses of the 2016 blue, fin, and humpback whale tracking results, including deployment specifics and tracking information through 8 April 2017, when the last tag stopped transmitting, as well as interannual comparisons of tracking results between 2014, 2015, and 2016. It includes maps of whale tracks, HRs, and CAs of highest use for all three years of the study, as well as the seasonality and extent of use of Navy training ranges and BIAs by blue and fin whales for all three years. This report also includes analyses of the dive characteristic data obtained from the DM tags used in 2016 and a comparison of these results with those from Advanced Dive Behavior (ADB) tags used in 2014 and 2015. It further provides a characterization of whale-tracking data in the context of environmental conditions and a comparison between years. Finally, the report provides the results of genetic analysis of biopsy samples from all three years, including sex determination, individual identification, and species and stock identification.

2. Methods

2.1 Field Efforts

Blue and fin whale tagging efforts in 2016 took place off the southern and central coast of California, where they are reliably found during summer and fall months, during one 30-day cruise aboard the research vessel (R/V) *Pacific Storm*. The 26-meter (m) *Pacific Storm* served as a home base and support vessel for the research crew, as well as an additional platform from which to search for whales and conduct visual observations. The cruise took place from 6 July to 5 August 2016, departing from Santa Barbara and returning to Half Moon Bay. There was one crew change on 20 July 2016 in Marina Del Rey. Tagging efforts were conducted on 12 days (d). Aerial observations to locate whales were conducted on 7 d between 1 and 26 July 2016. Tagging activities began off southern California, but switched to central California after 2 weeks due to a scarcity of "tagable" (i.e., in good body condition) whales in southern California. Whales were considered in poor body condition if they appeared emaciated (having a post-cranial depression, subdermal protrusion of the scapula, or depression along the dorsal aspect of the lateral flanks; Brownell and Weller 2001).

All tagging efforts were conducted from a small, 6.4-m rigid-hulled inflatable boat launched with a crane from the back deck of the R/V *Pacific Storm*. The tagging crew consisted of a tagger, biopsy darter, photographer, data recorder, and boat driver. Identification (ID) photos were taken of all tagged whales for comparison with existing ID catalogs for blue and humpback whales (maintained by Cascadia Research Collective, Olympia, Washington), and for fin whales (maintained by Marine Ecology and Telemetry Research, Seabeck, Washington). Candidate whales for tagging were selected based on visual observation of body condition. No whales were tagged that appeared emaciated or that were extensively covered by external parasites. Satellite tags were deployed using an Air Rocket Transmitter System air-powered applicator following the methods described in Mate et al. (2007). Tags were deployed from distances of 1 to 4 m with 85- to 90-pound force per square inch in the applicator's 70-cubic centimeter pressure chamber.

Humpback whale field efforts took place on two days (15 September and 11 October 2016) out of Newport, Oregon, aboard a 6.4 m tagging rigid-hulled inflatable boat, following identical procedures as for blue and fin whale tagging. Satellite tags were deployed from distances of 2 m with 95–100 pounds of pressure in the applicator.

2.2 Tagging

2.2.1 Satellite Tags

Two types of tags were used in 2016: Wildlife Computers' Smart Positioning or Temperature Transmitting Tag, version 6 (SPOT6, referred to hereafter as Location-Only or LO tags) and Telonics RDW-665 (hereafter referred to as Dive-Monitoring or DM tags). Both tag types follow the same design, which is composed of a main body, a penetrating tip, and an anchoring system (**Figures 1 and 2**). The main body consists of a stainless steel cylinder (2.0 centimeters [cm] in diameter × 20.7 cm in length for the LO tag, and 1.9 cm in diameter × 20.7 cm in length

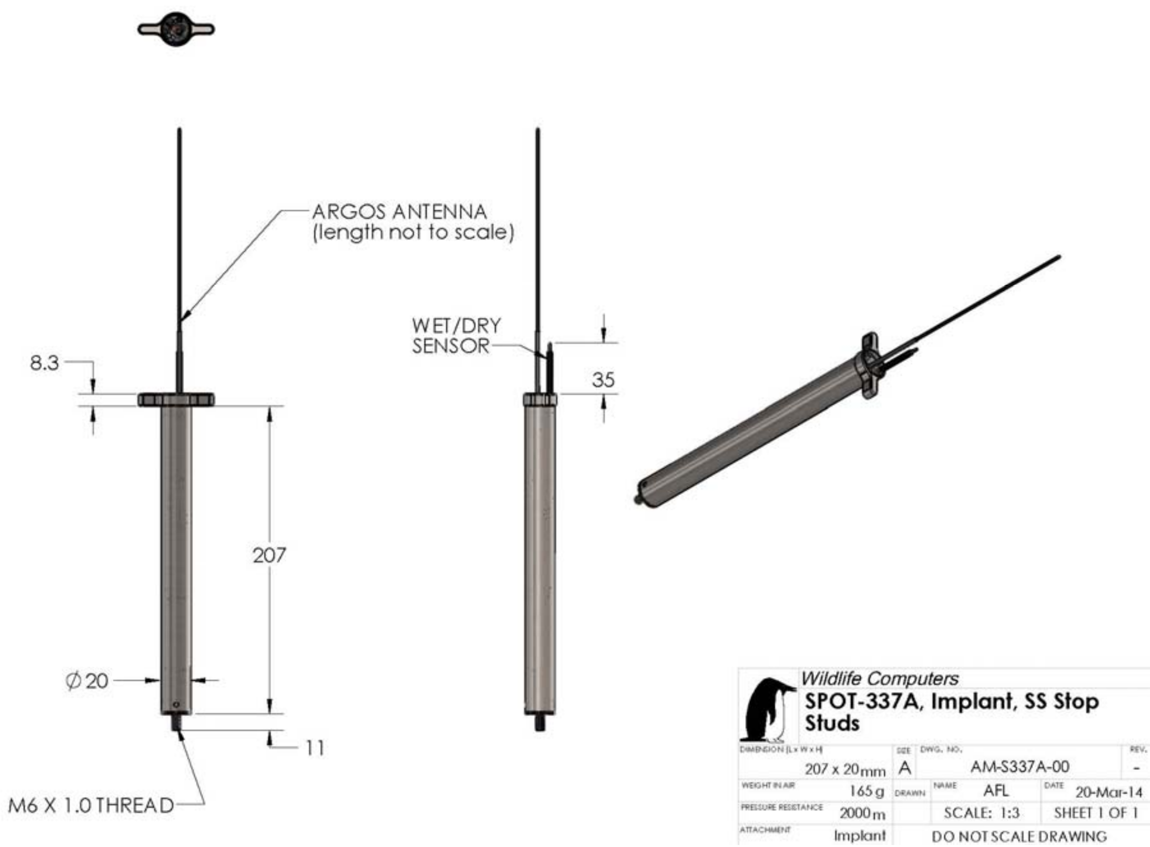

Figure 1. Schematic diagram of the Wildlife Computers SPOT6 (also known as SPOT-337A) LO tag, showing the main body and the distal endcap with the antenna and saltwater conductivity switch. The penetrating tip and anchoring system are depicted in Figure 2.

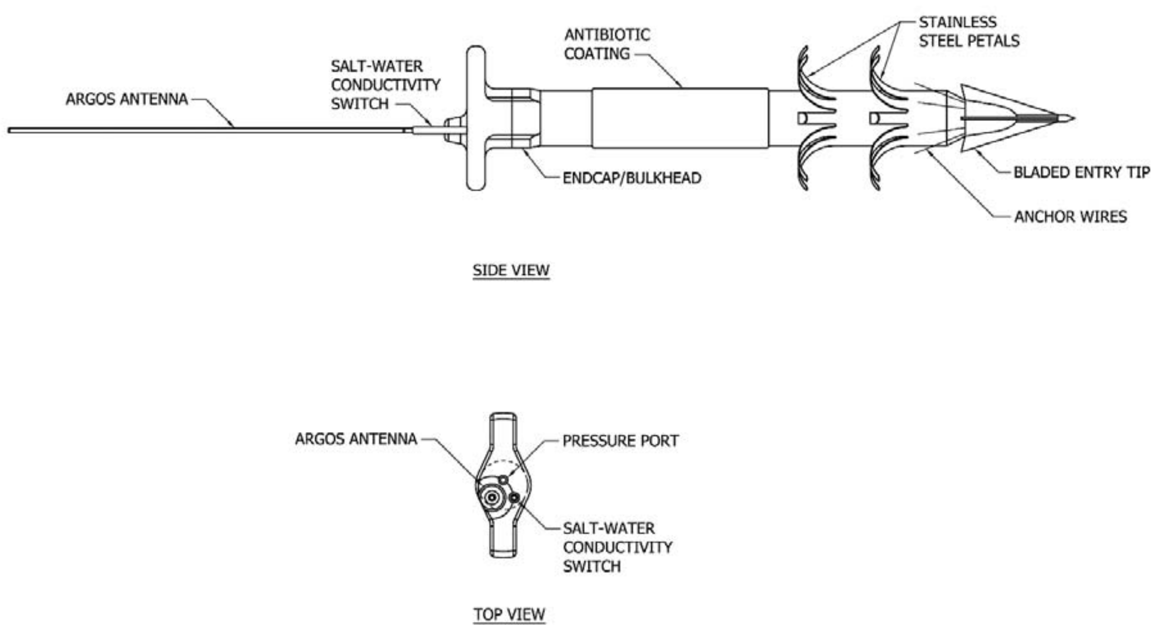

Figure 2. Schematic diagram of the Telonics RDW-665 DM tag showing the main body, the distal endcap with the antenna and saltwater conductivity switch endcap, as well as the penetrating tip and anchoring system.

for the DM tag) that houses a certified Argos transmitter. A flexible whip antenna and a saltwater conductivity switch are mounted on the distal endcap of this cylinder, while a penetrating tip is screwed onto the other end. The distal endcap has two perpendicular stops (0.83 cm thick for the LO tag and 0.63 cm thick for the DM tag) extending approximately 1.5 cm laterally to prevent tags from embedding too deeply on deployment or from migrating inward after deployment. The penetrating tip consists of a Delrin® nose cone, into which is pressed a ferrule shaft with four double-edged blades. The anchoring system consists of metal wires mounted behind the blades on the penetrating tip and two rows of outwardly curved metal strips mounted on the main body at the nose cone (proximal) end. Total tag weight is 200 grams (g) for the LO tags and 228 g for the DM tags. Tag cylinders are partially coated with a broad-spectrum antibiotic (gentamicin sulfate) mixed with a long-dispersant methacrylate. This allows for a continual release of antibiotic into the tag site for a period of up to 5 months (Mate et al. 2007). These tags are designed to be almost completely implantable (except for the perpendicular stops, antenna and saltwater switch) and are ultimately shed from the whale due to hydrodynamic drag and the natural migration of foreign objects out of the tissue (Mate et al. 2007).

In addition to providing transmissions for location calculation, the LO tag reports the percentage of time in user-specified temperature ranges. LO tags were programmed to transmit only when out of the water during four 1-hour (h) periods per day, coinciding with times when satellites were most likely to be overhead. With such a duty cycle, the life expectancy of a tag's battery is over 1 year. However, tags are generally shed sooner, or they may stop functioning due to electronic failure while still attached to a whale. The maximum tracking duration to date for a blue whale is 505 d, but the average duration is 102.5 d (Mate et al. 2015). Tag retention on humpback whales has proved to be shorter, as discussed in Mate et al. (2007).

The DM tag generates Argos locations similar to the LO tag and also incorporates a pressure sensor and tri-axial accelerometers, so it is able to record dive depth, duration, and body orientation and motion while attached to a whale. During a deployment, dive depth was recorded every 5 seconds (s) with 2 m vertical resolution up to a maximum of 511 m. Accelerometer readings were recorded every 0.25 s. For every dive exceeding a user-specified duration and depth (a "selected dive") the magnitude of the acceleration vector (*A*; Simon et al. 2012) was calculated as:

$$A = \sqrt{ax^2 + ay^2 + az^2}$$

Where *ax*, *ay*, and *az* are the *x*, *y*, and *z* components of the acceleration vector relative to the Earth's gravitational field.

The rate of change in this acceleration vector, or Jerk (Simon et al. 2012), was then calculated as:

$$\text{Jerk} = A_{(t+1)} - A_{(t)}$$

Peaks in Jerk value are associated with feeding lunges (Simon et al. 2012), so we used Jerk values that exceeded the mean Jerk $\pm$2.5 (or 3.5) standard deviations (SDs) (depending on the tag), calculated from all selected dives, to identify feeding lunges. Acceleration data recorded in the first 5 s or final 5 s of a selected dive were not used in these calculations to eliminate spurious peaks from strong fluking at the start or end of a dive. Lunges for each selected dive were then counted if they occurred more than 30 s from the previous lunge.

For this study, selected dives were identified as dives > 1-minute (min) duration and 10-m depth (or > 2-min duration and 10 m depth for tags deployed after 14 July 2016 after a preliminary assessment of the dives being reported by the first tags deployed). In addition to providing transmissions for location calculation, DM tags reported the start date and time of each selected dive, duration (1 s resolution up to a maximum of 4,095 s), maximum depth, and number of lunges for 4 to 6 consecutive selected dives, depending on data compression. DM tags were programmed to transmit only when out of the water during six 1-h periods per day, also coinciding with times when satellites were most likely to be overhead. With more transmission periods than the LO tags, and the extra power consumed by the tag sensors, the life expectancy of the DM tag's battery was approximately 100 d.

2.2.2 Argos Telemetry

Tagged whales were tracked using the Argos satellite-based system that assigns a quality to each location, depending, among other things, on the number and temporal distribution of transmissions received per satellite pass (Collecte Localisation Satellites 2015). The accuracy associated with each Argos satellite location is reported as one of six possible location classes (LCs) ranging from less than 200 m (LC = 3) to greater than 5 kilometers (km) (LC = B) (Vincent et al. 2002). Tag transmissions were processed by Argos using the Kalman filter to calculate locations (Collecte Localisation Satellites 2015). Received Argos locations were then filtered by OSU to remove locations occurring on land. Remaining Argos locations were further filtered by LCs and speeds, as follows. Locations of class Z were removed from analyses because of the large errors frequently associated with this class. Lower-quality LCs (LC = 0, A, or B) were not used if they were received within 20 min of higher-quality locations (LC = 1, 2, or 3). Speeds between remaining locations were computed, and if a speed between two locations exceeded 12 kilometers per hour, one of the two locations was removed, with the location resulting in a shorter overall track length being retained.

2.2.3 Tracking Analysis

2.2.3.1 CALCULATION OF DISTANCE FROM SHORE

The closest point on land was determined for each filtered Argos location in the Navy training ranges, using the NEAR toolbox function in ESRI® ArcMap v.10.3. The geodesic distance was then computed between each point and its corresponding whale location using the WGS 1984 ellipsoid parameters in ESRI® ArcMap v.10.3.

It should be noted here that distances to shore for the 2014 and 2015 data were calculated as great-circle distances (Mate et al. 2016). They have been recalculated here as geodesic distances following the methods outlined above, and are reported as such in the Interannual Comparison sections in the Results.

2.2.3.2 OCCURRENCE IN NAVY AREAS AND BIAS

Numbers of locations occurring inside versus outside Navy areas were computed for each whale track, with the percentage of locations inside reported as a proportion of the total number of locations obtained for each whale. Numbers of blue whale locations and corresponding percentages were also computed for areas that were identified in Calambokidis et al. (2015) as Biologically Important Areas (hereafter referred to as BIAs) for blue whales. Four of the nine BIAs (Calambokidis et al. 2015) overlapped completely or partially with the SOCAL area: Santa Monica Bay to Long Beach, San Nicolas Island, Tanner-Cortez Bank, and San Diego (using the same nomenclature for BIAs as in Calambokidis et al. [2015]). Two blue whale BIAs overlapped with the PT MUGU area: Santa Barbara Channel and San Miguel BIA and Point Conception/Arguello BIA. The other three blue whale BIAs (Calambokidis et al. 2015) did not overlap Navy areas and were not considered in this report.

To compute estimates of residence time inside Navy areas and overlapping BIAs, interpolated locations were derived at 10 min intervals between filtered Argos locations, assuming a linear track and a constant speed. These interpolated locations provided evenly spaced time segments from which reasonable estimates of residence times could be generated and were especially useful when tracklines crossed training area or BIA boundaries. Residence time was calculated as the sum of all 10 min segments from the interpolated tracks that were completely within each area of interest. Percentage of time spent in these areas was expressed as a proportion of the total track duration.

2.2.3.3 STATE-SPACE MODELING

A Bayesian switching state-space model (SSM) developed by Jonsen et al. (2005) was applied to the unfiltered Argos locations (except for the removal of Z-class locations) for each track, using the software R v. 2.12.1 and WinBUGS v. 1.4.3. The model provided a regularized track with one estimated location per day, after accounting for Argos satellite location errors (based on Vincent et al. 2002) and movement dynamics of the animals. The state-space model ran two Markov Chain Monte Carlo simulations each for 30,000 iterations, with the first 10,000 iterations being discarded as a burn-in, and the remaining iterations being thinned, removing every fifth one to reduce autocorrelation (Bailey et al. 2009). Included in the model was the classification of locations into two behavioral modes based on mean turning angles and autocorrelation in speed and direction: transiting (mode 1) and area-restricted searching (ARS; mode 2). Even though only two behavioral modes were modeled, the means of the Markov Chain Monte Carlo samples provided a continuous value from 1 to 2 (Bailey et al. 2009). As in Bailey et al. (2009) and Irvine et al. (2014), we chose behavioral modes greater than 1.75 to represent ARS locations and behavioral modes lower than 1.25 to represent transiting. Locations with behavioral modes in between these values were considered uncertain.

2.2.3.4 HOME RANGE ANALYSIS

Kernel HRs were created for the portion of each SSM track inside the U.S. Exclusive Economic Zone (EEZ; ocean waters extending out to 200 nautical miles of the U.S. coastline) using the least-squares cross-validation bandwidth selection method (Worton 1995, Powell 2000, Irvine et al. 2014). Kernel analysis was implemented using the "adehabitat" package (Calenge 2006) in R v. 2.12.1. The 90 percent (HR) and 50 percent (CA) isopleths were produced for each track with

30 or more estimated locations (Seaman et al. 1999) and all portions that overlapped land were removed. The areas of each whale's HR and CA were then calculated in ESRI® ArcMap v.10.0.

2.2.3.5 INTERANNUAL COMPARISONS

Comparisons between the three tagging years were conducted for tracking duration, total distance traveled for each whale, as well as HR and CA size using the STATGRAPHICS® Centurion XVI v.16.1.03 software package. Analysis of variance (ANOVA) was used to test whether there were any significant differences in the yearly mean values, and multiple range tests using the Fisher's least significant difference procedure determined which means were significantly different from one another. Test results were reported as ANOVA p-values because multiple range tests in STATGRAPHICS® only report a 95percent significance level, rather than an exact p-value. ANOVAs were also used for yearly comparisons in time spent by whales in Navy training ranges and BIAs (for blue whales), and for mean distances to shore in Navy training ranges. Locations of whales tagged in 2014 were retroactively assigned to BIAs for these comparisons, despite the fact that BIAs were not formerly designated until 2015.

2.2.4 ADB Tag Analysis

ADB tags were used in 2014 and 2015 to characterize dive behavior. A description of the design and characteristics of the ADB tag was presented in last year's report (Mate et al. 2016). To establish a baseline orientation for the position of the tag on the whale, a series of three temporally close Fastloc® Global Positioning System (GPS) locations were identified from each whale's track where the whale was traveling in a consistent direction. Accelerometer and magnetometer readings during surfacing sequences from the dives that occurred between those locations were averaged. Pitch and roll angles were calculated from the baseline tag orientation and the yaw angle was calculated from the whale's true heading as determined from the series of three GPS locations. The resulting angles were used to re-orient the tag data to the whale's frame of reference, so that the X-axis was aligned with the longitudinal axis of the whale, the Y-axis was perpendicular to the X-axis (i.e., left-right), and the Z-axis was pointing down toward the center of the earth (up-down) (Johnson and Tyack 2003, Simon et al. 2012). Once the tag data were rotated to the whale's reference frame, the magnitude of the acceleration change (Jerk) was calculated from the accelerometer data as described in Allen et al. (2016) to identify lunge-feeding events in the data record. Regardless of the whale's activity, gravity is the dominant acceleration vector, so Jerk measures the rate at which the whale is changing orientation relative to the Earth's gravitational vector. Lunge-feeding events in rorquals are characterized by a peak in Jerk with a coincident increase in the roll angle for multiple seconds as the whale typically accelerates and rolls as it opens its mouth to engulf prey (Goldbogen et al. 2006, Simon et al. 2012, Allen et al. 2016). A subsequent minimum in the Jerk value as the whale ceases most movement to expel the water and filter out prey signals the end of the lunge. Together, these three criteria (Jerk maximum, increase in roll, and subsequent Jerk minimum) were used to identify feeding lunges in a modified version of the lunge detection methodology described by Allen et al. (2016). Dives >10 m in depth were isolated from each track and summarized by calculating maximum dive depth, dive duration, and the number of lunges that occurred during the dive. The dive end times were then matched to the nearest GPS location recorded by the tag. If there was not a location within 10 min of the dive, a location for the dive was estimated by linear interpolation between the two closest GPS locations using the dive time to determine where on the line the dive should fall. This means that tracks with less frequent locations may have linear segments that do not represent the exact movement of the whale.

A log-survivorship analysis (Holford 1980) was conducted on the time between feeding dives (dives with at least one detected lunge) in order to obtain an objective criterion to distinguish between series of related feeding dives. Sequences of dives defined by this criterion were isolated and labeled feeding bouts. Dive summary statistics were calculated for each feeding bout, and minimum convex polygons were created using the corresponding locations to assess the spatial extent of each feeding bout and the overall scale of foraging effort by comparing the area of each feeding bout and the distance between feeding bouts. The tortuosity of each feeding bout was also calculated as the ratio of the straight-line distance between the first and last location in the dive sequence to the total distance traveled (Benhamou 2004).

It is important to note that the criteria used for this analysis are slightly different than those used in last year's final project report (Mate et al. 2016) as newer methodologies have been developed. Additionally, an ADB tag deployed on a fin whale in 2014 (Tag #2014_5838) was found on a beach and returned, so those data have been added to this report. All previous data were re-analyzed using the newer criteria and previously unavailable data.

2.2.5 DM Tag Analysis

DM tags were used in 2016 to characterize dive behavior. The goal of these analyses was to better understand the diving and feeding behavior of tagged whales over their tracking duration and examine how it changed temporally and spatially. For this purpose, a more restrictive location-filtering protocol (compared to the Argos telemetry methods described in **Section 2.2.2.**) was needed in order to be confident of where identified behaviors were occurring. Argos locations received from DM tags were filtered to remove the lowest-quality locations (LCs Z and B from one message). Locations from redundant satellite passes were also removed and a 12-kilometers per hour swim-speed filter was applied to remove locations that would require the whale to travel at an unreasonably high speed. A position was then assigned to each dive based on the start time of the dive and the temporally closest filtered Argos location. Positions of dives more than 10 min from an Argos location were estimated by linear interpolation between the temporally closest Argos location before and after the dive occurred using the dive time to determine where on the line the dive should fall.

Summary plots showing dive depth and number of feeding lunges over time and versus time of day were generated for each individual to visualize temporal trends in the dive data. Due to the large number of plots generated, examples from one individual are presented to illustrate the trends that are described in the results. The number of feeding lunges for each whale was then mapped onto a 0.25-degree hexagonal grid so that each grid cell showed the total number of lunges that occurred within that cell for one whale. The number of lunges in each cell was then divided by the sum of the dive durations for all dives occurring in the cell (i.e., the total time spent diving in that cell) to get the number of lunges per hour reported for each grid cell. This process was repeated for each DM-tagged whale, then the value of each grid cell was averaged across all whales of a species and relativized so that all values fell from 0 to 1. The result shows the spatial distribution of where higher feeding effort occurred (i.e., higher lunges/h) after accounting for day-to-day differences in the number of dives both within and between whales.

Cells that averaged data from a greater number of whales are more likely to be representative of the overall feeding effort occurring in that cell so the gridded map of feeding effort is presented with a corresponding gridded map showing the number of DM-tagged whales that occupied each grid cell. This map indicates where DM-tagged whales were more likely to be found and/or spend time. A similar gridded analysis was conducted using the average daytime maximum dive depths recorded in each grid cell to examine spatial differences in dive depths across whales.

DM tags occasionally reported abnormally long-duration dives lasting up to the maximum possible value recorded by the tag (4,095 s or 68.3 min)[1]. Such instances were limited to less than 5 percent of all transmitted dives; however, in extreme cases such "dives" appeared to have lasted for over 1 d. To account for these abnormally long dives in the analyses, dives with durations > 25 min were identified and removed from the DM-transmitted dive summaries. No dives longer than that were recorded by the ADB tags we deployed on blue and fin whales in 2014 and 2015 (Mate et al. 2016) or have been reported in the literature (Acevedo-Gutiérrez et al. 2002). Dives < 2 min duration were also removed to standardize across DM tags deployed with different dive summary criteria.

After the initial deployment of five DM tags (6–14 July 2016), we observed that the maximum number of lunges per dive being reported by some tags was higher than expected and that dives with no lunges were also rarely reported. This suggested that the lunge detection threshold ($\pm$2.5 SDs) was set too low and the tag was recording non-feeding behavior in addition to feeding lunges. Therefore, subsequent deployments used a lunge detection threshold of $\pm$3.5 SDs as the lunge detection criteria. Despite apparently recording non-feeding events, DM-tag-summarized dives with larger numbers of lunges were also of deeper depth and generally during the day, which corresponds to known rorqual feeding behavior (Acevedo-Gutiérrez et al. 2002, Mate et al. 2016). This suggests the tags could adequately record feeding behavior; however, the number of lunges recorded by the tag should be interpreted as a relative measure of feeding "effort" rather than a specific number of feeding lunges that occurred during a dive. The pressure sensor of one tag (Tag #5701) appears to have malfunctioned as almost all depth readings reported by the tag were the maximum allowable value (511 m), which far exceeds known maximum dive depths of rorquals (Acevedo-Gutiérrez et al. 2002). Therefore, only dive durations and lunge counts were analyzed for that tag.

2.3 Ecological Relationships

In order to provide an environmental context to the tracking data collected in 2016, we obtained relevant variables for each SSM location from remotely sensed measurements acquired by

[1] Diagnostic information on this problem is unfortunately limited; however, the most likely explanation is related to the tag's saltwater conductivity switch, which detects when the tag breaks the surface of the water, allowing it to set the start and end times of a dive. Anecdotally, the abnormally long dives seemed to occur more frequently during periods of bad weather in the region whales were occupying, so we believe waves sloshing onto the whale's back (and therefore the tag) during a surfacing may have somehow compromised the saltwater conductivity switch. To mitigate this, the threshold value Where the tag senses a change in conductivity has been modified to make it more likely to sense a change from salt water to fresh water/dry air; however, none of the tags in this report were deployed with the updated threshold.

oceanographic satellites and from digital elevation models of seafloor relief. The environmental products are available through the web service Environmental Research Division Data Access Program (ERDDAP), hosted by the National Oceanic and Atmospheric Administration's (NOAA's) NMFS/Southwest Fisheries Science Center (http://coastwatch.pfeg.noaa.gov/erddap/index.html). The extraction process was automated using the R package "xtractomatic" v. 3.2.0 (Mendelssohn 2017), a collection of functions that permit client-side access to the data sets served by ERDDAP. The oceanographic variables extracted included: vertical upwelling velocity (or Ekman pumping, WEKM), sea surface temperature (SST), and phytoplankton chlorophyll-*a* (CHL). Variables describing the seafloor relief were depth (DEPTH), slope (or depth gradient, SLOPE), slope aspect (ASPECT), and distance to the 200-m isobath (or distance to the shelf break, DISTSHELF). Finally, the distance to the nearest shoreline (DISTSHORE) was also computed for each SSM location (**Table 1**).

Table 1. List of environmental data products and variables on the ERDDAP server accessed through the R package "xtractomatic." Columns include variable name (and abbreviation), measurement unit, data set or parameter (dtype) required by xtractomatic, satellite sensor or product, and temporal and spatial resolution.

Variable	Unit	dtype	Sensor/Product	Temporal resolution	Spatial resolution
Vertical upwelling velocity (WEKM)	$m\ s^{-1}$	erdQAstress8dayupwelling	Advanced SCATterometer (ASCAT) on * Metop-A satellite	8 d†	0.25 deg (27.28 km)
Sea surface temperature (SST)	°C	jplMURSST	Multi-scale Ultra-high Resolution (MUR) SST Analysis fv04.1	1 d	0.01 deg (1.11 km)
Chlorophyll-*a* concentration (CHL)	$mg\ m^{-3}$	mbchla8day	Moderate Resolution Imaging Spectroradiometer (MODIS) on Aqua satellite	8 d†	0.025 deg (2.78 km)
Depth (DEPTH)	m	ETOPO180	ETOPO1 global relief model of Earth's surface	NA	0.0167 deg (1.85 km)
Slope (SLOPE)‡	$m\ km^{-1}$	ETOPO180	ETOPO1	NA	0.0167 deg (1.85 km)
Aspect (ASPECT)‡	degrees	ETOPO180	ETOPO1	NA	0.0167 deg (1.85 km)
Distance to 200-m isobath (DISTSHELF)‡	km	ETOPO180	ETOPO1	NA	0.0167 deg (1.85 km)
Distance to shore (DISTSHORE)§	km	cntry_06.shp	ESRI World Countries 2006	NA	50 m

*National Oceanic and Atmospheric Administration CoastWatch processes ASCAT wind velocity to wind stress and wind stress curl, from which vertical upwelling velocity is computed.
†Although these variables cover 8-day periods, they are computed as running composites, such that they provide a value for every day.
‡The variables SLOPE, ASPECT, and DISTSHELF were not available on ERDDAP. They were derived from a DEPTH extract covering the entire study area.
§The variable DISTSHORE was not obtained from ERDDAP. It was computed from the World Countries 2006 shoreline available in ArcGIS.

The xtractomatic functions permit the use of a box of arbitrary size to extract the underlying data around each location. In order to account for the uncertainty in the location estimation by the SSM, we obtained the median value for the environmental variables closest in time and space to each location occurring within a box defined by the 95 percent credible limits in longitude and in latitude, respectively. The number of values used in this computation was dependent not only on the extent of the credible limits around each location, but also on the spatial resolution of the environmental products used, which varied from 1.852 km (for DEPTH) to 27.28 km (for WEKM) (**Table 1**). In addition to reflecting the uncertainty in location estimation, this approach had the benefit of minimizing the number of locations with missing environmental values due to cloud cover in some of the products had we simply obtained the single pixel value nearest to a location. To reduce the bias introduced by locations with large estimation uncertainty, we excluded locations with 95 percent credible limits exceeding 1 degree in longitude and/or in latitude from the analyses. We also excluded SSM locations that were estimated on land.

Ecological relationships were assessed using the regional biogeographic framework developed by Longhurst (1998, 2006). Although there are a number of alternative biogeographic frameworks available, we chose Longhurst's regionalization for its objective and consistent approach based on physiognomic and ecological considerations, as discussed in our 2015 report (Mate et al. 2016). We obtained the digital boundaries (polygons) for the Longhurst provinces as shapefiles from the Gazetteer of marine regions available in the Marine Regions (Claus et al. 2014) web site (http://marineregions.org/, Marine Regions Geographic Identifier, MRGID: 22538), and extracted SSM locations occurring inside each province. The study area comprised eight biogeographic provinces: Alaska Downwelling Coastal Province (ALSK), Pacific Subarctic Gyre-East Province (PSAE), North Pacific Transition Zone Province (NPPF), North Pacific Tropical Gyre Province (NPTG), California Current Province (CCAL), North Pacific Equatorial Countercurrent Province (PNEC), Pacific Equatorial Divergence Province (PQED), and Central American Coastal Province (CAMR). As described in our 2015 report (Mate et al. 2016), we modified the boundaries of two of these provinces to better reflect whale distribution, as follows. First, the jagged offshore edge of the CCAL boundary was replaced by a straight line to avoid interrupting some of the whale tracks that occurred near it. Second, because very few locations occurred in CAMR outside of the Gulf of California (which Longhurst considered part of CAMR) we created a new province designation for the Gulf of California (GUCA), where whales did occur, by slightly altering the boundaries of CCAL and PNEC, and did not further consider the rest of CAMR as a separate province in this study.

The percentage of SSM locations occurring in each province was calculated to assess the regional biogeography of the tagged whales. The number and proportion of locations classified into behavioral modes by the SSM is only reported for CCAL, which was the only province consistently occupied by all species in all years. For the same reason, summary statistics for the associated environmental variables are reported for CCAL only. In addition to these summary statistics, interannual differences in ecological relationships in CCAL between the three years of this project (2014, 2015, and 2016) were assessed using graphical methods (i.e., maps and violin plots [Hintze and Nelson 1998]).

For context, we used three indices of climate variability with well-known linkages to changes in marine ecosystem productivity in the Pacific Ocean: the Oceanic Niño Index (ONI), the Pacific Decadal Oscillation (PDO) index, and the North Pacific Gyre Oscillation (NPGO) index. The ONI quantifies interannual fluctuations in SST in the eastern equatorial Pacific and is considered the official indicator of El Niño and La Niña events by NOAA (Barnston 2015). It is computed as the three-month running mean of SST anomalies in the Niño 3.4 region (5°N-5°S, 120-170°W), based on centered 30-year base periods updated every five years. El Niño/La Niña events are declared when a threshold anomaly of ±0.5 degrees Celsius (°C) is met for a minimum of five consecutive overlapping seasons. The three-month running mean (i.e., "monthly") ONI indices were downloaded from NOAA's National Weather Service/Climate Prediction Center (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml).

The PDO quantifies fluctuations in SST persisting for 20 to 30 years (i.e., warm and cool phases) in the North Pacific (Mantua et al. 1997, Zhang et al. 1997). Standardized values of the PDO index come from the leading principal component of monthly SST anomalies in the North Pacific Ocean (poleward of 20°N), after removal of the monthly mean global average SST anomalies, to separate this pattern of variability from any "global warming" signal that may be present in the data. The monthly PDO values were downloaded from the University of Washington's Joint Institute for the Study of the Atmosphere and Ocean PDO web page (http://research.jisao.washington.edu/pdo).

The NPGO quantifies deviations in sea surface height varying at similar time scales as the PDO (Di Lorenzo et al. 2008). However, the NPGO is derived as the second principal component of monthly sea surface height, and is similar to the second principal component of SST anomalies (also known as the "Victoria Mode"). The PDO tracks fluctuations in temperature observations throughout the North Pacific, while the NPGO tends to track fluctuations in salinity, nutrients and chlorophyll-*a* observations (Di Lorenzo et al. 2008). The monthly NPGO values were downloaded from the Georgia Institute of Technology's Ocean Climate and Ecosystem Science NPGO web page (http://www.oces.us/npgo/).

Time series of these climate indices are presented here covering the 18-year period January 1999–February 2017, to include the period since the last PDO phase or "regime" shift (Mantua and Hare 2002, Peterson and Schwing 2003) as well as several El Niño and La Niña events.

2.4 Genetics

2.4.1 DNA Extraction and mtDNA Sequencing

Total genomic deoxyribonucleic acid (DNA) was extracted from skin tissue following standard proteinase K digestion and phenol/chloroform methods (Sambrook et al. 1989) as modified for small samples by Baker et al. (1994). An approximate 800-base-pair (bp) fragment of the mitochondrial deoxyribonucleic acid (mtDNA) control region was amplified with the forward primer M13Dlp1.5 and reverse primer Dlp8G (Dalebout et al. 2004) under standard conditions (Sremba et al. 2012). Control region sequences were edited and trimmed to a 410-bp consensus region in Sequencher vs4.6. Unique haplotypes were then aligned with previously published haplotypes downloaded from GenBank® and from samples collected during previous tagging efforts. Published datasets include LeDuc et al. (2007), Attard et al. (2015), Torres et al.

(2017), and Sremba et al. (2012) for blue whales; Archer et al. (2013) for fin whales; and Baker et al. (2013) for humpback whales. New haplotypes were confirmed by reverse sequencing from a new Polymerase Chain Reaction (PCR) product following recommendations by Morin et al. (2010).

2.4.2 Microsatellite Genotypes

Up to 17 microsatellite loci were also amplified for each sample using previously published conditions (LeDuc et al. 2007, Sremba et al. 2012). These included the following loci: EV14, EV21, EV37, EV94, EV96, EV104 (Valsecchi and Amos 1996); GATA28, GATA417, GATA98 (Palsbøll et al. 1997); rw31, rw4-10, rw48 (Waldick et al. 1999); GT211, GT23, GT575 (Bérubé et al. 2000); 464/465 (Schlötterer et al. 1991); and DlrFCB17 (Buchanan et al. 1996). Microsatellite loci were amplified individually in 10-microliter reactions and co-loaded in four sets for automated sizing on an ABI3730xl (Applied Biosystems™). Microsatellite alleles were sized and binned using Genemapper vs4.0 (Applied Biosystems™) and all peaks were visually inspected.

2.4.3 Sex Determination

Sex was identified by multiplex PCR using primers P1-5EZ and P2-3EZ to amplify a 443–445-bp region on the X chromosome (Aasen and Medrano 1990) and primers Y53-3C and Y53-3D to amplify a 224-bp region on the Y chromosome (Gilson et al. 1998).

2.4.4 Individual Identification

Individual whales were identified from the multi-locus genotypes using CERVUS v v3.0.3 (Marshall et al. 1998). Mismatches of up to three loci were allowed as a precaution against false exclusion due to allelic dropout and other genotyping errors (Waits and Leberg 2000, Waits et al. 2001). Electropherograms from mismatching loci were reviewed and corrected or repeated. A final 'DNA profile' for each sample included up to 17 microsatellite genotypes, sex, and mtDNA control region sequence or haplotype.

2.4.5 Species and Stock Identification

Species identity from field observations was confirmed by submitting mtDNA sequences to the web-based program *DNA-surveillance* (Ross et al. 2003) and by Basic Local Alignment Search Tool (BLAST) search of GenBank®. If species identification from mtDNA did not agree with the field observations, we used the Bayesian clustering program STRUCTURE v2.3.1 to assess the potential for hybrid ancestry (Falush et al. 2003). In this method, individuals are assigned probabilistically to species or population units using allele frequencies of the multi-locus genotypes.

Stock identity of the tagged blue and fin whales was investigated by developing a reference database of published mtDNA sequences and by initiating collaboration with other holders of unpublished data. The mtDNA haplotypes of the tagged whales were compared to the relevant reference databases using standard indices of differentiation (e.g., F_{ST}) and tested using the permutation procedure available in the program Arlequin (Excoffier and Lischer 2010).

For blue whales, we considered differences of the tagged whales in relationship to a reference database of mtDNA haplotypes from unpublished results of samples from the eastern North Pacific and published reports of samples representing populations or subspecies in the Southern Hemisphere as described by Donovan (1991). To our knowledge, no samples are currently available to represent the proposed western North Pacific stock of blue whales, as described from vocalizations by Stafford et al. (2001) and Stafford (2003) and further characterized by Monnahan et al. (2014).

For analysis of fin whale stock structure, we initiated collaboration with F.I. (Eric) Archer of the NMFS/Southwest Fisheries Science Center, providing access to a large reference database of mtDNA haplotypes from fin whales in the North Pacific and elsewhere (Archer et al. 2013). For this, we considered differences of the tagged whales in relationship to seven *a priori* population strata: Gulf of California, Southern California Bight, California/Oregon/Washington, Gulf of Alaska, Central Pacific, Bering Sea, and Hawaii.

At present, it is not possible to include nuclear microsatellite loci in the comprehensive stock analyses of blue and fin whales because of differences in loci used by other investigators and the difficulties of standardizing allele sizes across laboratories (Morin et al. 2010). For the tagged humpback whales, however, there is a large 'DNA register' available from the ocean-wide survey referred to as the Structure of Populations, Levels of Abundance and Status of Humpbacks program, or SPLASH. This register includes mtDNA haplotypes, sex, and microsatellite genotypes at 10 loci, sufficient for individual identification of more than 1,800 individuals sampled in all known breeding and feeding grounds (Baker et al. 2013). The integration of the DNA register with photo-identification records from SPLASH was funded in part by the Office of Naval Research contract N0270A awarded to CSB, Oregon State University (Dick et al. 2014). Consequently, the mtDNA of tagged humpback whales can be compared to haplotype frequencies from any selected regions of the North Pacific and microsatellite genotypes could be used to match for individual identification with the DNA register.

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3. Results

3.1 Blue Whale

3.1.1 Tracking Analysis—2016

Nineteen tags were deployed on blue whales (11 LO, 8 DM) between 14 July and 3 August 2016. Of these, 11 tags were deployed off southern California: 10 at the west end of San Miguel Island and 1 off Palos Verdes Peninsula, Los Angeles County. The remaining eight tags were deployed off central California, near the continental shelf edge between Half Moon Bay and Pigeon Point. Locations were received from 18 of these tags, providing tracking periods ranging from 0.6 to 249.2 d (**Table 2**). The average tracking duration for LO tags was 81.3 d (SD = 67.8 d, median = 61.7 d) and for DM tags was 73.2 d (SD = 47.8 d, median = 62.2 d).

Table 2. Deployment and performance data for satellite-monitored radio tags deployed on blue whales in southern and central California, 2016. Unknown sex whales are cases where no biopsy sample was collected. See Section 2.2.2 for location filtering method. Deployment dates reflect Coordinated Universal Time [UTC] dates.

Tag #	Sex	Tag Type	Deployment Date	Last Location	# Days Tracked	# Filtered Locations	Total Distance (km)
836	Unknown	LO	16-Jul-16	28-Oct-16	103.2	345	3,677
843	Unknown	LO	1-Aug-16	13-Nov-16	103.2	419	3,613
4172	Unknown	LO	2-Aug-16	29-Sep-16	57.7	250	2,513
4173	Unknown	LO	16-Jul-16	19-Jul-16	2.3	9	38
5784	Unknown	LO	19-Jul-16	24-Jul-16	4.3	15	384
5826	Male	LO	17-Jul-16	27-Oct-16	102.6	395	2,965
5843	Male	LO	3-Aug-16	4-Oct-16	61.7	257	2,567
5878	Unknown	LO	17-Jul-16	8-Nov-16	113.8	346	5,842
5938	Unknown	LO	1-Aug-16	16-Sep-16	45.3	194	2,189
10825	Male	LO	2-Aug-16	8-Apr-17	249.2	928	16,168
10827	Female	LO	17-Jul-16	7-Sep-16	51.4	182	1,924
	Mean	**LO**			**81.3**	**304**	**3,807**
	Median	**LO**			**61.7**	**257**	**2,567**
833	Female	DM	14-Jul-16	3-Dec-16	141.9	34	3,125
839*	Unknown	DM	14-Jul-16	-	0	-	-
5685	Male	DM	1-Aug-16	4-Dec-16	124.8	420	7,035
5701	Male	DM	14-Jul-16	28-Aug-16	44.7	177	1,485
5746	Female	DM	31-Jul-16	30-Sep-16	61.7	143	2,269
5790	Male	DM	14-Jul-16	29-Sep-16	76.4	390	4,913
23032	Female	DM	14-Jul-16	15-Sep-16	62.2	343	1,961
23033	Male	DM	3-Aug-16	3-Aug-16	0.6	6	18
	Mean	**DM**			**73.2**	**216**	**2,972**
	Median	**DM**			**62.2**	**177**	**2,269**

KEY: DM = Telonics RDW-665 Dive-Monitoring tag; km = kilometer(s); LO = Wildlife Computers SPOT6 Location-Only tag, # = number; * No transmissions were received for Tag #839. This tag is not included in summary statistics.

Blue whale locations ranged over 26 degrees of latitude, from Puerto Vallarta, Mexico, to Coos Bay, Oregon (**Figure 3**). One whale contributed to this maximum range, with a distance between northern and southern most locations of more than 3,100 km, and a total tracking duration of 249 d. This whale (Tag #10825, tagged off central California on 2 August 2016) traveled south across the California/Mexico border on December 6 and reached its southern extent on 8 January 2017, approximately 650 km west-southwest of Puerto Vallarta. The whale then traveled east and north and spent three weeks (in February) in the lower part of the Gulf of California, over the Farallon Basin, southeast of Loreto, Mexico. This whale then headed out of the Gulf of California and spent 12 d (in early March) approximately 200 km southwest of Magdalena Bay on the west coast of Baja California, before heading north. Whale Tag #10825 crossed the U.S./Mexico border into California on March 29, moving up into the Southern California Bight, between San Nicolas Island and Santa Cruz Island, before heading offshore (approximately 160 km west of Tanner Bank) where it remained for over 24 hours (h) before its tag stopped transmitting on 8 April. Three other blue whales left U.S. waters during their tracking periods. One blue whale (Tag #5878, tagged in southern California on 17 July) traveled to Vizcaíno Bay on the central coast of Baja California, where it spent 2 d in early October before heading back into California waters. Another whale (Tag #5685, tagged off central California on 1 August) crossed the California/Mexico border on 15 October and was last located in the upper Gulf of California on 4 December. The third whale (Tag #833, tagged in southern California on 14 July) was also last located in the upper Gulf of California, on 3 December, but we received no locations from its tag between 19 July and 3 December, so the migration timing and route are unknown for this whale.

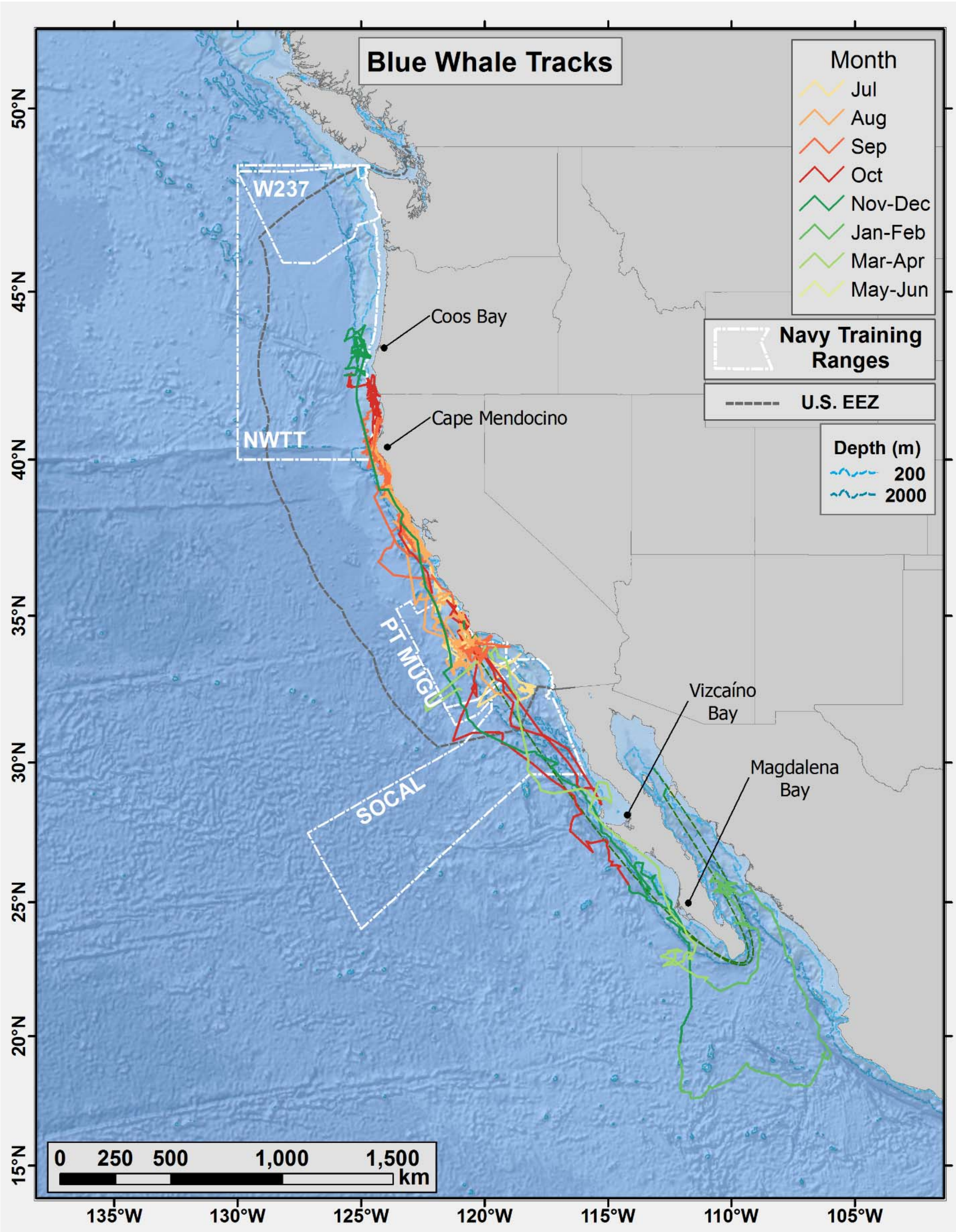

Figure 3. Satellite-monitored radio tracks for blue whales tagged off southern and central California in July and August 2016 (11 LO tags, 7 DM tags).

Most of the blue whales tagged in southern California remained in southern or central California waters for their tracking periods (**Figure 4**). Most of the locations for these whales were over continental slope waters, or over offshore banks or seamounts, such as the Santa Lucia Bank on the central California coast or the Rodriguez Seamount at the west end of the Santa Barbara Channel. Six blue whales spent extensive periods of time (from 7 to102 d) at the western end of the Santa Barbara Channel, from Santa Rosa Island to Point Conception, with the majority of locations to the west of San Miguel Island. One whale (Tag #5790) also spent approximately 8 d over the deeper water of the San Clemente Canyon south of San Clemente Island. One other whale (Tag #836) traveled north after tagging, spending time at multiple locations along the way, including 12 d near Cordell Bank off Point Reyes and 49 d off Cape Mendocino, before reaching Point St. George on the northern California coast by the end of October. On the central and northern California coast, locations for this latter whale occurred over both continental shelf and slope waters in almost equal proportions.

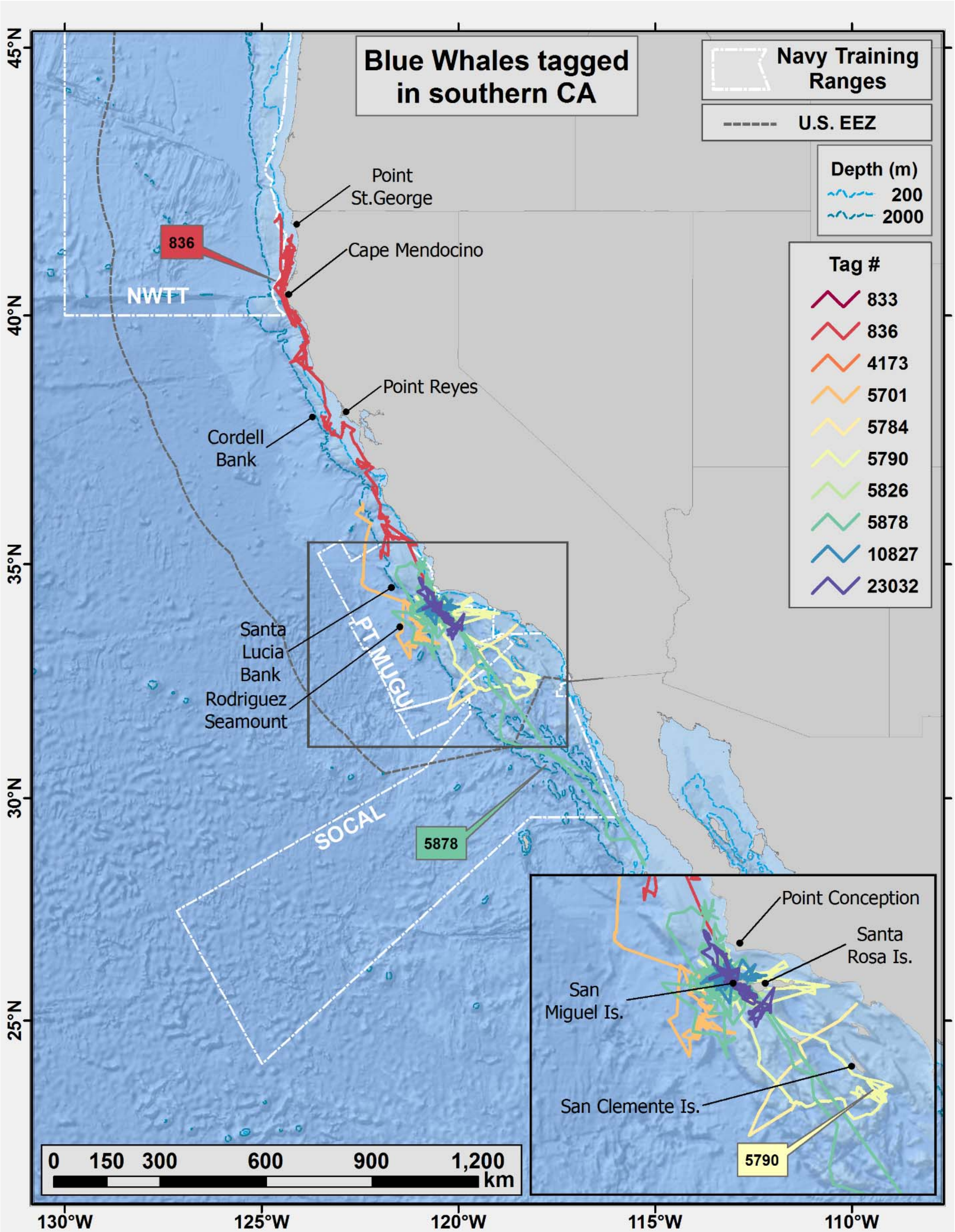

Figure 4. Satellite-monitored radio tracks for blue whales tagged off southern California in July 2016 (6 LO tags, 4 DM tags).

The locations of blue whales tagged off central California (**Figure 5**) were concentrated in several areas along the California and southern Oregon coast, with the Gulf of the Farallones and Cordell Bank being the most heavily used, followed by the area around Point Arena and off Fort Bragg, as well as the area off Pigeon Point. Aside from two whales (Tag #5685 and Tag #10825), which traveled south to Mexico, only one other blue whale tagged off central California traveled to southern California (Tag #5746). This latter whale spent at least 3 d in an area approximately 100 km west of San Miguel Island at the end of August before returning north to Point Arena. Locations for four of the tagged blue whales were primarily over continental slope waters (and some over deeper water), whereas the locations for three other blue whales were predominantly over continental shelf waters and the shelf edge. The blue whale that traveled into southern Oregon spent most of its time off Oregon over slope and deeper waters, but had locations over both shelf and slope waters while in California.

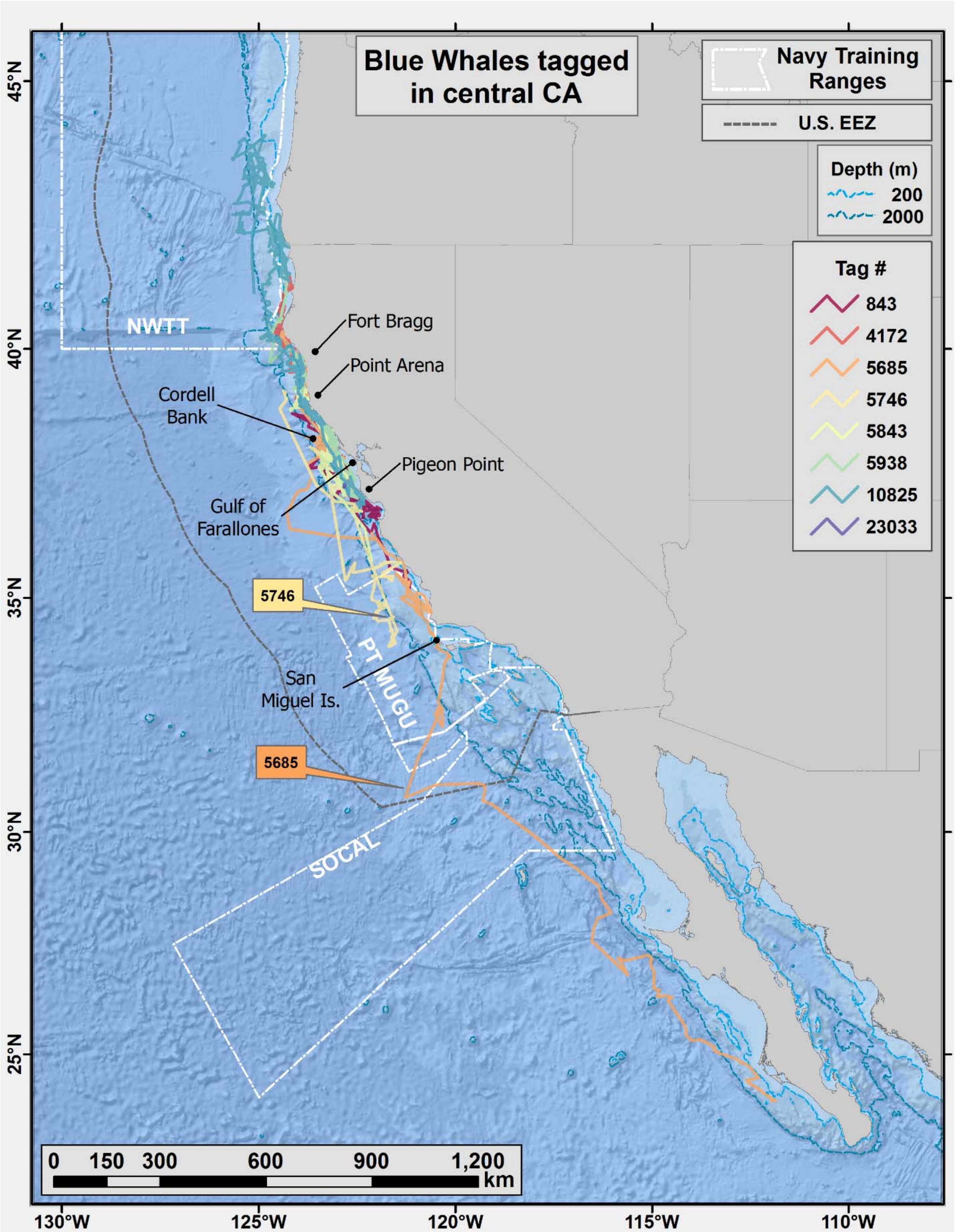

Figure 5. Satellite-monitored radio tracks for blue whales tagged off central California in July and August 2016 (5 LO tags, 3 DM tags).

3.1.1.1 USE OF NAVY TRAINING AREAS BY TAGGED BLUE WHALES

The most heavily used Navy training area for tagged blue whales was PT MUGU, with 14 of the 18 tracked whales having from <1 to 100 percent of their total locations there (**Table 3, Figure 6**). This represented from <1 to 100 percent of their total tracking periods or <1 to 102 d in PT MUGU. Distances to shore in PT MUGU averaged 52 km (SD = 32.9 km, maximum = 218 km; **Table 4**). Five blue whales had between 2 and 60 percent of their total locations within SOCAL, representing between 3 and 61 percent of their total tracking periods (3 to 13 d; **Table 3**, **Figure 7**). Distances to shore in SOCAL averaged 113 km (SD = 49.3 km, maximum = 265 km; **Table 4**). Two blue whales had locations within the NWTT; one whale accounted for 2 percent of total locations and 2 percent of tracking period (2 d), and the other whale for 26 percent of total locations and 21 percent of tracking period (52 d; **Figure 8**). The track of a third blue whale crossed the NWTT, representing <1 percent of its tracking period (<1 d), but no locations for this whale occurred within the NWTT (**Table 3**). Distances to shore in NWTT averaged 44 km (SD = 14.8 km, maximum = 109 km; **Table 4**). None of the tagged blue whales were tracked within W237, an area encompassing approximately the northern third of the NWTT, or within the Gulf of Alaska Temporary Maritime Activities Area (GOA). Blue whale locations occurred in PT MUGU during 8 months (July through December, and March and April), during 6 months in SOCAL (July, August, September, October, December, and March), and during 3 months in the NWTT (September, October, and November).

Table 3. Percentage of filtered locations and time spent inside the SOCAL, PT MUGU, NWTT, and W237 areas for blue whales tagged off southern and central California, 2016. See Section 2.2.2 for location filtering method.

Tag #	Tag Type	Total		SOCAL			PT MUGU			NWTT			W237		
		# Locs	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days
836	LO	345	103.2	0	0	0	6	6	6.6	2	2	1.8	0	0	0
843	LO	419	103.2	0	0	0	<1	<1	<1	0	0	0	0	0	0
4172	LO	250	57.7	0	0	0	0	0	0	0	0	0	0	0	0
4173	LO	9	2.3	0	0	0	100	100	2.3	0	0	0	0	0	0
5784	LO	15	4.3	60	61	2.6	47	45	1.9	0	0	0	0	0	0
5826	LO	395	102.6	0	0	0	99	99	101.8	0	0	0	0	0	0
5843	LO	257	61.7	0	0	0	0	0	0	0	0	0	0	0	0
5878	LO	346	113.8	4	10	11.5	91	83	94.8	0	0	0	0	0	0
5938	LO	194	45.3	0	0	0	0	0	0	0	<1	0.3	0	0	0
10825	LO	928	249.2	2	4	10.1	3	4	9.3	26	21	52.4	0	0	0
10827	LO	182	51.4	0	0	0	93	93	47.9	0	0	0	0	0	0
833	DM	34	141.9	0	0	0	94	10	13.8	0	0	0	0	0	0
839*	DM	0	0	-	-	-	-	-	-	-	-	-	-	-	-
5685	DM	420	124.8	3	3	4.0	15	13	15.8	0	0	0	0	0	0
5701	DM	177	44.7	0	0	0	92	96	42.8	0	0	0	0	0	0
5746	DM	143	61.7	0	0	0	49	32	20.0	0	0	0	0	0	0
5790	DM	390	76.4	24	17	13.1	76	81	61.6	0	0	0	0	0	0
23032	DM	343	62.2	0	0	0	99	97	60.1	0	0	0	0	0	0
23033	DM	6	0.6	0	0	0	0	0	0	0	0	0	0	0	0
	Mean⁺	**270**	**78.2**	**18**	**19**	**8.3**	**62**	**54**	**34.2**	**9**	**8**	**18.1**	-	-	-
	Median⁺	**254**	**62.0**	**4**	**10**	**10.1**	**83**	**63**	**17.9**	**2**	**2**	**1.8**	-	-	-

KEY: DM = Telonics RDW-665 Dive-Monitoring tag; LO = Wildlife Computers SPOT6 Location-Only; Locs = Locations; # = number; * No transmissions were received for Tag #839. This tag is not included in summary statistics; ⁺Summary statistics do not include zero values in their calculation.

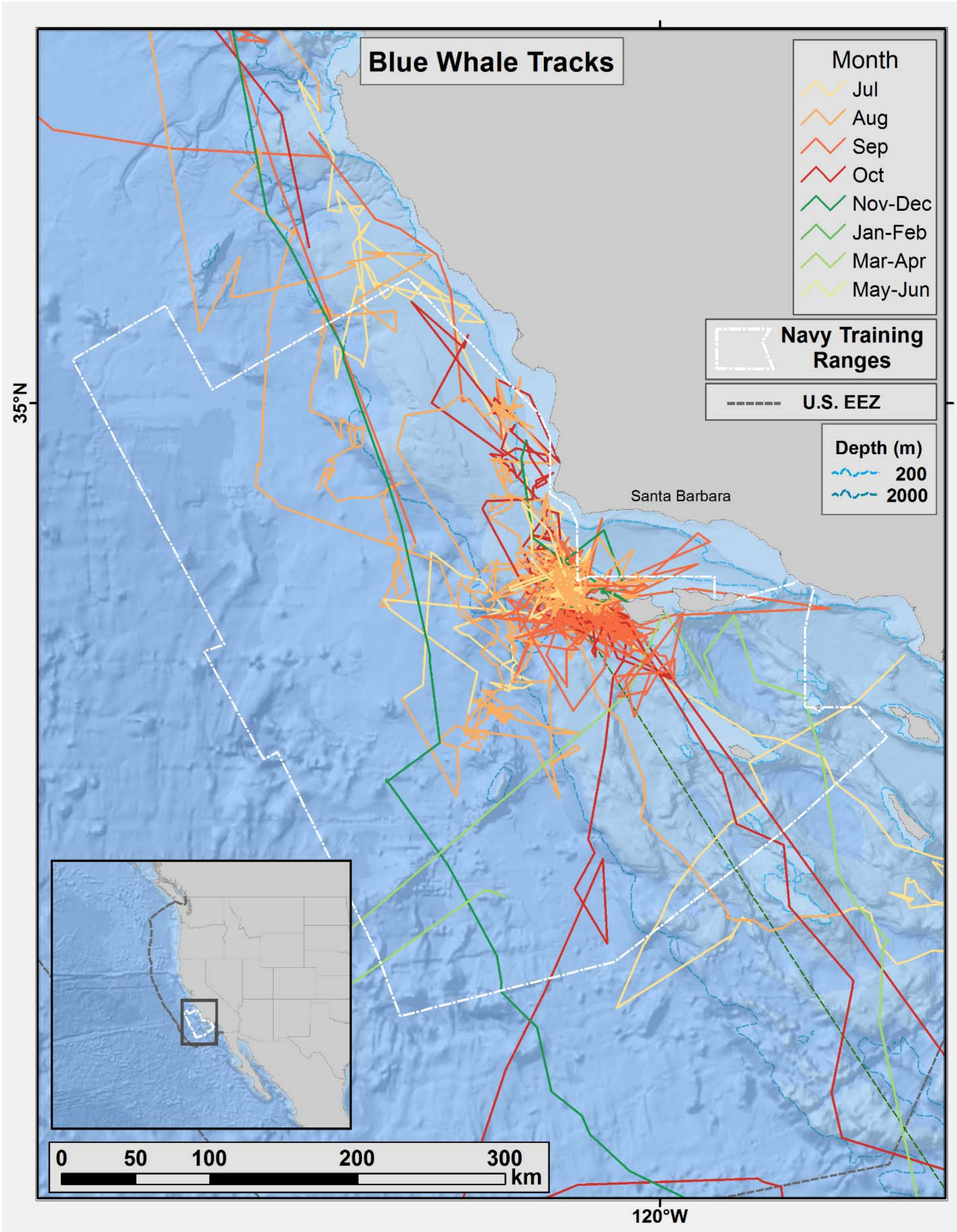

Figure 6. Satellite-monitored radio tracks in PT MUGU for blue whales tagged off southern and central California in July and August 2016 (8 LO tags, 6 DM tags).

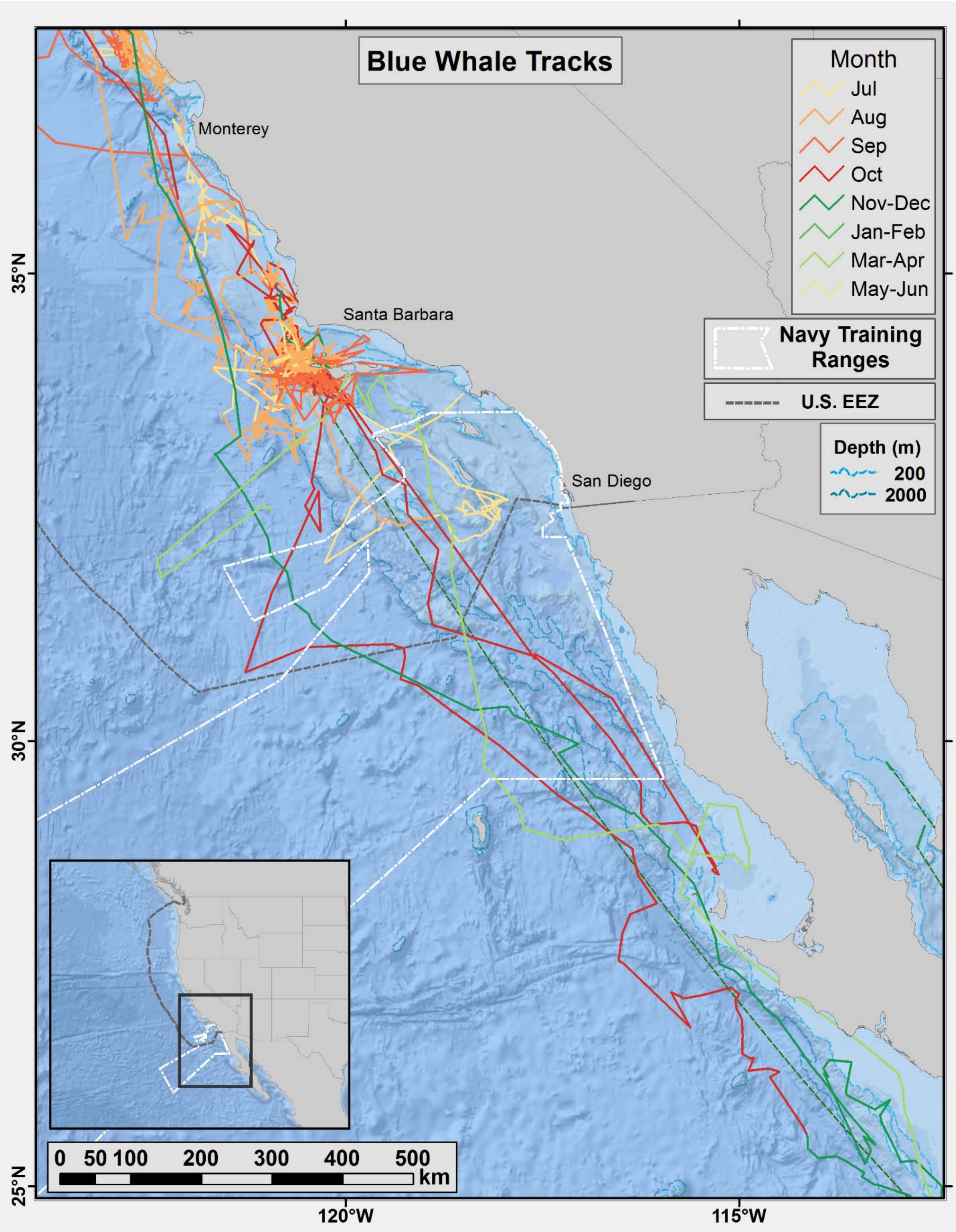

Figure 7. Satellite-monitored radio tracks in SOCAL for blue whales tagged off southern and central California in July and August 2016 (3 LO tags, 2 DM tags).

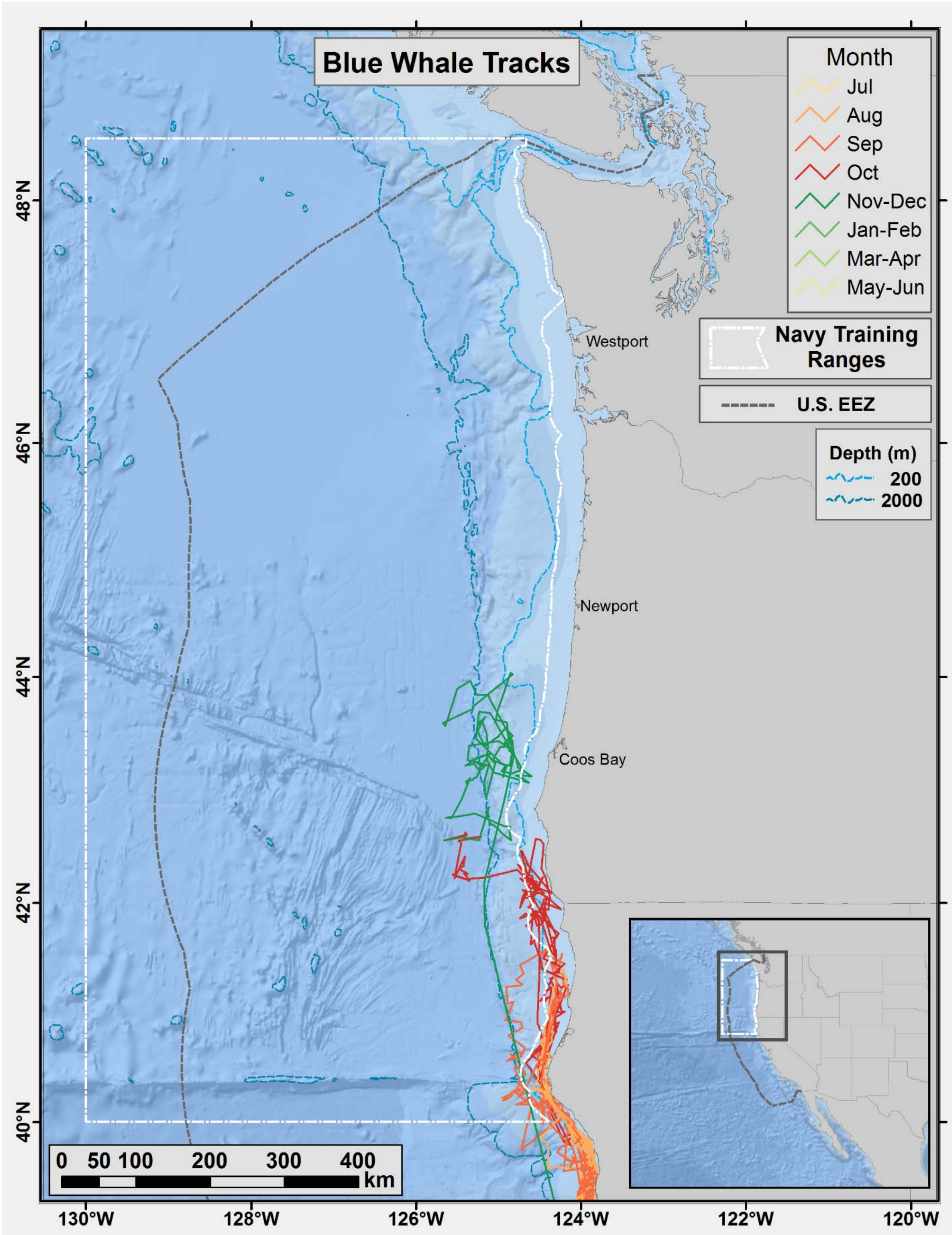

Figure 8. Satellite-monitored radio tracks in NWTT for blue whales tagged off southern and central California in July and August 2016 (3 LO tags).

Table 4. Geodesic distances to nearest point on shore in Navy training ranges for blue whales tagged off southern and central California, 2016 (including mean, median, and maximum distance to shore for each whale). The number of locations includes filtered locations (see Section 2.2.2 for filtering method) plus deployment location (when the deployment location occurred within a Navy range).

Tag #	Tag Type	SOCAL				PT MUGU				NWTT				W237			
		n	Mean	Median	Max	n	Mean	Median	Max	n	Mean	Median	Max	n	Mean	Median	Max
836	LO	0	-	-	-	23	46	35	90	8	33	31	38	0	-	-	-
843	LO	0	-	-	-	1	28	28	28	0	-	-	-	0	-	-	-
4172	LO	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-
4173	LO	0	-	-	-	10	33	34	37	0	-	-	-	0	-	-	-
5784	LO	9	114	116	195	7	103	93	148	0	-	-	-	0	-	-	-
5826	LO	0	-	-	-	393	25	26	65	0	-	-	-	0	-	-	-
5843	LO	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-
5878	LO	13	101	95	177	314	39	34	115	0	-	-	-	0	-	-	-
5938	LO	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-
10825	LO	19	118	110	252	28	112	113	218	237	54	52	109	0	-	-	-
10827	LO	0	-	-	-	170	30	29	73	0	-	-	-	0	-	-	-
833	DM	0	-	-	-	33	31	31	37	0	-	-	-	0	-	-	-
839*	DM	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-
5685	DM	11	186	210	265	62	36	26	182	0	-	-	-	0	-	-	-
5701	DM	0	-	-	-	164	87	89	162	0	-	-	-	0	-	-	-
5746	DM	0	-	-	-	70	102	102	133	0	-	-	-	0	-	-	-
5790	DM	91	48	41	115	299	32	32	127	0	-	-	-	0	-	-	-
23032	DM	0	-	-	-	340	26	28	60	0	-	-	-	0	-	-	-
23033	DM	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-
	Mean		**113**	**114**	**201**		**52**	**50**	**105**		**44**	**42**	**74**		-	-	-
	Median		**114**	**110**	**195**		**34**	**33**	**102**		**44**	**42**	**74**		-	-	-

KEY: DM = Telonics RDW-665 Dive-Monitoring tag; LO = Wildlife Computers SPOT6 Location-Only; n = number of locations; * No transmissions were received for Tag #839.

3.1.1.2 USE OF BIAS BY TAGGED BLUE WHALES

The amount of time spent in BIAs by tagged blue whales ranged from <1 to 100 percent of their total tracking periods (**Table 5**). The two most heavily used BIAs (of the six overlapping Navy training ranges), in terms of number of whales having locations there, were the Santa Barbara Channel and San Miguel BIA and the Point Conception/Arguello BIA (**Figures 9 and 10**). Ten blue whales had locations in the Santa Barbara Channel and San Miguel BIA, spending 1 to 100 percent of their total tracking time there, or 1 to 63 d. This represented 1 to 100 percent of the total number of locations for these 10 whales. Seven blue whales had locations in the Point Conception/Arguello BIA, spending 1 to 6 percent of their total time there, or <1 to 7 d. For these seven whales, this represented 1 to 6 percent of their total number of locations. Blue whale locations occurred in these former two BIAs over 5 months (July through November). One blue whale had locations within the Tanner-Cortez Bank BIA and the track of another blue whale crossed this same area, representing <1 of the total number of locations and <1 percent of the tracking period (1 d) for the former whale, and <1 percent of the tracking period (<1 d) for the latter whale (**Figure 11**). Blue whale locations/tracks occurred in the Tanner-Cortez Bank BIA in August, September, and October. One blue whale had 7 percent of its locations in the Santa Monica Bay to Long Beach BIA (**Figure 12**), but this represented just 1 percent of the total tracking period (<1 d). One other blue whale had 1 percent of its locations within the San Nicolas Island BIA, representing <1 percent of its total tracking period, or <1 d (**Figure 13**). Blue whale locations occurred in the Santa Monica Bay to Long Beach BIA and the San Nicolas Island BIA in July. None of the blue whales tagged in 2016 were tracked within the San Diego BIA.

Table 5. Percentage of filtered locations and time spent inside the BIAs for blue whales tagged off southern and central California, 2016. See Section 2.2.2 for location filtering method.

Tag #	Tag Type	Total		Santa Monica Bay			San Diego			San Nicolas			Tanner Cortez			Santa Barbara			Point Conception		
		# Locs	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days
836	LO	345	103.2	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1.1	1	1	0.8
843	LO	419	103.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4172	LO	250	57.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4173	LO	9	2.3	0	0	0	0	0	0	0	0	0	0	0	0	100	100	2.3	0	0	0
5784	LO	15	4.3	7	1	<0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5826	LO	395	102.6	0	0	0	0	0	0	0	0	0	0	0	0	61	62	63.3	1	1	1.0
5843	LO	257	61.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5878	LO	346	113.8	0	0	0	0	0	0	0	0	0	<1	<1	0.8	30	29	32.7	6	6	6.9
5938	LO	194	45.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10825	LO	928	249.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10827	LO	182	51.4	0	0	0	0	0	0	0	0	0	0	0	0	74	75	38.4	1	1	0.3
833	DM	34	141.9	0	0	0	0	0	0	0	0	0	0	0	0	88	4	5.0	0	0	0
839*	DM	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5685	DM	420	124.8	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1.1	5	4	4.6
5701	DM	177	44.7	0	0	0	0	0	0	0	0	0	0	0	0	10	14	6.1	0	0	0
5746	DM	143	61.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5790	DM	390	76.4	0	0	0	0	0	0	1	<1	0.3	0	<1	0.1	48	50	38.5	2	1	0.9
23032	DM	343	62.2	0	0	0	0	0	0	0	0	0	0	0	0	69	71	44.4	3	3	2.0
23033	DM	6	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean+		**270**	**78.2**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**<1**	**<1**	**0.4**	**48**	**41**	**23.3**	**3**	**2**	**2.4**
Median+		**254**	**62.0**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**<1**	**<1**	**0.4**	**54**	**40**	**19.4**	**2**	**1**	**1.0**

KEY: DM = Telonics RDW-665 Dive-Monitoring tag; LO = Wildlife Computers SPOT6 Location-Only tag; Locs = Locations; # = number; * No transmissions were received for Tag #839. This tag is not included in summary statistics; + Summary statistics do not include zero values in their calculation.

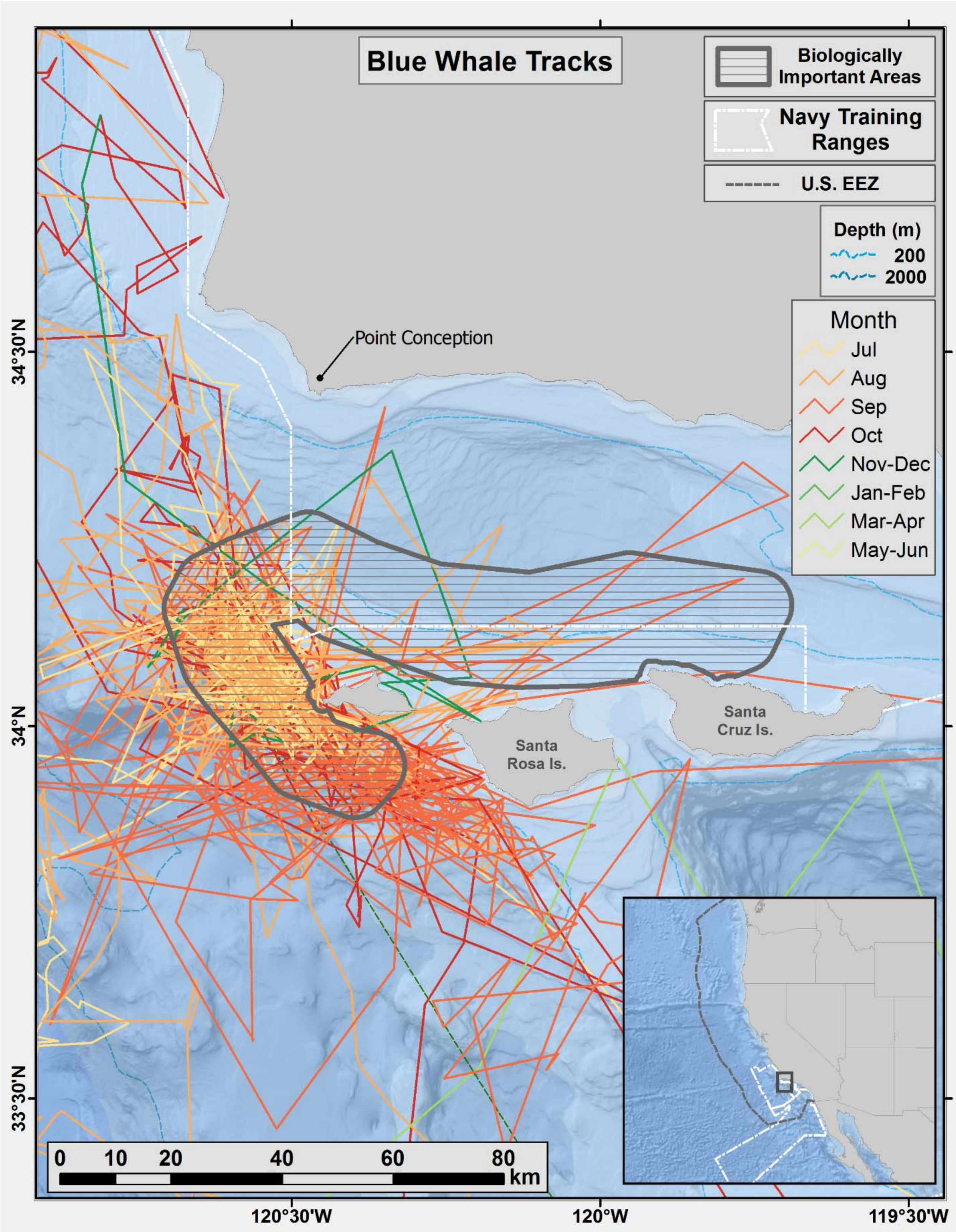

Figure 9. Satellite-monitored radio tracks in the Santa Barbara Channel and San Miguel BIA for blue whales tagged off southern and central California in July and August 2016 (5 LO tags, 5 DM tags).

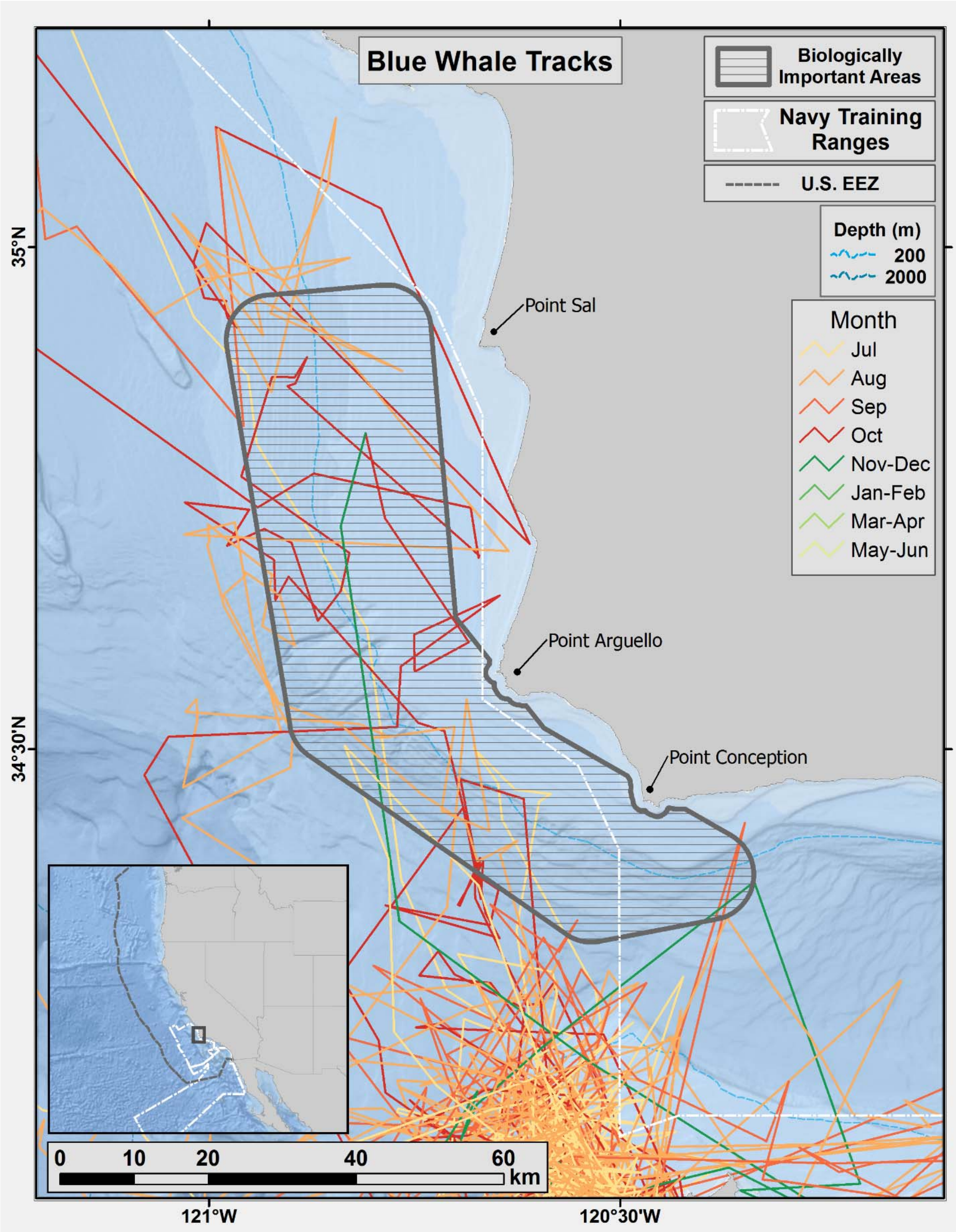

Figure 10. Satellite-monitored radio tracks in the Point Conception/Arguello BIA for blue whales tagged off southern and central California in July and August 2016 (4 LO tags, 3 DM tags).

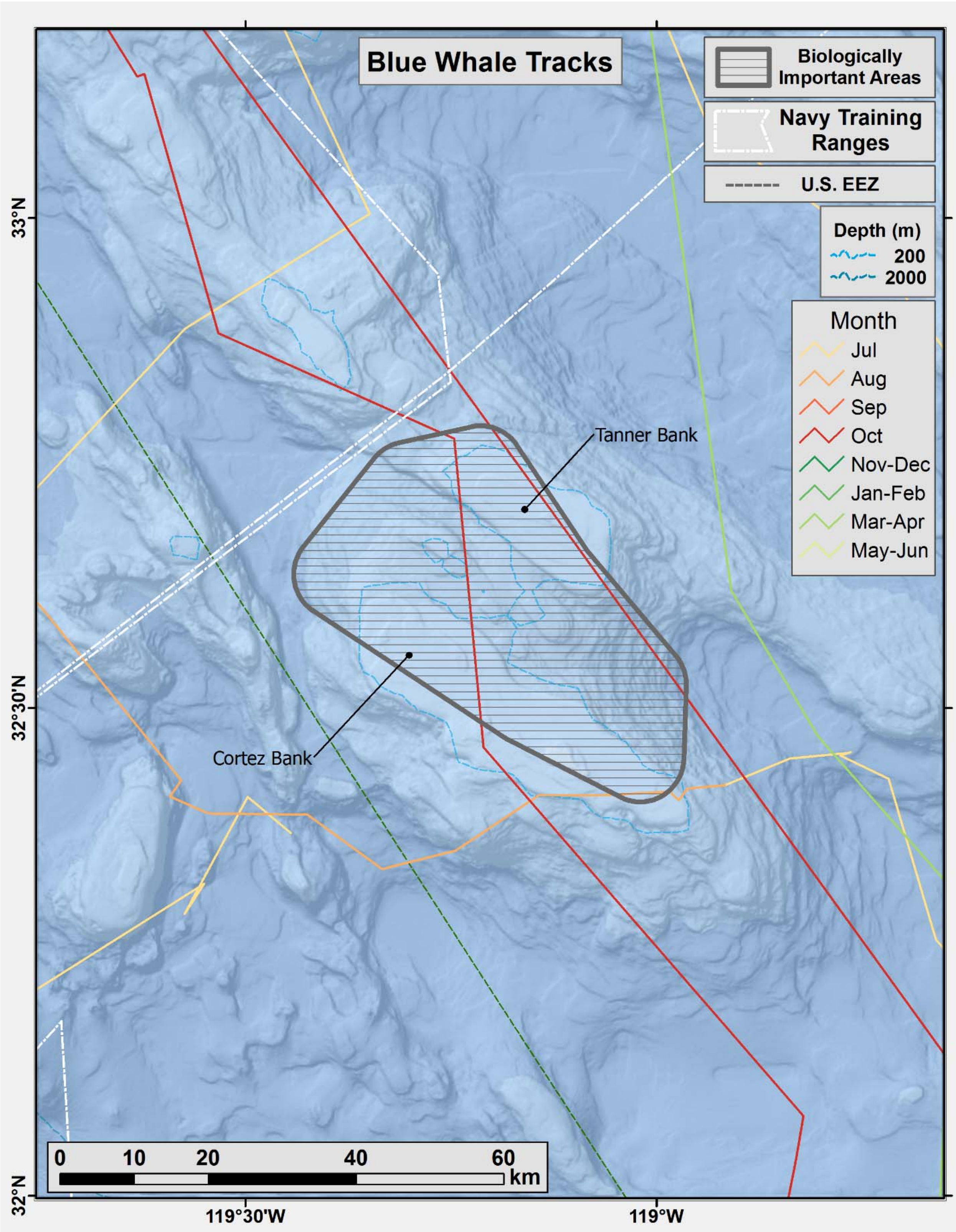

Figure 11. Satellite-monitored radio tracks in the Tanner-Cortez Bank BIA for blue whales tagged off southern California in July 2016 (1 LO tag, 1 DM tag).

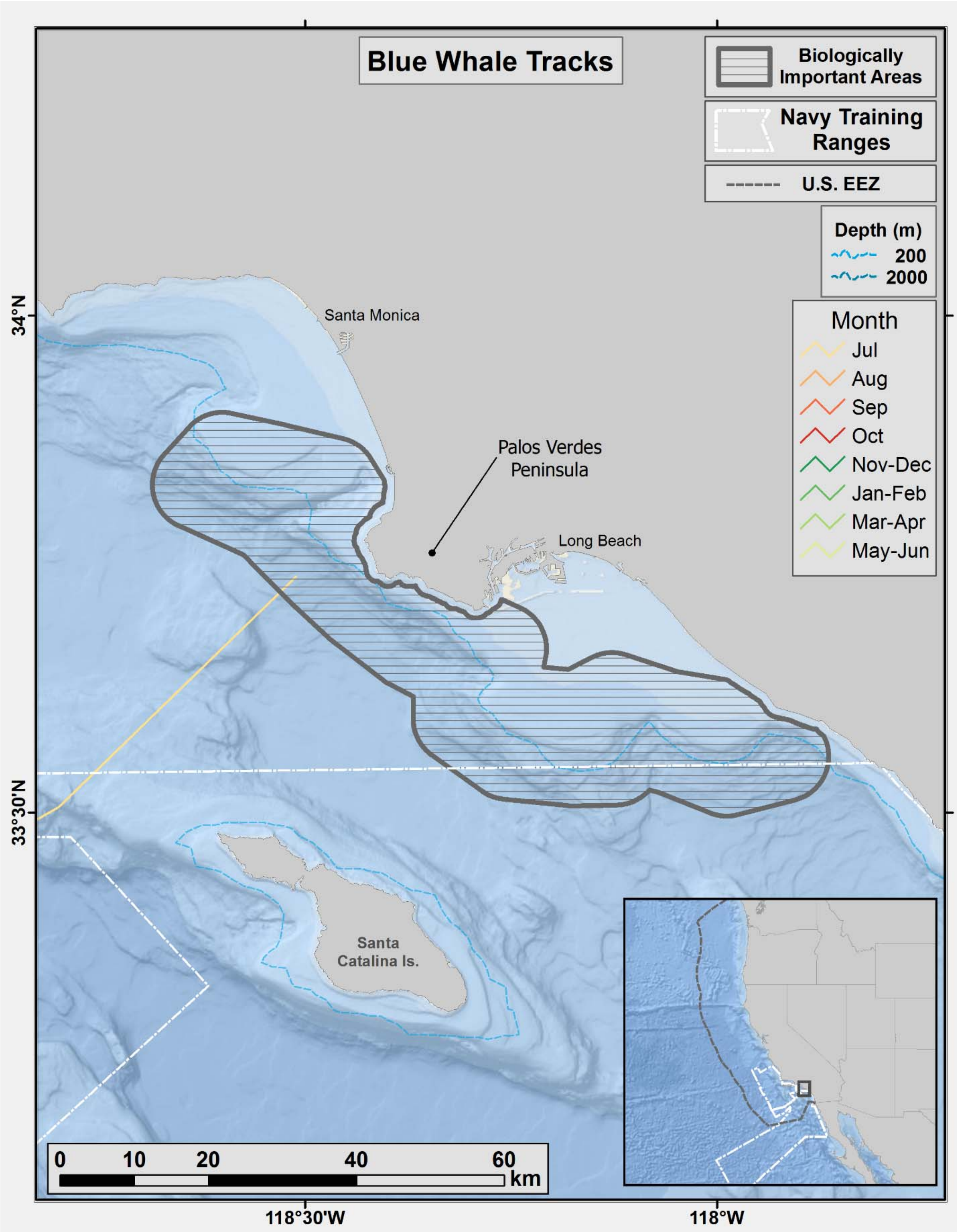

Figure 12. Satellite-monitored radio tracks in the Santa Monica Bay to Long Beach BIA for a blue whale (Tag #5784) tagged off southern California in July 2016 (1 LO tag).

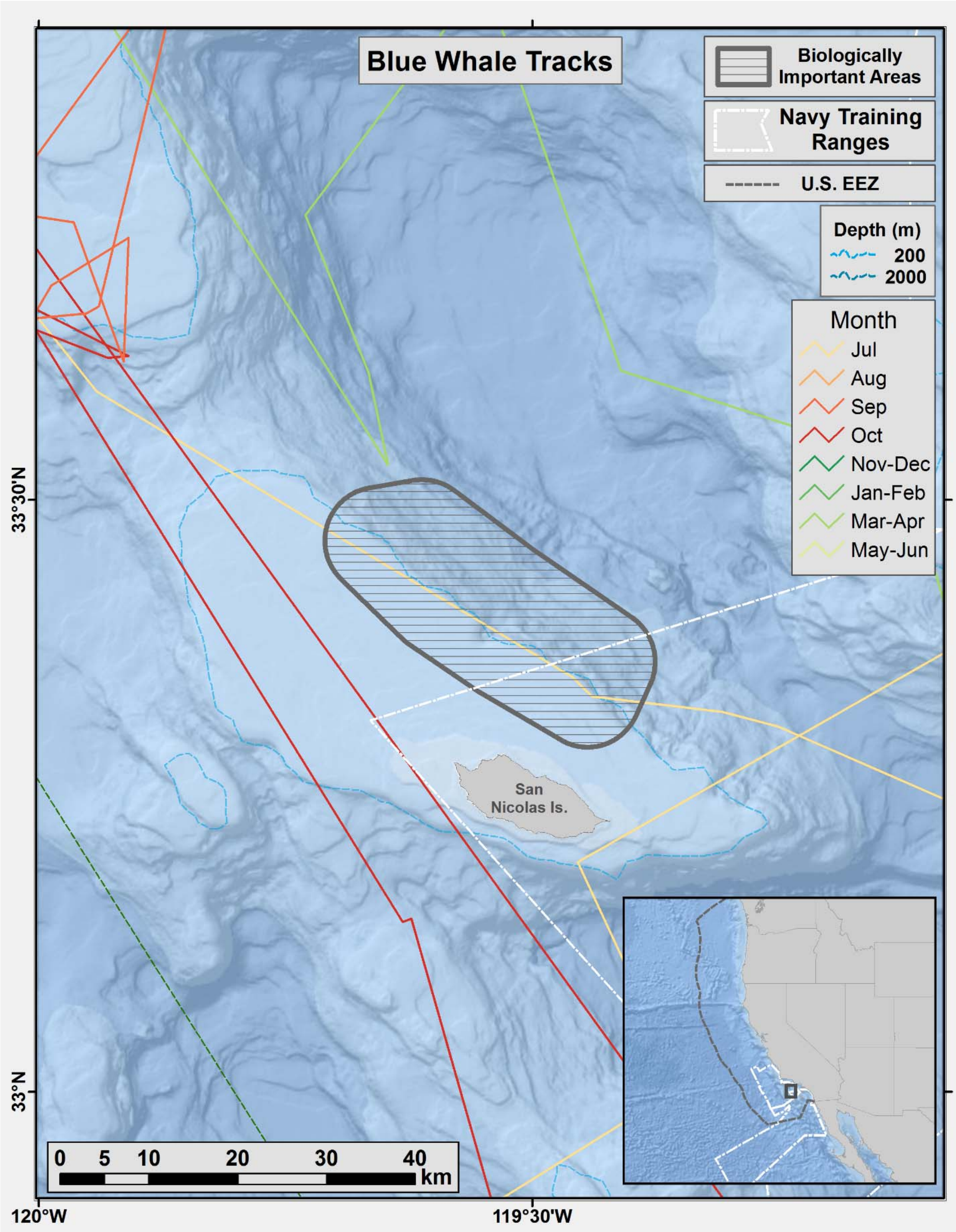

Figure 13. Satellite-monitored radio tracks in the San Nicolas Island BIA for a blue whale (Tag #5790) tagged off southern California in July 2016 (1 DM tag).

3.1.1.3 HOME RANGE ANALYSIS

Fourteen blue whales provided enough locations to calculate HRs and CAs within waters of the U.S. EEZ (**Table 6, Figures 14 and 15**). HR sizes ranged from 879 to 103,237 square kilometers (km^2) (mean = 25,611.0 km^2; SD = 31,306.0 km^2) and covered the U.S. West Coast from the California/Mexico border to central Oregon. The densest location of HRs occurred at the west end of the Channel Islands in southern California, off central California from Half Moon Bay to Point Reyes, and off Point Arena, where HRs overlapped for up to eight whales. CAs ranged in size from 157 to 27,711 km^2 (mean = 6,305.9 km^2, SD = 8,880.2 km^2), extending from the Channel Islands to Coos Bay, central Oregon. The areas of highest use, with overlapping CAs for five blue whales, were at the west end of San Miguel Island in the Channel Islands and between Point Arena and Cape Mendocino on the northern California coast, extending out to 20 km offshore. There was no relationship between the number of SSM locations used in the analysis and the size of either HRs or CAs (linear regression of log-transformed HR and CA, $P > 0.39$).

Table 6. Sizes of HRs and CAs of use in the U.S. EEZ calculated from state-space modeled (SSM) locations for 15 blue whales tagged off southern and central California, 2016. In the Sex column, Unknown sex whales are cases where no biopsy sample was collected.

Tag #	# SSM Locations	Sex	HR Size (km^2)	CA Size (km^2)
Blue Whales				
836	104	Unknown	43,613	9,680
843	104	Unknown	11,352	2,642
4172	58	Unknown	14,040	3,841
5685	79	Male	58,203	8,366
5701	45	Male	7,462	1,900
5746	62	Female	71,064	24,504
5790	77	Male	7,347	1,085
5826	103	Male	879	196
5843	62	Male	10,153	2,432
5878	103	Unknown	11,046	1,619
5938	46	Unknown	17,456	3,822
10825	141	Male	103,237	27,711
10827	52	Female	1,693	328
23032	63	Female	1,009	157
		Mean	**25,611.0**	**6,305.9**

Key: km^2 = square kilometer(s).
Note: The U.S. EEZ is located 370.4 km (200 nautical miles) from shore.

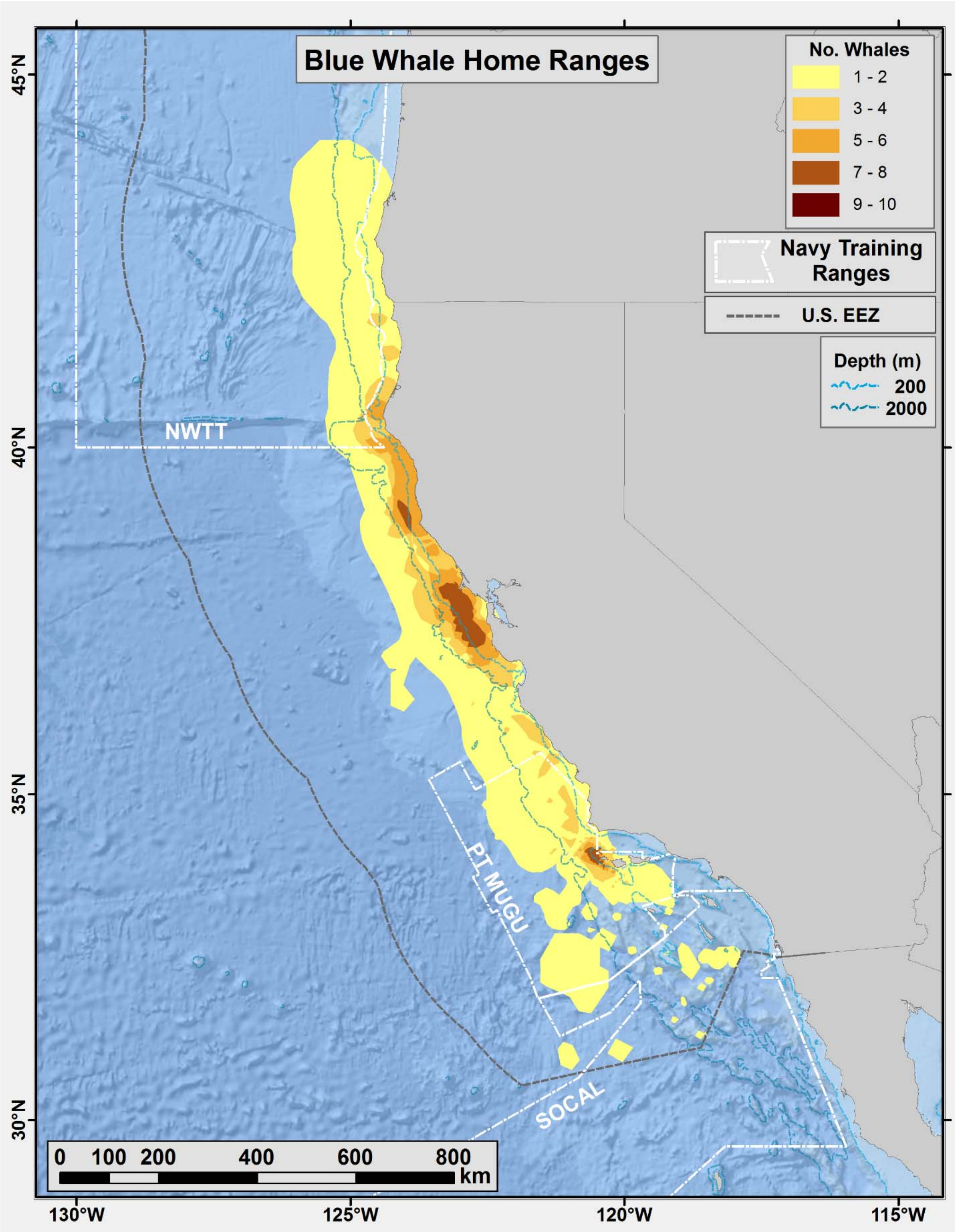

Figure 14. HRs in the U.S. EEZ for 14 blue whales tagged off southern and central California in 2016. Shading represents the number of individual whales with overlapping HRs.

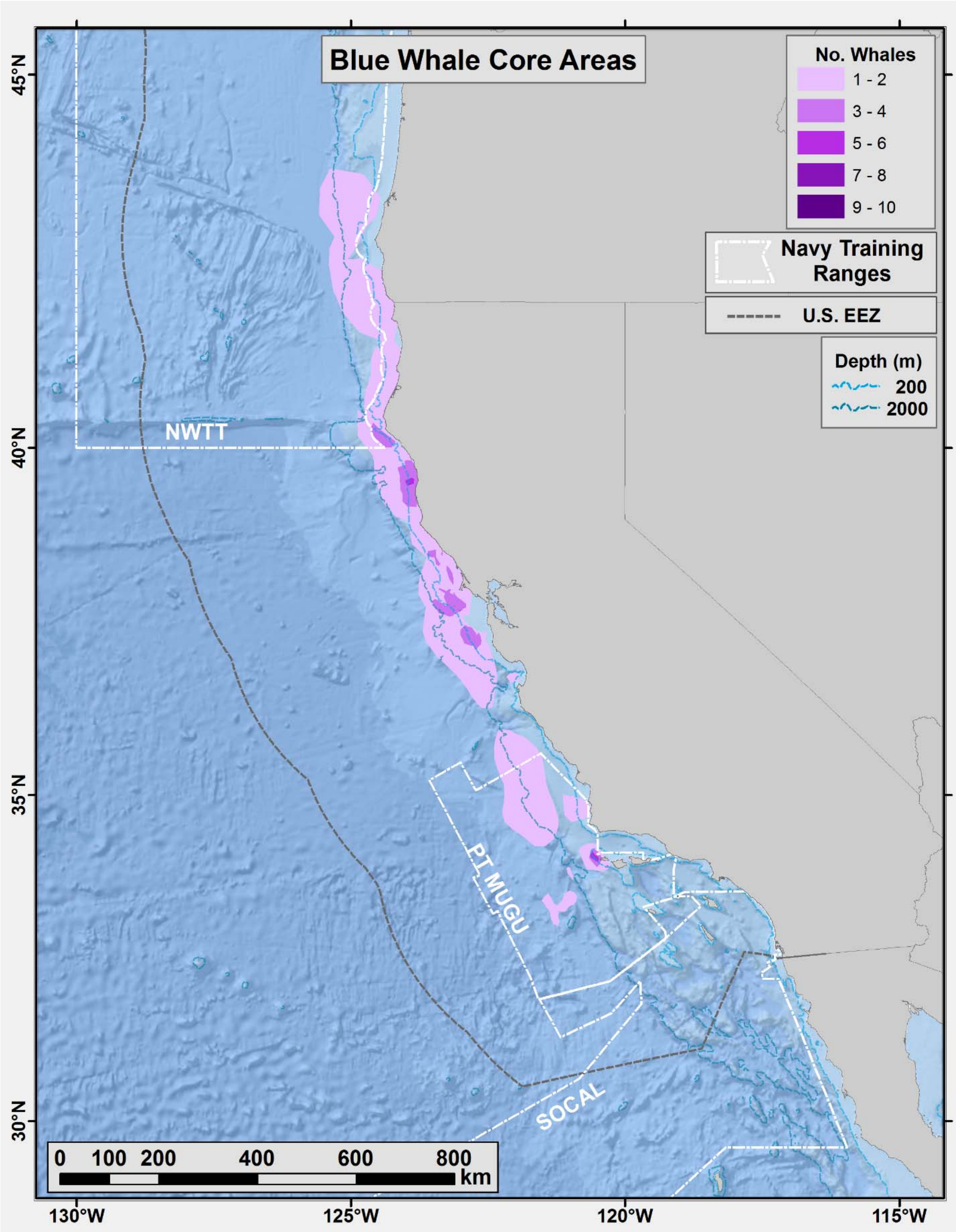

Figure 15. CAs of use in the U.S. EEZ for 14 blue whales tagged off southern and central California in 2016. Shading represents the number of individual whales with overlapping CAs.

3.1.2 Tracking Analysis—Interannual Comparison

Tracking durations of non-ADB tags deployed on blue whales were not significantly different between 2014, 2015, and 2016 (ANOVA, P = 0.57; **Table 7**). Tracking durations were not compared for ADB tags, as ADB tags were designed to come off a whale approximately 3–4 weeks after tagging and thus had much shorter tracking durations than non-ADB tags. The average tracking duration for all non-ADB tags on blue whales in these three years was 77.9 d (SD = 62.3 d, median = 61.7, n = 54). Tracking durations were not significantly different between LO and DM tags on blue whales in 2016, despite the expected electronic life of the LO tags being over three times longer than that of DM tags, so LO and DM tag results were combined in analyses.

Table 7. Mean (and SE) tracking duration, total distance traveled, home range, and core area for blue whales tracked with LO and DM satellite tags off California in 2014, 2015, and 2016.

	2014			2015			2016		
	Mean	**SE**	**n**	**Mean**	**SE**	**n**	**Mean**	**SE**	**n**
Tracking Duration (d)	66.7	16.6	18	88.8	13.7	18	78.2	14.0	18
Total Distance (km)	2,999.0	1.1	19	2,342.4	1.1	18	1,873.2	1.1	18
Home Range (km^2)	145,302.0	25,191.0	5	48,604.9	9,689.4	17	25,611.0	8,381.3	14
Core Area (km^2)	32,639.2	5,775.9	5	10,625.3	2,393.7	17	6,305.9	2,373.4	14

KEY: d = days; km = kilometers; km^2 = square kilometers, n = sample size; SE = standard error.

The latitudinal range, or the difference between the latitudes of the northern-most and southern-most locations for all blue whales in a given tagging year, was virtually the same in 2014 and 2015 (44 degrees), and much larger than in 2016 (26 degrees; **Figures 16 and 17**). The locations of these northern-most and southern-most extents were not similar, however, between 2014 and 2015. In 2014 whale locations were spread out between the northern tip of Vancouver Island, British Columbia (50.55°N) and the Costa Rica Dome off Central America (6.76°N). In 2015 the locations ranged between the central Oregon coast (43.70°N) and the equator (0.14°N). In 2016, the northern-most location was in a similar location off central Oregon as that in 2015 (44.04°N) but the southern-most location only extended to the west coast of mainland Mexico (17.62°N).

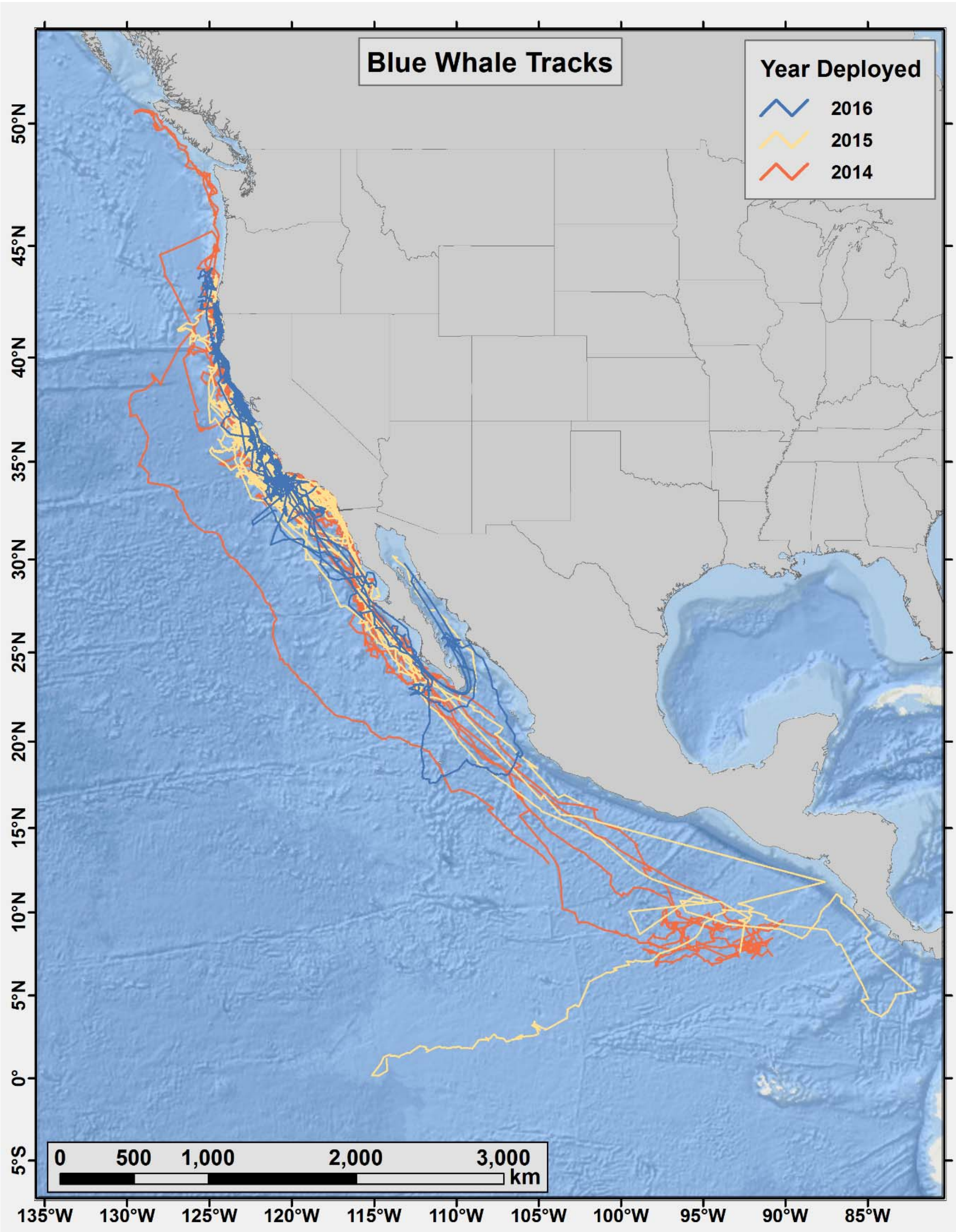

Figure 16. Satellite-monitored radio tracks for blue whales tagged off southern and central California during July and/or August, 2014 to 2016, with different tagging years being shown in different colors. Tracks show northern- and southern-most destinations.

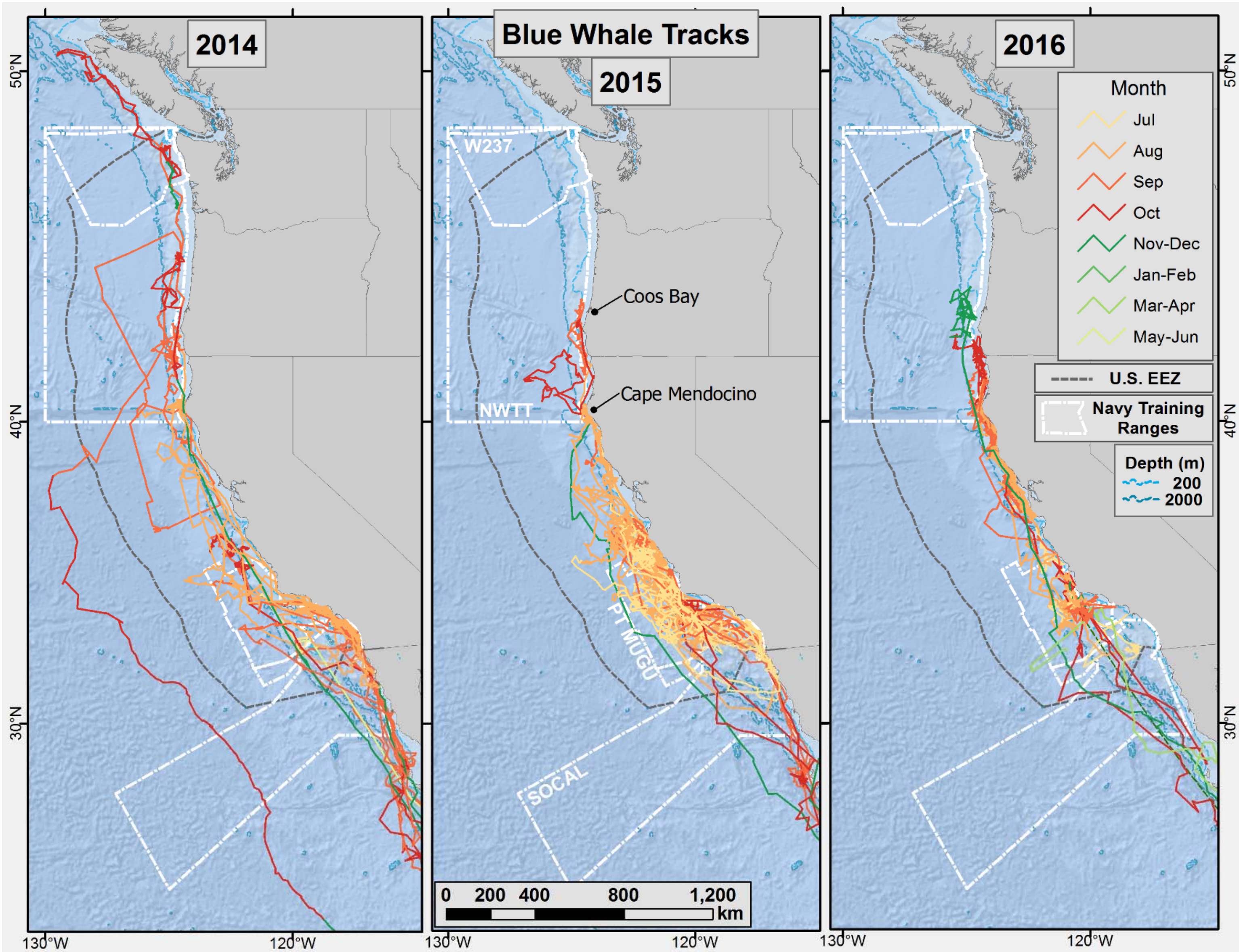

Figure 17. Satellite-monitored radio tracks for blue whales tagged off southern and central California in July and/or August, 2014 to 2016, zoomed-in to highlight feeding season movements rather than winter migratory destination.

Sixty-three percent of the blue whales tagged with LO tags in 2014 (12 of 19) migrated south of the California/Mexico border, with three of these whales reaching their migratory destination at the Costa Rica Dome. Thirty-nine percent of the blue whales tagged with LO tags in 2015 (7 of 18) migrated south of the border, with two whales reaching migratory destinations; one at the Costa Rican Dome and one in the northern Gulf of California. A third whale in 2015 was last located at the equator, approximately 4,200 km west of Ecuador. Only 22 percent of the blue whales tagged with LO and DM tags in 2016 (4 of 18) migrated south of the border, with the three that reached migratory destinations all traveling to the Gulf of California (two to the northern Gulf and one to the central Gulf).

There was a positive relationship between tracking duration and total distance traveled by blue whales tagged with LO and DM tags (linear regression using log-transformed variables, $P < 0.0001$). After accounting for this relationship, distance traveled was found to be significantly different between 2014 and the other two years (general linear model of log-transformed variables, $P = 0.0004$), with 2014 having longer distances than 2015 and 2016 (**Table 7**).

SOCAL was the most heavily used Navy training range for blue whales in 2014 (78 percent of all transmitting tags had locations/tracks there), followed by the PT MUGU range (61 percent of tracked whales; **Table 8**, **Figures 18 and 19**). In 2015 and 2016 PT MUGU was the most heavily used range (100 and 78 percent of tracked whales for 2015 and 2016, respectively), followed by SOCAL (64 and 28 percent for 2015 and 2016, respectively; **Table 8**, **Figures 18 and 19**). The NWTT range was used by 17 percent of tracked blue whales in both 2014 and 2016, and by 9 percent of tracked whales in 2015 (**Table 8**, **Figure 20**). Only one blue whale had locations/tracks in area W237 of the NWTT in 2014 (**Table 8**, **Figure 21**). For blue whales using SOCAL, number of days spent in the range did not differ between the three tagging years (ANOVA, $P = 0.64$), with whales spending an overall average of 6.9 d there (standard error [SE] = 0.7 d; **Table 8**). For whales using the PT MUGU range (**Figure 19**), number of days spent there was significantly different in 2014 (mean = 7.8 d, SE = 1.6 d) than in either 2015 (mean = 32.3 d, SE = 4.2 d) or 2016 (mean = 34.2 d, SE = 9.2 d; ANOVA using log-transformation, $P = 0.002$; **Table 8**). Mean number of days spent in the NWTT area ranged from 18.2 to 28.9 for the three tagging years, but sample sizes were not large enough to test for differences between years (**Table 8**). The one blue whale with locations in area W237 spent 19.5 d there (**Table 8**). Seasonality in the Navy training ranges was very similar between tagging years, with locations occurring predominantly in the summer and fall (July through November in SOCAL and PT MUGU, August through November in NWTT, September through November [2014] in W237). There were also December locations in PT MUGU in 2016. In the case of two blue whales that were tracked returning to U.S. waters after migrating south for the winter, additional locations occurred in SOCAL in March and June, and in PT MUGU in March and April. Mean distances to shore for tagged blue whales did not differ significantly between tagging years in any of the Navy training ranges (ANOVA P-values > 0.22), and ranged from 49 km in area W237 to 74 km in SOCAL (**Table 9**).

Table 8. Mean (and SE) number of days spent inside the SOCAL, MUGU, NWTT, and W237 areas for blue whales tagged off California in 2014, 2015, and 2016.

Year (# Whales Tracked)	# Days											
	SOCAL			MUGU			NWTT			W237		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
2014 (23)	6.3	1.1	18	7.8	1.6	14	28.9	11.0	4	19.5	-	1
2015 (22)	7.3	1.0	14	32.3	4.2	22	20.4	19.9	2	-	-	0
2016 (18)	8.3	2.1	5	34.2	9.2	14	18.2	17.1	3	-	-	0
All Years (63)	**6.9**	**0.7**	**37**	**26.0**	**3.5**	**50**	**23.4**	**7.7**	**9**	**-**	**-**	**-**

KEY: n = sample size; SE = standard error; # = number.

Table 9. Geodesic distances to nearest point on shore in Navy training ranges for blue whales tagged off southern and central California, 2014–2016 (including mean, median, and maximum distances to shore).

Tag #	SOCAL				PT MUGU				NWTT				W237			
	n	Mean	Median	Max	n	Mean	Median	Max	n	Mean	Median	Max	n	Mean	Median	Max
2014	18	57	25	359	14	55	34	145	4	66	55	108	1	49	49	49
2015	14	57	40	187	22	57	55	155	2	52	52	75	0	-	-	-
2016	5	114	114	186	14	52	34	112	2	44	44	54	0	-	-	-
Mean		**76.0**	**59.7**	**244.0**		**54.7**	**41.0**	**137.3**		**54.0**	**50.3**	**79.0**		**-**	**-**	**-**
Median		**57.0**	**40.0**	**187.0**		**55.0**	**34.0**	**145.0**		**52.0**	**52.0**	**75.0**		**-**	**-**	**-**

KEY: n = number of whales having locations in that particular training range.

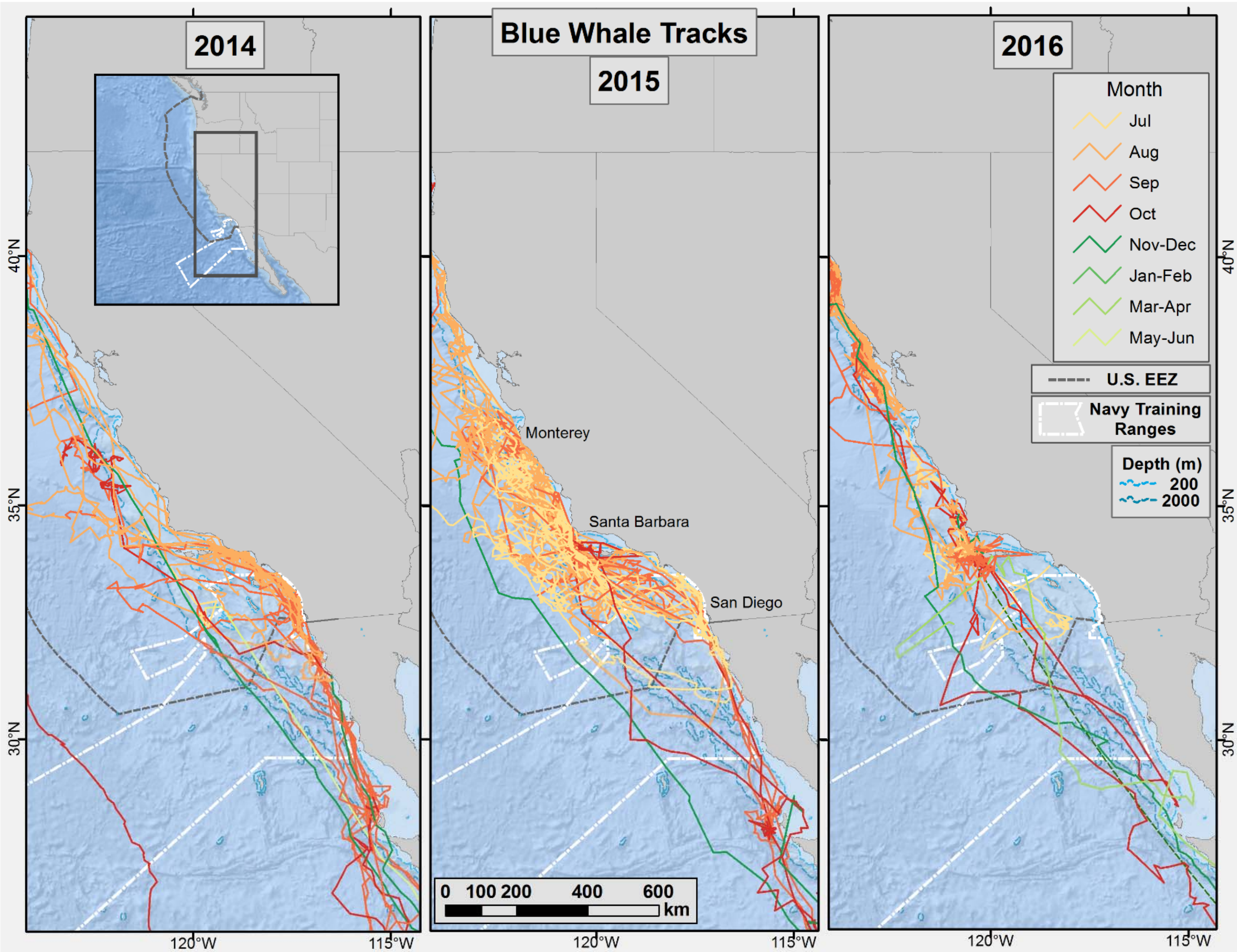

Figure 18. Satellite-monitored radio tracks of blue whales utilizing the SOCAL range, by tagging year (2014–2016).

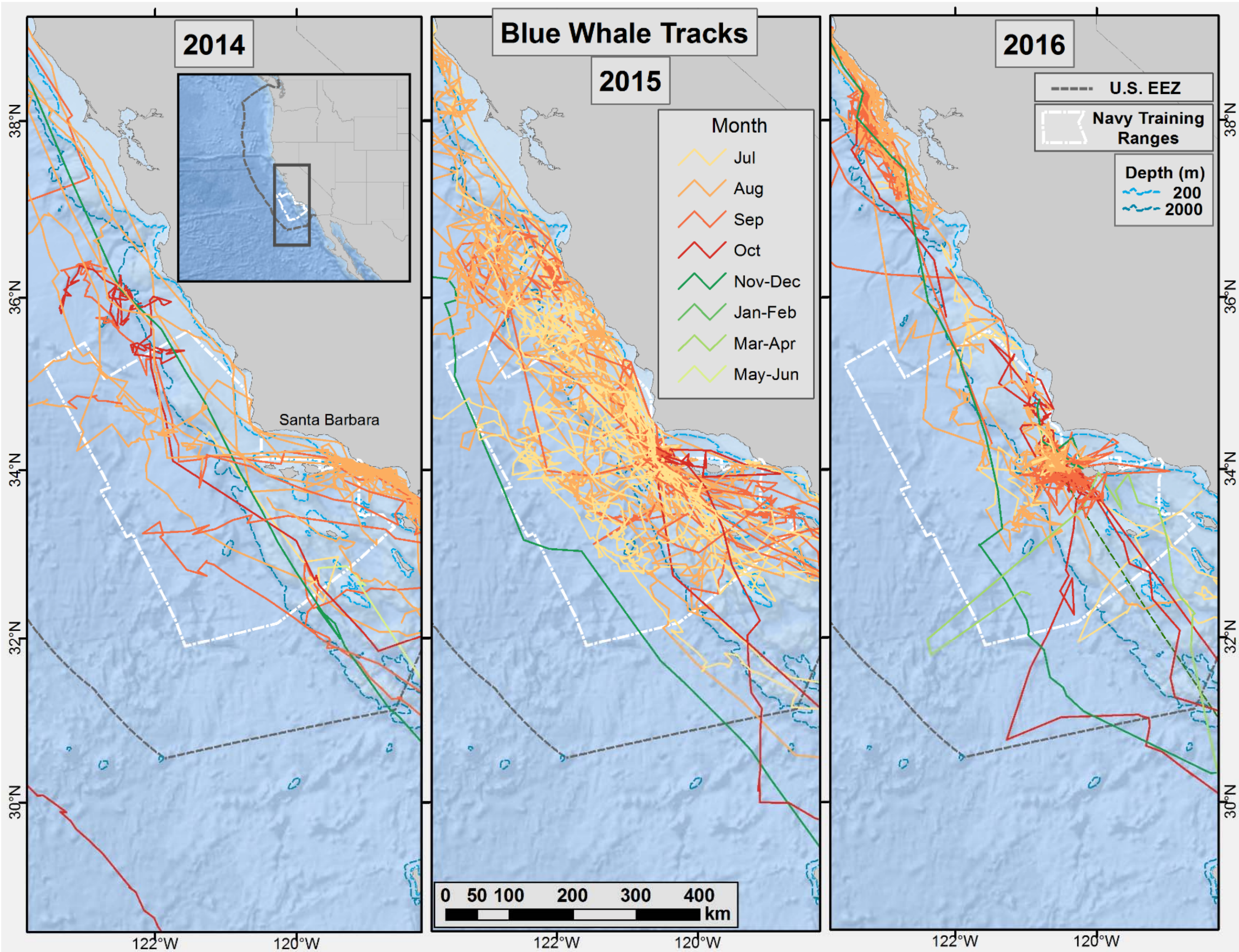

Figure 19. Satellite-monitored radio tracks of blue whales utilizing the PT MUGU range, by tagging year (2014–2016).

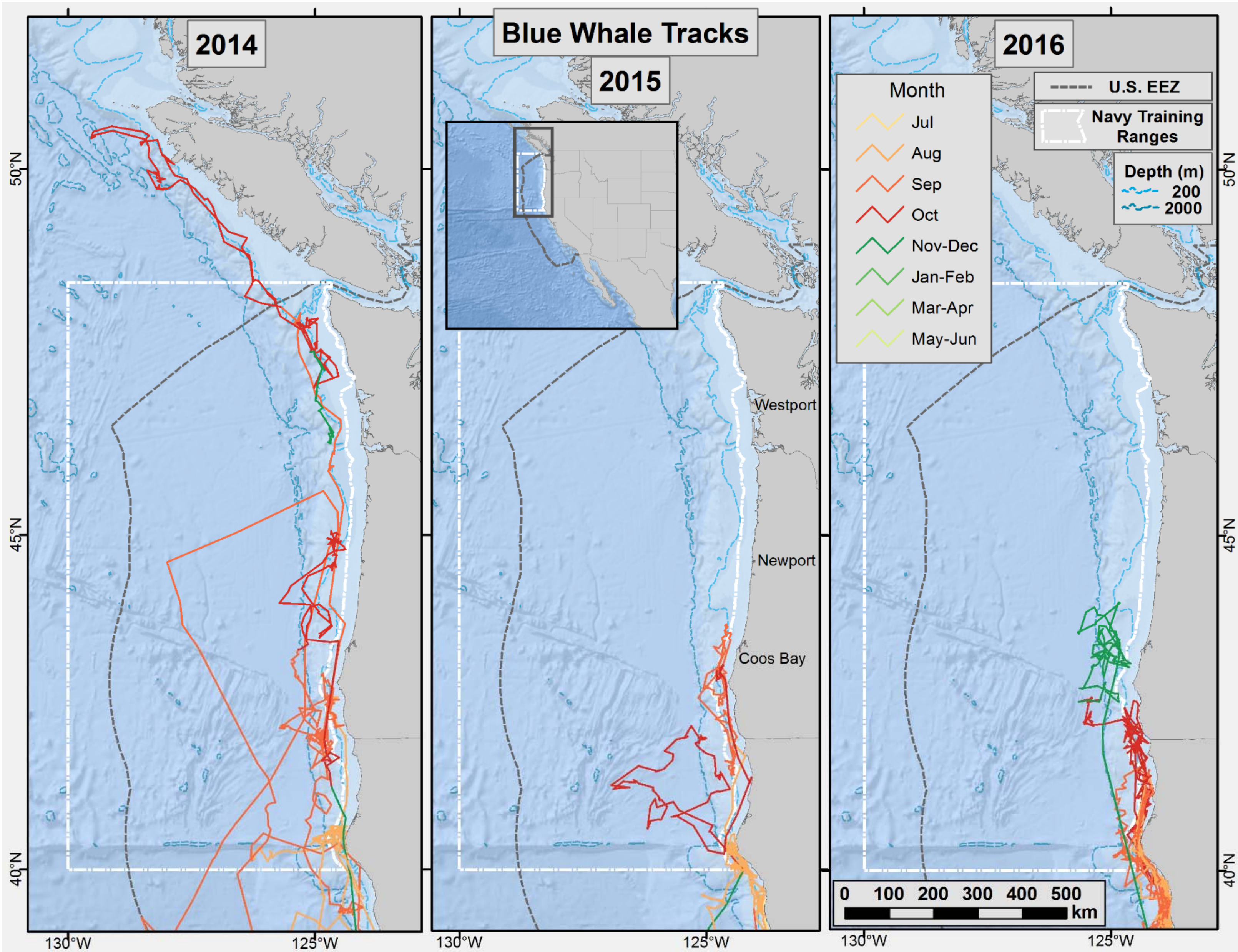

Figure 20. Satellite-monitored radio tracks of blue whales utilizing the NWTT range, by tagging year (2014–2016).

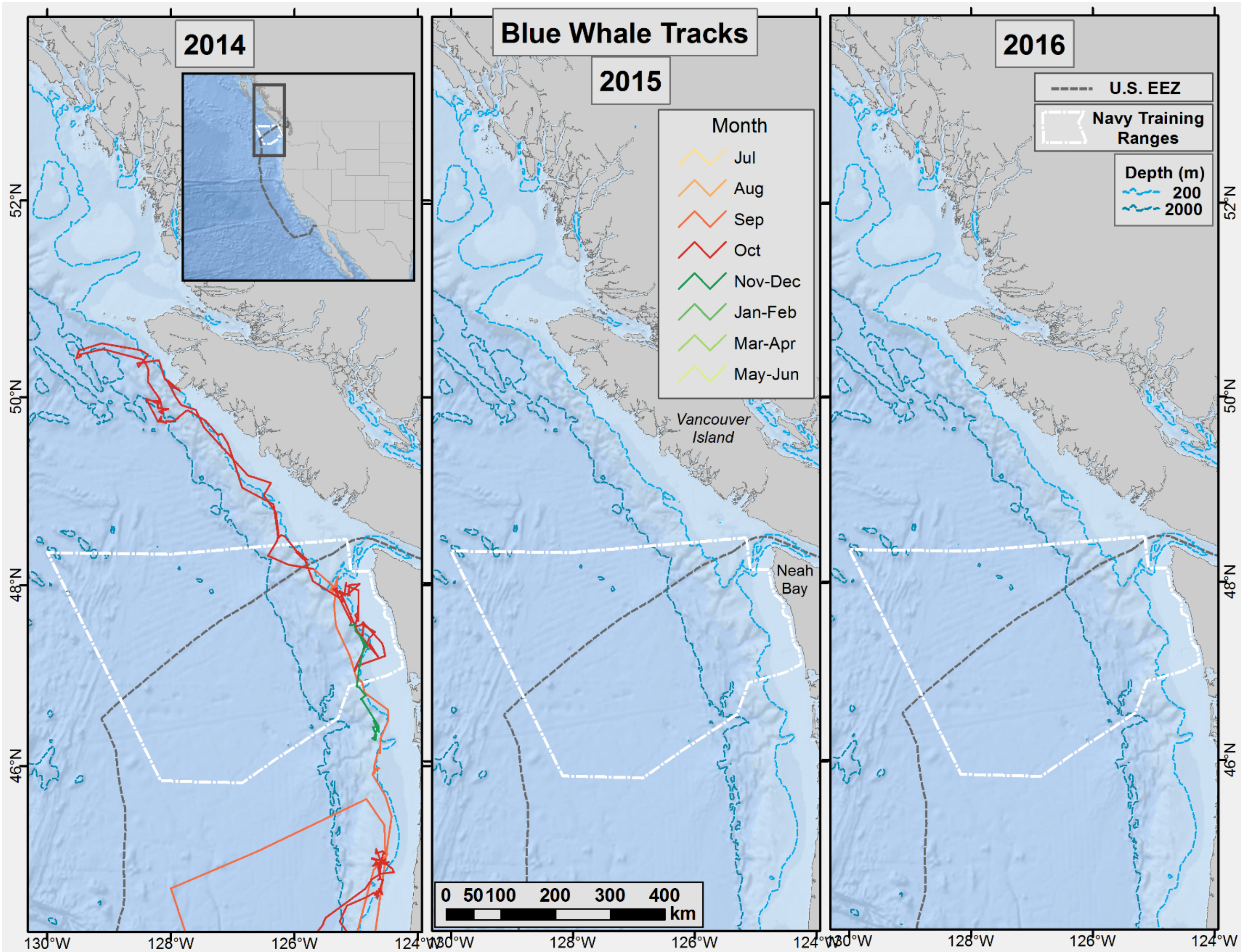

Figure 21. Satellite-monitored radio tracks of blue whales utilizing area W237 of the NWTT range, by tagging year (2014–2016). No blue whales tagged in 2015 or 2016 were tracked in area W237.

Only the Santa Barbara Channel and San Miguel BIA and the Point Conception/Arguello BIA had large enough sample sizes to allow statistical comparisons between all three tagging years (**Figures 24 and 25**). Time spent by blue whales in the Santa Barbara Channel and San Miguel BIA was significantly different between 2014 (mean = 0.6 d, SE = 0.2 d, n = 4) and both 2015 (mean = 11.0 d, SE = 2.6 d, n = 21) and 2016 (mean = 23.3 d, SE = 7.2 d, n = 10; ANOVA using log transformation P = 0.002; **Table 10**). Time spent in the Point Conception/Arguello BIA was not significantly different between the three tagging years (overall mean = 1.8 d, SE = 0.5 d, n = 27; ANOVA P = 0.51; **Table 10, Figure 25)**. Blue whale seasonality in BIAs was very similar between tagging years, occurring in August, September, and October in all three years. Blue whale locations/tracks occurred in BIAs in July in 2015 and 2016, when tag deployments occurred one month earlier (in July) than in 2014 (in August/September) (**Figures 22 through 27**). Blue whale locations also occurred in the Santa Barbara Channel and San Miguel and Point Conception/Arguello BIAs in November in 2016 (**Figures 24 and 25**).

Table 10. Mean (and SE) number of days spent inside the Biologically Important Areas (BIAs) for blue whales tagged off California in 2014, 2015, and 2016.

	# Days																	
Year (# tracked)	**Santa Monica Bay**			**San Diego**			**San Nicolas**			**Tanner Cortez**			**Santa Barbara**			**Pt. Conception**		
	Mean	**SE**	**n**	**Mean**	**SE**	**n**	**Mean**	**SE**	**n**	**Mean**	**SE**	**n**	**Mean**	**SE**	**n**	**Mean**	**SE**	**n**
2014 (23)	1.8	0.6	10	1.5	0.3	14	0.3	-	1	1.7	-	1	0.6	0.2	4	0.3	0.04	4
2015 (22)	1.0	0.8	3	1.0	0.4	9	0.2	0.1	3	0.5	0.3	4	11.0	2.6	21	1.9	0.8	16
2016 (18)	0.1	-	1	-	-	0	0.3	-	1	0.4	0.4	2	23.3	7.2	10	2.4	0.9	7
All Years (63)	**1.6**	**0.4**	**14**	**1.3**	**0.2**	**23**	**0.2**	**0.1**	**5**	**0.6**	**0.3**	**7**	**13.3**	**2.8**	**35**	**1.8**	**0.5**	**27**

KEY: n = sample size; SE = standard error; # = number.

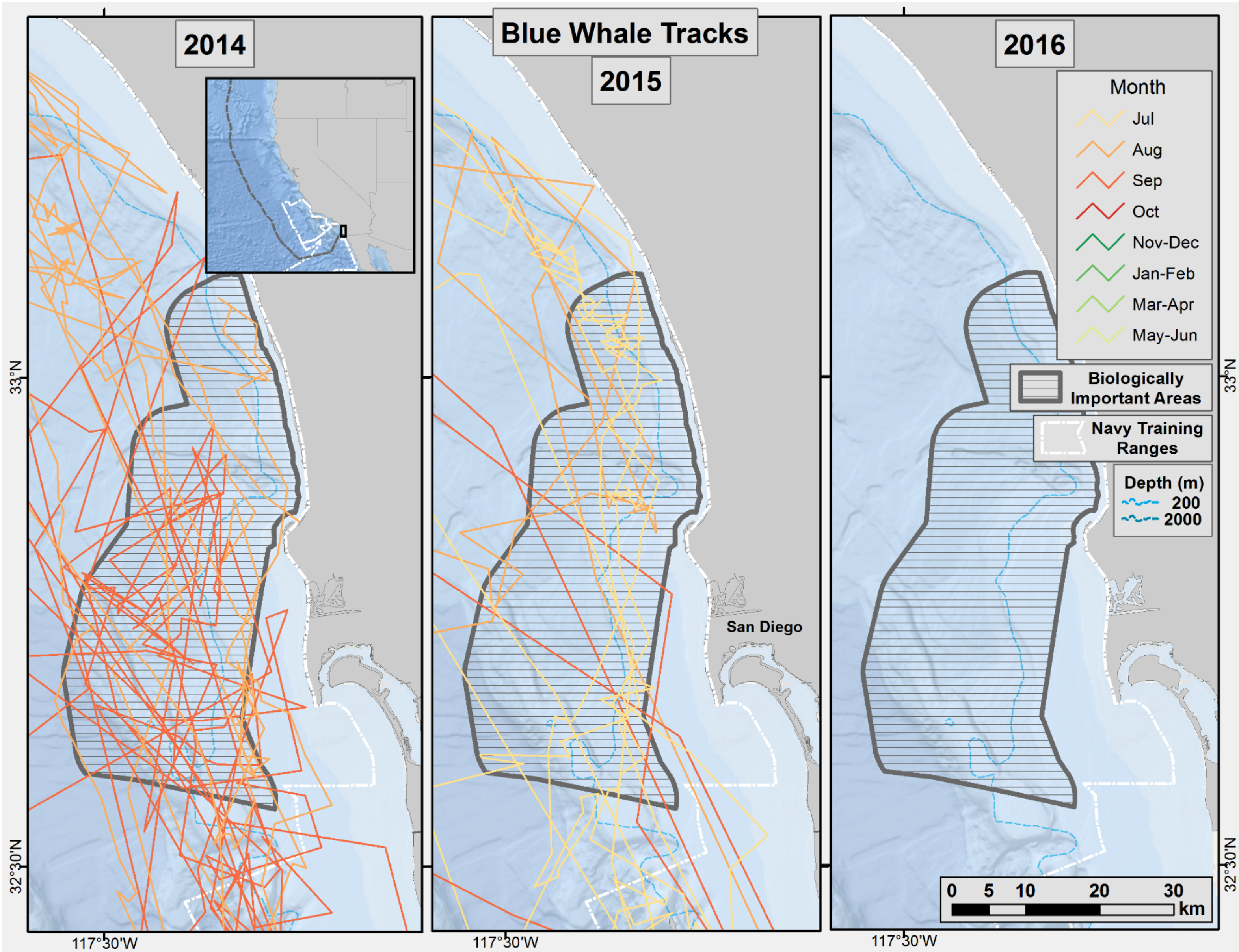

Figure 22. Satellite-monitored radio tracks of blue whales utilizing the San Diego BIA (located in the SOCAL range), by tagging year (2014–2016). No blue whales tagged in 2016 were tracked in the San Diego BIA.

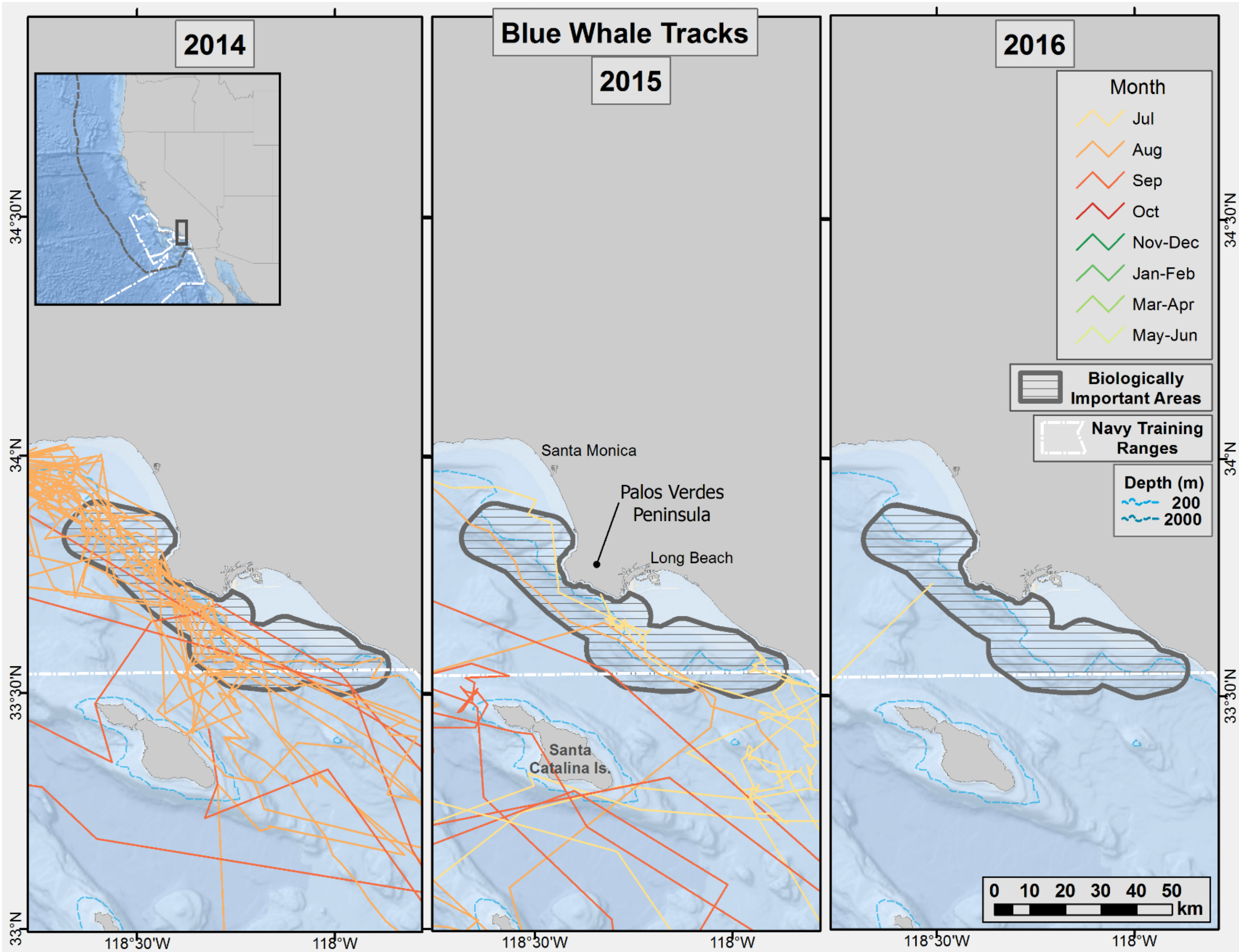

Figure 23. Satellite-monitored radio tracks of blue whales utilizing the Santa Monica Bay to Long Beach BIA (partially located in the SOCAL range), by tagging year (2014–2016).

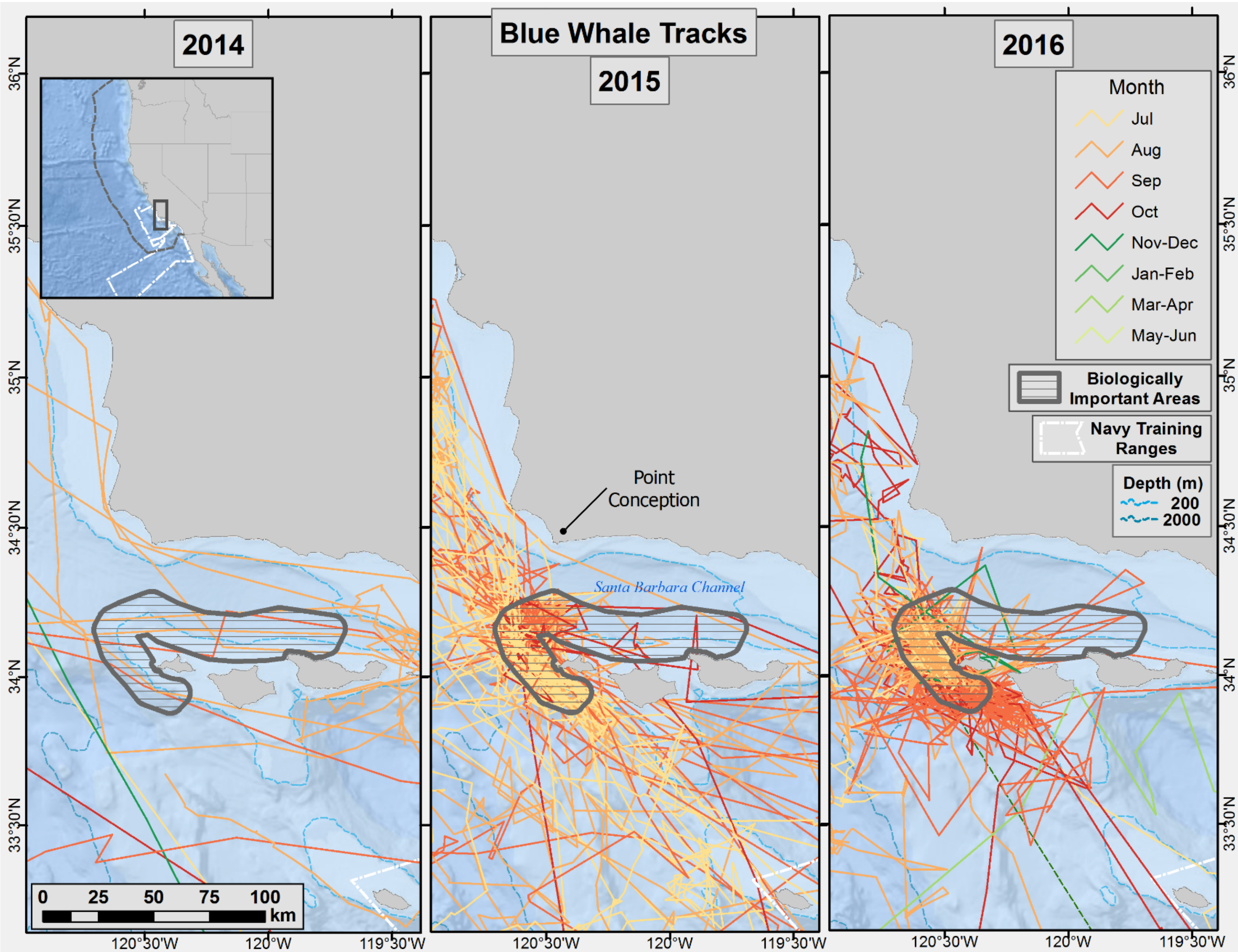

Figure 24. Satellite-monitored radio tracks of blue whales utilizing the Santa Barbara Channel and San Miguel BIA (partially located in the PT MUGU range), by tagging year (2014–2016).

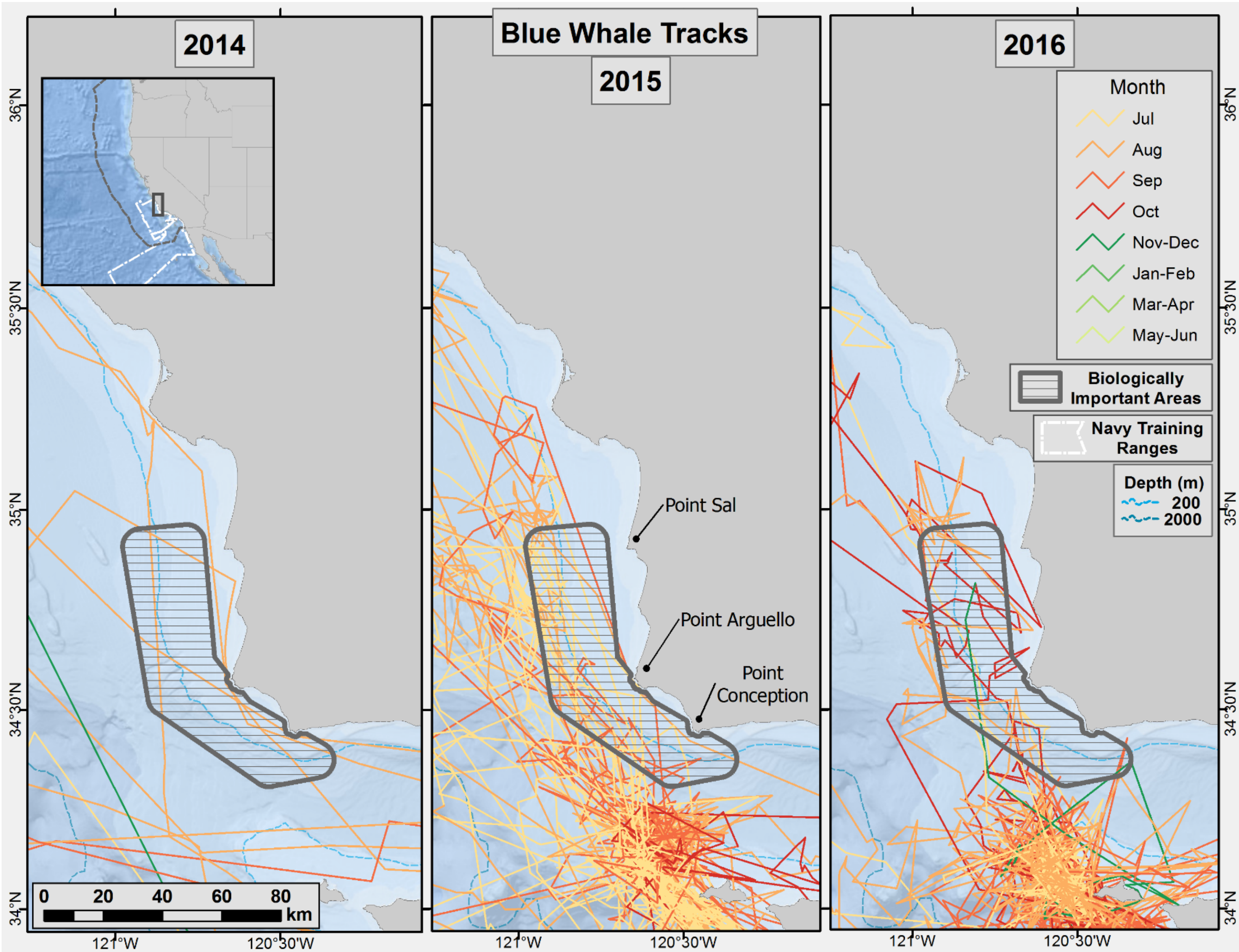

Figure 25. Satellite-monitored radio tracks of blue whales utilizing the Point Conception/Arguello BIA (partially located in the PT MUGU range), by tagging year (2014–2016).

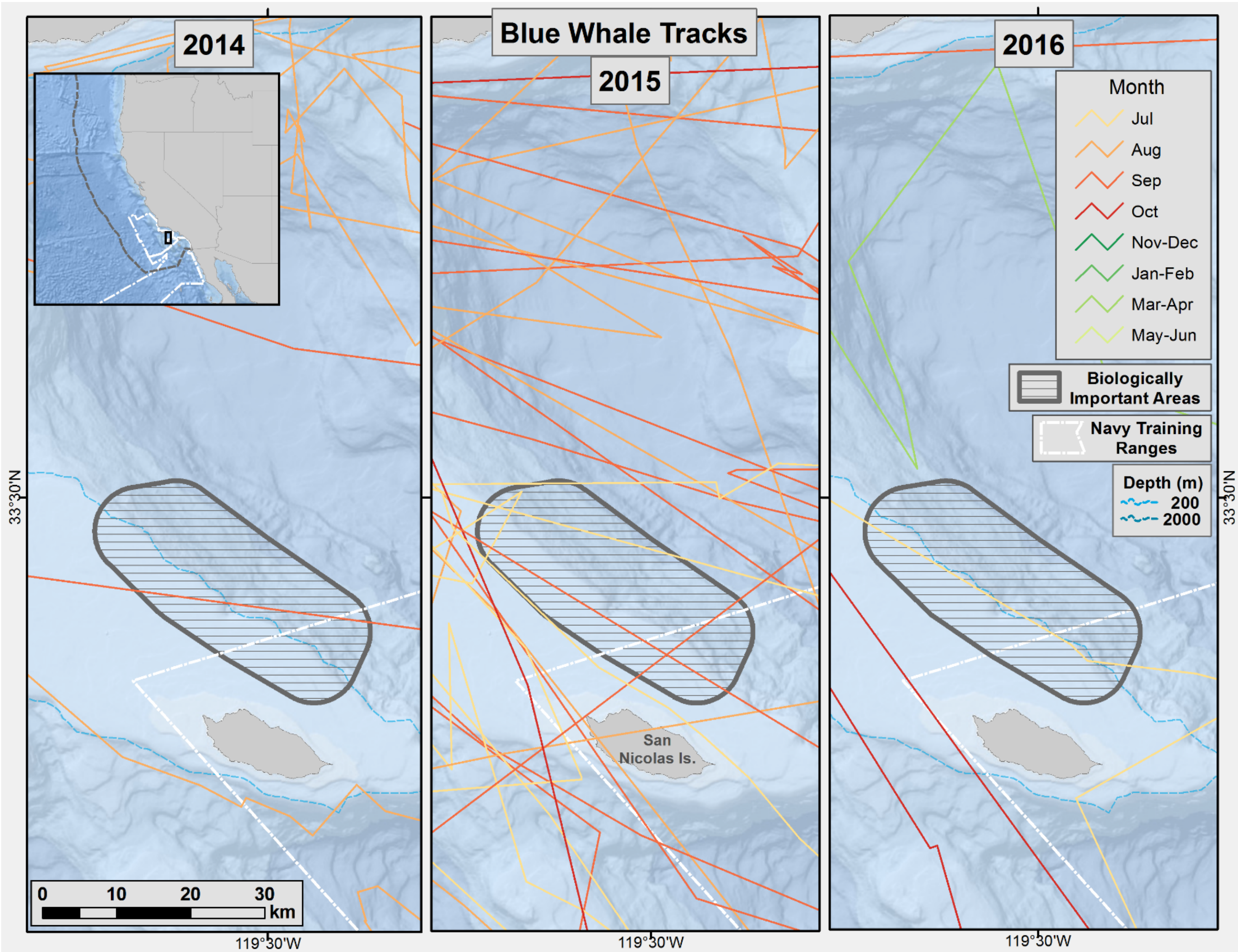

Figure 26. Satellite-monitored radio tracks of blue whales utilizing the San Nicolas Island BIA (located in the PT MUGU range and partially in the SOCAL range), by year (2014–2016).

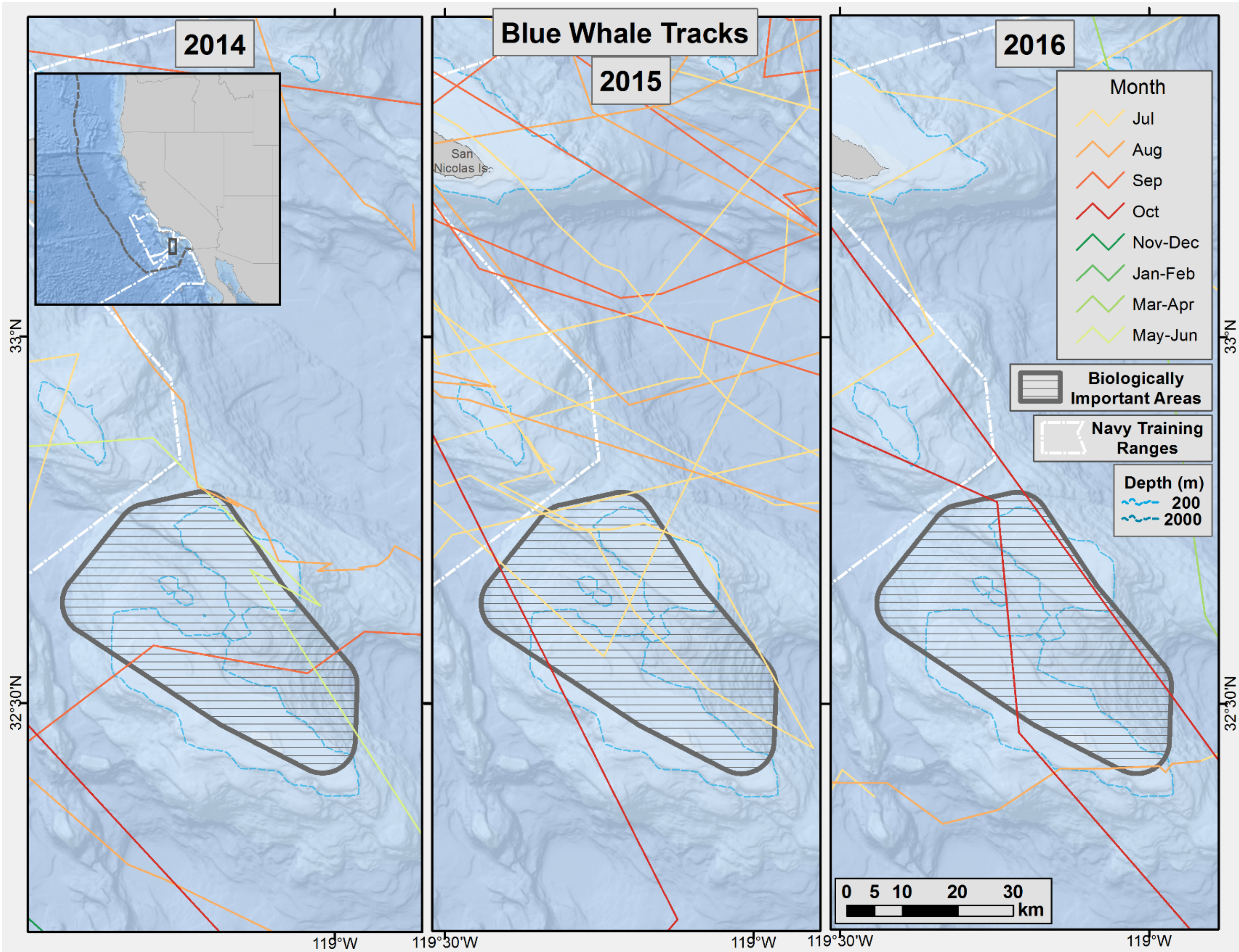

Figure 27. Satellite-monitored radio tracks of blue whales utilizing the Tanner-Cortez Bank BIA (located in the SOCAL range), by tagging year (2014–2016).

HRs (90% kernel isopleths) and CAs (50% kernel isopleths) for blue whales were significantly different between 2014 and the other two years (ANOVA, P values < 0.0002; **Table 7; Figures 28 and 29**), with mean sizes of HRs and CAs being much larger for whales tagged in 2014 than in either 2015 or 2016. Areas of highest use (where CAs overlapped for the most number of whales) were off Point Dume in southern California in 2014, but off the west end of San Miguel Island in the Channel Islands in 2015 and 2016, and just north of Point Arena in northern California in 2016.

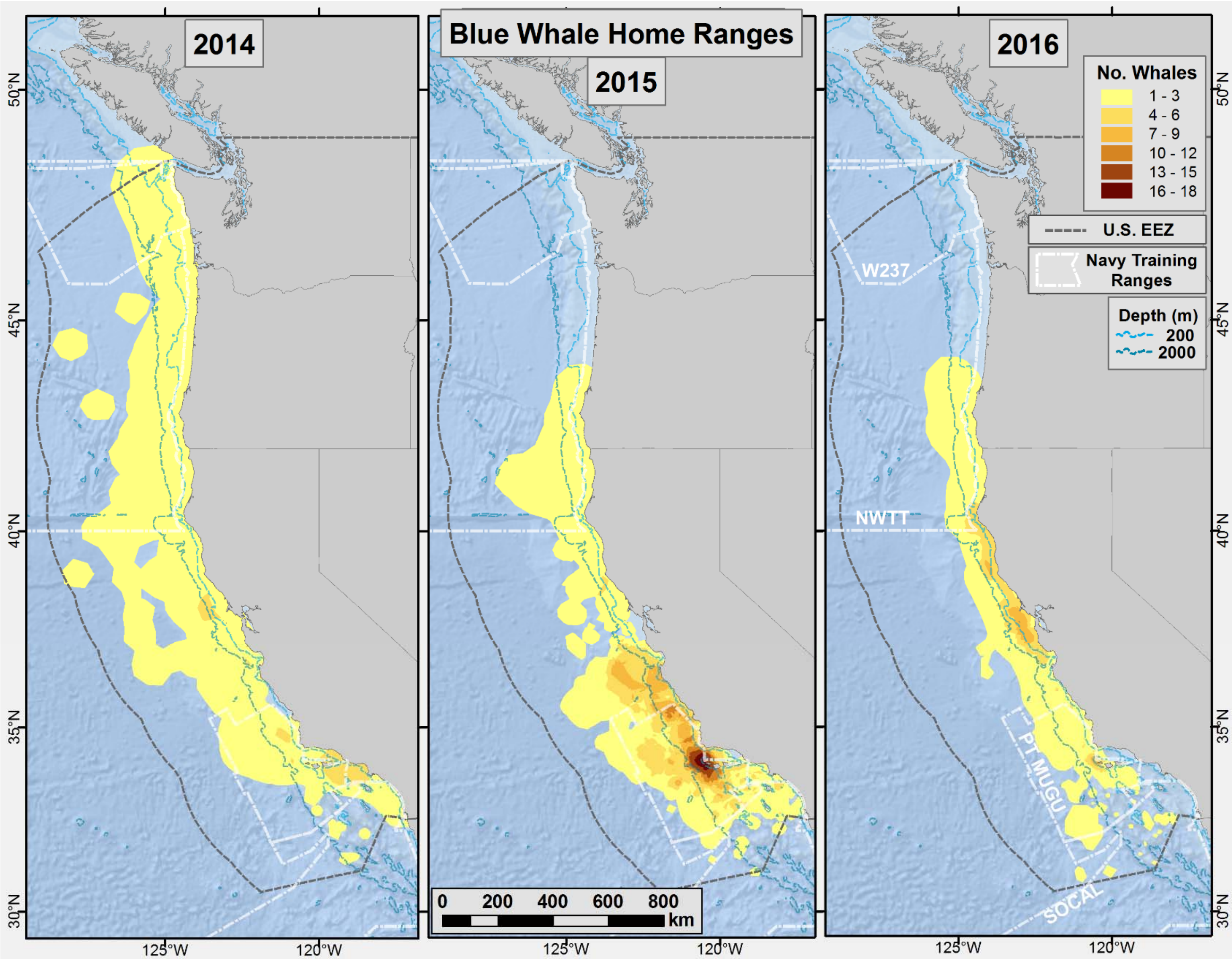

Figure 28. HRs in the U.S. EEZ for blue whales tagged off southern California in 2014 (5 whales), off southern California in 2015 (17 whales), and off southern and central California in 2016 (14 whales). Shading represents the number of individual whales with overlapping HRs

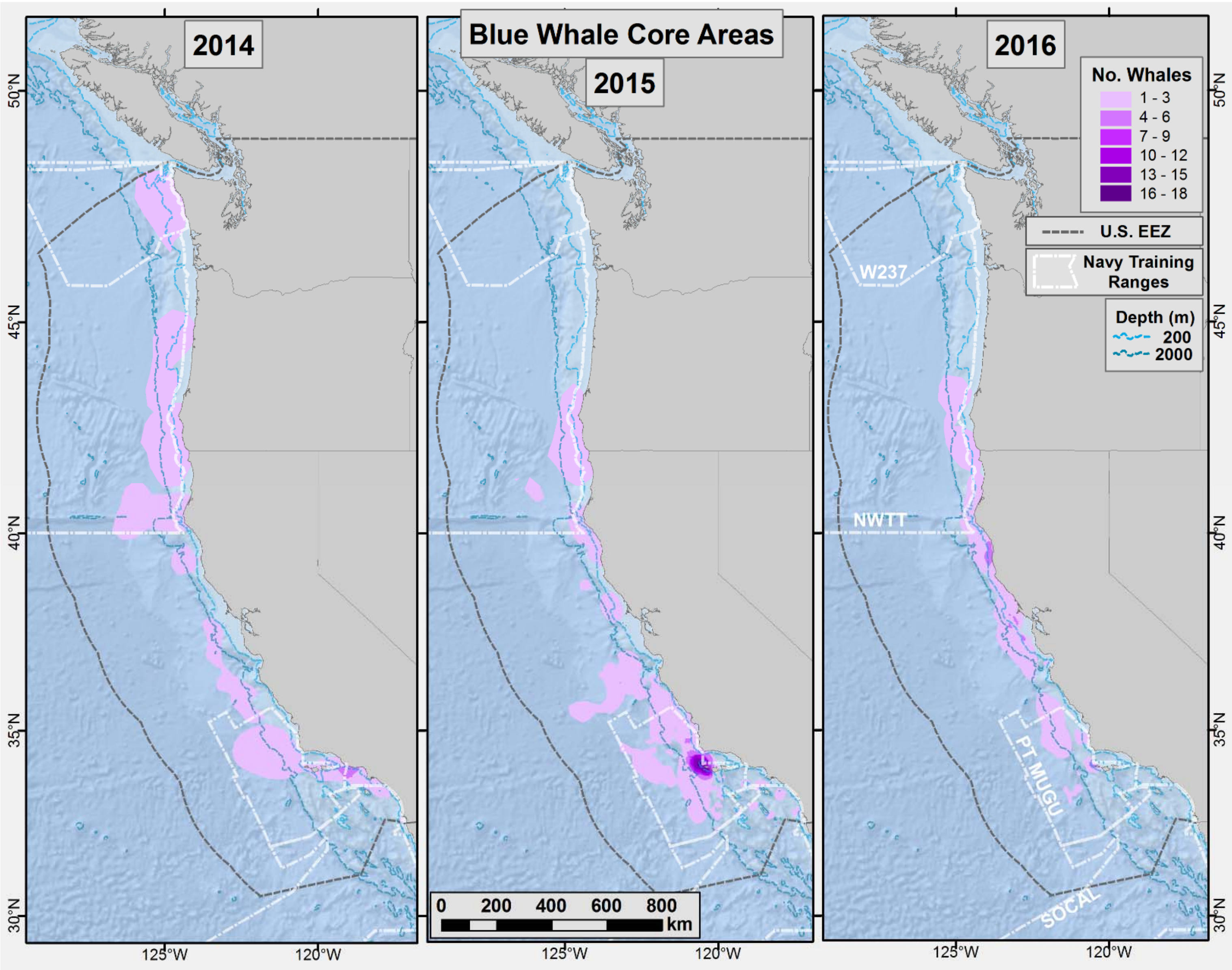

Figure 29. CAs of use in the U.S. EEZ for blue whales tagged off southern California in 2014 (5 whales), off southern California in 2015 (17 whales), and off southern and central California in 2016 (14 whales). Shading represents the number of individual whales with overlapping CAs.

To investigate potential geographic separation of blue whales occurring off the coast of California, we visually compared the tracks of blue whales tagged off central and northern California (from Point Arguello to the California/Oregon border, referred to hereafter as "central") with those of blue whales tagged off southern California (south of Point Arguello; **Figure 30**) during the three years of this study (2014, 2015, 2016), and with those of previously tagged blue whales by OSU in these two areas from 1994 to 2008 (which were presented in our 2014 report; Mate et al. 2015). All combined, almost three times as many blue whales were tagged off southern California (n = 133) than off central California (n = 47). The latitudinal spread in blue whale locations was slightly greater for whales tagged in southern California (53 degrees) than for those tagged in central California (43 degrees), as was maximum distance to shore (approximately 2,800 km and 2,200 km for southern and central whales, respectively). Summer/fall feeding season movements and winter destinations were very similar between the two groups, however. With a few exceptions, the range of locations for blue whales tagged in both central and southern California covered the entire coast of California and into central Oregon. The northern extreme for whales tagged in southern California was west of Haida Gwaii, British Columbia, and west of Vancouver Island, British Columbia, for whales tagged in central California. Blue whales tagged in both locations had similar migratory destinations, with both southern and central whales migrating to the Costa Rica Dome as well as to the Gulf of California. The blue whale that traveled to the equator was one that was tagged off southern California in 2015.

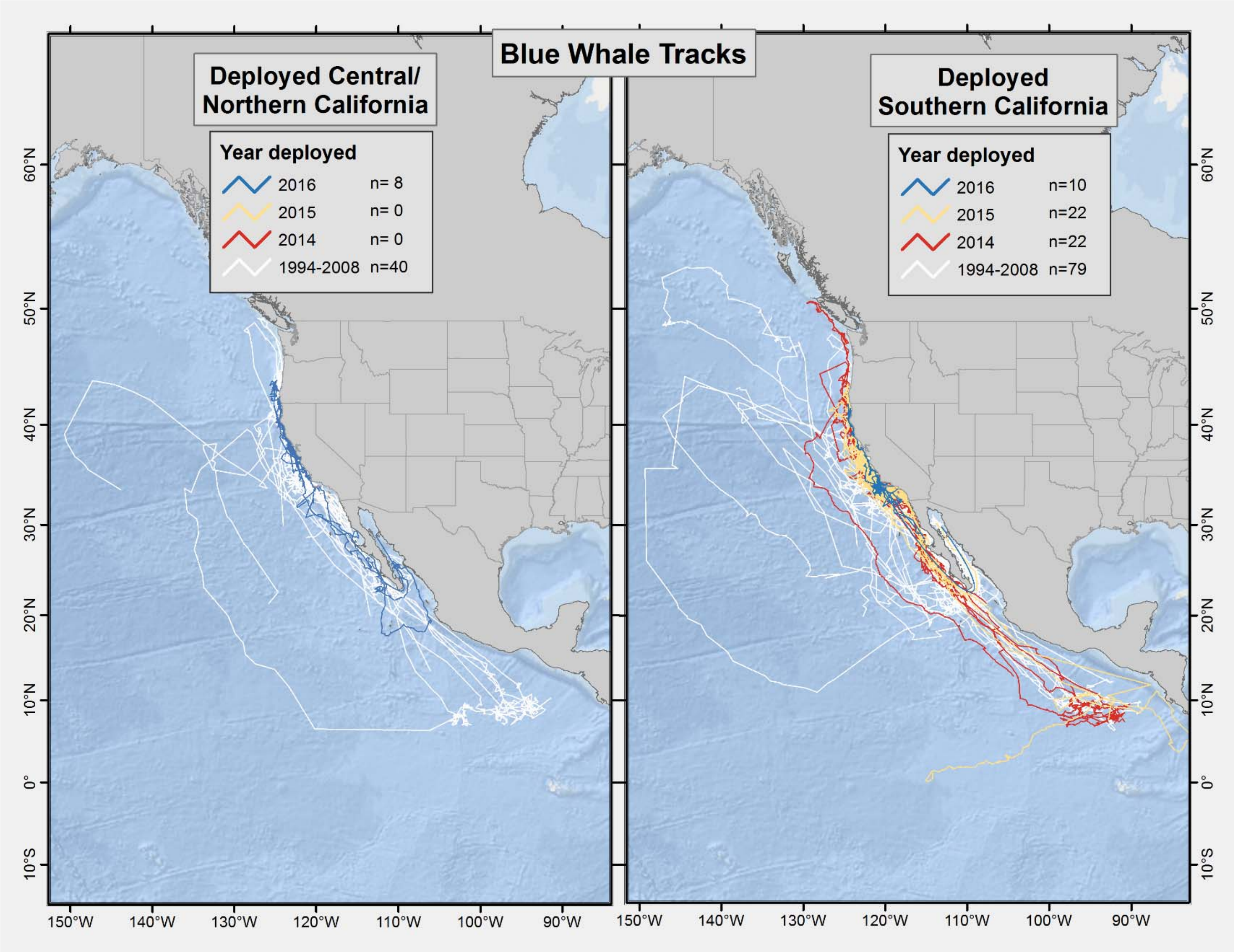

Figure 30. Satellite-monitored radio tracks of blue whales tagged by OSU off central and northern California (left panel) and southern California (right panel) between 1994 and 2016.

3.1.3 ADB Tag Analysis

Eight blue whales were tagged with ADB tags from 2014 to 2015 and tracked for a median of 22.4 d (**Table 11**). In 2014, three of the four tags reached their programmed release dates while still attached to the whales. The other one was shed and sank to the bottom while still attached to its housing. It was later recovered, as the tag triggered a programmed premature release after detecting it had been on the bottom for more than 24 h. In 2015, all four tags reached their programmed release dates while still attached to the whales, but did not release as scheduled. Three of the tags eventually released from their housings and were recovered, but the fourth tag was shed while still attached to the housing and never surfaced. ADB-tagged whales generally occupied areas farther offshore in 2015 compared to 2014 with the exception of Tag #2015_838, which remained close to the southern California coast for the majority of the tracking period (**Figures 31 and 32**). In 2014, three of the four ADB-tagged blue whales remained in southern California waters after departing the tagging area, but only one remained there in 2015. One whale in each year (Tag #2014_5650 and Tag #2015_4177) made a clockwise loop across a large portion of southern California waters. Both whales were male, while females remained closer to shore **(Figure 33)**.

Table 11. ADB tag deployment summary information for tags deployed on blue whales off southern California in August 2014 and July 2015.

Species	Tag #	Recovered?	# Days Tracked	# Dives	# GPS locations	Mean Dives/Day	Mean GPS Locs/Day	Total Distance (km)
2014								
Blue Whale	5644+	Yes	19.0	1392	185	73. 3	10	1,454.
Blue Whale	5650+++	Yes	20.0	3004	2297	150.2	115	1,708.
Blue Whale	5655+	Yes	19.8	4089	799	206.5	40	1,563.
Blue Whale	5803+++	Yes	18.3	2789	2539	152.4	139	2,033
		Median	**19.4**	**2897**	**1548**	**151.3**	**78**	**1636**
2015								
Blue Whale	838+++	No*	25.9	2289	69	88	3	2137
Blue Whale	840+	Yes	24.8	2252	1558	91	63	1610
Blue Whale	4177+++	Yes	27.5	2824	1480	103	54	2545
Blue Whale	5650+++	Yes	28.9	2298	2337	80	81	2509
		Median	**26.7**	**2294**	**1519**	**90**	**58**	**2323**
		Total	**107.1**	**9663**	**5444**	**361.4**	**200**	**8801**

KEY: d = day(s); GPS = Global Positioning System; km = kilometer(s); Locs = locations; # = number; +Tag is Fastloc® v.1, +++Tag is Fastloc® v.3, *Data were transmitted through Service Argos, Inc.

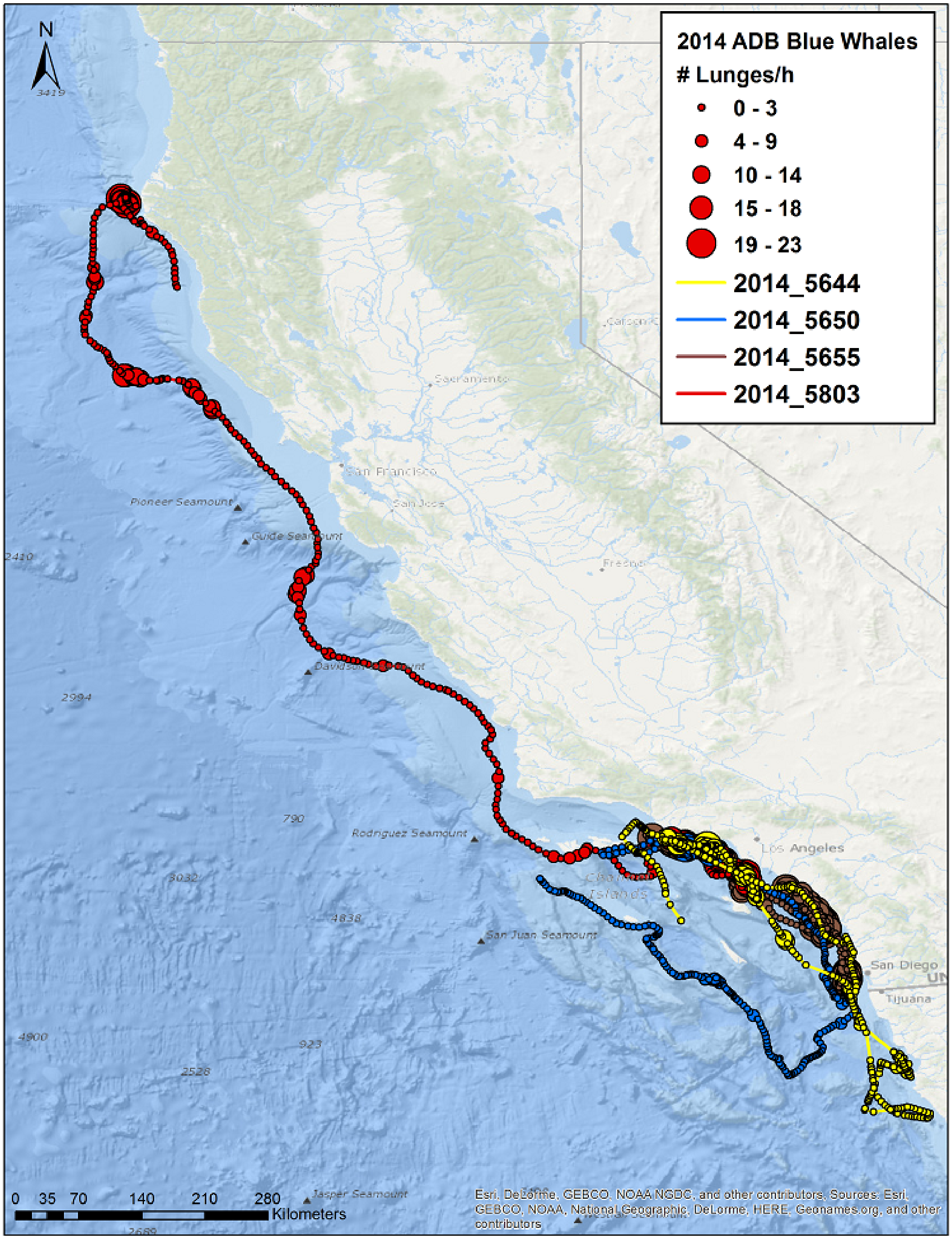

Figure 31. Tracks of four ADB-tagged blue whales off southern California in August 2014. Size of the circles represents the number of feeding lunges recorded by a tag per hour. The circle is centered on the portion of track that was summarized .

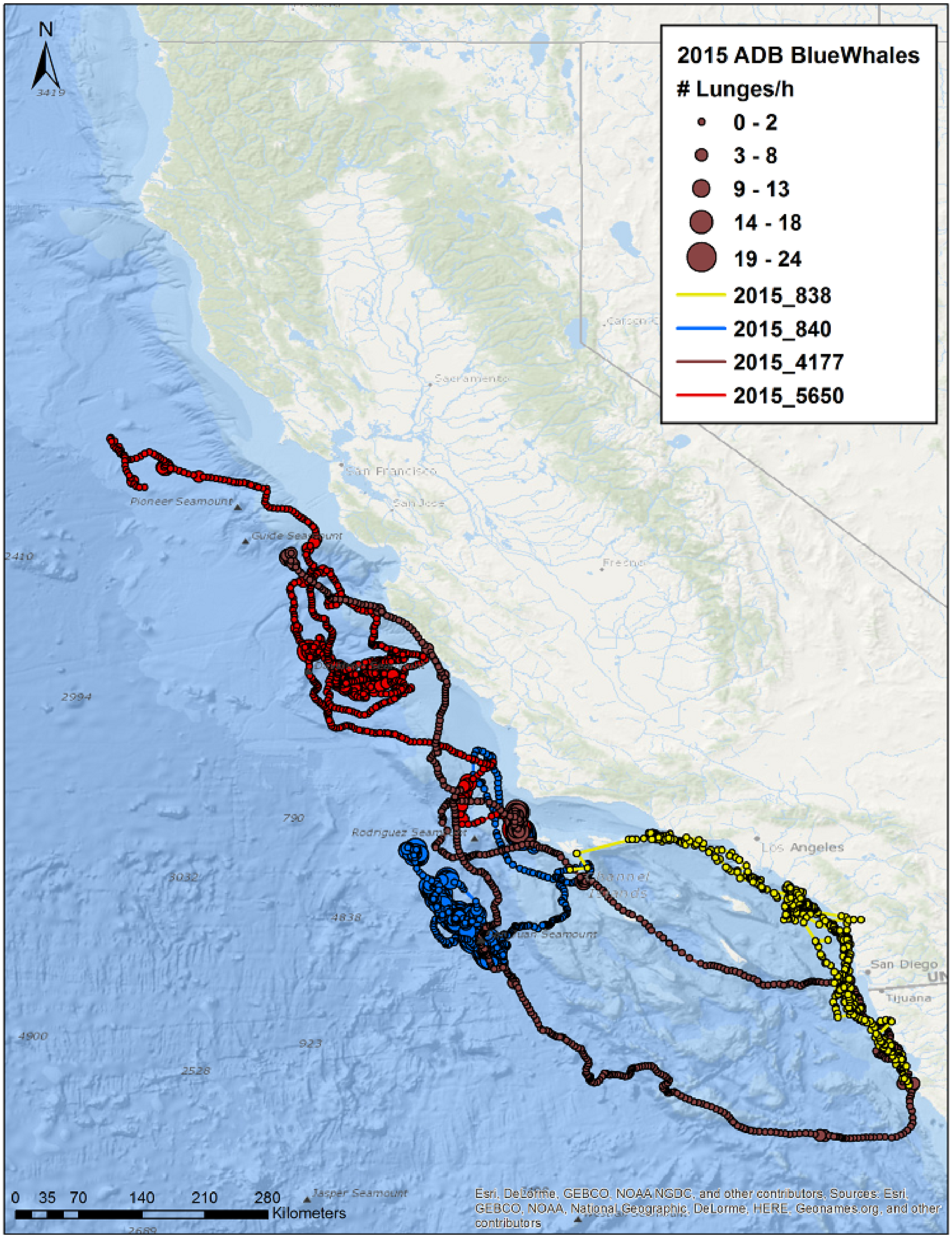

Figure 32. Tracks of four ADB-tagged blue whales off southern California in July 2015. Size of the circles represents the number of feeding lunges recorded by a tag per hour. The circle is centered on the portion of track that was summarized. Tag #2015_838 was not recovered so no foraging data were available, but locations received through Argos are shown.

Figure 33. Map of all blue whale ADB tracks colored by sex.

The seven recovered ADB tags each recorded more than 1,300 dives > 10 m in depth, with a median of 151 dives/d (**Table 11**). The number of Fastloc® GPS locations recorded by the tags varied widely, with all but one tag using newer Fastloc® v. 3 technology, recording > 2,300 locations, compared to the Fastloc® v.1 tags, two of which recorded < 800 locations (**Table 11**). ADB-tagged blue whales generally made deeper dives during the daytime than at night (**Figures 34 and 35)**; however, there was high variability within and between individuals and daytime surface feeding was recorded on multiple occasions both visually while in the field and in the data record. Feeding activity (as measured by lunge-feeding events) generally took place during the daylight hours, though nighttime lunges were recorded on some occasions for multiple whales. High rates of feeding activity occurred near the tagging location, with periodic clusters of feeding activity recorded after departure from the tagging area (**Figures 31 and 32**).

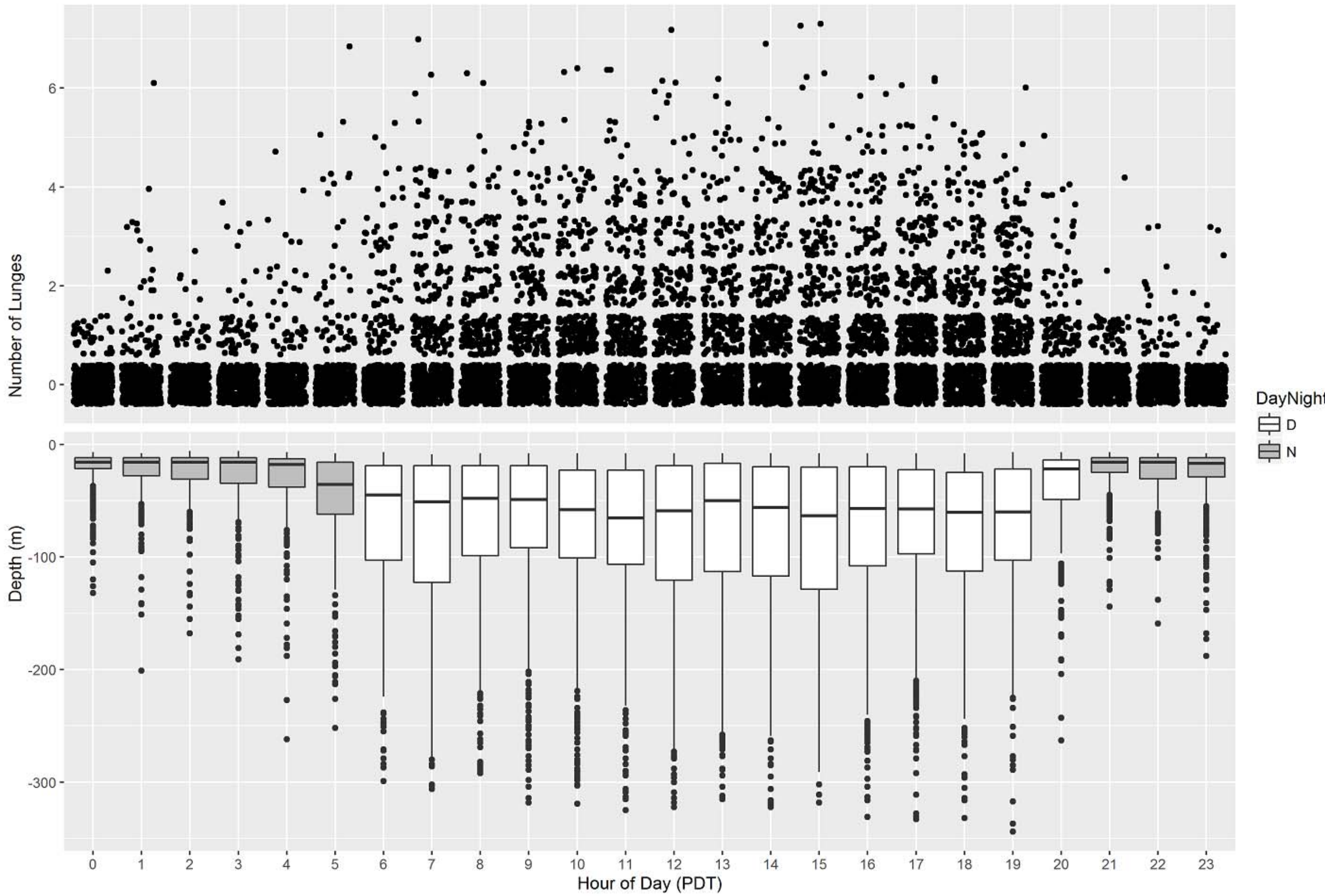

Figure 34. Number of lunges per dive (upper panel) and maximum dive depth (lower panel) of ADB-tagged blue whales tracked off southern California during August 2014 (n = 4). Data are presented by hour of day to better visualize diel variability and the data in the top panel are jittered to avoid overplotting.

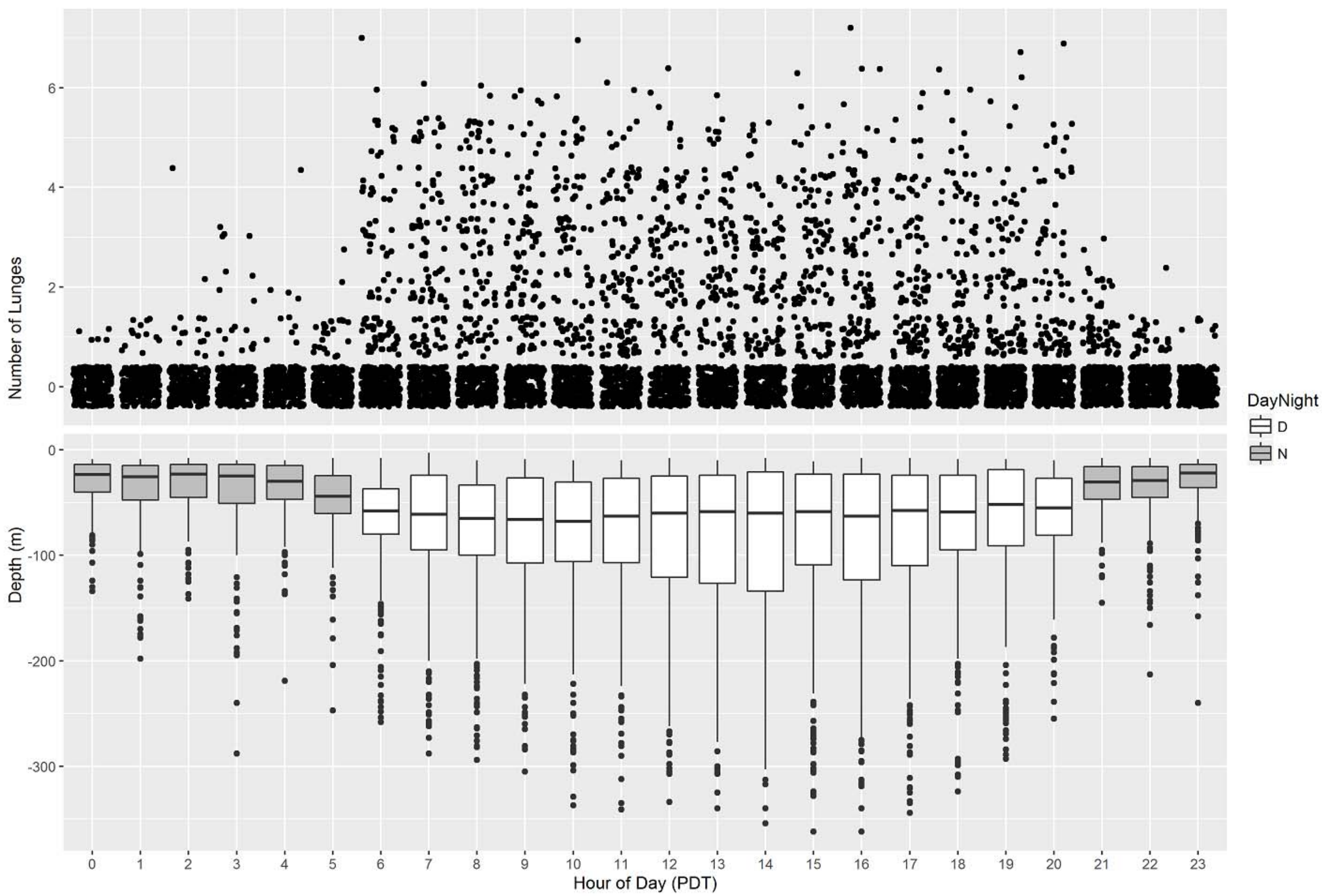

Figure 35. Number of lunges per dive (upper panel) and maximum dive depth (lower panel) of ADB-tagged blue whales tracked off southern California during July 2015 (n = 3). Data are presented by hour of day to better visualize diel variability and the data in the top panel are jittered to avoid overplotting.

The overall dive behavior of tagged whales was generally similar; however, there were differences between individuals, both in the areas occupied and in behavior. While the maximum dive depth of all the tagged blue whales showed a diel trend, with deeper dives occurring during the day, dives recorded by some whales were frequently almost double the depth of those made by others (**Table 12**) and overall daytime dive depths were highly variable for all whales. The location, duration, and intensity (i.e., number of lunges per dive) of feeding effort varied by individual and were generally located near areas of high bottom slope (**Figures 31 and 32**).

Table 12. Summary of dives occurring during foraging bouts made by seven ADB-tagged blue whales tagged off southern California in August 2014 and July 2015. Feeding bouts are sequences of dives with no more than 60 minutes between dives with recorded feeding lunges. Unknown sex whales are cases where no biopsy sample was collected.

Tag ID	Sex		Bout Duration (h)	# Dives/ Bout	Avg Max Dive Depth (m)	Avg Duration (minutes)	Avg Lunges per Dive	Dives with No Lunges	Tortuosity	Area of Bout (km^2)	Time to Next Bout (h)	Dist to Next Bout (km)
2014_5644	Female	Med	1.9	26	83.1	9.4	1.0	4.5	1.0	0.02	12.1	16.2
# bouts = 22		Min	0.7	105	14.7	1.4	0.3	0.0	0.6	0.00	1.1	0.4
		Max	9.1	5	206.6	15.7	3.1	27.0	1.0	40.89	139.9	214.3
2014_5650	Male	Med	1.5	16	51.3	6.9	0.7	6.0	0.6	1.19	2.5	4.1
# bouts = 38		Min	0.3	145	15.0	2.4	0.2	0.0	0.1	0.01	1.1	0.0
		Max	13.4	4	253.5	13.1	3.5	85.0	1.0	56.13	78.4	184.3
2014_5655	Female	Med	4.3	62	98.3	6.1	1.5	6.0	0.7	4.24	3.7	6.5
# bouts = 38		Min	0.5	220	16.2	2.1	0.2	0.0	0.1	0.00	1.0	0.0
		Max	16.2	5	210.0	11.1	3.3	46.0	1.0	216.46	17.5	95.0
2014_5803	Female	Med	4.0	55	78.4	6.2	0.8	7.0	0.9	10.84	6.6	11.7
# bouts = 35		Min	0.6	196	33.7	1.7	0.2	0.0	0.1	0.10	1.1	0.0
		Max	15.3	4	215.6	11.3	2.9	69.0	1.0	546.47	22.3	113.5
2015_840	Unknown	Med	12.2	42.5	134.9	10.1	2.1	9.0	0.6	26.94	9.0	5.7
# bouts = 19		Min	0.2	100	13.0	2.9	0.8	0.0	0.1	0.00	1.7	0.0
		Max	17.4	4	229.2	13.6	3.5	31.0	1.0	96.99	231.9	173.7
2015_4177	Male	Med	1.9	10.5	72.0	11.7	0.8	4.0	0.9	1.96	13.5	34.2
# bouts = 17		Min	0.7	100	23.8	3.9	0.4	1.0	0.3	0.00	1.1	0.0
		Max	13.5	4	187.7	17.4	2.2	19.0	1.0	25.22	227.6	484.0
2015_5650	Male	Med	1.8	15	90.3	11.4	1.0	3.0	0.9	1.55	9.9	12.8
# bouts = 26		Min	0.3	97	18.2	2.0	0.4	0.0	0.3	0.00	1.4	0.0
		Max	16.1	4	192.5	14.7	3.0	22.0	1.0	234.90	80.3	205.6

KEY: avg = average; d = day(s); dist = distance; h = hour(s); km = kilometer(s); km^2 = square kilometer(s); Locs = locations; max = maximum; min = minimum; # = number

A total of 195 feeding bouts (see **Section 2.2.4** for the definition of a feeding bout) were identified from the blue whale ADB data (**Table 12**). The median number of bouts made per whale was higher in 2014 (35; range = 22–38 bouts) compared to 2015 (19; range = 17–26) despite tags remaining attached for a median of over seven days longer in 2015 (**Table 11**). Feeding bouts across years were temporally distinct (median = 7.1 h; range = 1–231.9 h apart) and generally small in area (median = 2.6 km^2; range = 0.003–546.5 km^2), with a median feeding bout containing 17 dives over 2.6 h (**Table 12**). Median bout duration was substantially longer for female whales compared to males and generally had a lower proportion of non-foraging dives. Size of the feeding bout areas is likely an overestimate as the bouts were relatively linear in many cases and GPS locations were somewhat sparse in others. Median maximum dive depth of feeding bouts was highly variable with some whales feeding at a median maximum dive depth of almost twice the depth of others (**Table 11**).The distribution of feeding bout duration was bimodal, with a strong peak near 2 h and a secondary peak at close to 14 h (**Figure 36**). Average number of feeding lunges per dive within bouts varied substantially, but it tended to increase with increasing foraging bout duration ($P < 0.001$, R^2 = 0.37 from linear regression; **Figure 37**). Dive depths during feeding bouts varied widely with one whale (Tag #2015_840) that fed at a median depth almost twice that of others (**Table 12**). The average fraction of non-feeding dives within a feeding bout was $\geq$ 39 percent for all but one whale (Tag #2015_840) which fed for all but 21 percent of its dives during a bout. This whale also made the longest duration feeding bouts of all ADB-tagged blue whales (**Table 12**), suggesting it fed almost continuously during daylight hours for many days.

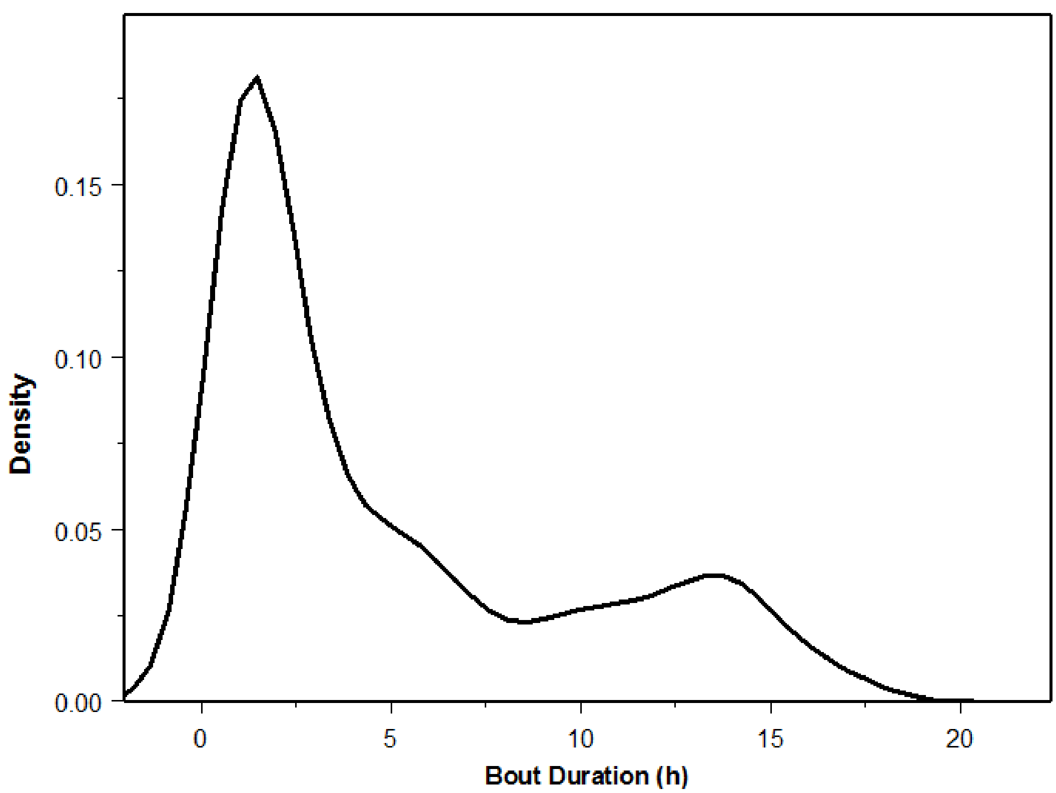

Figure 36. Density plot of foraging bout duration for ADB-tagged blue whales in 2014–2015.

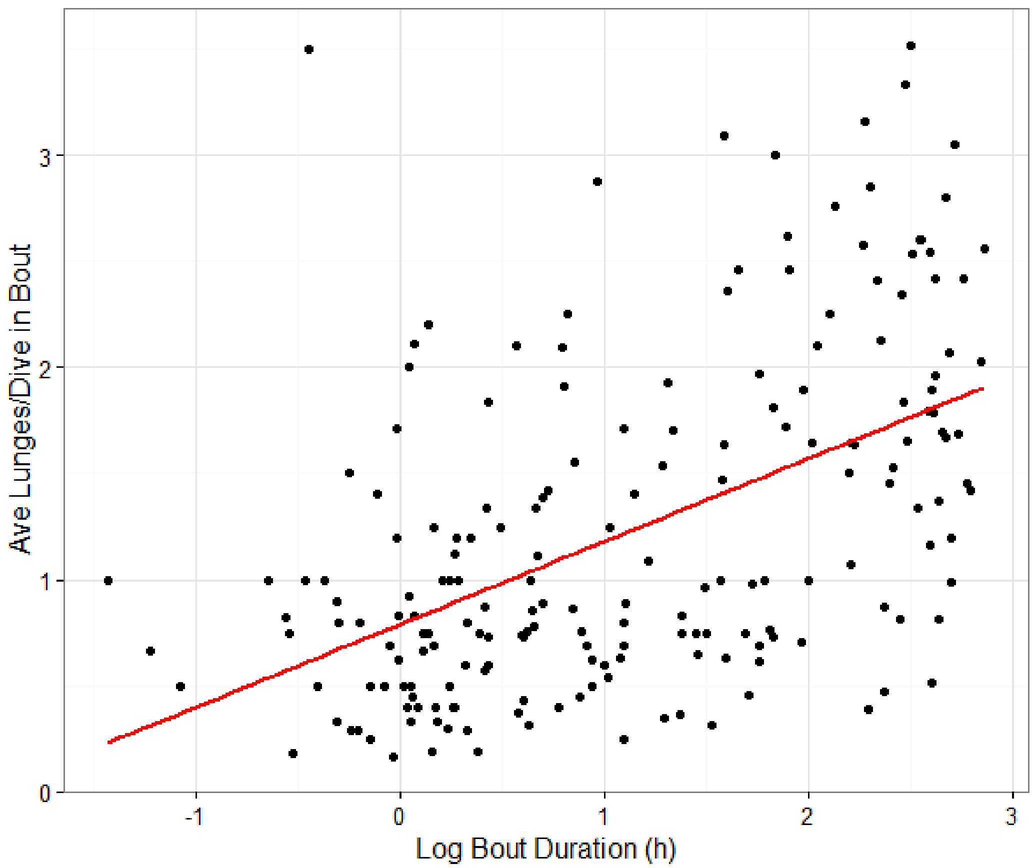

Figure 37. A plot comparing the average number of feeding lunges made per dive within a feeding bout to the duration of that bout. The result of a linear regression is shown in red. Data are from blue whales tracked with ADB tags in 2014–2015.

3.1.4 DM Tag Analysis

Telonics DM tags were deployed on eight blue whales off central and southern California during July and early August 2016. One tag was not heard from. For the remaining seven, median tracking duration was 61.7 d (range = 0.6–96.9 d; **Table 13**) and the tags provided a median of 2,294 dive summaries (range = 88–7,480) and 178 filtered Argos locations (range = 7–425). Five whales were tagged off San Miguel Island, California, and generally remained in that area for the duration of the tracking period, with the exception of one whose tag stopped transmitting off Point Sur, California (Tag #5701), and a male (Tag #5790) that made a loop to waters south of San Clemente Island before returning to San Miguel Island. Three blue whales were tagged off Half Moon Bay, central California and, of the two whose tags lasted an extended period of time, both subsequently moved to the waters west of San Francisco Bay. From there, one whale meandered south to an area approximately 100 km west of San Miguel Island before returning north to an area off Point Arena, while the other whale moved north as far as Cape Mendocino, before moving south and eventually beginning its southward migration with the tag stopping off southern Baja California, Mexico. Tag #833 transmitted for 4.3 d and then did not provide a location until 3 December 2016 when it provided two locations in the northern Gulf of California and did not transmit further. Only the first 4.3 d of data were used for Tag #833 due to the long data gap.

Table 13. Summary statistics of DM tags deployed on blue whales off southern and central California, 2016. Unknown sex whales are cases where no biopsy sample was collected.

Tag #	Sex	Tag Type	Deployment Date	# Days Tracked	Mean Locs per Day	Distance (km)	# Dives Transmitted	Filtered Locs
833	Female	DM	14-Jul-16	4.3**	7.7	163	672	33
5790	Male	DM	14-Jul-16	76.4	5.2	4,919	7,480	396
5701	Male	DM	14-Jul-16	44.7	4.0	1,482	2,294	178
839*	Unknown	DM	14-Jul-16	0	-	-	-	-
23032	Female	DM	14-Jul-16	62.2	5.6	1,989	4,438	349
5746	Female	DM	31-Jul-16	61.7	2.4	2,223	983	145
5685	Male	DM	1-Aug-16	96.9	4.4	5,952	4,511	425
23033	Male	DM	3-Aug-16	0.6	11.4	13	88	7
			Sum	**346.8**		**16740.1**	**20466**	**1509**
			Median	**61.7**	**5.2**	**1,989**	**2,294**	**178**

KEY: DM = Telonics RDW-665 Dive-Monitoring tag; km = kilometer(s); Locs = Locations; # = number; * No transmissions were received for Tag #839. This tag is not included in summary statistics. ** Two locations were received for Tag #833 on 3 December 2016, after a 137 d data gap; however those locations were excluded from the analysis due to this large data gap.

Dive depths reported by all DM tags showed a diel trend with fewer lunges and shallower dives occurring at night (mean = 0.8 lunges versus 4.7 lunges and mean = 26 m depth versus 87 m depth; **Figure 38)** and while traveling linearly (**Figure 39**). Daytime dive depths were highly variable within and across individuals, with whales tagged off central California generally making shallower dives than those tagged off San Miguel Island (median/maximum = 73 m/233 m versus median/maximum = 123 m/379 m, **Figure 40**). Most feeding effort was concentrated near the tagging area west of San Miguel Island, California; off Point Reyes, California; near Cordell Bank; and offshore of Point Conception (**Figure 41**). Tracks of DM tagged whales did not overlap substantially after they departed from the tagging areas (**Figure 41 right panel**)**.**

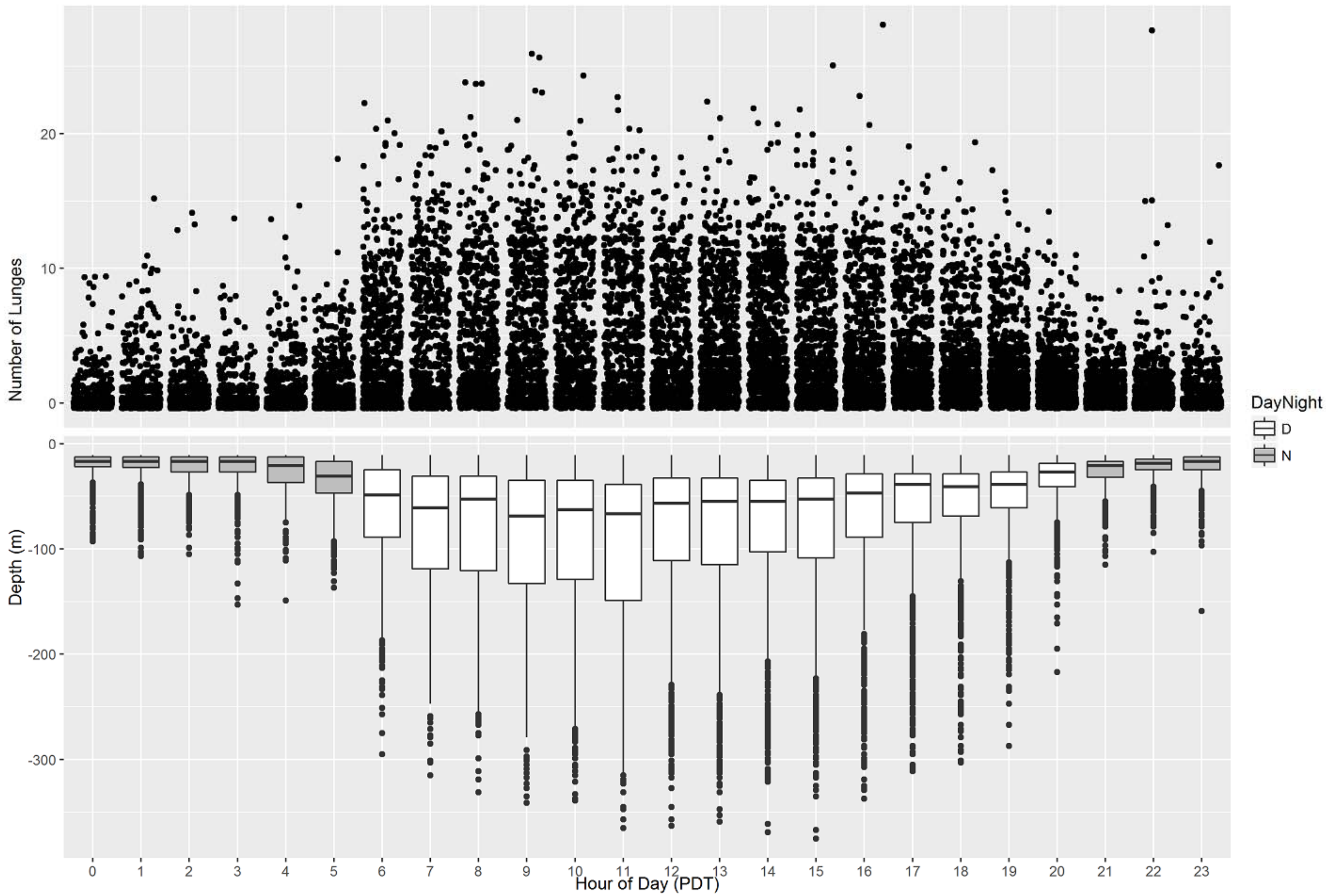

Figure 38. Number of lunges per dive (upper panel) and maximum dive depth (lower panel) of DM-tagged blue whales tracked off southern California during July–September 2016. Data are presented by hour of day to better visualize diel variability and the data in the top panel are jittered to avoid overplotting.

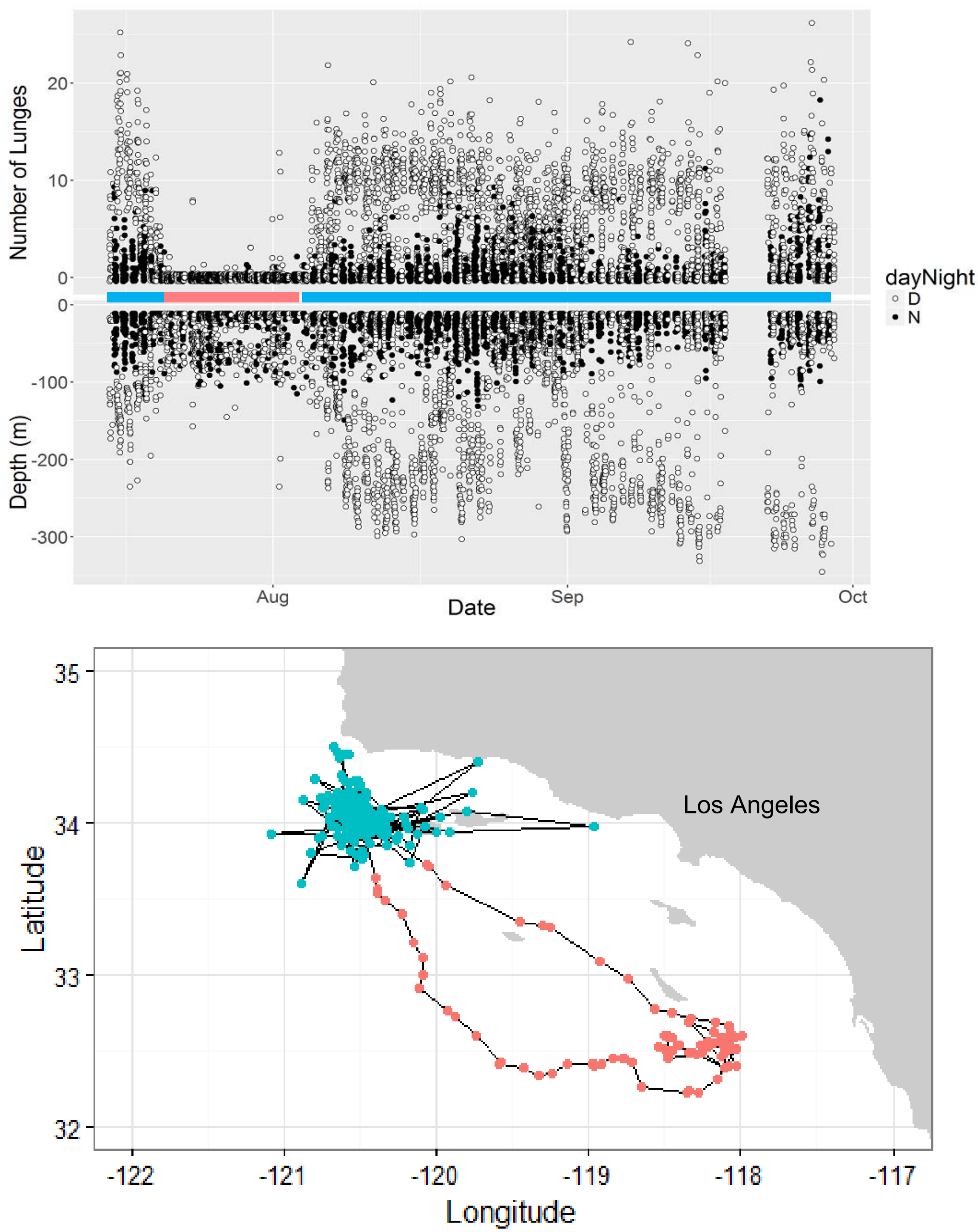

Figure 39. The number of lunges per dive (top) and maximum depth of dives (bottom) made by a DM-tagged blue whale (Tag #5790; a male) off southern California showing a strong diel trend of deeper dives with more lunges during the daytime. The colored line corresponds to the color of portions of the whale's track shown in the bottom panel. The greatly reduced number of lunges in late July–early August coincides with the whale moving to an area south of San Clemente Island before returning to the tagging area off San Miguel Island. The data gap in late September is likely due to an issue with the tag's saltwater conductivity sensor (see Section 2.2.5).

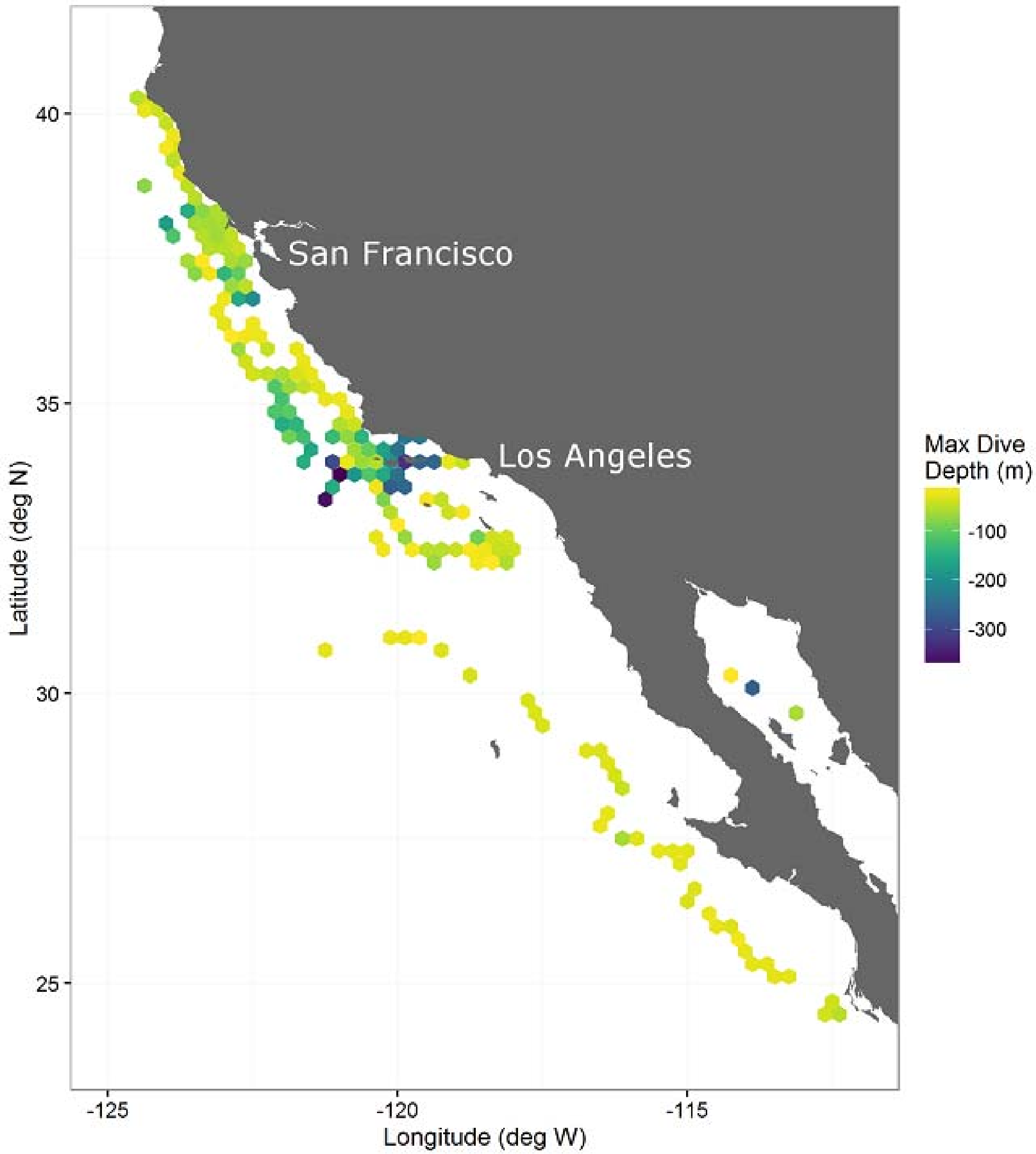

Figure 40. A 0.25-degree hexagonal grid showing the average daytime maximum dive depth reported by DM-tagged blue whales tagged in July–August 2016.

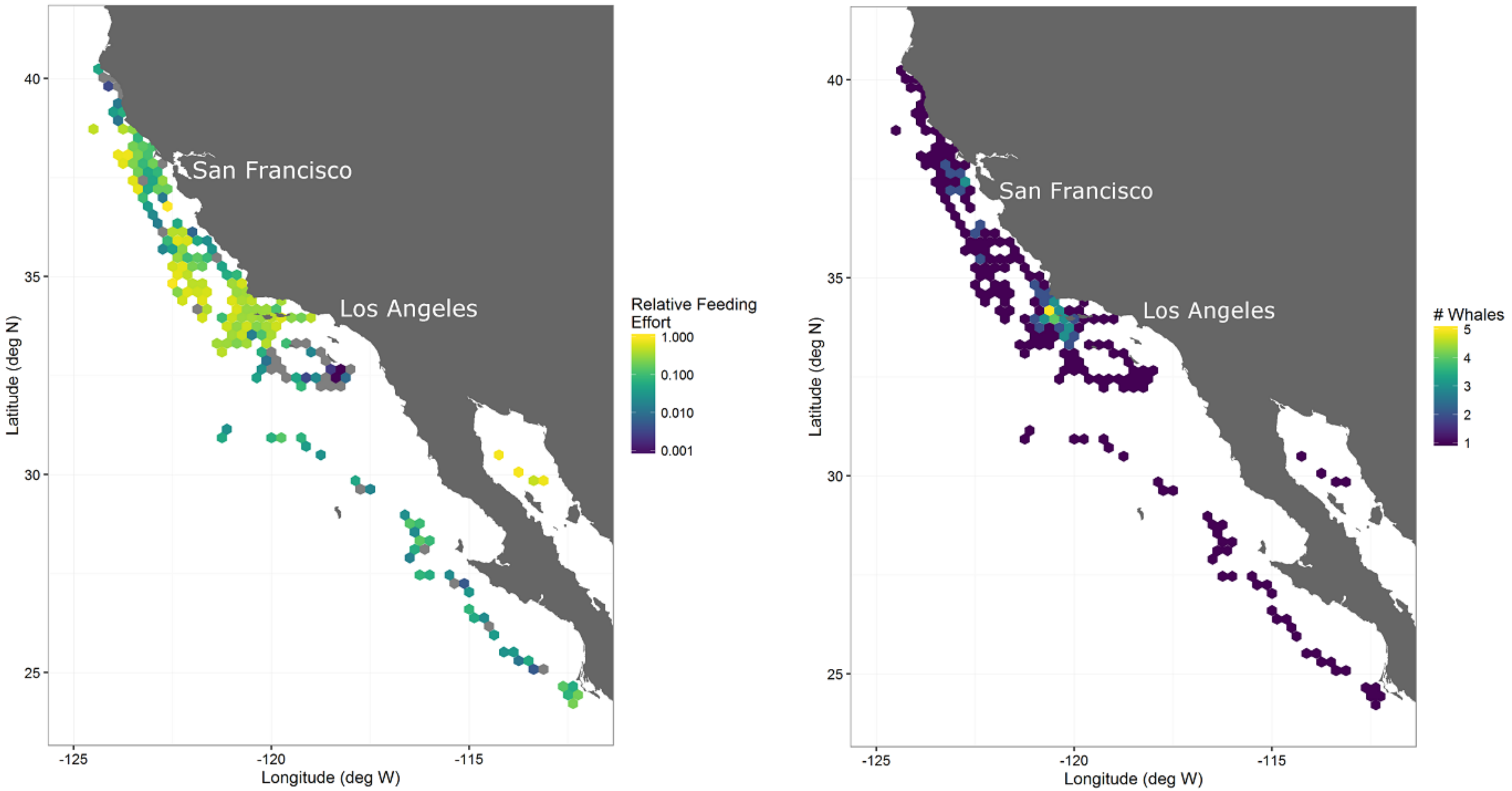

Figure 41. Left panel: A 0.25-degree hexagonal grid showing the average relative feeding effort (lunges/h) reported by DM-tagged blue whales tagged in July–August 2016. Right panel: The number of whales occupying each grid cell.

3.1.5 Body Condition Assessment and Tagging Rates

In 2016, nineteen blue whales were tagged during approaches to 295 whales (6 percent; **Table 14**). Thirty-six percent of blue whales approached were in poor body condition and were not considered candidates for tagging (**Table 14**). Seven percent and 23 percent of blue whales approached were in poor body condition in 2014 and 2015, respectively (**Table 14**).

Table 14. Approach details for tagging efforts in California and Oregon during 2014, 2015, and 2016.

Species	# Whales Approached	# Whales Tagged	# Whales in Poor Body Condition	% Whales in Poor Body Condition	Average Time in Tagging Vessel (h/d)
Southern California Deployments – 2014 – 22 Days of Tagging Effort (42-day cruise)					
blue	204	24	15	7	8.11
fin	108	6	0	0	
humpback	4	0	0	0	
Southern California Deployments – 2015 – 15 Days of Tagging Effort (30-day cruise)					
blue	392	22	90	23	8.68
fin	110	13	0	0	
Bryde's	5	1	0	0	
minke	2	0	0	0	
Southern and Central California Deployments – 2016 - 13 Days of Tagging Effort (30-day cruise)					
blue	295	19	105	36	9.87
fin	160	14	3	2	
humpback	82	0	0	0	
Central Oregon Deployments – 2016 - 2 Days of Tagging Effort					
humpback	39	2	0	0	8.54

Daily tagging rates were comparable between 2015 and 2016, with 2.4 whales tagged per day in 2015 (36 tags in 15 days on the water) compared to 2.5 whales tagged per day in 2016. Our success rate in 2014 was quite a bit lower, at 1.3 whales tagged per day (30 tags in 22 days on the water). Many factors contribute to tagging rates, including weather conditions, number of whales encountered, number of untagged whales encountered, condition of the whales encountered, and our tagging priorities (blue versus fin whales). These tagging rates reflect overall rates for both blue and fin whales combined, but we would likely see a difference between species if we could categorize our effort accurately between the two species. During the past three years of this study our field efforts for blue and fin whales have been combined. We can encounter and tag both species in the same day, often in the same general location. It would be difficult to quantify exactly how much effort goes into tagging each species separately. Also, there are days in which we pass up tagging opportunities on blue whales in favor of fin whales, the latter of which are typically less abundant and harder to approach and tag, which leads to decreased tagging rates.

3.1.6 Behavioral Responses to Tagging

Two of the 19 tagged blue whales exhibited short-term startle responses to the tagging/biopsy process. One of these responses consisted of a quick surfacing and the other consisted of the whale rolling on its side upon tagging and giving a moderate "tail flick." A tail flick is defined here as a swift or abrupt movement of the tail flukes dorso-ventrally (up and down). The level of response follows definitions described in Weinrich et al. (1992), Hooker et al. (2001), and Baumgartner et al. (2015), with "moderate" referring to relatively forceful modifications to behavior (such as hard tail flicks) with no prolonged evidence of behavioral disturbance.

3.1.7 Wound Healing

Five blue whales tagged in 2016 were photographed 1 to 2 d after tagging, with two of these showing slight swelling at the tag site (**Table 15**). No blue whales tagged in 2014 or 2015 were resighted during our tagging efforts in 2016.

Table 15. Resightings and tag site descriptions for blue whales satellite-tagged off southern and central California, 2016. Wound size estimates are approximate.

Tag # (Type)	Days After Tagging	
	1	2
833 (DM)		Swelling, 5 × 5 cm, 2 cm high
5701 (DM)		Swelling, 25 × 15 cm, 2 cm high
5826 (LO)	no change	
10825 (LO)	no change	
23032 (DM)	no change	

KEY: cm = centimeter(s); DM = Telonics RDW-665 Dive-Monitoring tag;
LO = Wildlife Computers SPOT6 Location-Only tag; # = number

3.1.8 Photo-ID

A total of 6,026 photographs of blue whales was taken during the field efforts in 2016, from which 100 individual whales were identified. Seven of these IDs (six from southern California, one from central California) represented resightings of blue whales photographed in 2014 or 2015 (289 individuals), resulting in a resight rate of 2.4 percent. Photo-IDs were obtained of all 19 tagged blue whales in 2016, with both left- and right-side photos of nine of these, four with right-side photographs only, and six with left-side photographs only. Fluke photographs also were obtained for two of the tagged blue whales.

3.1.9 Ecological Relationships—2016

The SSMs generated regularized daily locations for 18 blue whale tags in 2016, resulting in 1,225 estimated locations, of which 7 occurred on land and 15 had unacceptable estimation uncertainty (**Table 16**). The geographic extent of these tracks covered approximately 20 degrees of longitude (125.7–106°W) and 26 degrees of latitude (17.6–43.9°N) (**Figure 42**). The majority of the 1,203 accepted locations occurred in CCAL (95.3 percent), followed by PNEC (2.5 percent) and GUCA (2.2 percent). The ALSK, NPPF, NPTG, and PQED provinces were not occupied in 2016 (**Table 16 and Figure 42**).

Table 16. Number (and percentage) of accepted SSM locations inside each province for blue whales in each year. Also provided are the number of locations that fell on land and the number of locations excluded from the analyses because their high estimation uncertainty. Unclassified locations correspond to the end-of-track locations, which do not receive a behavioral mode classification by the SSM. This number can be lower than the number of tracks because of the exclusion of locations on land and those with high estimation uncertainty. The number of SSM tracks is indicated (n).

	2014 (n = 20)	2015 (n = 22)	2016 (n = 18)
Longitudinal range	39.0 degrees (129.8–90.8°W)	43.6 degrees (126.8–83.2°W)	20.3 degrees (125.7–106.0°W)
Latitudinal range	43.6 degrees (6.9–50.5°N)	43.6 degrees (0.1–43.7°N)	26.3 degrees (17.6–43.9°N)
Province			
ALSK	1 (0.1%)	NA	NA
CCAL	841 (73.1%)	1425 (89.8%)	1146 (95.3%)
GUCA	NA	13 (0.8%)	27 (2.2%)
NPPF	1 (0.1%)	NA	NA
NPTG	1 (0.1%)	NA	NA
PNEC	307 (26.7%)	107 (6.7%)	30 (2.5%)
PQED	NA	41 (2.6%)	NA
Accepted locs.	1151 (100%)	1586 (100%)	1203 (100%)
Unclassified locs.	16	18	17
Excluded locs.	18	101	15
Land locs.	14	28	7
Total locs.	1183	1715	1225

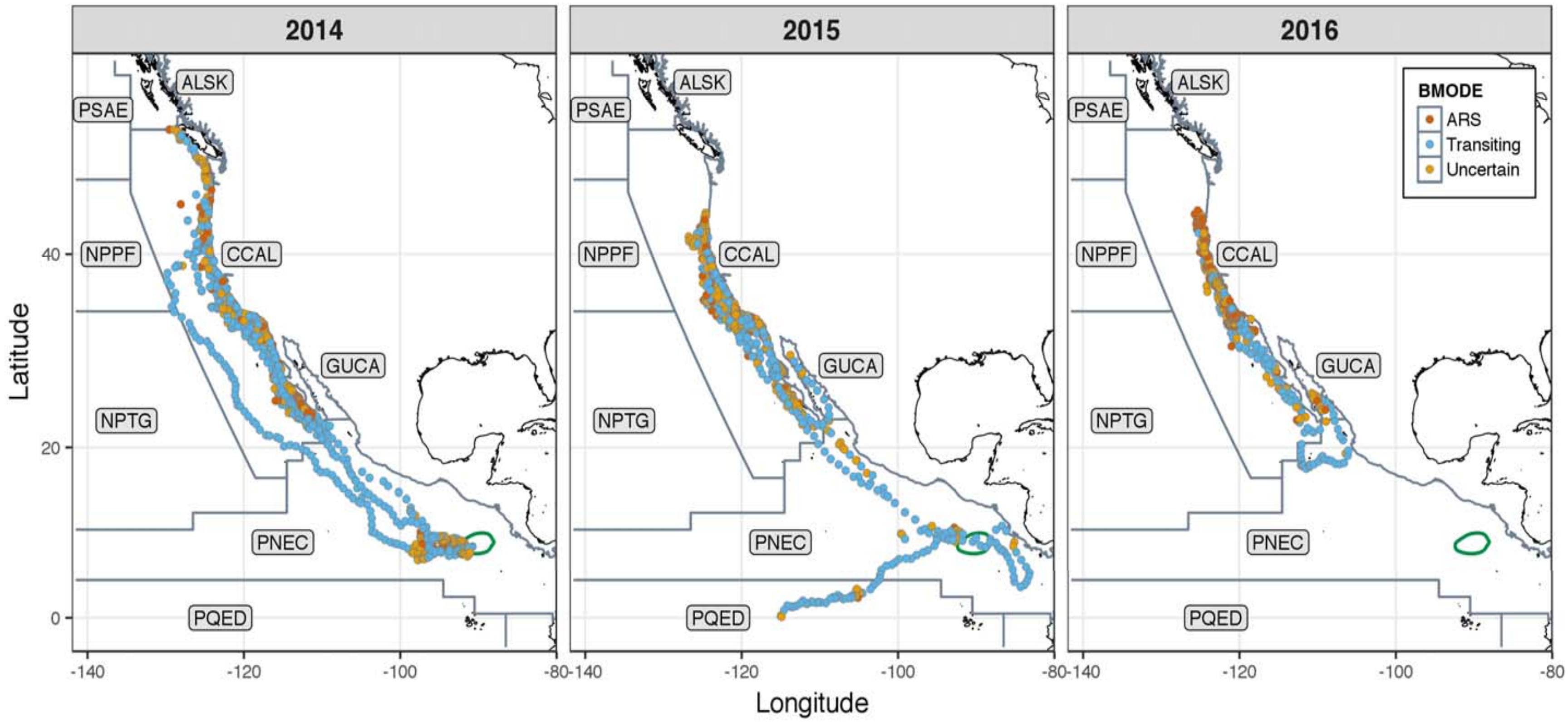

Figure 42. Accepted SSM locations for blue whales colored by behavioral mode for each year in the study. The eight biogeographic provinces identified by Longhurst (1998, 2006) in the eastern North Pacific are outlined and labeled. The green, oval-shaped contour in PNEC outlines the position of the Costa Rica Dome (CRD), as determined by the mean location of the depth of the 20°C isotherm (from Fiedler 2002).

The behavioral classification for each location for all tracks is shown in the map in **Figure 42**. The number and proportion of locations classified by behavioral mode in CCAL is reported in **Table 17**. Of 1,129 SSM locations, 576 (51 percent) were classified as ARS, 440 (39 percent) were classified as uncertain, and 113 (10 percent) were classified as transiting (**Table 17**).

Table 17. Number of classified SSM locations (and percentage) in CCAL for each behavioral mode for blue whales in each year. The number of SSM tracks is indicated (n).

Behavioral mode	2014 (n = 20)	2015 (n = 22)	2016 (n = 18)
Transiting	383 (46.3%)	321 (22.8%)	113 (10%)
Uncertain	352 (42.5%)	830 (58.9%)	440 (39%)
ARS	93 (11.2%)	259 (18.4%)	576 (51%)
Classified locs.	828 (100%)	1410 (100%)	1129 (100%)

Details of the environmental variables examined are provided in **Table 1**. Summary statistics for these variables obtained for the SSM locations are reported for CCAL only (**Tables 18 and 19**), as this was the only biogeographic province consistently occupied by all species and in all years (calculations reported are based on values measured closest in space and time to each whale SSM location, per the temporal and spatial resolution of each sensor listed in **Table 1**). In 2016, average WEKM was 3.4e-07 m s^{-1}, average SST was 15.87 °C, and average CHL was 2.05 milligrams per cubic meter [mg m^{-3}] (**Table 18**). The values at each location for these environmental variables are shown in the maps in **Figures 43 through 45**.

Table 18. Summary statistics (average [Mean] and standard deviation [SD]) for the remotely sensed variables obtained for each SSM location in CCAL. The total number of locations (N Total) and the number of locations with valid matching environmental values (n) are given for each species and year. SSM locations falling on land, those with high estimation uncertainty, and those with unclassified behavioral mode have been excluded.

Species/Year	N Total	WEKM (m s^{-1})			SST (°C)			CHL (mg m^{-3})		
		n	Mean	SD	n	Mean	SD	n	Mean	SD
Blue whale 2014	828	469	7.2e-07	6.0e-06	772	21.26	4.53	820	0.82	2.49
Blue whale 2015	1410	813	6.8e-07	4.5e-06	1364	19.78	2.88	1408	0.74	1.44
Blue whale 2016	1129	398	3.4e-07	6.9e-06	1129	15.87	2.34	980	2.05	3.1
Fin whale 2014	256	154	1.0e-06	4.6e-06	248	18.80	2.26	254	0.56	0.7
Fin whale 2015	439	369	6.1e-07	6.0e-06	433	17.76	2.17	438	0.64	0.65
Fin whale 2016	344	245	1.1e-06	5.5e-06	344	15.40	1.08	244	1.47	4.25
Humpback whale 2016	23	6	-3.8e-07	5.8e-06	23	13.36	0.92	23	6.78	10.21

Table 19. Summary statistics (average [Mean] and standard deviation [SD]) for the seafloor relief variables obtained for each SSM location in CCAL. The total number of locations (N Total) and the number of locations with valid matching environmental values (n) are given for each species and year. SSM locations falling on land, those with high estimation uncertainty, and those with unclassified behavioral mode have been excluded.

Species/Year	N Total	DEPTH (m)			DISTSHELF (km)			DISTSHORE (km)			SLOPE (m km^{-1})			ASPECT (deg)		
		n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD
Blue whale 2014	828	819	-1684.6	1489.89	819	59.1	100.16	819	88.6	113.38	819	46.7	47.01	819	208.5	76.58
Blue whale 2015	1410	1401	-1482.8	1367.54	1401	37.7	45.37	1401	62.1	49.28	1401	45.7	43.22	1401	220.9	71.95
Blue whale 2016	1129	1125	-759.0	1048.02	1129	18.1	29.02	1125	38.4	35.35	1128	39.8	46.59	1126	233.1	63.63
Fin whale 2014	256	255	-1696.4	1254.46	255	45.1	44.45	255	62.4	47.58	255	50.1	51.71	255	212.1	69.38
Fin whale 2015	439	438	-2145.7	1285.89	438	62.1	59.12	438	90.3	63.76	438	42.8	44.42	438	223.7	65.9
Fin whale 2016	344	343	-1492.3	1296.65	344	35.4	44.26	344	60.9	46.23	344	47.6	49.78	344	232.0	52.11
Humpback whale 2016	23	22	-143.2	134.23	23	12.2	7.33	23	27.5	16.79	23	7.7	6.88	23	258.3	44.95

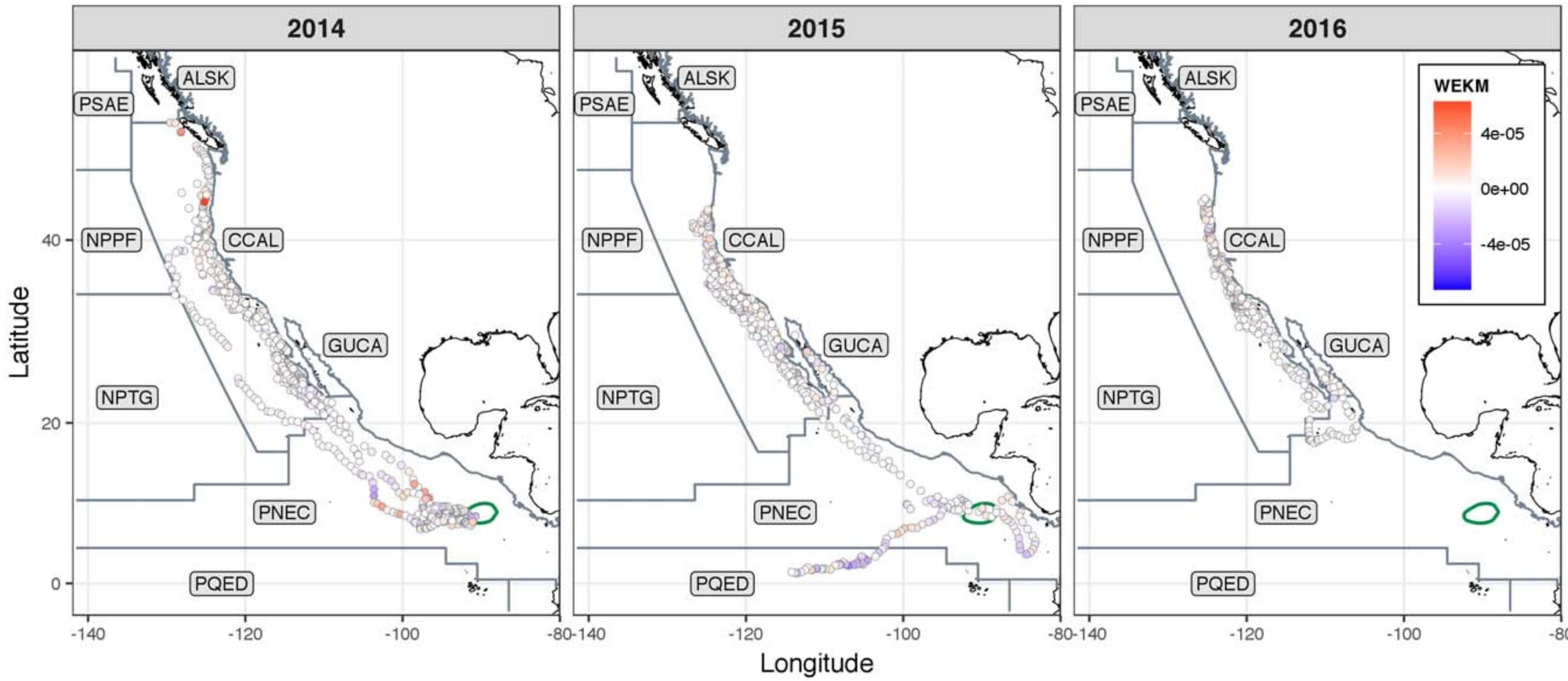

Figure 43. Map representation of vertical upwelling velocity (WEKM, m s^{-1}) values obtained from satellite remote sensing around each blue whale location for each year in the study. The Longhurst biogeographic provinces are indicated. The green, oval-shaped contour in PNEC outlines the position of the CRD.

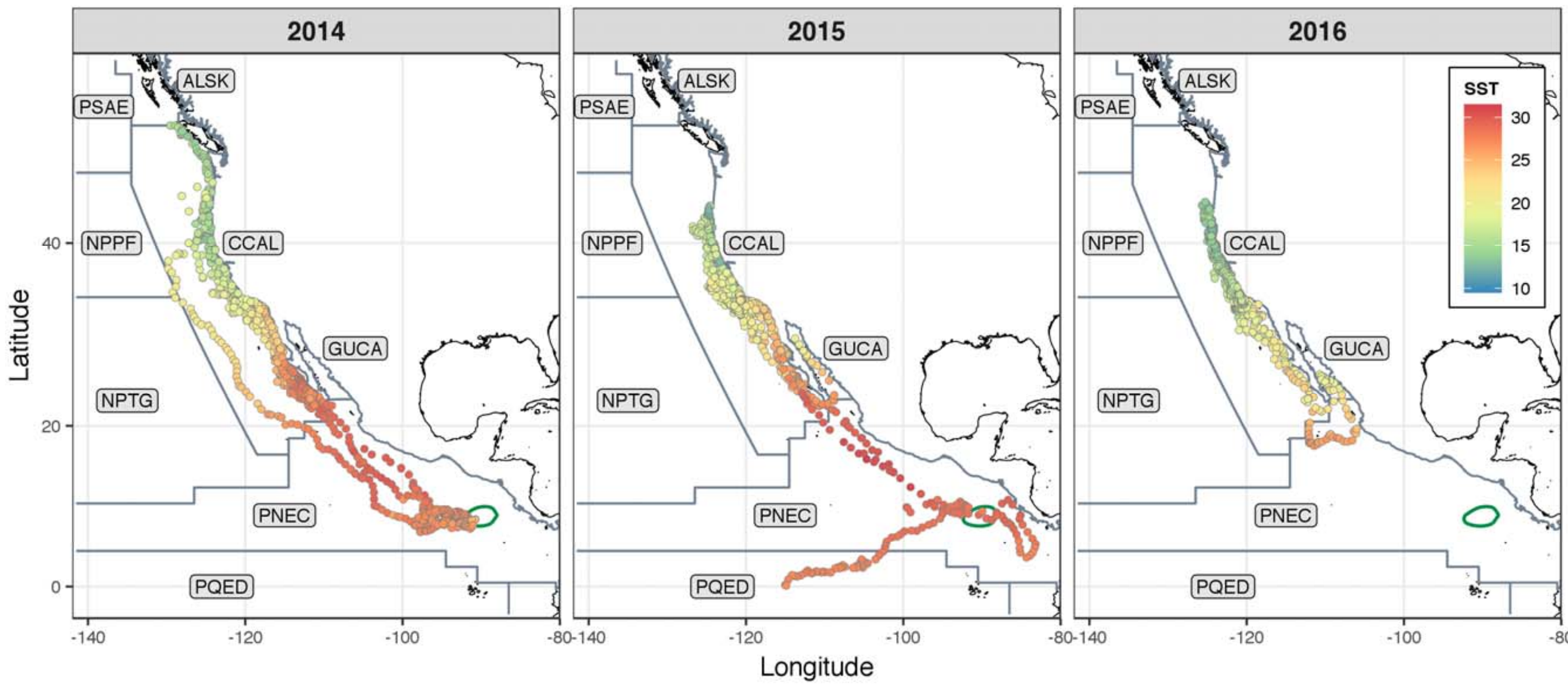

Figure 44. Map representation of sea surface temperature (SST, °C) values obtained from satellite remote sensing around each blue whale location for each year in the study. The Longhurst biogeographic provinces are indicated. The green, oval-shaped contour in PNEC outlines the position of the CRD.

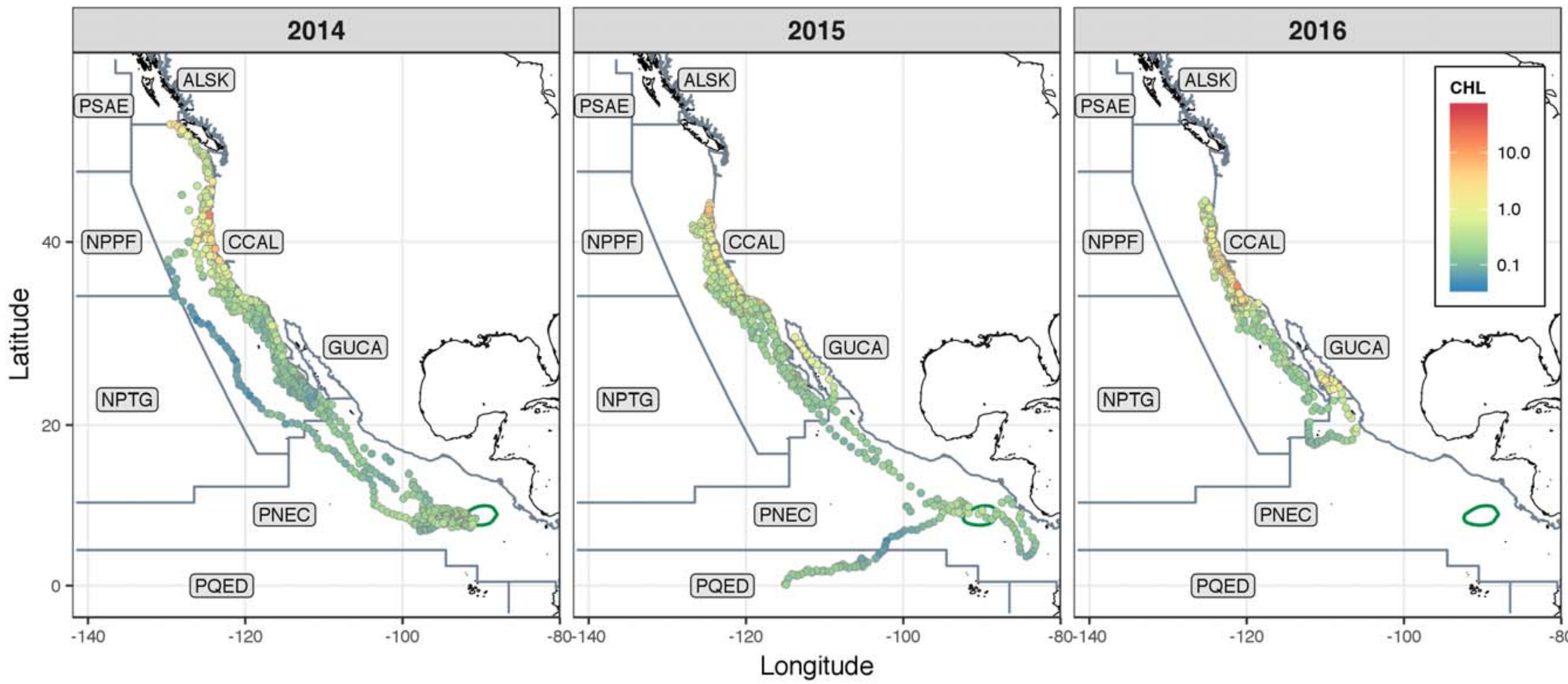

Figure 45. Map representation of chlorophyll-*a* concentration (CHL, mg m^{-3}) values obtained from satellite remote sensing around each blue whale location for each year in the study. The Longhurst biogeographic provinces are indicated. The green, oval-shaped contour in PNEC outlines the position of the CRD.

In terms of seafloor characteristics, in 2016 blue whales occurred in areas with an average DEPTH of -758.97 m, average DISTSHELF of 18.12 km, and average DISTSHORE of 38.37 km. The average SLOPE in these areas was 39.84 m km^{-1} and faced toward the southwest (average ASPECT = 233.1°) (**Table 19**). The values at each location for these seafloor relief variables are shown in the maps in **Figures 46 through 50**.

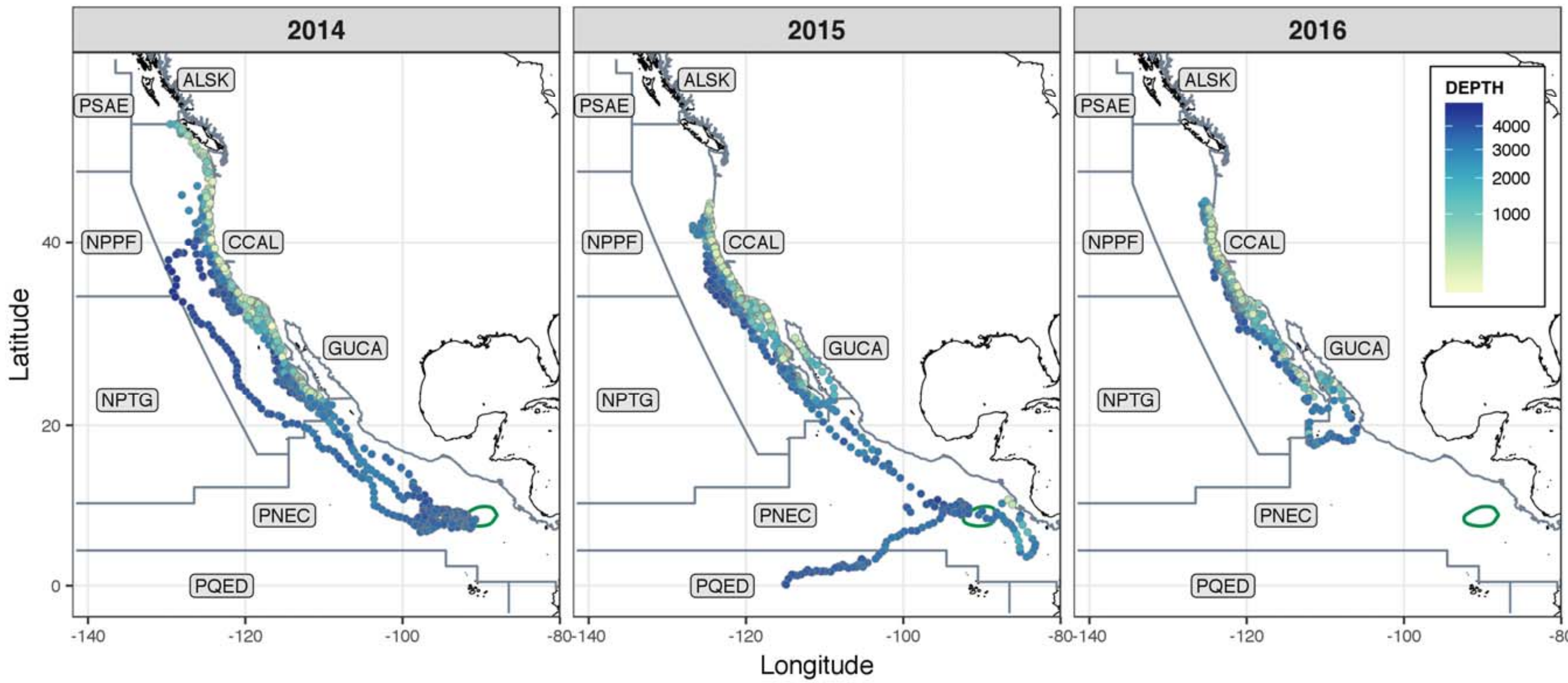

Figure 46. Map representation of seafloor depth (DEPTH, m) values obtained from ETOPO1 around each blue whale location for each year in the study. The Longhurst biogeographic provinces are indicated. The green, oval-shaped contour in PNEC outlines the position of the CRD.

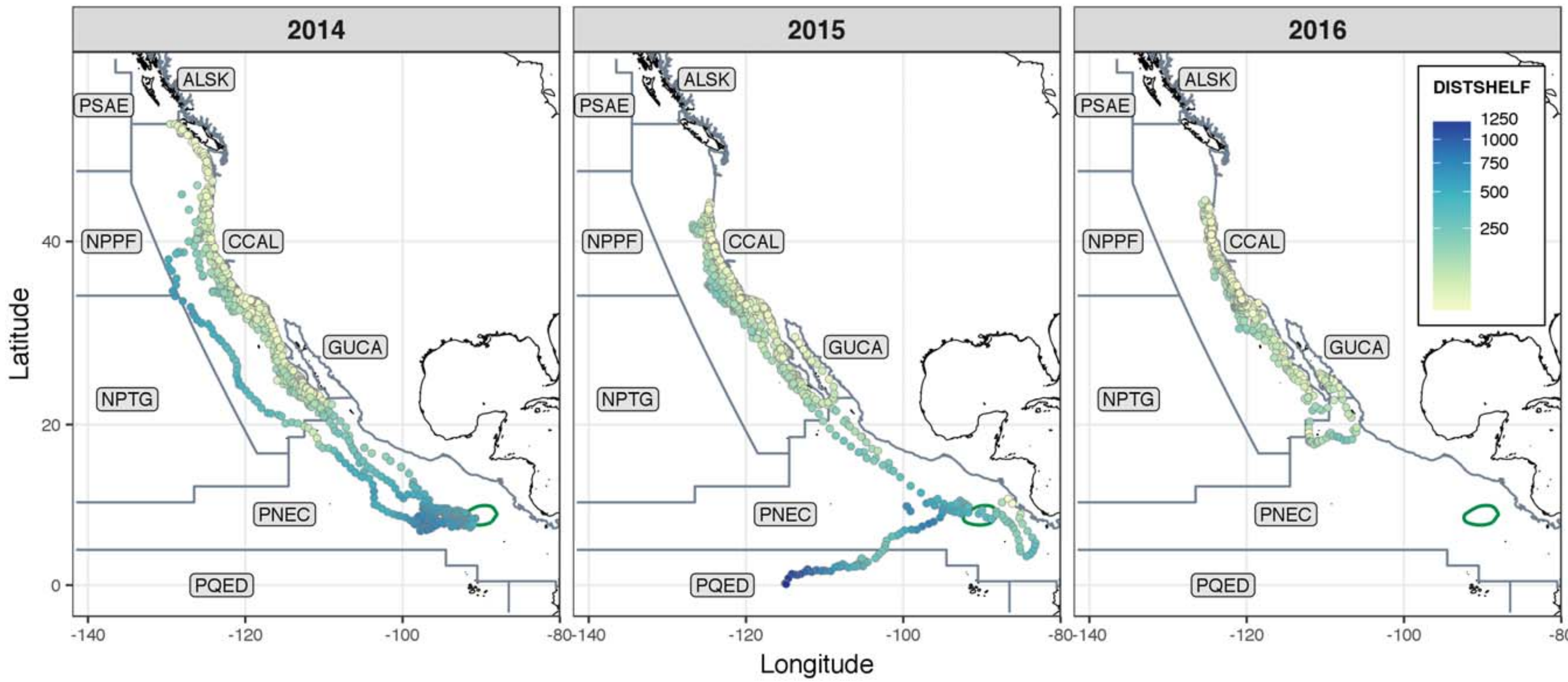

Figure 47. Map representation of distance to the 200 m isobath (DISTSHELF, km) values obtained from ETOPO1 around each blue whale location for each year in the study. The Longhurst biogeographic provinces are indicated. The green, oval-shaped contour in PNEC outlines the position of the CRD.

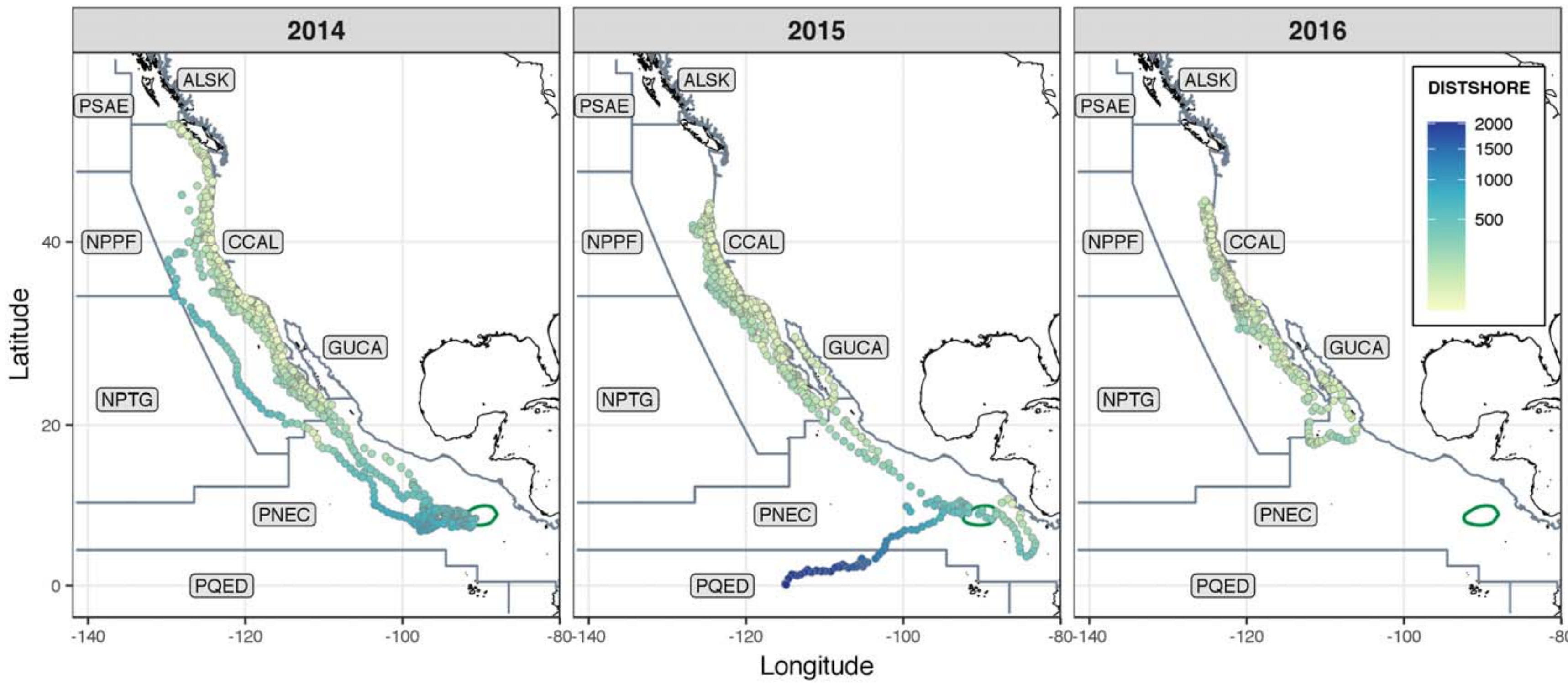

Figure 48. Map representation of distance to the shoreline (DISTSHORE, km) values obtained from ETOPO1 around each blue whale location for each year in the study. The Longhurst biogeographic provinces are indicated. The green, oval-shaped contour in PNEC outlines the position of the CRD.

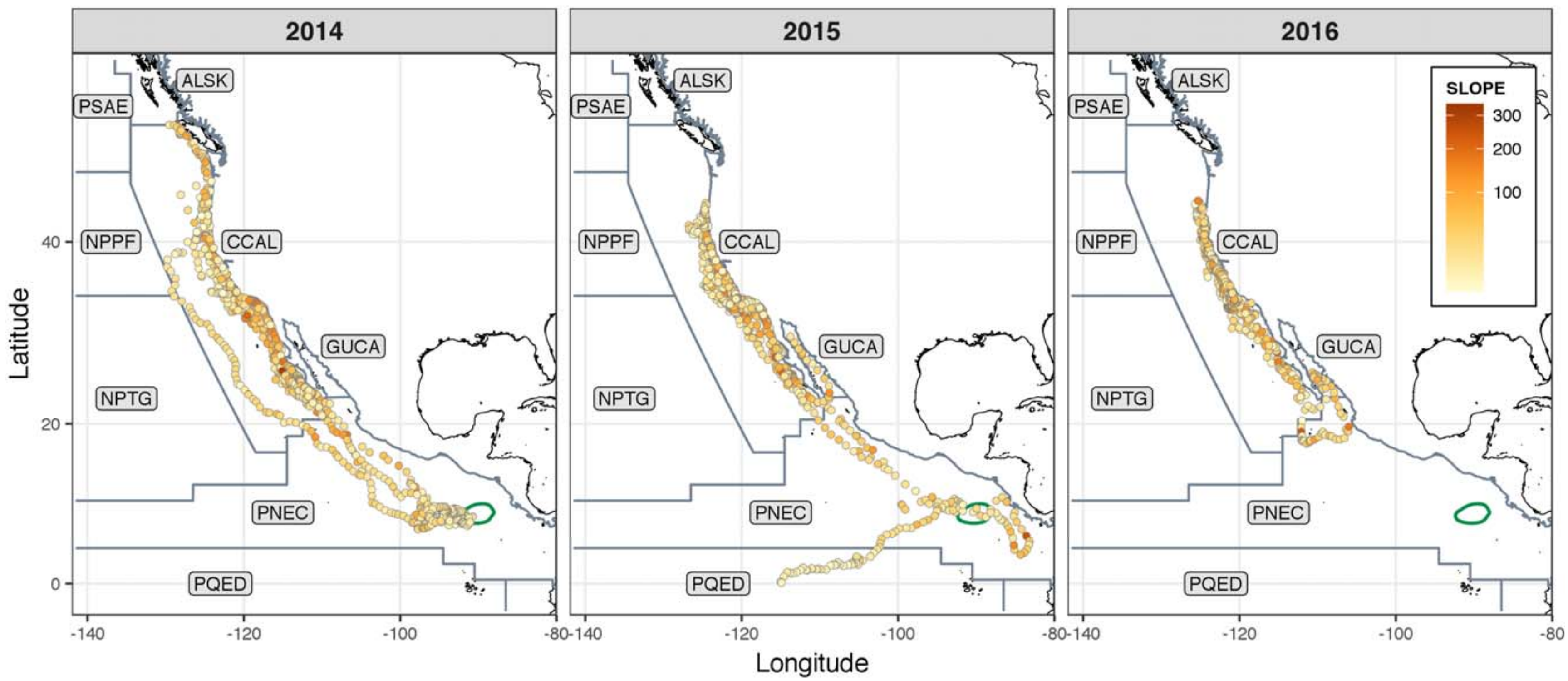

Figure 49. Map representation of seafloor slope (SLOPE, m km^{-1}) values obtained from ETOPO1 around each blue whale location for each year in the study. The Longhurst biogeographic provinces are indicated. The green, oval-shaped contour in PNEC outlines the position of the CRD.

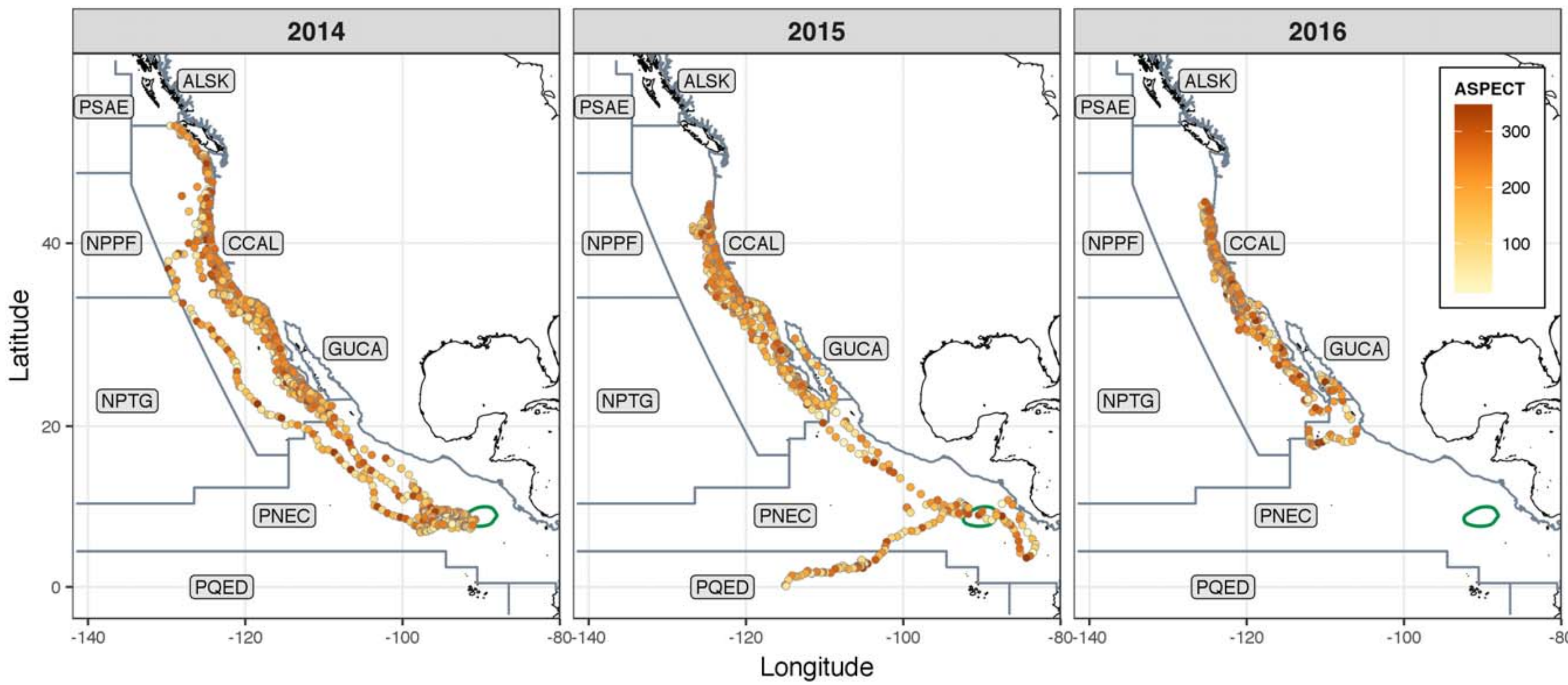

Figure 50. Map representation of seafloor slope aspect (ASPECT, degrees) values obtained from ETOPO1 around each blue whale location for each year in the study. The Longhurst biogeographic provinces are indicated. The green, oval-shaped contour in PNEC outlines the position of the CRD.

3.1.10 Ecological Relationships—Interannual Comparisons

The number of tracked blue whales in each of the three years was comparable (n = 20 in 2014, n = 22 in 2015, and n = 18 in 2016) (**Table 16**). The longitudinal range of these tracks was similar in 2014 and 2015 (39 and 43.6 degrees, respectively), but it was approximately half of that in 2016 (20 degrees), as animals did not migrate to the eastern tropical Pacific in winter. Correspondingly, the latitudinal range was the same (43.6 degrees) in 2014 and 2015, but only 26 degrees in 2016 (**Table 16 and Figure 42**). The northernmost extent in summer-fall was shifted further to the north in 2014 (50.5°N), while in 2015 and 2016 animals only ranged to 43.7°N and 43.9°N, respectively. During this season, animals also reached their westernmost (offshore) extent in 2014 (129.8°W), while in 2015 and 2016 they remained closer to the North American continent (126.8°W and 125.7°W, respectively). During the winter migration to the eastern tropical Pacific, animals ranged furthest to the east and south in 2015, reaching the equator (0.1°N), while in 2016 they only migrated as far south as the mouth of the Gulf of California (17.6°N) (**Table 16 and Figure 42**).

Blue whales were present in seven of the eight biogeographic provinces of the eastern North Pacific considered here, although they primarily occupied CCAL in summer-fall and PNEC in winter-spring (**Table 16**). However, their pattern of occurrence was different between the three years. Occupation of CCAL was lowest in 2014 (73.1 percent of locations), intermediate in 2015 (89.8 percent), and highest in 2016 (95.3 percent). Conversely, occupation of PNEC was highest in 2014 (26.7 percent), intermediate in 2015 (6.7 percent), and lowest in 2016 (2.5 percent). In 2015 blue whales additionally occurred in PQED (2.6 percent), and in 2015 and 2016 they also were present in GUCA (0.8 and 2.2 percent, respectively). The ALSK, NPPF, and NPTG provinces were occupied to a very small extent (0.1 percent) and only in 2014 (**Table 16 and Figure 42**).

The behavioral classification in CCAL was based on 828 SSM locations in 2014, 1,410 locations in 2015, and 1,129 locations in 2016. The proportion of locations classified as ARS was lower in 2014 and 2015 (11.2 percent and 18.4 percent of locations, respectively), while it was very high in 2016 (51 percent). The proportion of locations classified as transiting was highest (46.3 percent) in 2014, intermediate in 2015 (22.8 percent), and lowest in 2016 (10 percent). Locations considered uncertain made up the remainder (42.5 percent in 2014, 58.9 percent in 2015, and 39 percent in 2016) (**Table 17**).

In terms of oceanographic characteristics in CCAL, blue whales were found in areas with average positive upwelling velocities (WEKM) in all three years, being higher in 2014 and 2015 (7.2e-07 and 6.8e-07 m s^{-1}, respectively) and lower in 2016 (3.4e-07 m s^{-1}). Average SST was warmest in 2014 and 2015 (21.26 and 19.78°C, respectively), and coolest in 2016 (15.87°C). Average CHL was low in 2014 and 2015 (0.82 and 0.74 mg m^{-3}, respectively) and high in 2016 (2.05 mg m^{-3}) (**Table 18**). The values at each location for these environmental variables are shown in the maps in **Figures 43 through 45**, and their distributional properties are shown in the violin plots in **Figures 51 through 53**.

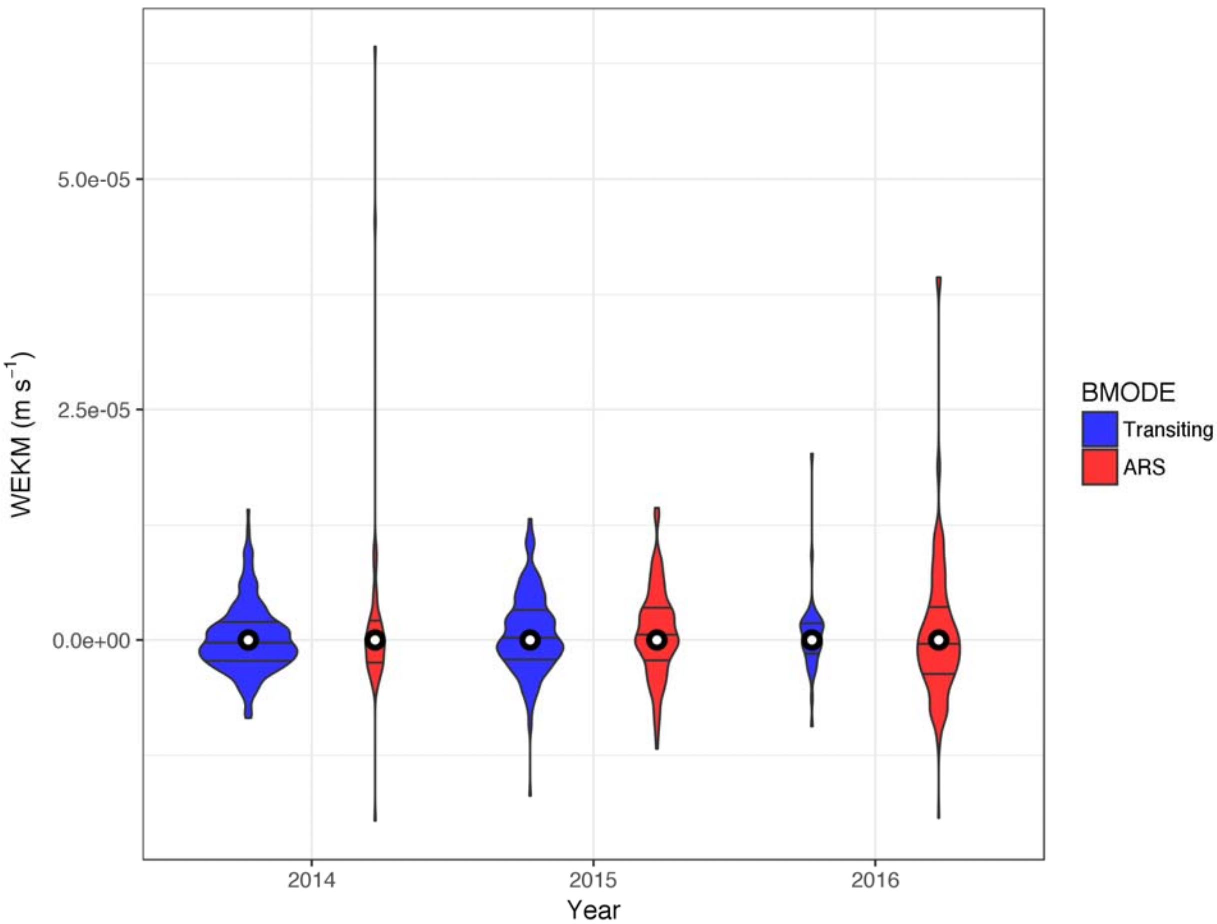

Figure 51. Paired violin plots of vertical upwelling velocity (WEKM, m s^{-1}) values in CCAL for blue whale locations classified as transiting and ARS for each year in the study. Horizontal lines inside each violin indicate the quartiles of the data distribution and white circle with black outline indicates the mean.

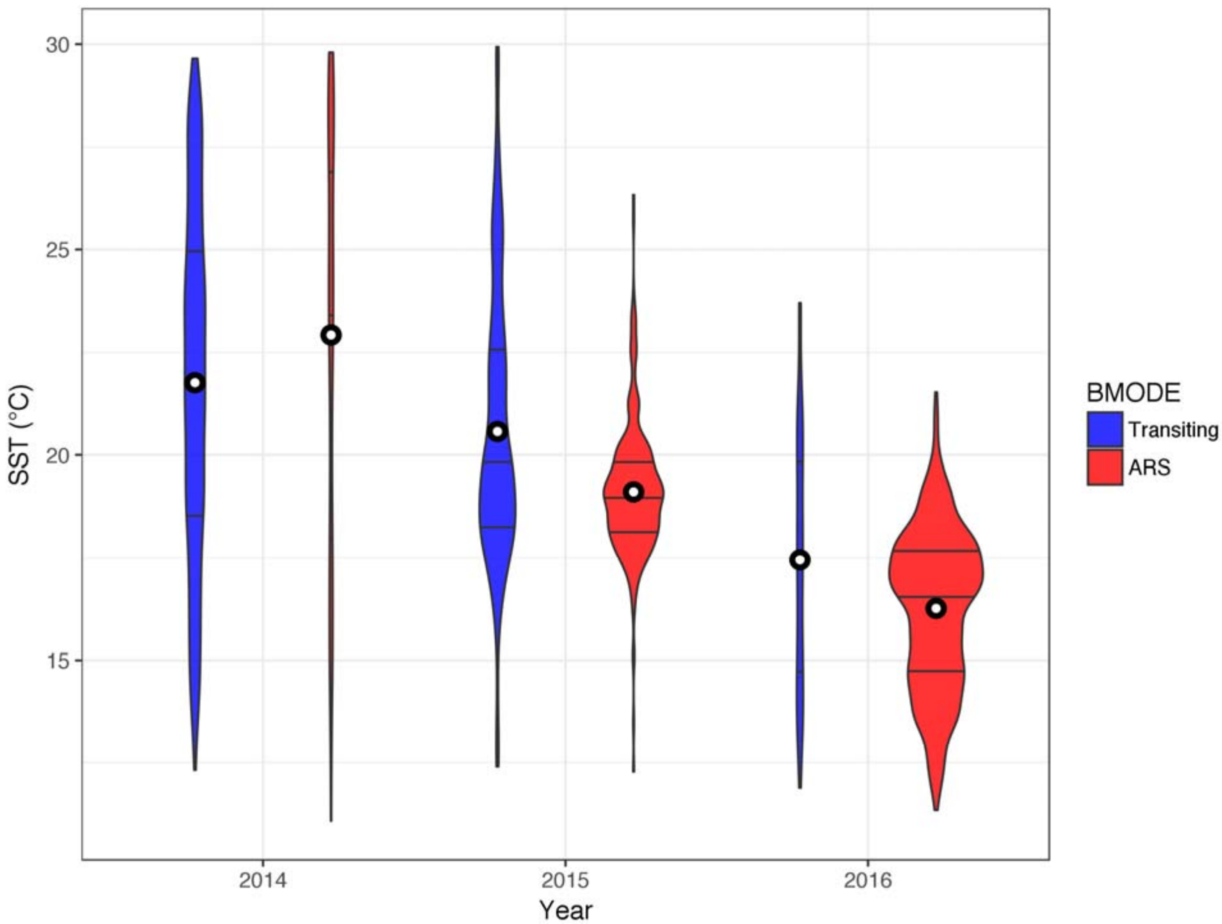

Figure 52. Paired violin plots of sea surface temperature (SST, °C) values in CCAL for blue whale locations classified as transiting and ARS for each year in the study. Horizontal lines inside each violin indicate the quartiles of the data distribution and white circle with black outline indicates the mean.

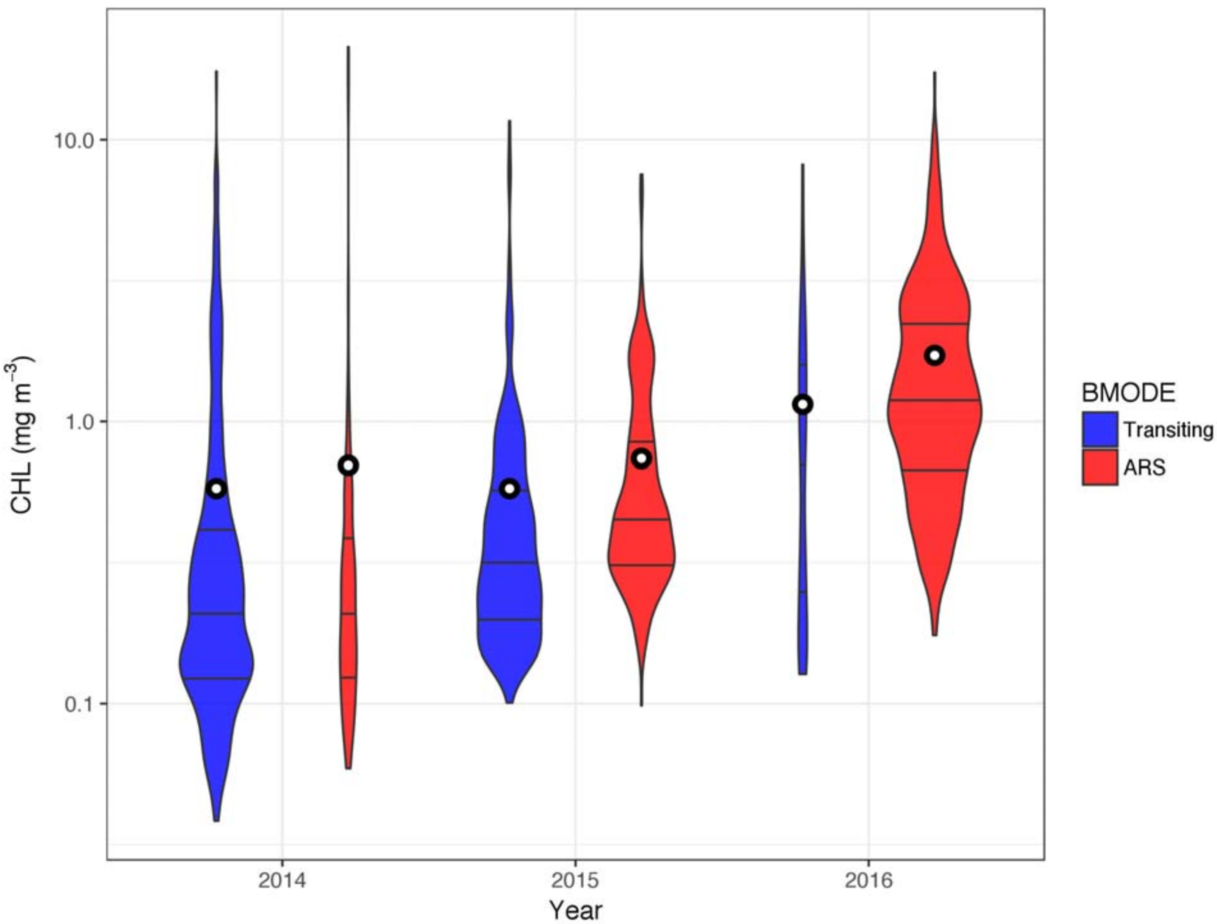

Figure 53. Paired violin plots of chlorophyll-*a* concentration (CHL, mg m^{-3}) values in CCAL for blue whale locations classified as transiting and ARS for each year in the study. Horizontal lines inside each violin indicate the quartiles of the data distribution and white circle with black outline indicates the mean. Note that data were log-transformed to improve visualization.

In terms of seafloor characteristics in CCAL, blue whales occurred in areas with average DEPTH that became shallower with every year of the study (1684.63 m in 2014, 1482.8 m in 2015, and 758.97 m in 2016). Similarly, average DISTSHELF became smaller over the three years (59.15 km in 2014, 37.67 km in 2015, 18.12 km in 2016), as did average DISTSHORE (88.56 km in 2014, 62.06 km in 2015, 38.37 km in 2016). However, average SLOPE (46.70 m km^{-1} in 2014, 45.68 m km^{-1} in 2015, and 39.84 m km^{-1} in 2016) and average ASPECT (208.52° in 2014, 220.88° in 2015, and 233.10° in 2016) values remained similar in all three years (**Table 19**). The values at each location for these seafloor relief variables are shown in the maps in **Figures 46 through 50**, and their distributional properties are shown in in the violin plots **Figures 54 through 58**.

Time series of monthly values of the ONI and the PDO for the 18-year period January 1999–February 2017 are presented in **Figure 59**. Based on the ±0.5°C threshold anomaly, five El Niño events (2002–2003, 2004–2005, 2006–2007, 2009–2010, and 2015–2016) and six La Niña events (1999–2000, 2000–2001, 2007–2008, 2010–2011, 2011–2012, and 2016–2017) occurred in this period (**Figure 59**). Although over the course of this study (2014–2017) only the period 2015–2016 was officially recognized as El Niño, warm anomalies occurred in the Niño 3.4 region in every month between September 2014 and June 2016 (Jacox et al. 2016, Levine and McPhaden 2016). This period was followed by a continuous series of cold anomalies starting in July 2016 and lasting through February 2017, associated with the La Niña event of 2016–2017 (**Figure 59**).

The PDO indicated that two regime shifts occurred during the period January 1999–February 2017 in the North Pacific: a mostly cool phase from 1999 to 2013 (Mantua and Hare 2002, Peterson and Schwing 2003), and a warm phase starting in January 2014 through the present time (**Figure 59**). The NPGO similarly indicated a long period of mostly positive sea-surface height anomalies from 1999 through late 2013, followed by a shift to negative anomalies after that time (**Figure 59**). (Because of this similarity in behavior between PDO and NPGO, the NPGO is not discussed further in this report.) Thus, the period of this study (2014–2017) was characterized by the combined effects of warm ONI and PDO anomalies, only temporarily suppressed by the La Niña event of 2016–2017. Furthermore, from 2013 to 2015 the west coast of North America was affected by a marine heat wave originating in the Gulf of Alaska, resulting in unprecedented and persistent warm conditions in the North Pacific (Bond et al. 2015, Leising et al. 2015, Di Lorenzo and Mantua 2016, McClatchie et al. 2016).

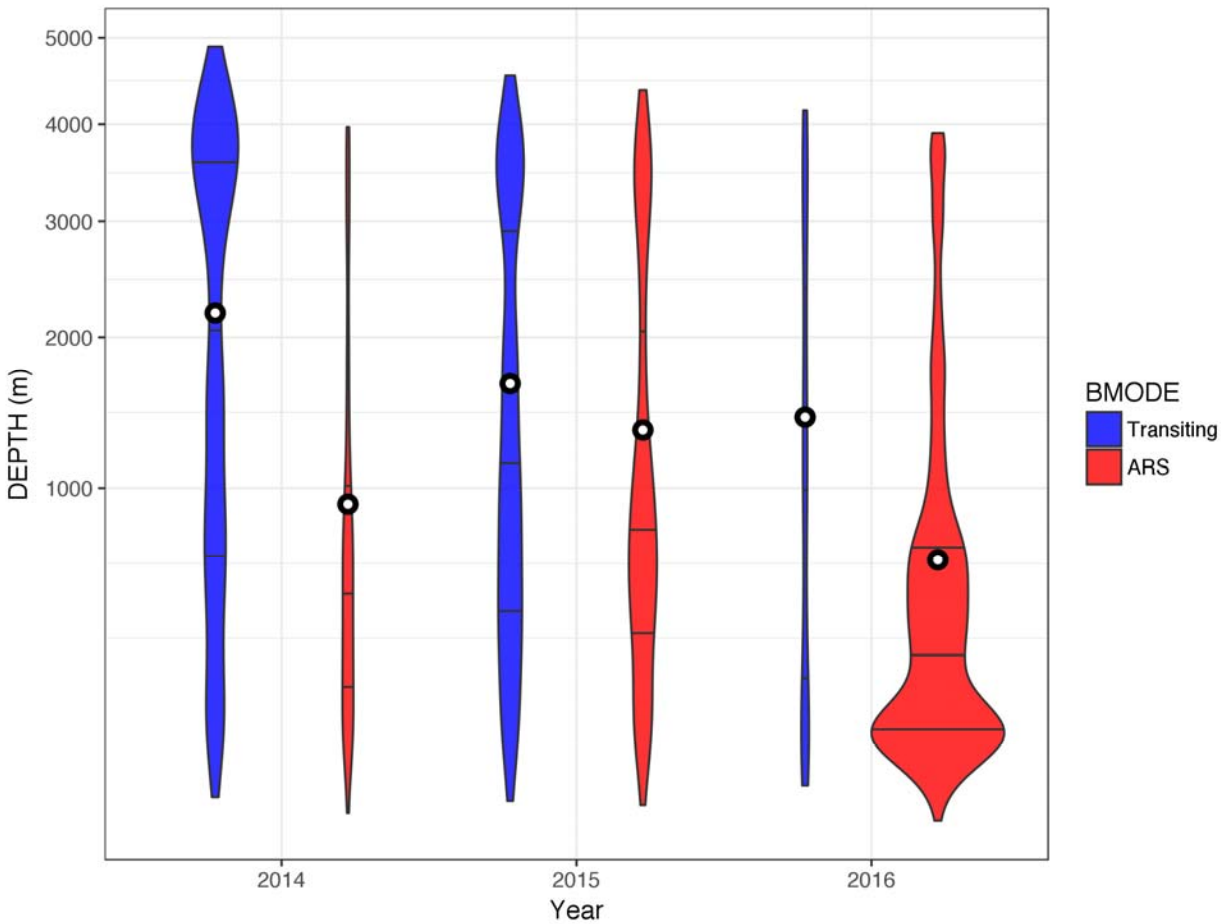

Figure 54. Paired violin plots of seafloor depth (DEPTH, m) values in CCAL for blue whale locations classified as transiting and ARS for each year in the study. Horizontal lines inside each violin indicate the quartiles of the data distribution and white circle with black outline indicates the mean. Data were square-root-transformed to improve visualization.

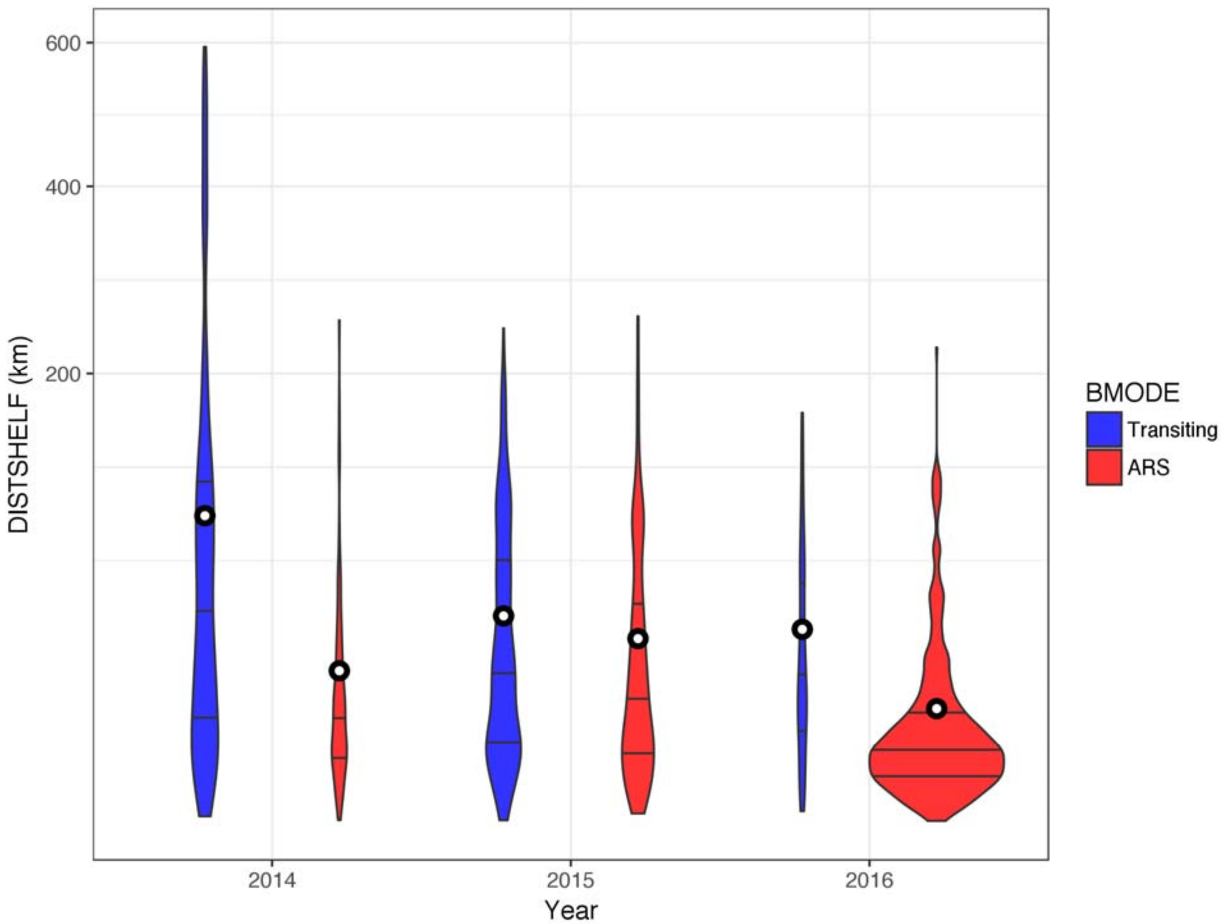

Figure 55. Paired violin plots of distance to the 200 m isobath (DISTSHELF, km) values in CCAL for blue whale locations classified as transiting and ARS for each year in the study. Horizontal lines inside each violin indicate the quartiles of the data distribution and white circle with black outline indicates the mean. Data were square-root-transformed to improve visualization.

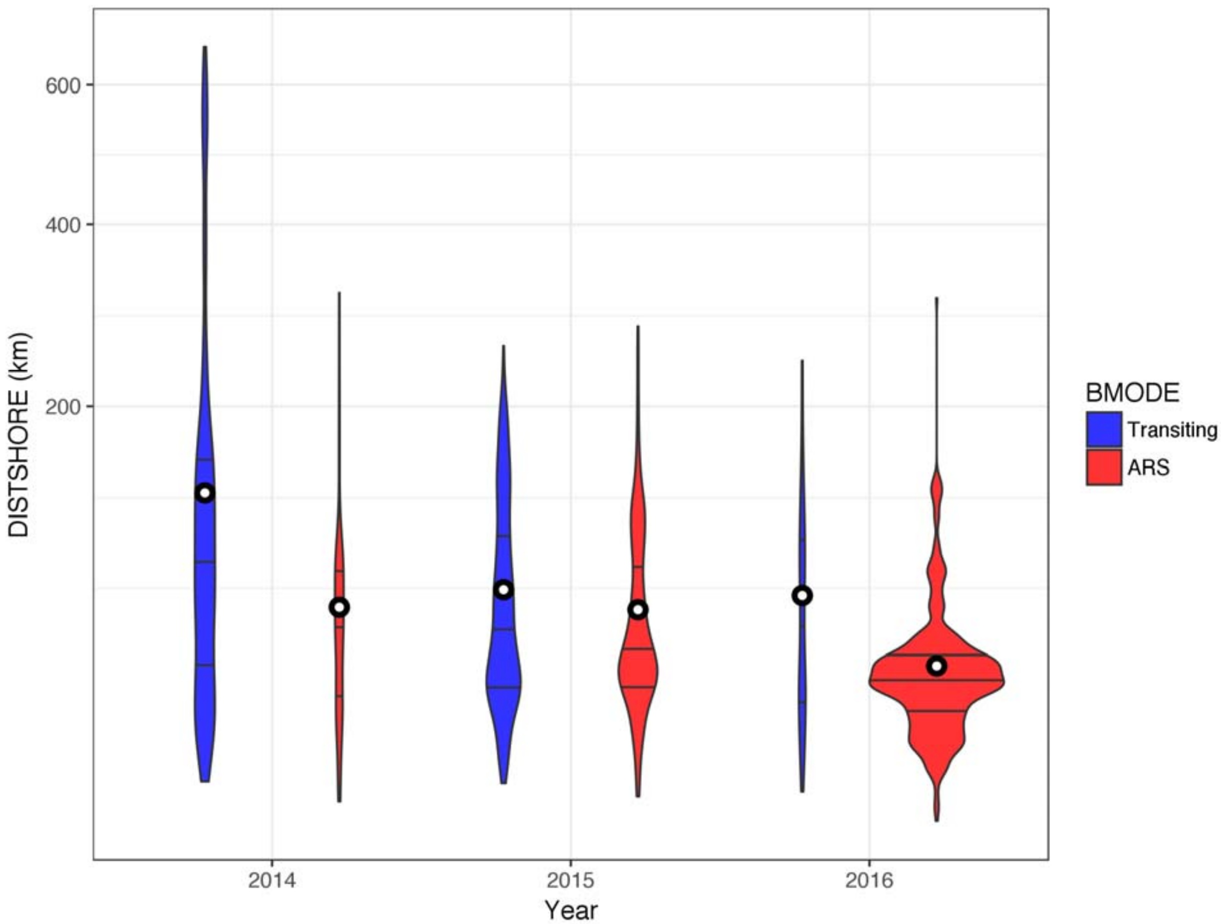

Figure 56. Paired violin plots of distance to the shoreline (DISTSHORE, km) values in CCAL for blue whale locations classified as transiting and ARS for each year in the study. Horizontal lines inside each violin indicate the quartiles of the data distribution and white circle with black outline indicates the mean. Data were square-root-transformed to improve visualization.

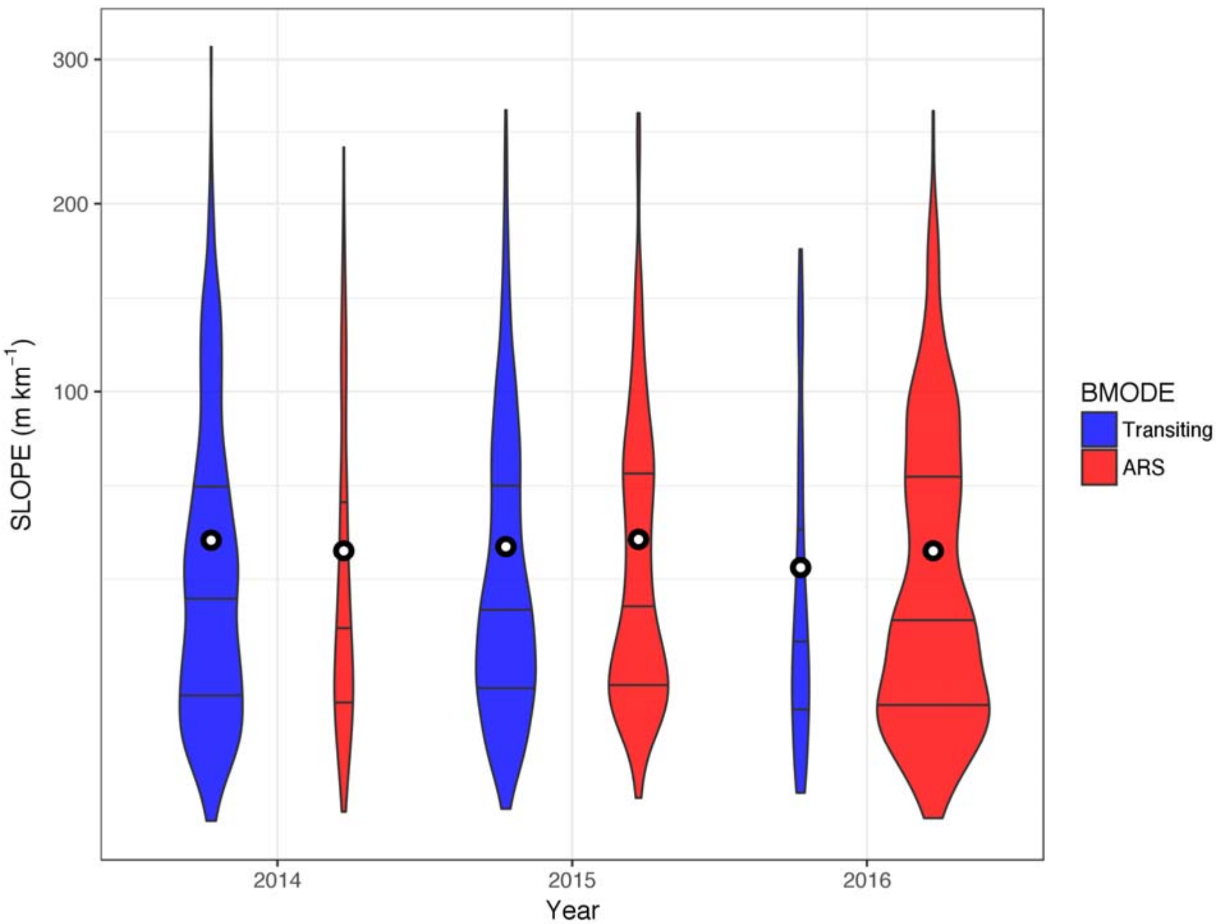

Figure 57. Paired violin plots of seafloor slope (SLOPE, m km^{-1}) values in CCAL for blue whale locations classified as transiting and ARS for each year in the study. Horizontal lines inside each violin indicate the quartiles of the data distribution and white circle with black outline indicates the mean. Data were square-root-transformed to improve visualization.

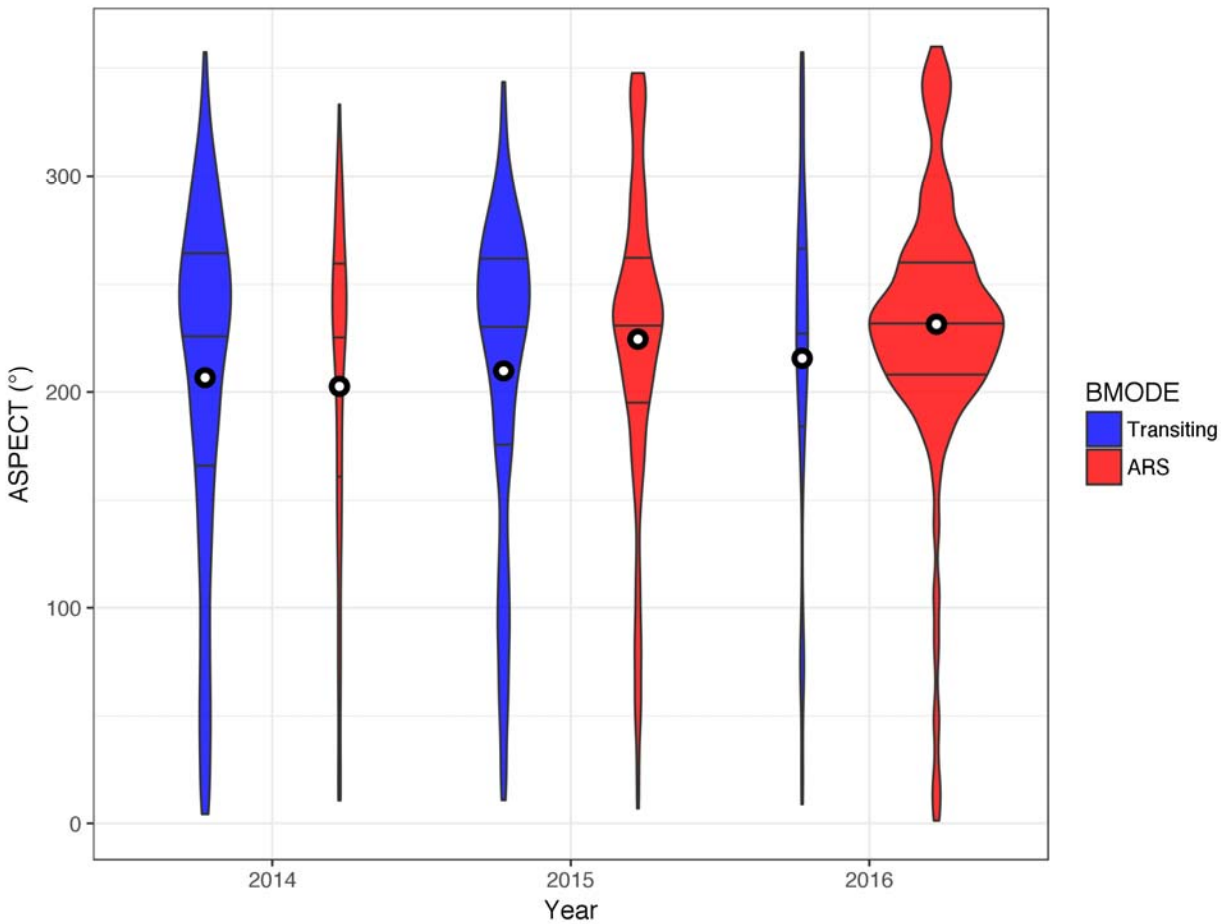

Figure 58. Paired violin plots of seafloor slope aspect (ASPECT, degrees) values in CCAL for blue whale locations classified as transiting and ARS for each year in the study. Horizontal lines inside each violin indicate the quartiles of the data distribution and white circle with black outline indicates the mean.

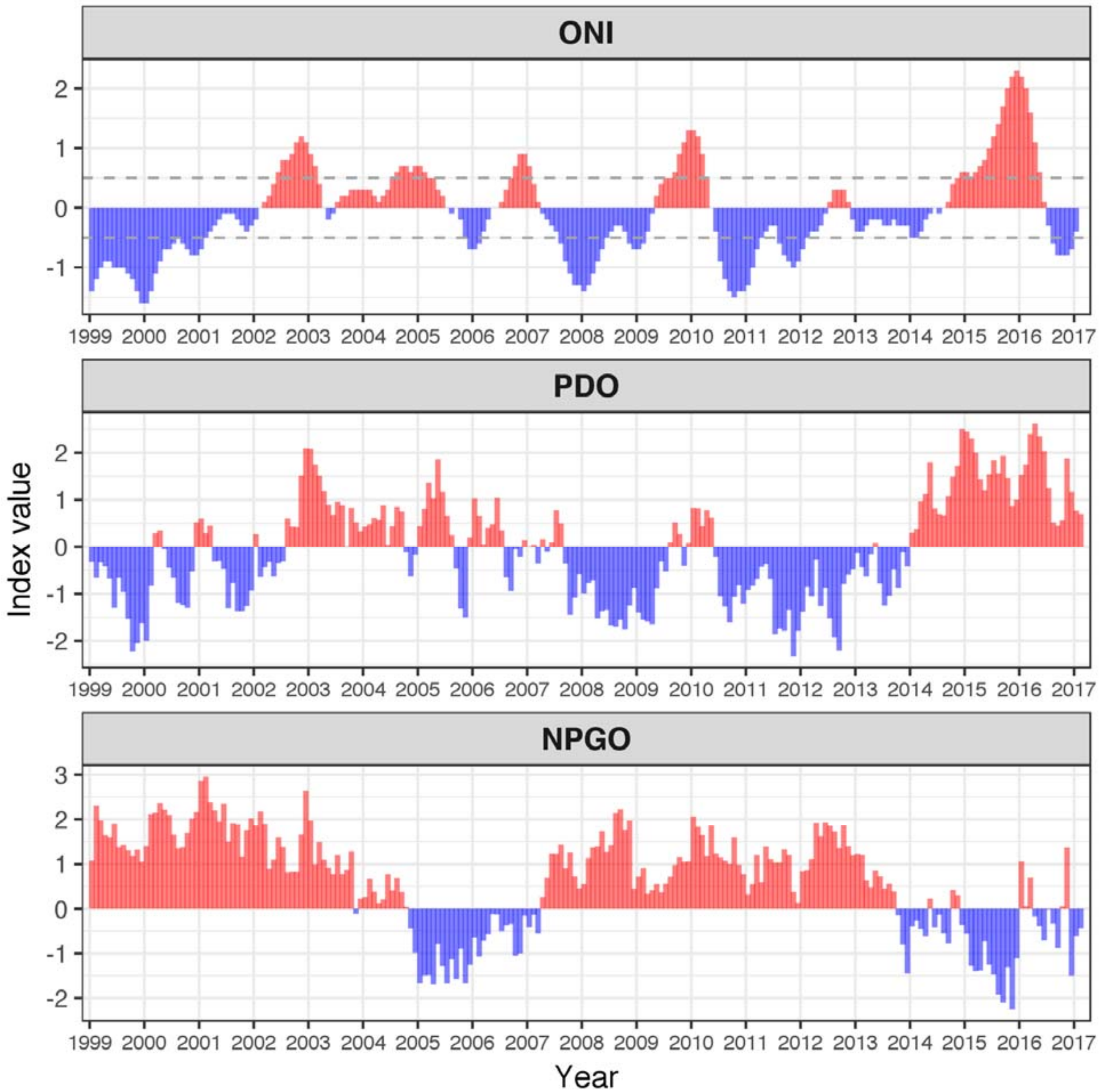

Figure 59. Time series of monthly values of the Oceanic Niño Index (ONI; top panel), the Pacific Decadal Oscillation (PDO; middle panel), and the North Pacific Gyre Oscillation (NPGO; bottom panel) for the period January 1999–February 2017. NOAA declares an El Niño/La Niña event in the Niño 3.4 region when a threshold anomaly of ±0.5°C (horizontal dashed lines in top panel) is met for a minimum of five consecutive overlapping seasons.

3.1.11 Genetics and Species Identification

In 2014, skin biopsy samples were collected from 16 of the 24 tagged whales considered to be blue whales based on field observations (Mate et al. 2016). All samples provided DNA profiles sufficient for subsequent analyses. In 2015, skin biopsy samples were collected from 15 of the 22 tagged whales considered to be blue whales based on field observations (Mate et al. 2016). All samples provided DNA profiles sufficient for subsequent analyses. In 2016, skin biopsy samples were collected from 12 of the 19 tagged whales considered to be blue whales based on field observations (**Figure 60**). All samples provided DNA profiles sufficient for subsequent analyses.

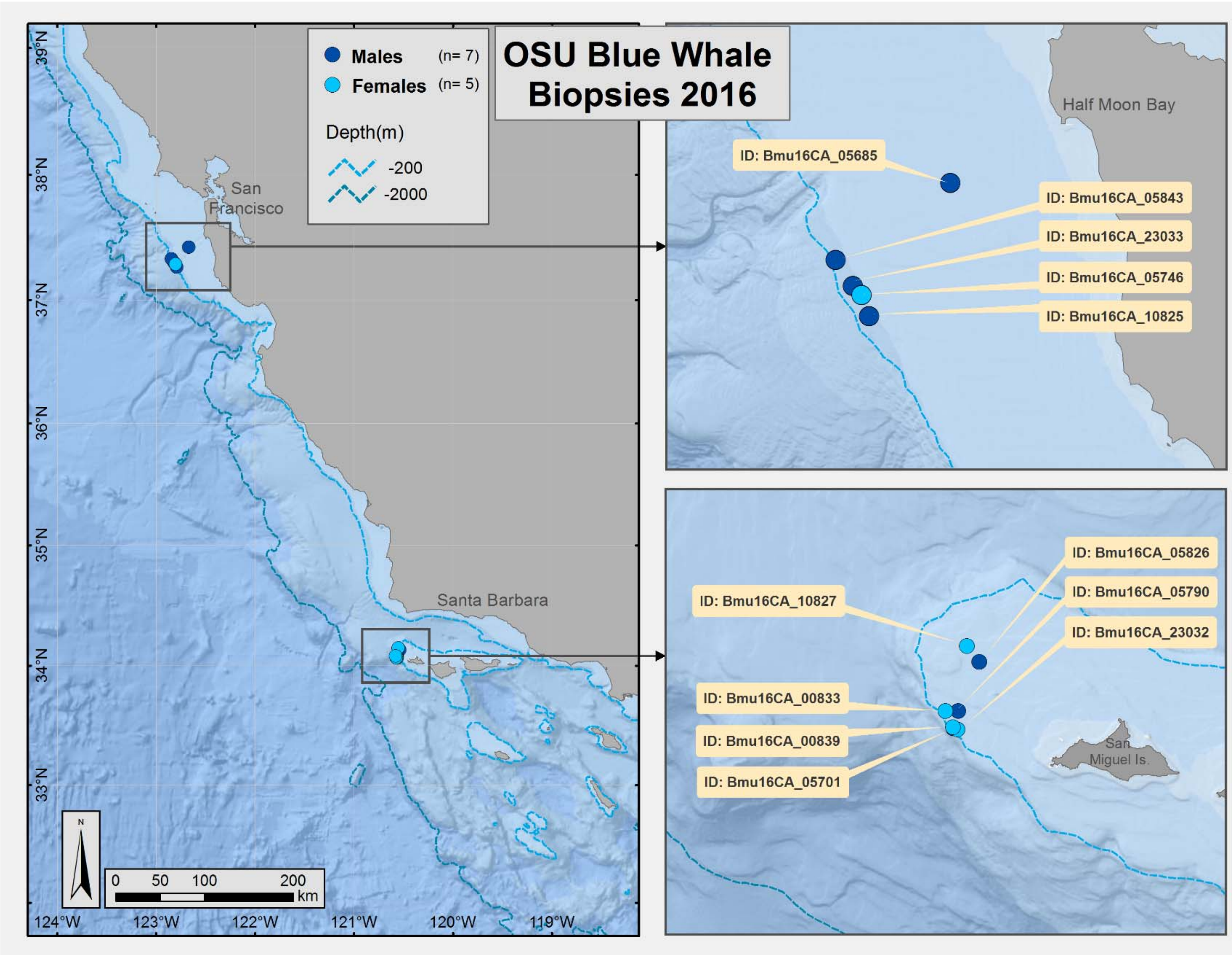

Figure 60. The locations of biopsy sample collections from blue whales tagged in 2016.

The mtDNA sequences of the 43 samples resolved 13 haplotypes for a consensus region of 410 bp in length. Based on submission to *DNA-surveillance* and a BLAST search of GenBank®, all of the mtDNA haplotypes were consistent with field identification of blue whales.

3.1.11.1 SEX DETERMINATION

The 43 blue whale samples represented 18 females and 25 males (**Table 2** and Mate et al. 2016).

3.1.11.2 INDIVIDUAL IDENTIFICATION

All 43 samples were represented by unique multi-locus genotypes and the probability of identity for the 17 loci was very low, 6.8×10^{-16} (i.e., there was a very low probability of a match by chance). Consequently, we are confident that the 43 unique multi-locus genotypes represented 43 individuals, i.e., there were no replicate samples among the blue whales tagged in 2014–2016. This was consistent with sex and mtDNA haplotypes, as provided in the full DNA profile.

The DNA profiles of the 43 blue whales tagged in 2014–2016 were compared to a reference database of blue whales sampled previously in the eastern North Pacific by OSU or made available through a collaborative agreement with Cascadia Research (**Figure 61**). Although the quality of the DNA profiles for the archived samples was variable, there were 76 individuals with genotypes sufficient for individual identification and most of these included mtDNA haplotypes and sex. None of these were a match to any of the 43 blue whales tagged in 2014–2016.

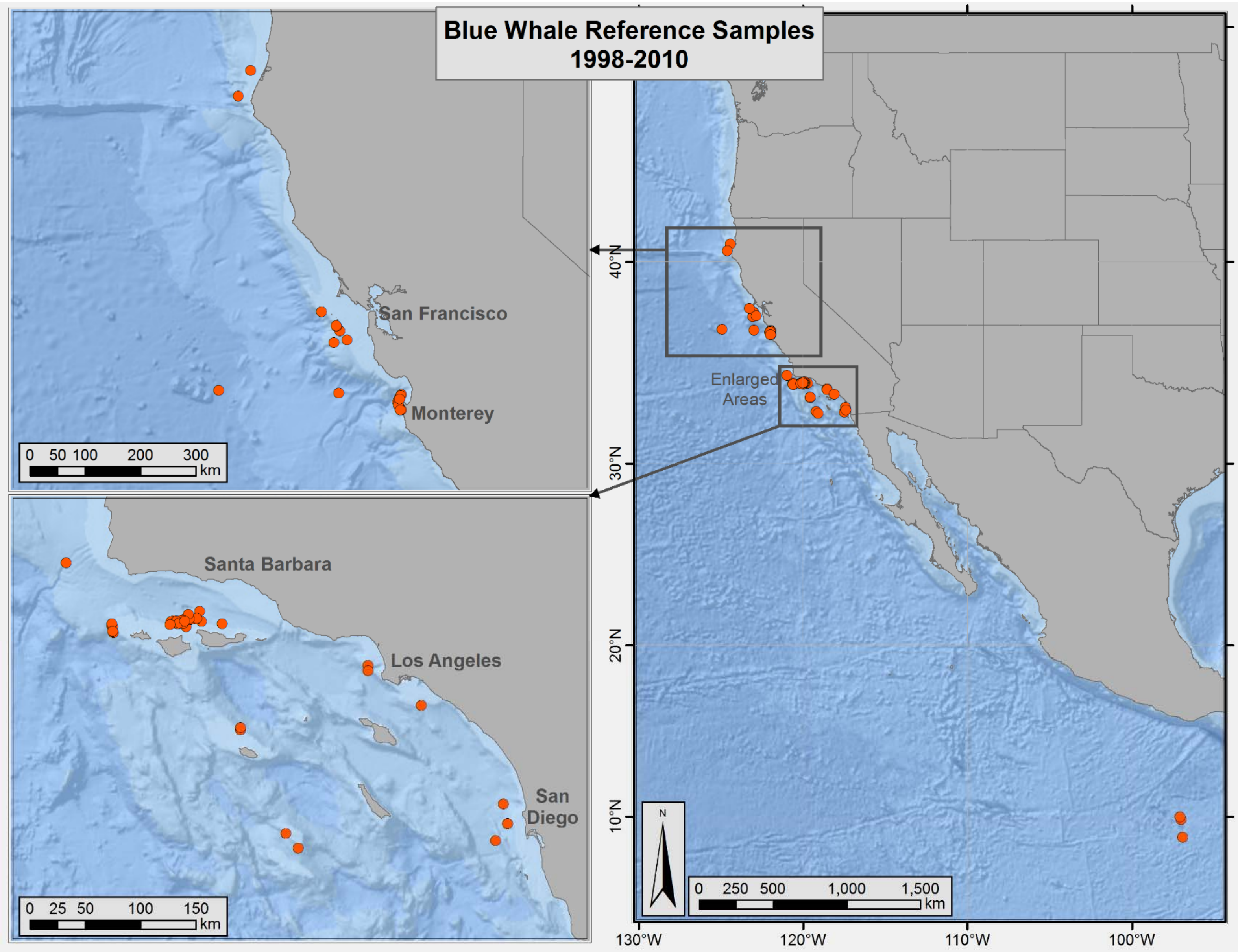

Figure 61. The sample location of blue whales used in the reference database for population structure.

3.1.11.3 STOCK IDENTIFICATION

A review of published literature and datasets on *GenBank* provided information on identity and frequencies of mtDNA haplotypes from blue whales representing several populations or subspecies (**Table 20**): the eastern South Pacific (Chile), Australia and New Zealand, and the Antarctic. The total of 327 samples represented 74 mtDNA haplotypes based on sequence variation in the first 410 bp of the control region. Unpublished information on the identity and frequencies of mtDNA haplotypes in the eastern North Pacific was also available for samples of blue whales archived by OSU or made available through collaboration with Cascadia Research, as archived with the Southwest Fisheries Science Center (see above). Of the 76 individuals with partial or complete DNA profiles, there were 64 individuals with mtDNA sequences. These 64 individuals from the eastern North Pacific represented 16 haplotypes based on the consensus length of 410 bp.

Table 20. The frequency and identity of 20 mtDNA haplotypes for blue whales in the eastern North Pacific, including 13 from the 2014–2016 tagging, and the sharing of these haplotypes with other populations or subspecies of blue whales.

mtDNA haplotype	GenBank code	Antarctic	Australia/ New Zealand	Eastern South Pacific	Eastern North Pacific	2014–2016 Tagged Whales
haplotype d	EU093921	4	38	1	4	1
haplotype dd	EU093947			4		1
haplotype e	EU093922		6		1	3
haplotype p				21		1
haplotype q	EU093934			20	8	5
haplotype r	EU093935	2	1	19	25	21
haplotype t	EU093937			15	1	
BMCH01	JX035887			2	2	4
NPBW06(Bmu07CA001)	JQ717166				5	2
NPBW13(Bmu07Ca016)	JQ717173				3	
NPBW15(Bmu06Ca005)	JQ717175				3	1
NPBW16(Bmu07Ca002)	JQ717176				2	
NPBW18(Bmu06CA002)	JQ717178				4	1
Hap53(Bmu07Ca004)	KP187717				1	
Bmu07Ca006					1	
Bmu08Ca002					1	
Bmu51118					2	
Bmu15CA007						1
Bmu15CA004						1
Bmu24035					1	1
Unshared haplotypes (66)		178 (50)	14 (8)	38 (9)		
	Total individuals	**184**	**51**	**113**	**64**	**43**

Of the 13 haplotypes resolved among the 43 tagged blue whales from 2014–2016, nine matched to the 16 haplotypes represented in reference database from the eastern North Pacific, resulting in a total of 20 haplotypes for this stock. Of these 20 haplotypes, eight were also shared with one or more of the other stocks or subspecies, including two shared with the Antarctic subspecies. In total, the available reference databases and the samples from the 2014–2016 tagging represented 86 haplotypes (**Table 20**).

The test of differentiation showed no significant differences in haplotype frequencies between the 18 females and 25 males ($p = 0.145$) or between the 2016 tagged whales and the previous two years ($p = 0.255$). The combined sample of 43 tagged whales showed no significant differences with the reference dataset representing the eastern North Pacific (**Table 21**). This is consistent with the available information suggesting a single stock of blue whales in the eastern North Pacific (Lang and LeDuc 2015). There was, however, significant differentiation between the 2014–2016 tagged whales and the other populations or subspecies of blue whales, despite the sharing of some haplotypes. The differentiation with the eastern North Pacific was most pronounced for the Antarctic and Australian/New Zealand stocks or subspecies and least pronounced for the eastern South Pacific, perhaps indicating recent or ongoing genetic exchange across the equator (Torres-Florez et al. 2015).

Table 21. Pairwise tests of differentiation (FST) for mtDNA haplotype frequencies of the tagged blues whales and available reference datasets representing the eastern North Pacific and other populations or subspecies of blue whales. Pairwise tests with significant differences are shown in bold.

Stratum 1	n 1	Stratum 2	n 2	F_{ST}	P value
Antarctic	184	SoCal tagging	43	**0.127**	< 0.001
Australia/New Zealand	51	SoCal tagging	43	**0.325**	< 0.001
Eastern South Pacific	113	SoCal tagging	43	**0.090**	< 0.001
Eastern North Pacific	64	SoCal tagging	43	0.000	0.446

3.2 Fin Whale

3.2.1 Tracking Analysis—2016

Fourteen tags were deployed on fin whales (5 LO, 9 DM) between 28 July and 4 August 2016. All tags were deployed off central California, near the continental shelf edge between Half Moon Bay and Pigeon Point. Transmissions were received from 13 of the 14 fin whale tags. Tracking periods for these 13 tags ranged from 1.3 to 104.3 d, with average fin whale tracking durations of 28.7 d (SD = 8.4 d, median = 26.7 d) for LO tags and 38.6 d (SD = 33.4 d, median = 28.7 d) for DM tags (**Table 22**).

Table 22. Deployment and performance data for satellite-monitored radio tags deployed on fin whales in central California, 2016. Unknown sex whales are cases where no biopsy sample was collected. See Section 2.2.2 for location filtering method. Deployment dates reflect UTC dates.

Tag #	Sex	Tag Type	Deployment Date	Most Recent Location	# Days Tracked	# Filtered Locations	Total Distance (km)
5709	Unknown	LO	3-Aug-16	30-Aug-16	26.7	29	505
5719	Unknown	LO	2-Aug-16	25-Aug-16	22.3	75	948
5883	Unknown	LO	1-Aug-16	7-Sep-16	36.6	136	1,317
10836	Unknown	LO	3-Aug-16	23-Aug-16	19.7	22	527
23039	Female	LO	4-Aug-16	11-Sep-16	38.2	101	1,830
	Mean	**LO**			**28.7**	**73**	**1,026**
	Median	**LO**			**26.7**	**75**	**948**
831*	Unknown	DM	29-Jul-16	-	0	-	-
5655	Unknown	DM	28-Jul-16	10-Nov-16	104.3	365	5,659
5700	Female	DM	29-Jul-16	26-Sep-16	58.9	267	2,693
5726	Male	DM	29-Jul-16	29-Aug-16	31.2	111	1,381
5743	Female	DM	30-Jul-16	24-Aug-16	24.1	133	1,247
10829	Female	DM	29-Jul-16	24-Aug-16	26.2	60	943
10839	Unknown	DM	28-Jul-16	5-Aug-16	7.1	30	229
23030	Male	DM	28-Jul-16	22-Sep-16	55.8	341	4,441
23035	Unknown	DM	3-Aug-16	5-Aug-16	1.3	6	43
	Mean	**DM**			**38.6**	**164**	**2,055**
	Median	**DM**			**28.7**	**122**	**1,314**

KEY: DM = Telonics RDW-665 Dive-Monitoring tag; km = kilometer(s); LO = Wildlife Computers SPOT6 Location-Only tag; # = number; * No transmissions were received for Tag #831. This tag is not included in summary statistics.

Fin whale locations ranged over 20 degrees of latitude, from San Nicolas Island in southern California to Hecate Strait in British Columbia, Canada (**Figure 62**). One fin whale (Tag #23030) was primarily responsible for this long range, traveling from Pigeon Point in central California to Hecate Strait between Haida Gwaii (formerly Queen Charlotte Island) and mainland British Columbia, with a distance between northern- and southern-most locations of over 1,900 km. This latter whale spent 39 d in Hecate Strait before its tag stopped transmitting on 22 September. The other 13 tracked fin whales covered ranges between approximately 25 and 515 km. Most fin whale locations were concentrated along the central California coast, between Monterey Bay and Point Reyes, with lesser concentrations off Point Arena and Point Buchon. Few fin whale locations occurred over continental shelf waters, with the majority being over the continental slope and deeper offshore water.

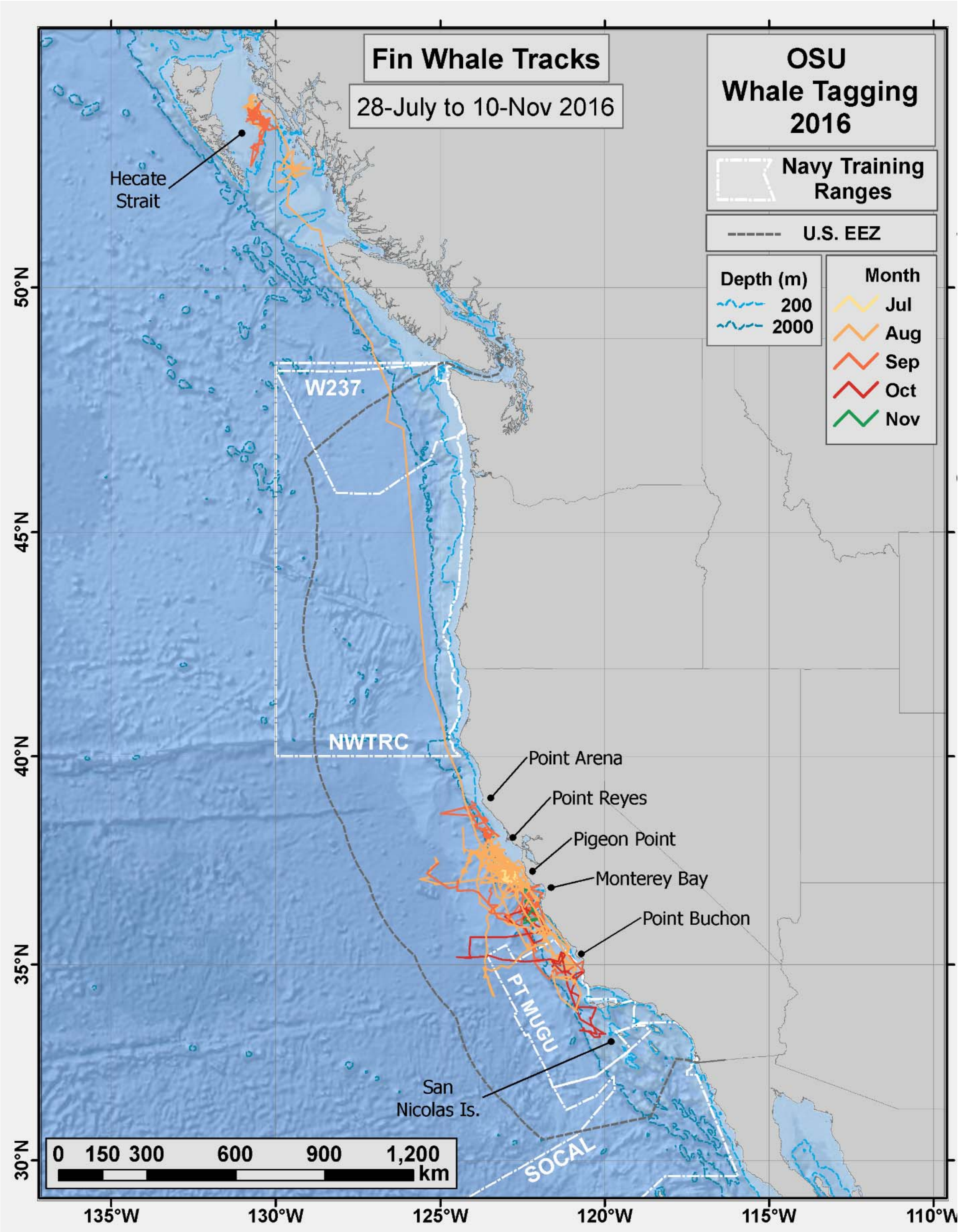

Figure 62. Satellite-monitored radio tracks for fin whales tagged off central California in July and August 2016 (5 LO tags, 8 DM tags).

3.2.1.1 USE OF NAVY TRAINING AREAS BY TAGGED FIN WHALES

PT MUGU was the most heavily used training range for fin whales tagged in 2016, with 3 of the 13 tracked whales having between 5 and 47 percent of their total number of locations in the area (**Table 23 and Figure 63**). These whales spent from 3 to 42 percent of their total tracking periods in the PT MUGU area, representing 1 to 44 d. Distances to shore in PT MUGU averaged 94 km (SD = 75.1 km, maximum = 195 km; **Table 23**). Locations in PT MUGU occurred in 3 of the 5 months in which these whales were tracked (August, September, and October). Only one fin whale had locations within the NWTT and W237 training areas, as it traveled from central California to British Columbia (**Figures 64 and 65**). This whale (Tag #23030) had 4 percent of its total number of locations and 11 percent of its tracking period within the NWTT, representing 6 d. Distance to shore in NWTT averaged 108 km for this whale (SD = 37.7 km, maximum = 165 km; **Table 23**). Two percent of the total locations for whale Tag #23030 and 3 percent of its tracking period were spent within area W237 of the NWTT, representing 2 d. Distance to shore in W237 averaged 140 km (SD = 17.8 km, maximum = 165 km; **Table 24**). Locations in the NWTT and W237 for this fin whale occurred during the month of August. None of the tagged fin whales were tracked within the SOCAL or GOA training areas.

Table 23. Percentage of filtered locations and time spent inside the SOCAL, PT MUGU, NWTT, and W237 areas for fin whales tagged off central California, 2016. See Section 2.2.2 for location filtering method.

Tag #	Tag Type	Total		SOCAL			PT MUGU			NWTT			W237		
		# Locs	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days
5709	LO	29	26.7	0	0	0	0	0	0	0	0	0	0	0	0
5719	LO	75	22.3	0	0	0	0	0	0	0	0	0	0	0	0
5883	LO	134	36.6	0	0	0	0	0	0	0	0	0	0	0	0
10836	LO	22	19.7	0	0	0	0	0	0	0	0	0	0	0	0
23039	LO	101	38.2	0	0	0	5	3	1.0	0	0	0	0	0	0
831*	DM	0	0	-	-	-	-	-	-	-	-	-	-	-	-
5655	DM	365	104.3	0	0	0	47	42	44.3	0	0	0	0	0	0
5700	DM	267	58.9	0	0	0	0	0	0	0	0	0	0	0	0
5726	DM	111	31.2	0	0	0	0	0	0	0	0	0	0	0	0
5743	DM	133	24.1	0	0	0	0	0	0	0	0	0	0	0	0
10829	DM	60	26.2	0	0	0	42	32	8.3	0	0	0	0	0	0
10839	DM	30	7.1	0	0	0	0	0	0	0	0	0	0	0	0
23030	DM	341	55.8	0	0	0	0	0	0	4	11	6.1	2	3	1.7
23035	DM	6	1.3	0	0	0	0	0	0	0	0	0	0	0	0
Mean+		**129**	**34.8**	**-**	**-**	**-**	**31**	**26**	**17.9**	**4**	**11**	**6.1**	**2**	**3**	**1.7**
Median+		**101**	**26.7**	**-**	**-**	**-**	**42**	**32**	**8.3**	**4**	**11**	**6.1**	**2**	**3**	**1.7**

KEY: DM = Telonics RDW-665 Dive-Monitoring tag; LO = Wildlife Computers SPOT6 Location-Only tag; Locs = Locations; # = number; * No transmissions were received for Tag #831. This tag is not included in summary statistics; +Summary statistics do not include zero values in their calculation.

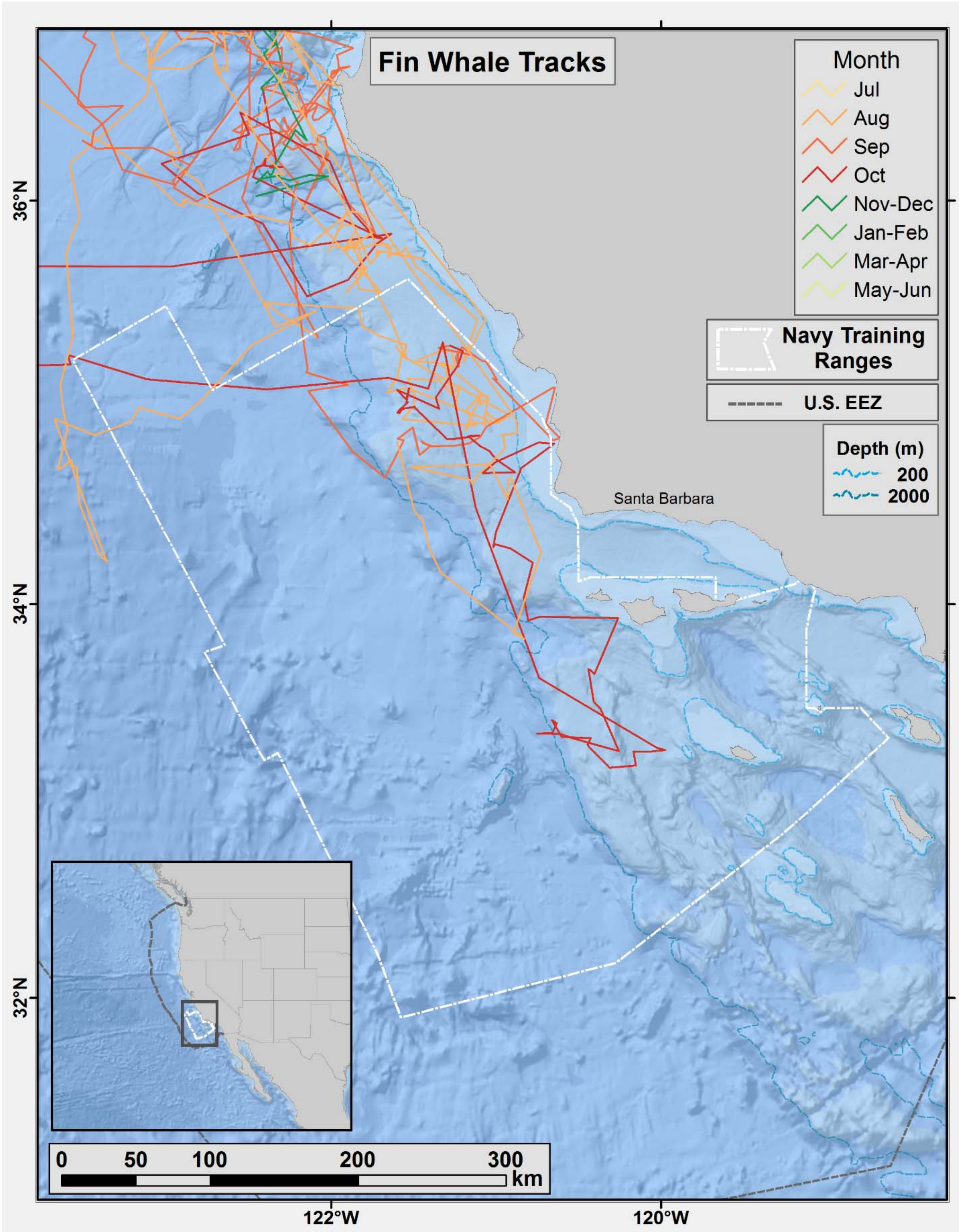

Figure 63. Satellite-monitored radio tracks in PT MUGU for fin whales tagged off central California in July and August 2016 (1 LO tag, 2 DM tags).

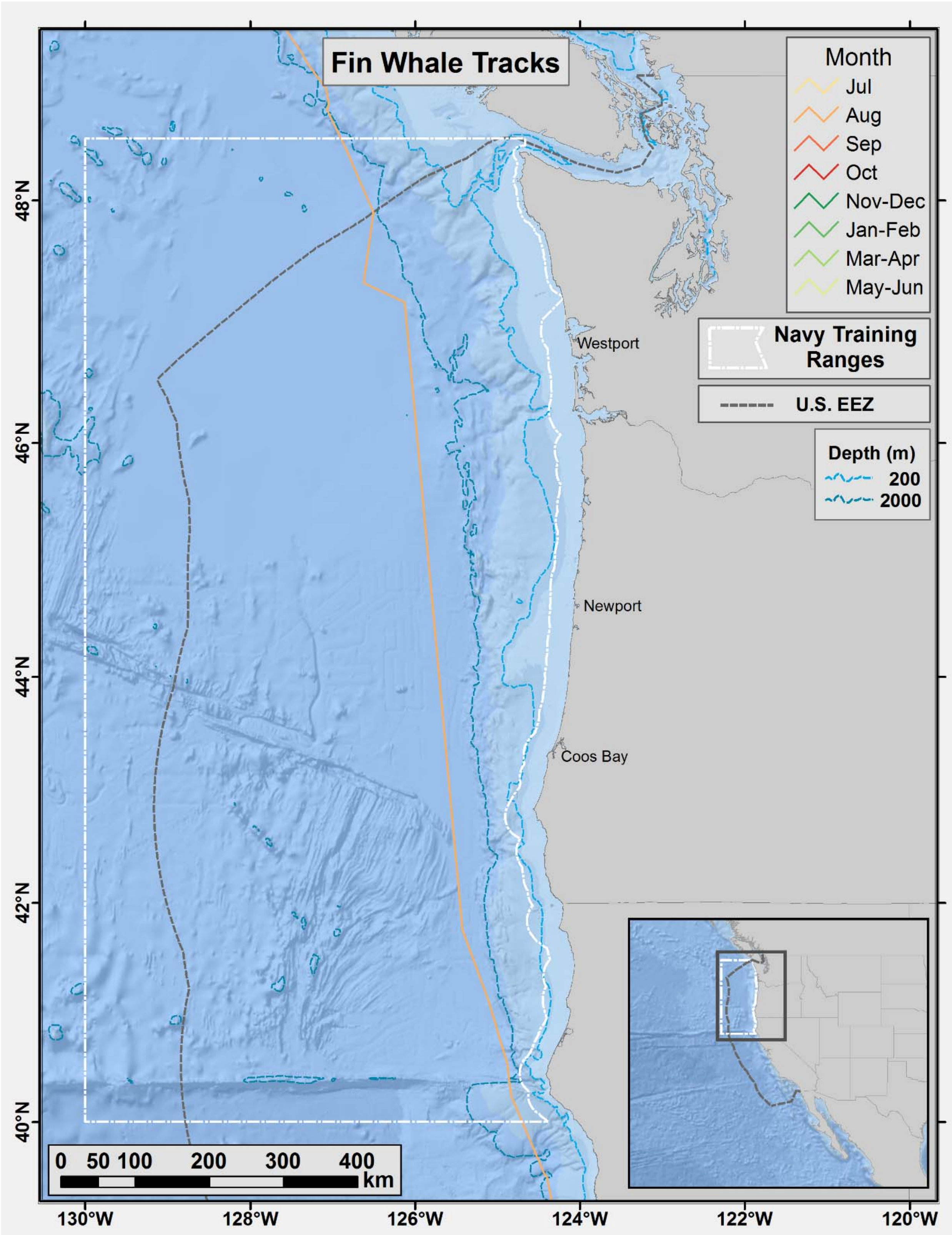

Figure 64. Satellite-monitored radio tracks in NWTT for a fin whale (Tag #23030) tagged off central California in July 2016 (1 DM tag).

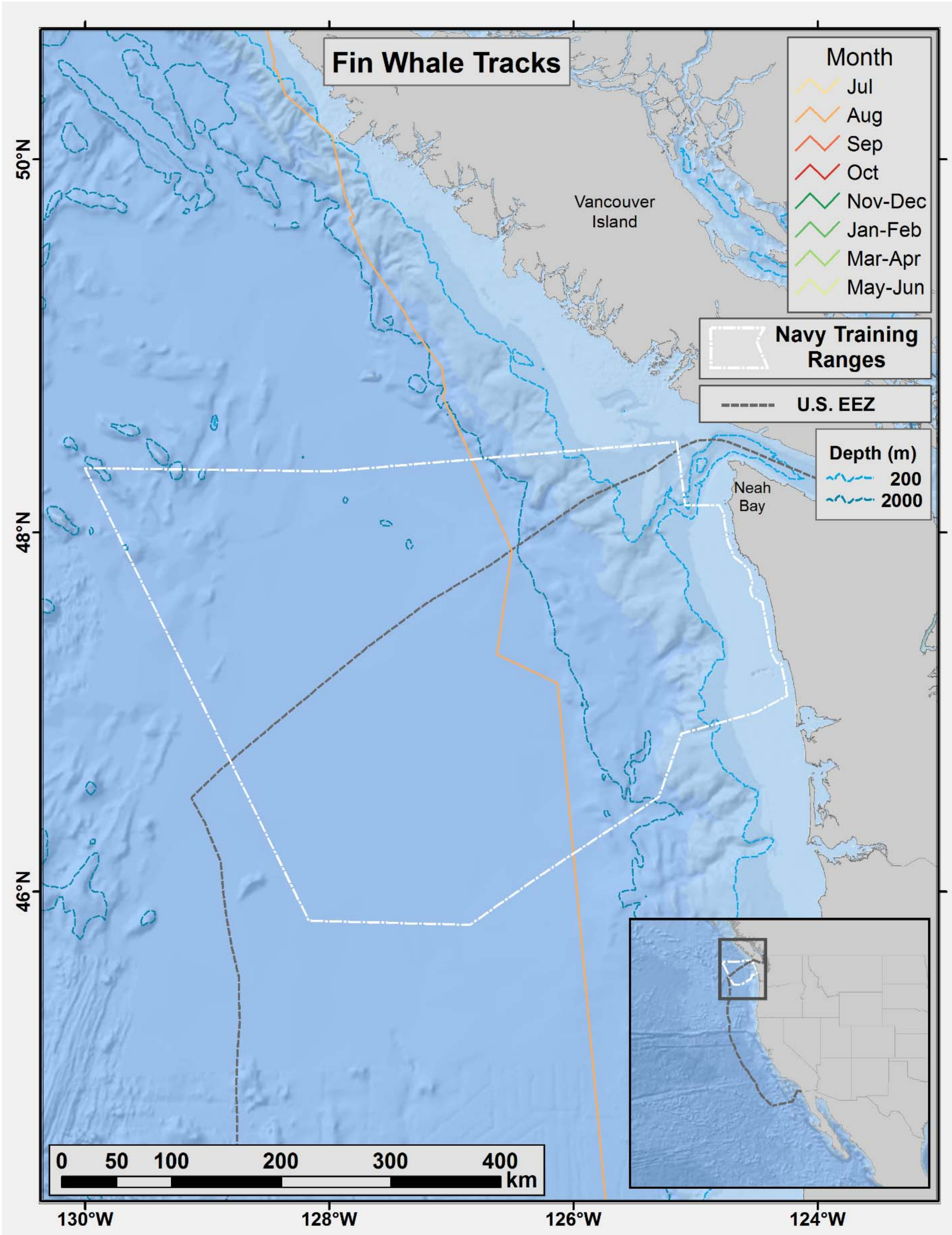

Figure 65. Satellite-monitored radio tracks in area W237 of NWTT for a fin whale (Tag #23030) tagged off central California in July 2016 (1 DM tag).

Table 24. Geodesic distances to nearest point on shore in Navy training ranges for fin whales tagged off central California, 2016 (including mean, median, and maximum distances to shore for each whale). The number of locations includes filtered locations (see Section 2.2.2 for filtering method) only, as no tags were deployed on fin whales within Navy ranges.

Tag #	Tag Type	SOCAL				PT MUGU				NWTT				W237			
		n	Mean	Median	Max	n	Mean	Median	Max	n	Mean	Median	Max	n	Mean	Median	Max
5709	LO	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-
5719	LO	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-
5883	LO	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-
10836	LO	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-
23039	LO	0	-	-	-	5	181	187	195	0	-	-	-	0	-	-	-
831*	DM	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-
5655	DM	0	-	-	-	172	52	50	172	0	-	-	-	0	-	-	-
5700	DM	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-
5726	DM	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-
5743	DM	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-
10829	DM	0	-	-	-	25	50	44	82	0	-	-	-	0	-	-	-
10839	DM	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-
23030	DM	0	-	-	-	0	-	-	-	13	108	105	165	6	140	137	165
23035	DM	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-
	Mean		**-**	**-**	**-**		**94**	**94**	**150**		**-**	**-**	**-**		-	-	-
	Median		**-**	**-**	**-**		**52**	**50**	**172**		**-**	**-**	**-**		-	-	-

KEY: DM = Telonics RDW-665 Dive-Monitoring tag; LO = Wildlife Computers SPOT6 Location-Only; n = number of locations; * No transmissions were received for Tag #831.

3.2.1.2 HOME RANGE ANALYSIS

Five fin whale tags provided enough locations to calculate HRs and CAs within U.S. EEZ waters (**Table 25, Figures 66 and 67**). HR sizes ranged from 4,456 to 68,715 km^2 (mean = 34,025.0 km^2, SD = 26,458.8 km^2) and extended from west of San Nicolas Island in southern California to Point Arena. The densest area of overlapping HRs (for all five fin whales) occurred off central California, from Monterey Bay to Half Moon Bay, and from approximately 6 to 60 km offshore. Areas of overlapping HRs for four fin whales extended from southwest of San Miguel Island (out to approximately 130 km offshore) to Point Reyes, California (out to approximately 80 km offshore). CAs ranged from 1,259 to 21,433 km^2 (mean = 10,278.2 km^2, SD = 8,312.1 km^2). The area of highest use for fin whales, where CAs overlapped for all five whales, was off Pigeon Point between Monterey Bay and Half Moon Bay, extending from approximately 18 to 44 km offshore. There was no relationship between the number of SSM locations used in the analysis and the size of either HRs or CAs (Linear Regression of log-transformed HR and CA, P values > 0.53).

Table 25. Sizes of HRs and CAs of use in the U.S. EEZ calculated from state-space modeled (SSM) locations for five fin whales tagged off central California, 2016. Unknown sex whales are cases where no biopsy sample was collected.

Tag #	# SSM Locations	Sex	HR Size (km^2)	CA Size (km^2)
Fin Whales				
5655	105	Unknown	53,230	16,113
5700	59	Female	16,483	4,744
5726	32	Male	27,241	7,842
5883	37	Unknown	4,456	1,259
23039	39	Female	68,715	21,433
		Mean	**34,025.0**	**10,278.2**

Key: km^2 = square kilometer(s).
Note: The U.S. EEZ is located 370.4 km (200 nautical miles) from shore.

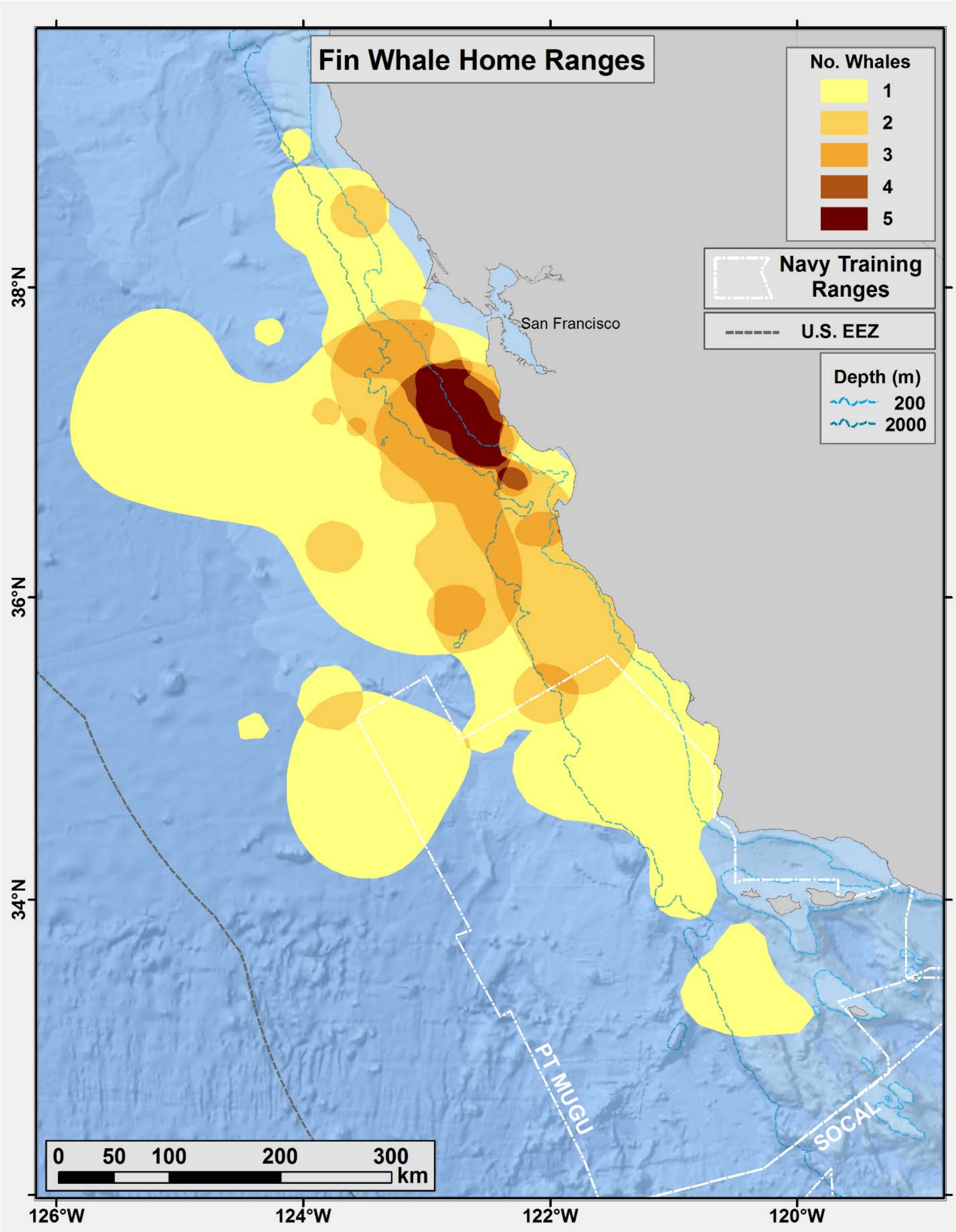

Figure 66. HRs in the U.S. EEZ for 5 fin whales tagged off central California in 2016. Shading represents the number of individual whales with overlapping HRs.

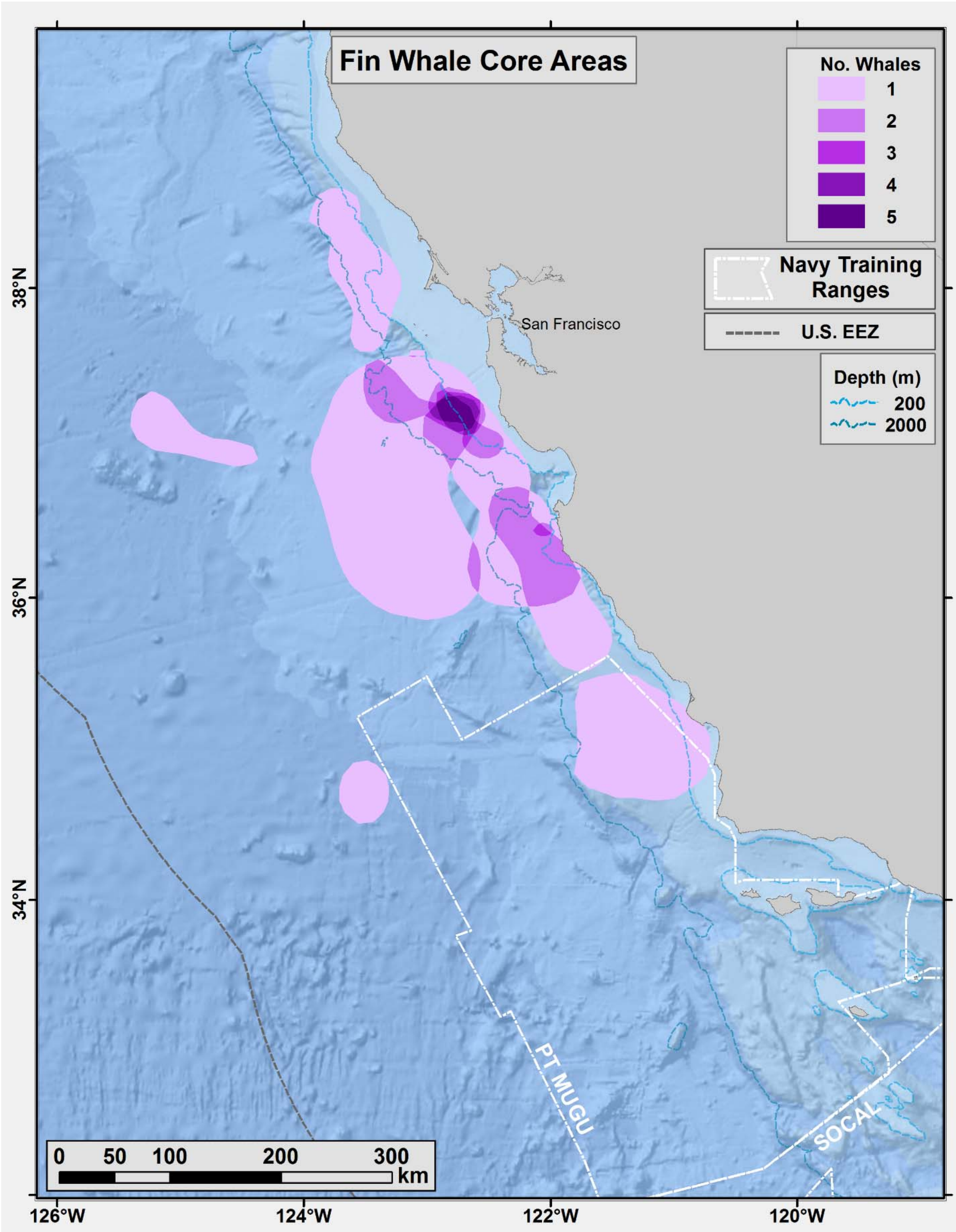

Figure 67. CAs of use in the U.S. EEZ for 5 fin whales tagged off central California in 2016. Shading represents the number of individual whales with overlapping CAs.

3.2.2 Tracking Analysis—Updated Information from 2015

One of the fin whale tags deployed in 2015 (Tag #5742) continued to transmit beyond the cutoff date for the 2015 final report (29 February 2016), and the complete data record for that tag was not presented in that report. This section presents updated tabular data for Tag #5742, and the following section on interannual comparisons presents updated maps, showing complete tracks for fin whales tagged in all three years. The fin whale with Tag #5742 was tracked for a total of 252.4 d and had a median distance to shore of 32 km (**Tables 26 and 27**). This whale was located in the Southern California Bight, from Point Dume to Dana Point, for the remainder of its tracking period (beyond the February cutoff date), spending three months in this area before its tag stopped transmitting on 1 April 2016. Whale Tag #5742 had an additional 4 locations in the SOCAL range, for a total of 23.2 d in that area (**Table 27**). With the addition of locations in the Southern California Bight for the remainder of the tracking period for this whale, the sizes of both its HR and CA were reduced (**Table 28**).

Table 26. Deployment and performance data for satellite-monitored radio tags deployed on fin whales in southern California, 2015, with updated information for Tag #5742 (in italics). Unknown sex whales are cases where no biopsy sample was collected. See Section 2.2.2 for location filtering method.

Tag #	Sex	Tag Type	Deployment Date	Most Recent Location	# Days Tracked	# Filtered Locations	# GPS/Argos Locations	Total Distance (km)
832	Female	SPOT5	22-Jul-15	20-Aug-15	28.7	23	0 / 23	1,509
839	Male	SPOT5	8-Jul-15	24-Sep-15	78.0	269	0 / 269	6,797
5742	*Male*	SPOT5	23-Jul-15	*1-Apr-16*	*252.4*	*757*	*0 / 752*	*14,556*
5743	Unknown	SPOT5	9-Jul-15	6-Aug-15	28.2	53	0 / 53	1,321
5790*	Female	SPOT5	28-Jul-15		0.0	0	0 / 0	0
5800	Female	SPOT5	17-Jul-15	7-Oct-15	81.8	290	0 / 290	5,234
5923	Male	SPOT5	28-Jul-15	21-Sep-15	54.6	92	0 / 92	3,349
10838	Unknown	SPOT5	17-Jul-15	12-Oct-15	86.9	378	0 / 378	5,161
23032	Female	SPOT5	28-Jul-15	3-Aug-15	6.2	29	0 / 29	565
	Mean	**SPOT5**			**77.1**	**236**		**4,807**
	Median	**SPOT5**			**66.3**	**181**		**4,255**
5644⁺	Unknown	ADB	10-Jul-15	26-Jul-15	15.4	186	175 / 11	1,570
5654⁺	Unknown	ADB	17-Jul-15	2-Aug-15	16.0	1,762	1,727 / 35	1,382
	Mean	**ADB**			**15.7**	**974**		**1,476**
	Median	**ADB**			**15.7**	**974**		**1,476**

KEY: ADB = Advanced Dive Behavior; km = kilometer(s); GPS = Global Positioning System; SPOT5 = Smart Positioning or Temperature Transmitting Tag, Version 5; # = number; * No transmissions were received for Tag #5790. This tag is not included in summary statistics; ⁺ Tag is Fastloc®, Version1.

Table 27. Percentage of filtered locations and time spent inside the SOCAL, PT MUGU, NWTT and W237 areas for fin whales tagged off southern California, 2015, with updated information for Tag #5742 (in italics). See Section 2.2.2 for location filtering method.

Tag #	Tag Type	Total		SOCAL			PT MUGU			NWTT			W237		
		# Locs	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days
832	SPOT5	23	28.8	26	18	5.1	74	87	25.1	0	0	0	0	0	0
839	SPOT5	269	78.0	3	5	3.6	20	16	12.8	24	31	23.9	0	0	0
5742	SPOT5	*752*	*252.4*	*8*	*9*	*23.2*	*8*	*9*	*23.1*	*3*	*6*	*14.1*	*1*	*2*	*5.1*
5743	SPOT5	53	28.2	0	0	0	75	79	22.3	0	0	0	0	0	0
5790*	SPOT5	0	0	-	-	-	-	-	-	-	-	-	-	-	-
5800	SPOT5	290	81.8	0	0	0	14	15	12.3	75	70	57.4	32	27	22.3
5923	SPOT5	92	54.6	20	26	14.1	71	65	35.7	0	0	0	0	0	0
10838	SPOT5	378	86.9	0	0	0	21	21	18.4	51	49	42.3	0	0	0
23032	SPOT5	29	6.2	0	0	0	90	88	5.4	0	0	0	0	0	0
5644[+]	ADB	186	15.4	0	0	0	58	48	7.3	0	0	0	0	0	0
5654[+]	ADB	1,762	16.0	0	0	0	76	69	11.0	0	0	0	0	0	0

KEY: ADB = Advanced Dive Behavior; Locs = Locations; SPOT5 = Smart Positioning or Temperature Transmitting Tag, Version 5; # = number; * No transmissions were received for Tag #5790. This tag is not included in summary statistics; +Summary statistics do not include zero values in their calculation. [+]Tag is Fastloc®, Version.1.

Table 28. Sizes of HRs and CAs of use in the U.S. EEZ calculated from state-space modeled (SSM) locations for five fin whales tagged off southern California, 2015, with updated information for Tag #5742 (in italics). Unknown sex whales are cases where no biopsy sample was collected.

		Fin Whales		
Tag #	# SSM Locations	Sex	HR Size (km^2)	CA Size (km^2)
839	77	Male	248,445	58,285
5742	*191*	*Male*	*128,154*	*12,118*
5800	79	Female	265,667	48,974
5923	52	Male	110,308	26,363
10838	87	Unknown	135,172	25,651
		Mean	**177,545.0**	**34,278.4**

Key: km^2 = square kilometer(s); # = number.
Note: The U.S. EEZ is located 370.4 km (200 nautical miles) from shore.

3.2.3 Tracking Analysis—Interannual Comparison

Tracking durations for non-ADB tagged fin whales were not significantly different between the three tagging years (ANOVA, P = 0.10), and the average tracking duration for all years combined was 55.9 d (SD = 54.0, median = 37.4 d, n = 24; **Table 29**). As with blue whales, there was no difference in tracking durations between LO and DM tags in 2016 (ANOVA, P = 0.53), so these two tag types were combined in analyses.

Table 29. Mean (and SE) tracking duration, total distance traveled, home range, and core area for fin whales tracked with LO and DM satellite tags off California in 2014, 2015, and 2016.

	2014			2015			2016		
	Mean	**SE**	**n**	**Mean**	**SE**	**n**	**Mean**	**SE**	**n**
Tracking Duration (d)	90.8	27.1	3	77.1	27.1	8	34.8	7.3	13
Total Distance (km)	1,911.9	1.2	3	2,239.8	1.1	8	1,466.5	1.1	13
Home Range (km^2)	64,515.5	8,634.9	3	177,545.0	32,821.7	5	34,025.0	11,832.8	5
Core Area (km^2)	11,580.0	642.6	3	34,278.4	8,427.5	5	10,278.2	4,670.9	5

KEY: d = days; km = kilometers; km^2 = square kilometers, n = sample size; SE = standard error.

After accounting for a positive relationship between tracking duration and distance traveled (linear regression using log-transformed variables, P < 0.0001), distance traveled by fin whales was found to be significantly different between 2015 and 2016 (general linear model of log-transformed variables, P = 0.02), with 2015 having the longest distances traveled, and 2016 having the shortest (**Table 29**). Distances traveled by fin whales in 2014 were of intermediate length and did not differ significantly from 2015 or 2016.

The latitudinal range, or the difference between the latitudes of the northern-most and southern-most locations for all fin whales in a given tagging year, was similar in 2015 and 2016 (22 degrees in 2015 and 20 degrees in 2016), and larger than in 2014 (12 degrees; **Figure 68**). Fin whales ranged as far north as Haida Gwaii off the coast of British Columbia in 2015 and 2016, and just south of Cape Blanco on the southern Oregon coast in 2014. Southern extents were similar in 2014 and 2015, approximately halfway down the coast of Baja California Norte, but only ranged as far south as west of San Nicolas Island, California, in 2016.

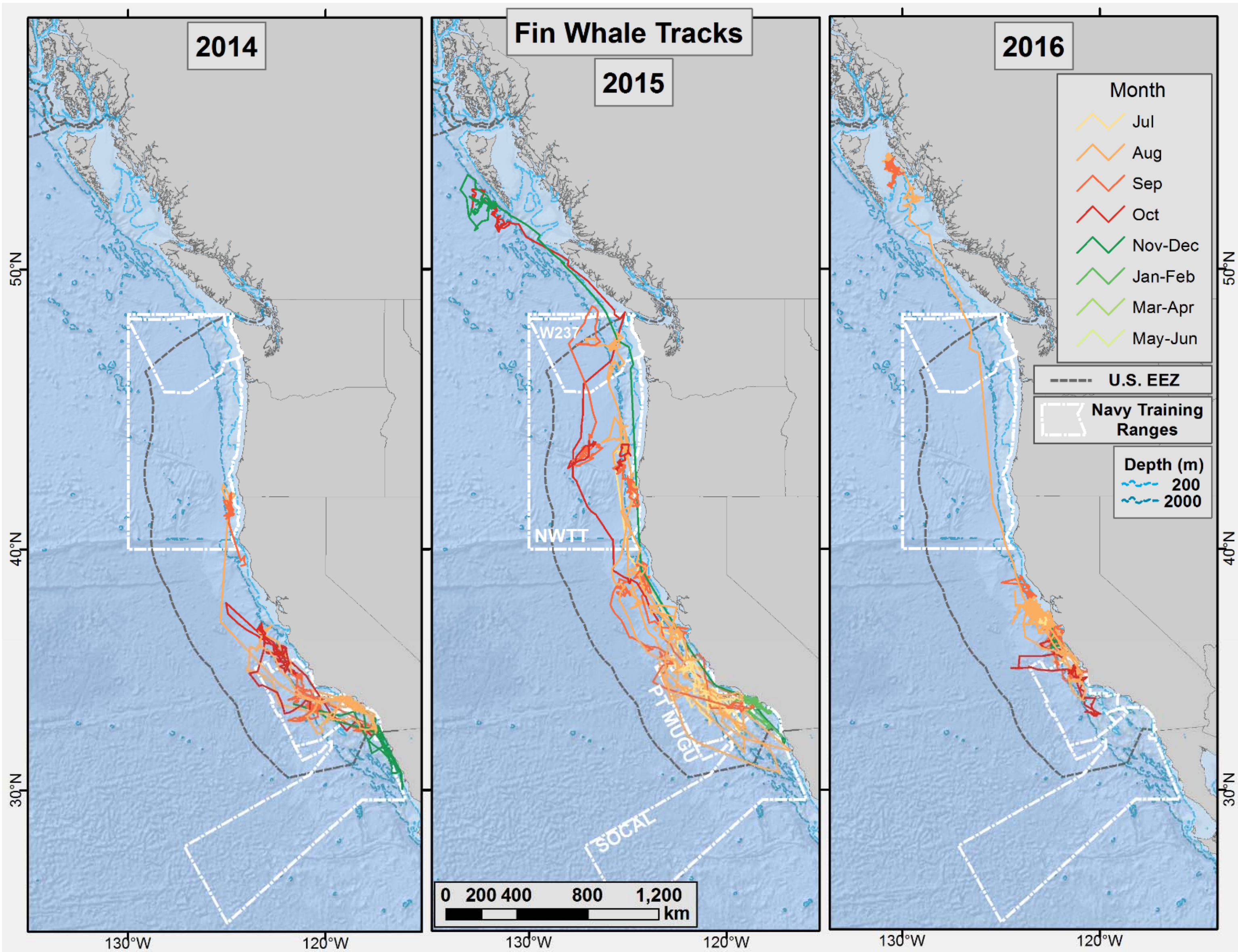

Figure 68. Satellite-monitored radio tracks for fin whales tagged off southern and central California during July and/or August, 2014 to 2016.

None of the fin whales tagged from 2014 to 2016 engaged in a typical baleen whale migration to a sub-tropical wintering ground. One of six fin whales tagged in 2014 traveled back and forth repeatedly between southern California and the west coast of Baja California Norte from late October to late December, and was last located off San Diego, California, on 24 December 2014. Three of 10 fin whales tagged in 2015 also traveled briefly to the west coast of Baja California Norte before coming back into southern California waters (two in August and one in December). None of the fin whales tagged in 2016 crossed south into Mexican waters.

PT MUGU was the most heavily used Navy training range for fin whales in all three tagging years (100 percent of all transmitting tags had locations there in both 2014 and 2015, and 23 percent had locations there in 2016; **Figure 69**). SOCAL was used by 67 percent of tracked fin whales in 2014 and by 40 percent in 2015, but no fin whale locations occurred there in 2016 (**Figure 70**). One fin whale in each of 2014 (17 percent of tracked whales) and 2016 (8 percent of tracked whales) had locations in the NWTT area, whereas four fin whales (40 percent of tracked whales) had locations in NWTT in 2015 (**Figure 71**). Two fin whales (20 percent) had locations within area W237 of the NWTT in 2015; one (8 percent) had locations in W237 in 2016; no fin whales occurred in W237 in 2014 (**Figure 72**).

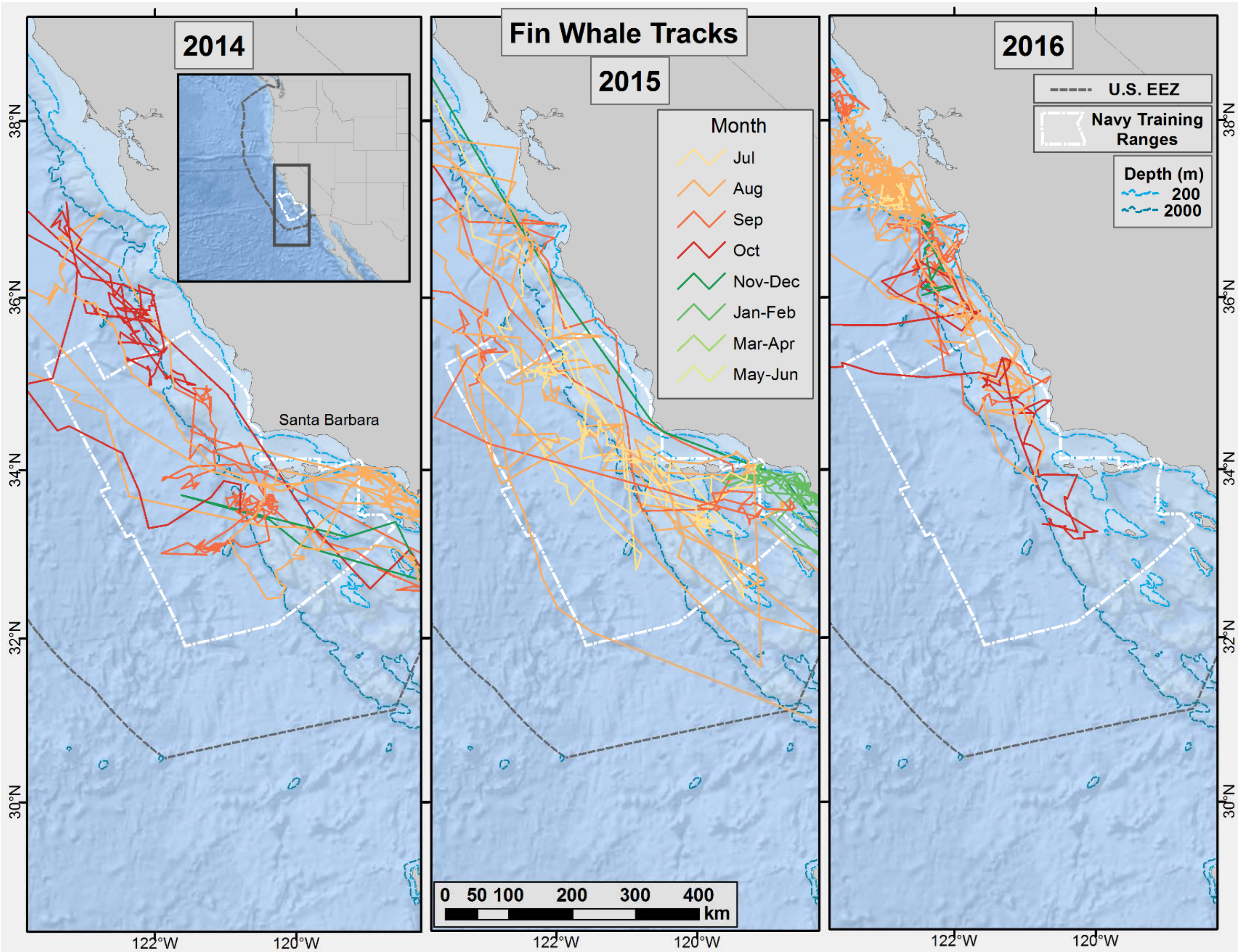

Figure 69. Satellite-monitored radio tracks of fin whales utilizing the PT MUGU range, by tagging year (2014–2016).

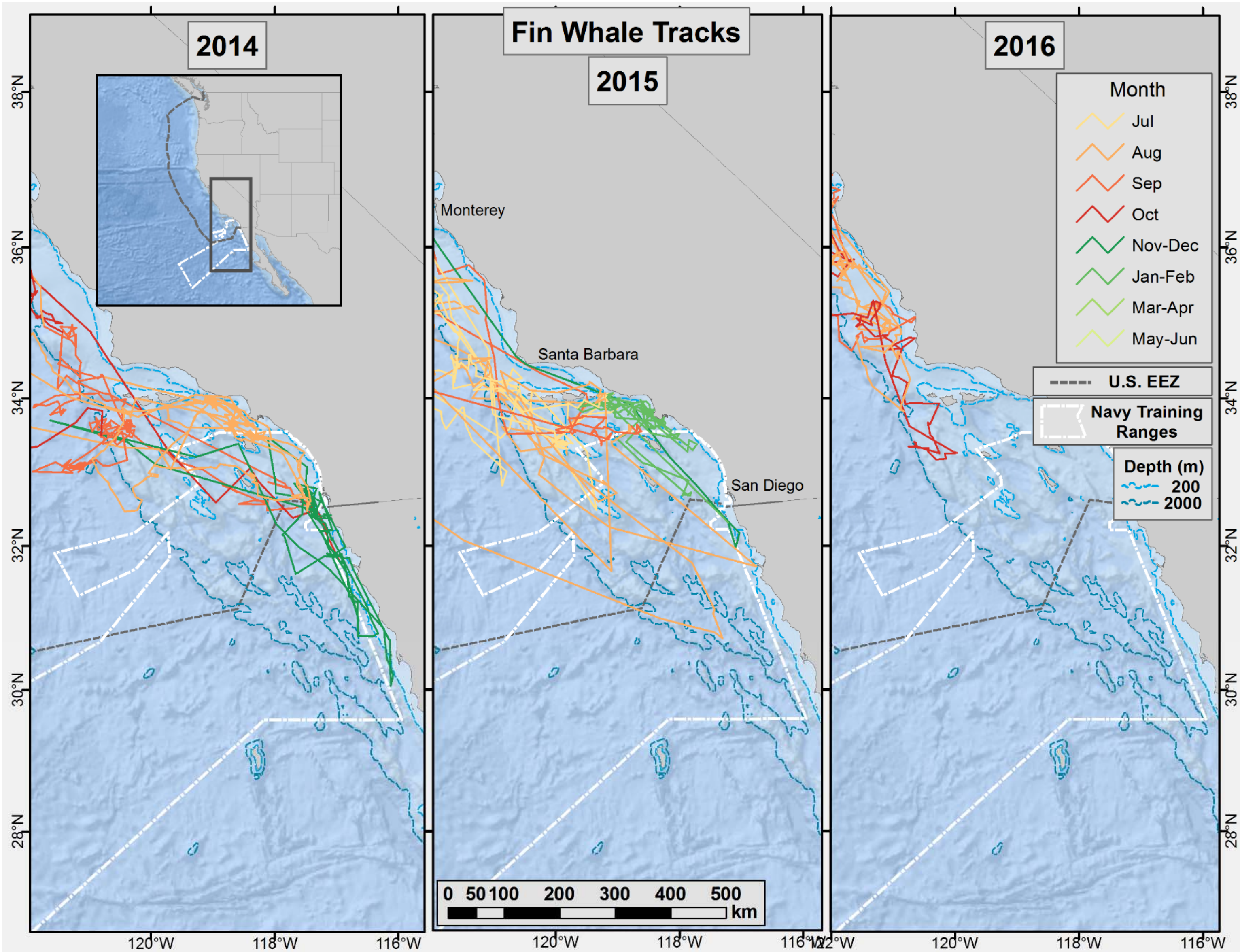

Figure 70. Satellite-monitored radio tracks of fin whales utilizing the SOCAL range, by tagging year (2014–2016). No fin whales tagged in 2016 were tracked in the SOCAL range.

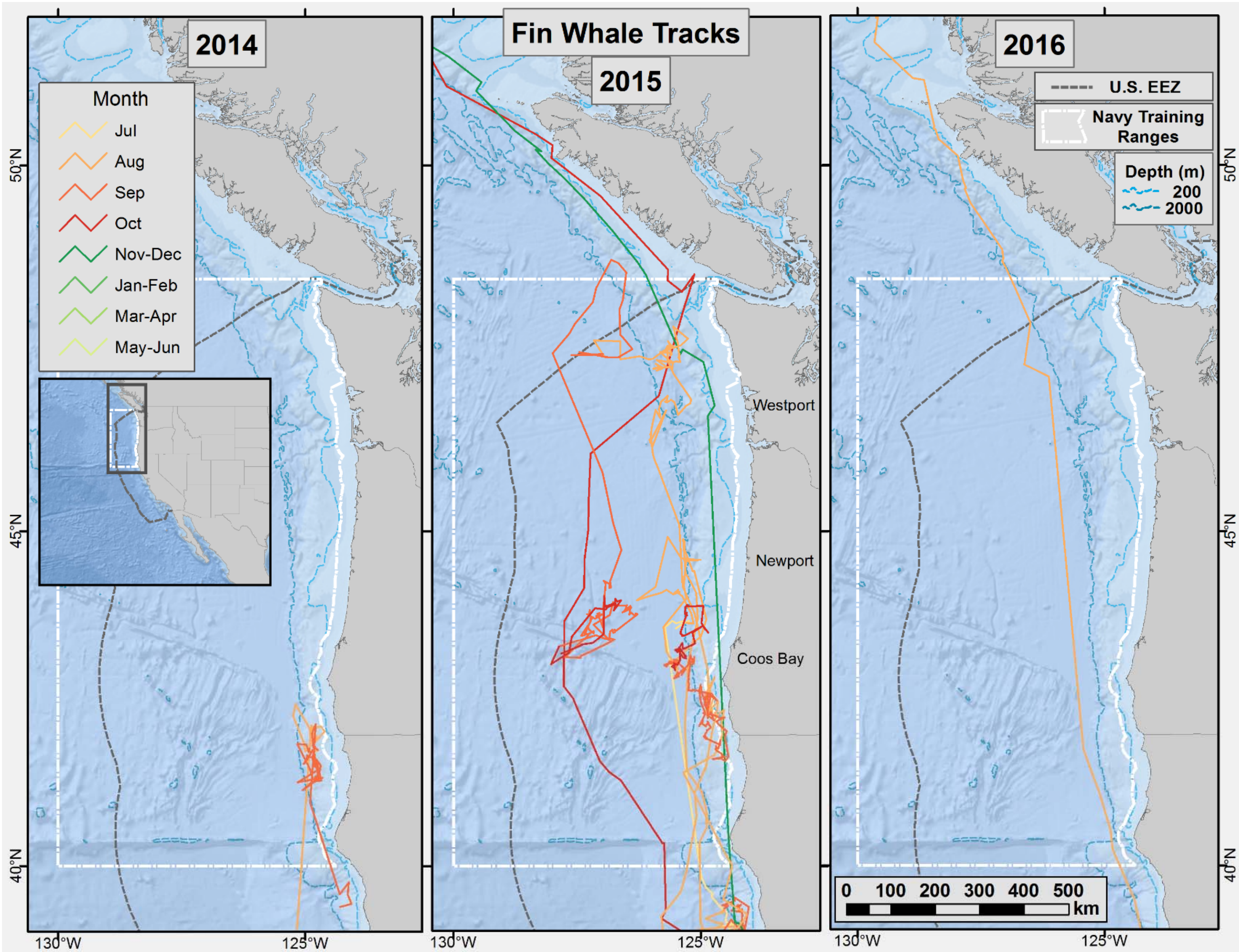

Figure 71. Satellite-monitored radio tracks of fin whales utilizing the NWTT range, by tagging year (2014–2016).

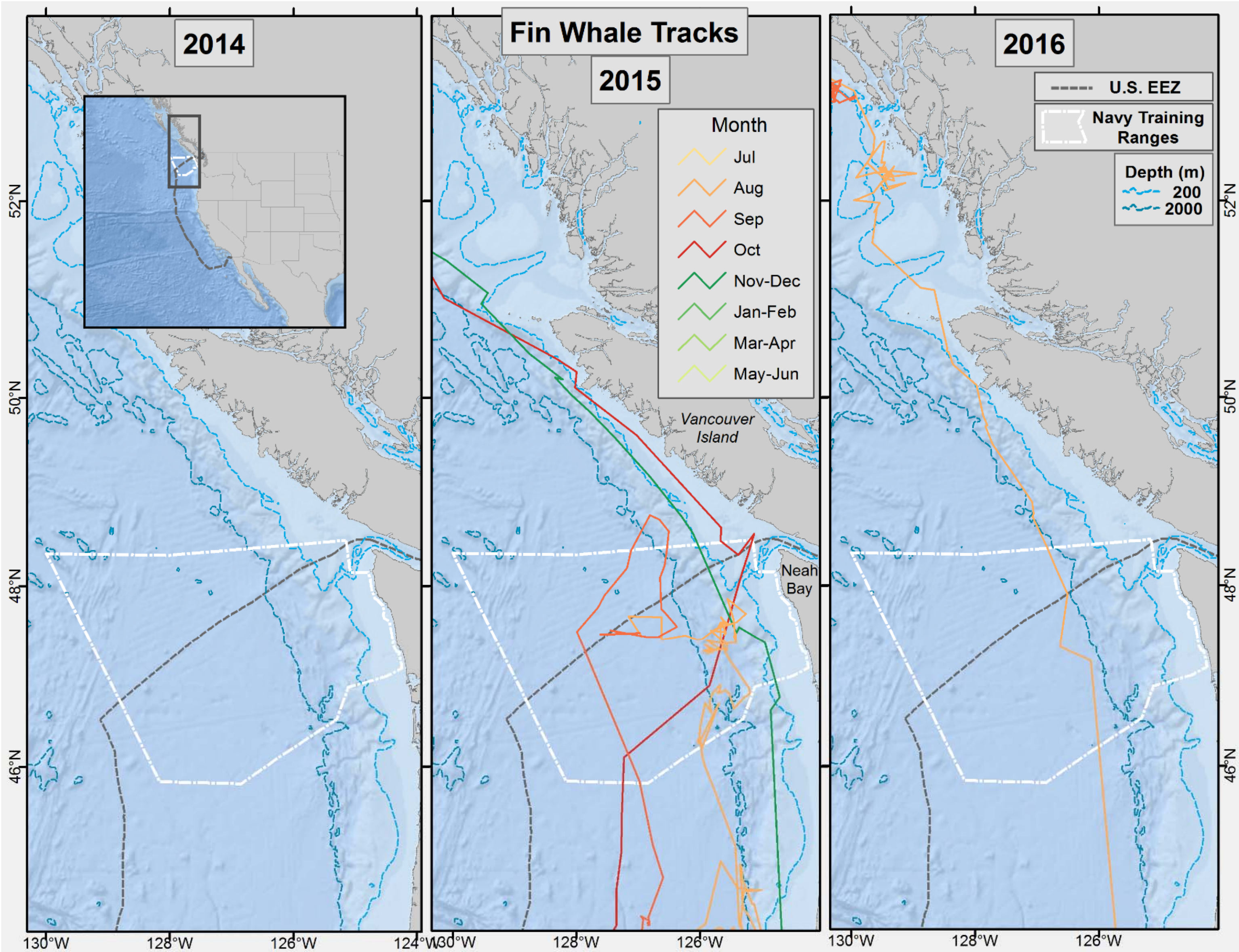

Figure 72. Satellite-monitored radio tracks of fin whales utilizing area W237 of the NWTT range, by tagging year (2014–2016). No fin whales tagged in 2014 were tracked in area W237.

For fin whales using PT MUGU, number of days spent in the range did not differ between the three tagging years (ANOVA, P = 0.998), with whales spending an overall average of 17.6 d there (SE = 3.6 d; **Table 30**). Number of days fin whales spent in SOCAL was not significantly different between 2014 and 2015 (ANOVA, P = 0.82), averaging 12.9 d (SE = 5.3 d) for both years combined. Mean number of days spent in the NWTT area ranged from 6.1 to 35.7 d for the three tagging years, but sample sizes were not large enough to test for differences between years (**Table 30**). The one fin whale that occurred in area W237 in 2016 spent 1.7 d there. In 2015, two fin whales spent 5.1 and 22.3 d, respectively, in area W237. Fin whales tagged in 2015 occurred in Navy training ranges in more months than those tagged in either 2014 or 2016. In 2015, fin whale locations occurred in SOCAL in 7 months (July, August, September, December, January, February, and March), in PT MUGU in 5 months (July, August, September, December, and January), in NWTT in 5 months (July, August, September, October, and December), and in W237 in 4 months (August, September, October, and December). Fin whale locations in training ranges occurred primarily in summer and fall months in the other tagging years. In 2014, fin whales occurred in SOCAL in 5 months (August through December), in PT MUGU in 4 months (August through November), and in NWTT in 2 months (August and September). In 2016, fin whales were located in PT MUGU in 3 months (August through October), and in NWTT and W237 in only 1 month (August). Mean distances to shore for tagged fin whales were not significantly different between the three tagging years in PT MUGU (ANOVA, P = 0.49) but were marginally different between 2014 and 2015 in SOCAL (ANOVA, P = 0.048; **Table 31**). Sample sizes in the other training ranges were insufficient for yearly comparisons in distance to shore.

HRs and CAs for fin whales were significantly different between 2015 and the other two years (ANOVA P values $\leq$ 0.03; **Table 28, Figures 73 and 74**), with mean sizes of HRs and CAs being much larger for whales tagged in 2015 than in either 2014 or 2016. Fin whale HRs covered the entire west coast of the contiguous U.S. in 2015. In contrast, HRs extended from the California/Mexico border to southern Oregon in 2014, and primarily along the central coast of California, from San Nicolas Island to Point Arena, in 2016. Multiple areas of highest use (where CAs overlapped for up to five whales) ranged from the southern California Bight to Coos Bay, Oregon in 2015. Areas of highest use were more concentrated in other years, occurring from southwest of San Miguel Island in southern California to Point Sur in central California in 2014 (two whales with overlapping CAs), and only off Half Moon Bay in central California in 2016 (five whales with overlapping CAs).

Table 30. Mean (and SE) number of days spent inside the SOCAL, MUGU, NWTT, and W237 areas for fin whales tagged off California in 2014, 2015, and 2016.

Year (# Whales Tracked)	# Days											
	SOCAL			MUGU			NWTT			W237		
	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
2014 (23)	14.2	10.4	4	17.8	9.2	6	35.7	-	1	-	-	0
2015 (22)	11.5	4.5	4	17.3	3.0	10	34.4	9.6	4	13.7	8.6	2
2016 (18)	-	-	0	17.9	13.4	3	6.1	-	1	1.7	-	1
All Years (63)	**12.9**	**5.3**	**8**	**17.6**	**3.6**	**19**	**29.9**	**7.7**	**6**	**9.7**	**6.4**	**3**

KEY: n = sample size; SE = standard error; # = number.

Table 31. Geodesic distances to nearest point on shore in Navy training ranges for fin whales tagged off southern and central California, 2014–2016 (including mean, median, and maximum distance to shore).

Tag #	SOCAL				PT MUGU				NWTT				W237			
	n	Mean	Median	Max	n	Mean	Median	Max	n	Mean	Median	Max	n	Mean	Median	Max
2014	4	18	18	28	6	62	64	96	1	56	56	56	0	-	-	-
2015	4	61	59	102	10	67	62	122	4	119	125	168	2	107	107	122
2016	0	-	-	-	3	94	52	181	1	108	108	108	1	140	140	140
Mean		**39.5**	**38.5**	**65.0**		**74.3**	**59.3**	**133.0**		**94.3**	**96.3**	**110.7**		**123.5**	**123.5**	**131.0**
Median		**39.5**	**38.5**	**65.0**		**67.0**	**62.0**	**122.0**		**108.0**	**108.0**	**108.0**		**123.5**	**123.5**	**131.0**

KEY: n = number of whales having locations in that particular training range.

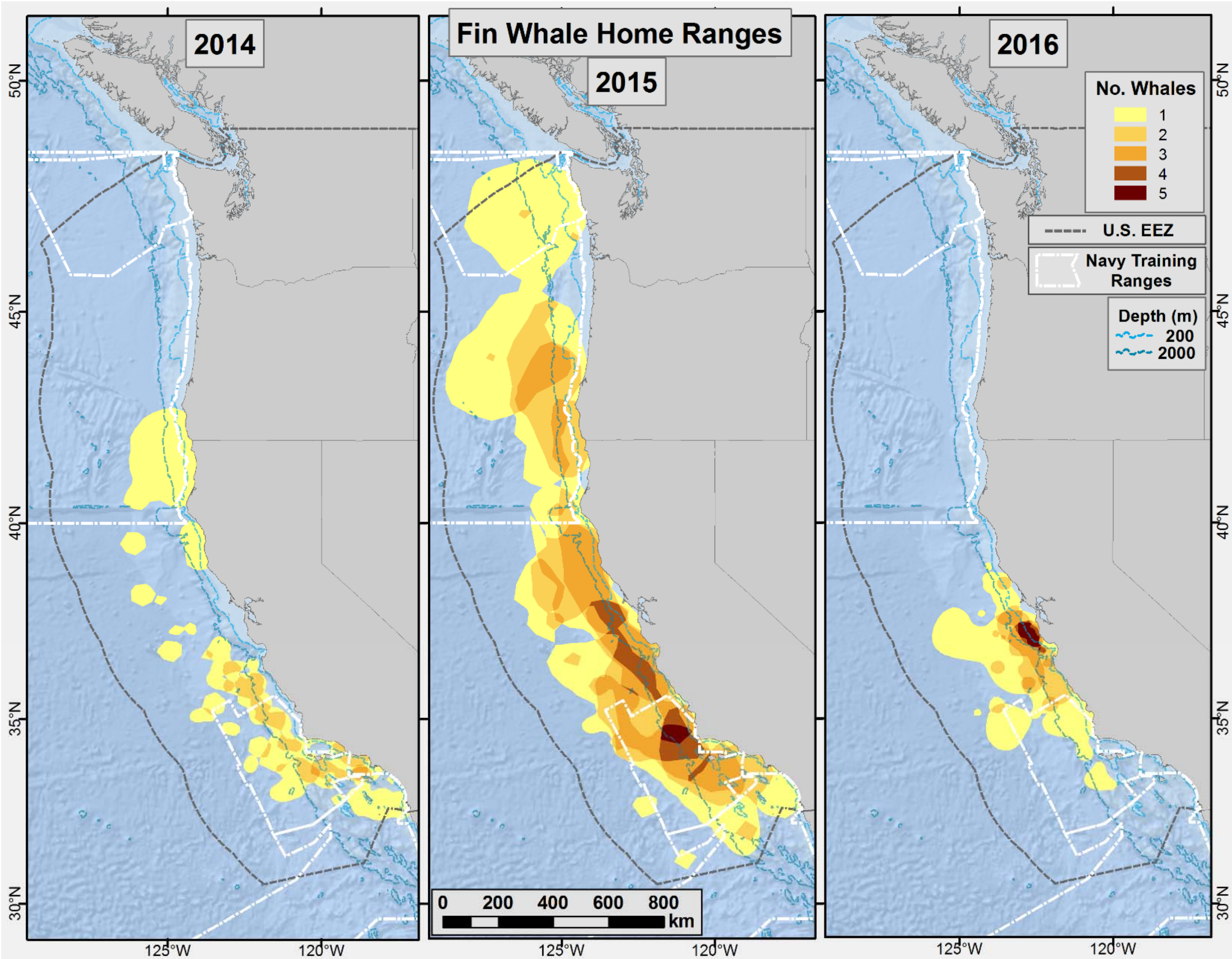

Figure 73. HRs in the U.S. EEZ for fin whales tagged off southern California in 2014 (3 whales), off southern California in 2015 (5 whales), and off central California in 2016 (5 whales). Shading represents the number of individual whales with overlapping HRs.

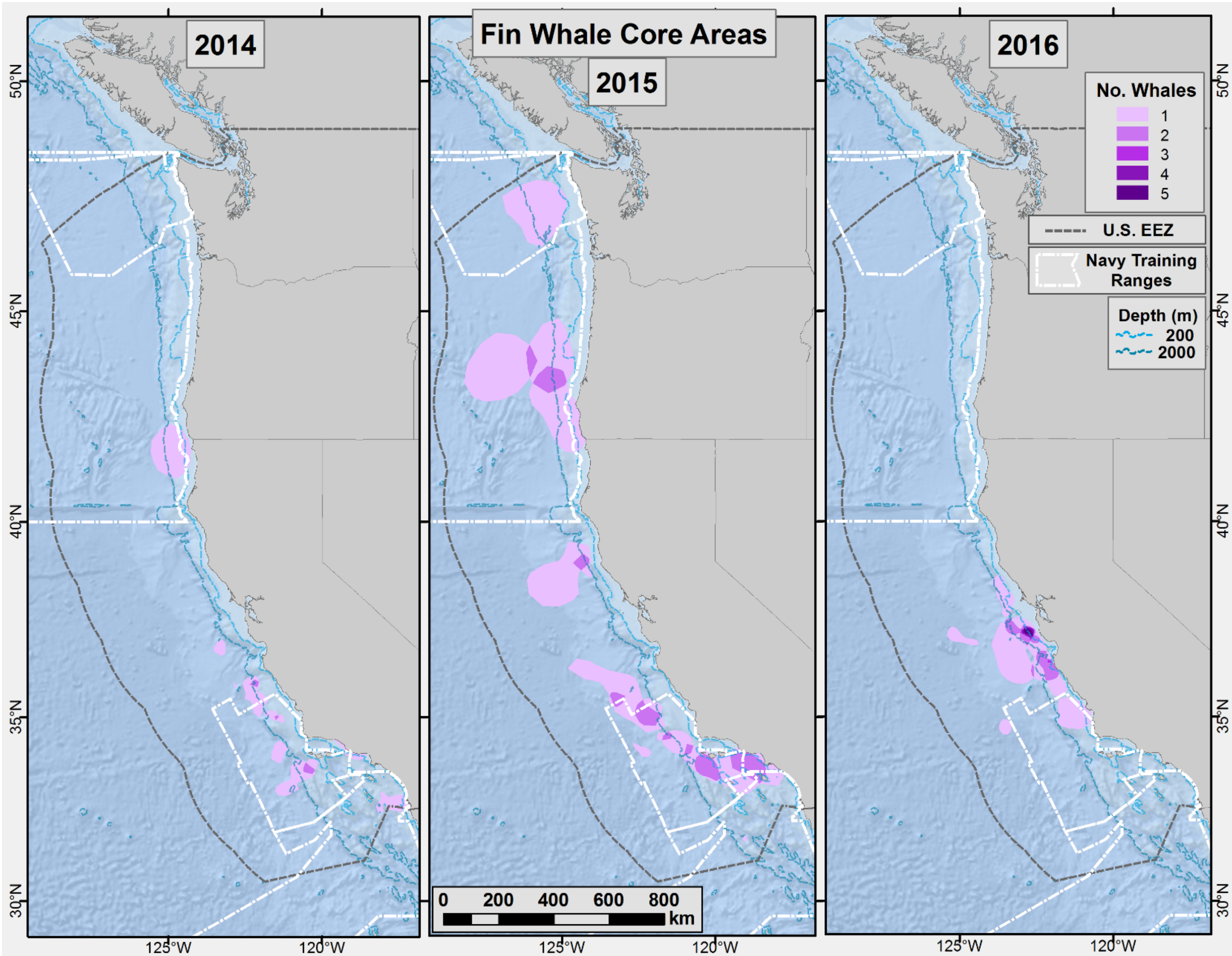

Figure 74. CAs of use in the U.S. EEZ for fin whales tagged off southern California in 2014 (three whales), off southern California in 2015 (5 whales), and off central California in 2016 (5 whales). Shading represents the number of individual whales with overlapping CAs.

3.2.4 ADB Tag Analysis

Five fin whales were tagged with ADB tags in the summers of 2014 and 2015 (**Table 32**); three tags were deployed in 2014 near Pt. Mugu, California, and two tags were deployed off the west end of San Miguel Island, California, in 2015. Tracking duration lasted a median of 13.3 d in 2014 and 15.7 d in 2015, with only one of the five tags (Tag #2015_5654) remaining attached to the whale until its programmed release date (**Table 32**). The other four tags were shed prior to their scheduled release date and sank to the bottom while attached to the deployment housing. Two tags released from their housings after triggering a programmed premature release after detecting they had been on the bottom for more than 24 h. One was subsequently recovered (Tag #2014_5685) but the other (Tag #2014_5790) was lost when its batteries were exhausted during bad weather that prevented a recovery effort. One tag (Tag #2015_5644) surfaced after spending 51 d on the bottom but drifted too far offshore for recovery and was lost. The last tag (Tag #2014_5838) was thought to be lost because it never surfaced or transmitted again, but it was found on a beach near San Diego, California, in mid-May 2016 and returned to OSU.

Table 32. Deployment summary for ADB tags attached to fin whales in southern California during summer 2014–2015. Unknown sex whales are cases where no biopsy sample was collected.

Species	Tag #	Sex	Recovered?	# Days Tracked	# of Dives	# GPS locations	Mean Dives/ Day	Mean GPS Locs/ Day	Total Distance (km)
2014									
Fin whale	5685	Male	Yes	14.2	1188	95	84	6	1,037
Fin whale	5790	Female	No*	13.3	279	14	N/A	N/A	426
Fin whale	5838	Female	Yes	4.9	1030	228	210	46	133
			Median	**13.3**	**1030**	**95**			
2015									
Fin whale	5644	Unknown	No*	15.4	406	12	N/A	N/A	1,517
Fin whale	5654	Unknown	Yes	16.0	1695	1,591	106	99	1,370
			Median	**15.7**					

KEY: *Data were transmitted through Service Argos, Inc.

In 2014, the whales carrying the two longest-lasting ADB tags used different portions of southern California waters (**Figure 75**). One whale (Tag #2014_5685) travelled in a long clockwise loop encircling most of the southern California waters and rarely stopping for any length of time. The other whale (Tag #2014_5790) was more coastally oriented, spending time between Catalina Island and Dana Point before travelling south off San Diego and eventually leaving southern California waters, travelling north when the tag was shed. The last tagged whale (Tag #2014_5838) generally stayed in an area southwest of the tagging area between Catalina Island and Dana Point. In 2015, after some initial movements near the tagging area, both tagged whales traveled north, generally staying offshore from the continental slope (>30 km from shore), until the tags released or were shed off San Francisco, California, and south of Cape Mendocino, California (**Figure 76**). In all, three of the five tagged fin whales left southern California waters during the tracking period.

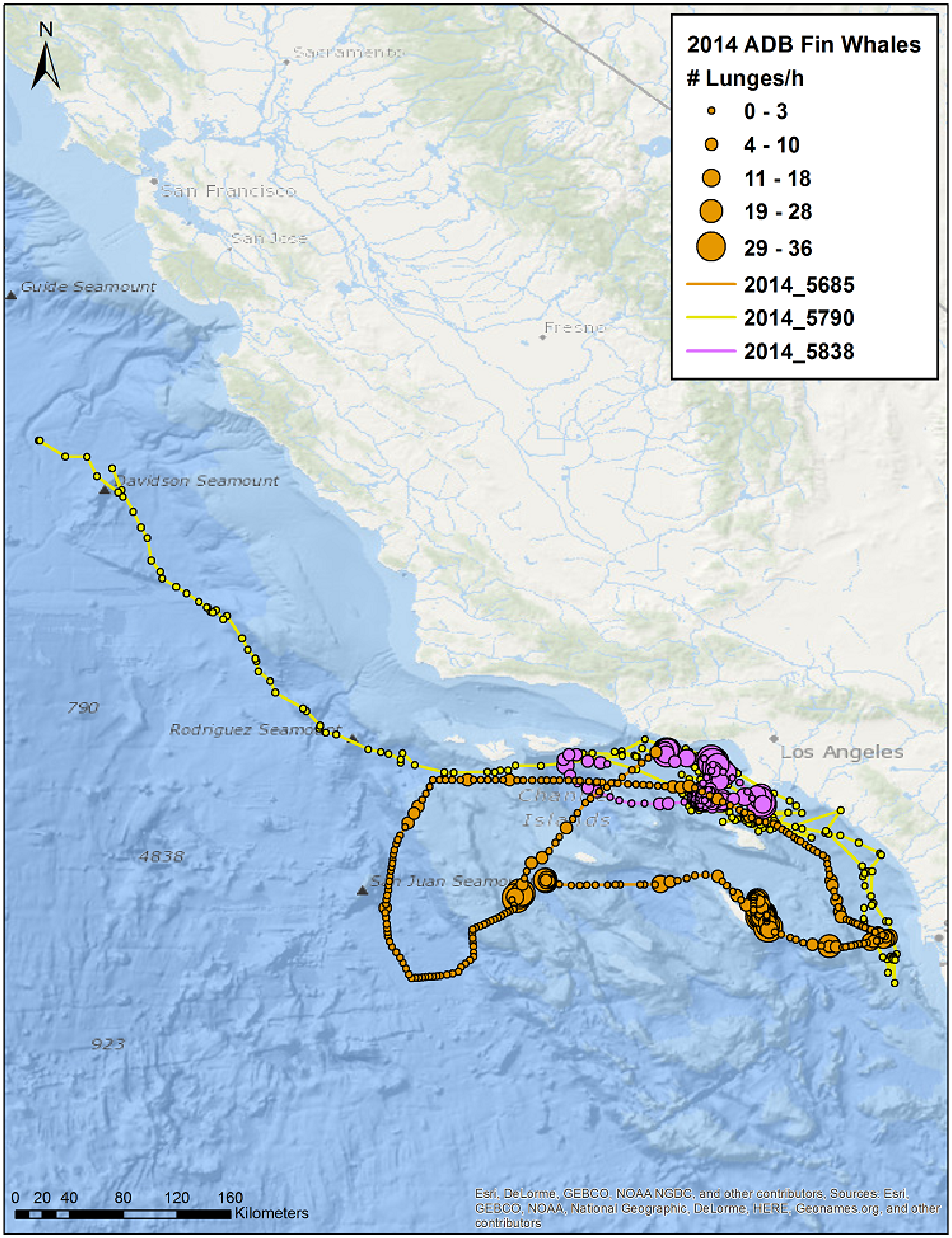

Figure 75. Tracks of three ADB-tagged fin whales off southern California in August 2014. Size of the circles represents the number of feeding lunges recorded by a tag per hour. The circle is centered on the portion of track that was summarized. Tag #2014_5790 was not recovered. Therefore, no feeding data are available, but locations received through Argos are shown.

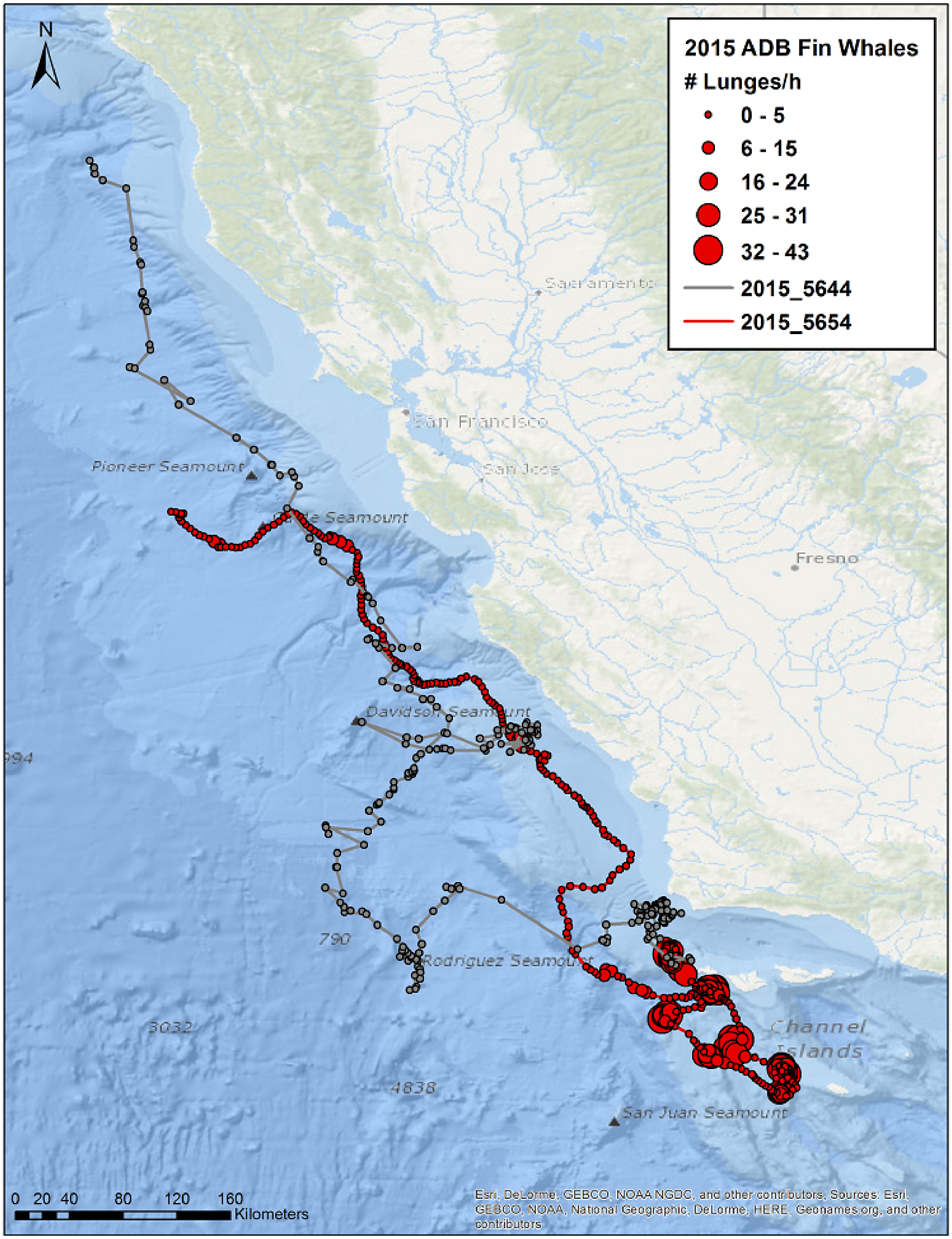

Figure 76. Tracks of two ADB-tagged fin whales off southern California in July 2015. Size of the circles represents the number of feeding lunges recorded by a tag per hour. The circle is centered on the portion of track that was summarized. Tag #2015_5644 was not recovered. No feeding data are available, but locations received through Argos are shown.

The three recovered tags recorded a median of 1,188 dives (range = 1,030–1,695; **Table 30**), and 228 Fastloc® GPS locations (range = 95–1,591) in the onboard archive. Feeding lunges were detected in the data record of each tag, although they were mostly concentrated early in the record. The two non-recovered tags transmitted dive summary information for 279 and 406 dives and 14 and12 GPS locations, respectively, via Argos (**Table 32**).

A diel pattern in maximum dive depths was recorded by the tags in both years, with deeper dives occurring during the daytime than at night (**Figures 77 and 78**). Dive durations were highly variable for all ADB-tagged fin whales, but none showed a diel trend to match the maximum dive depths. In 2014, most feeding activity occurred near the southeastern side of San Clemente Island and southwest of San Nicolas Island (**Figure 75**), with the majority of feeding in the 2015 track occurring in an area extending from the tagging area down almost to San Nicolas Island (**Figure 76**).

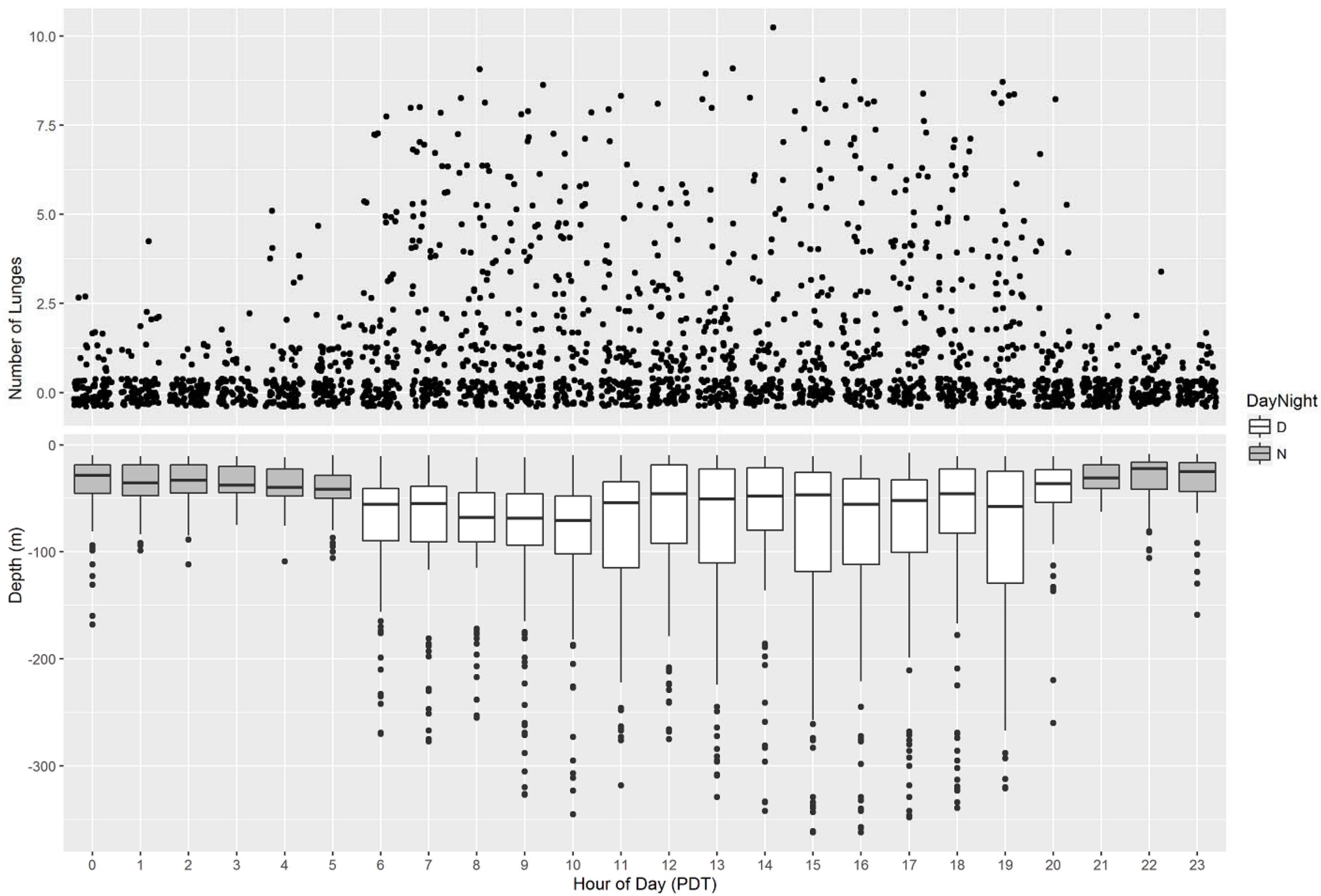

Figure 77. Number of lunges per dive (upper panel) and maximum dive depth (lower panel) of ADB-tagged fin whales tracked off southern California during August 2014 (n = 2).Data are presented by hour of day to better visualize diel variability and the data in the top panel are jittered to avoid overplotting.

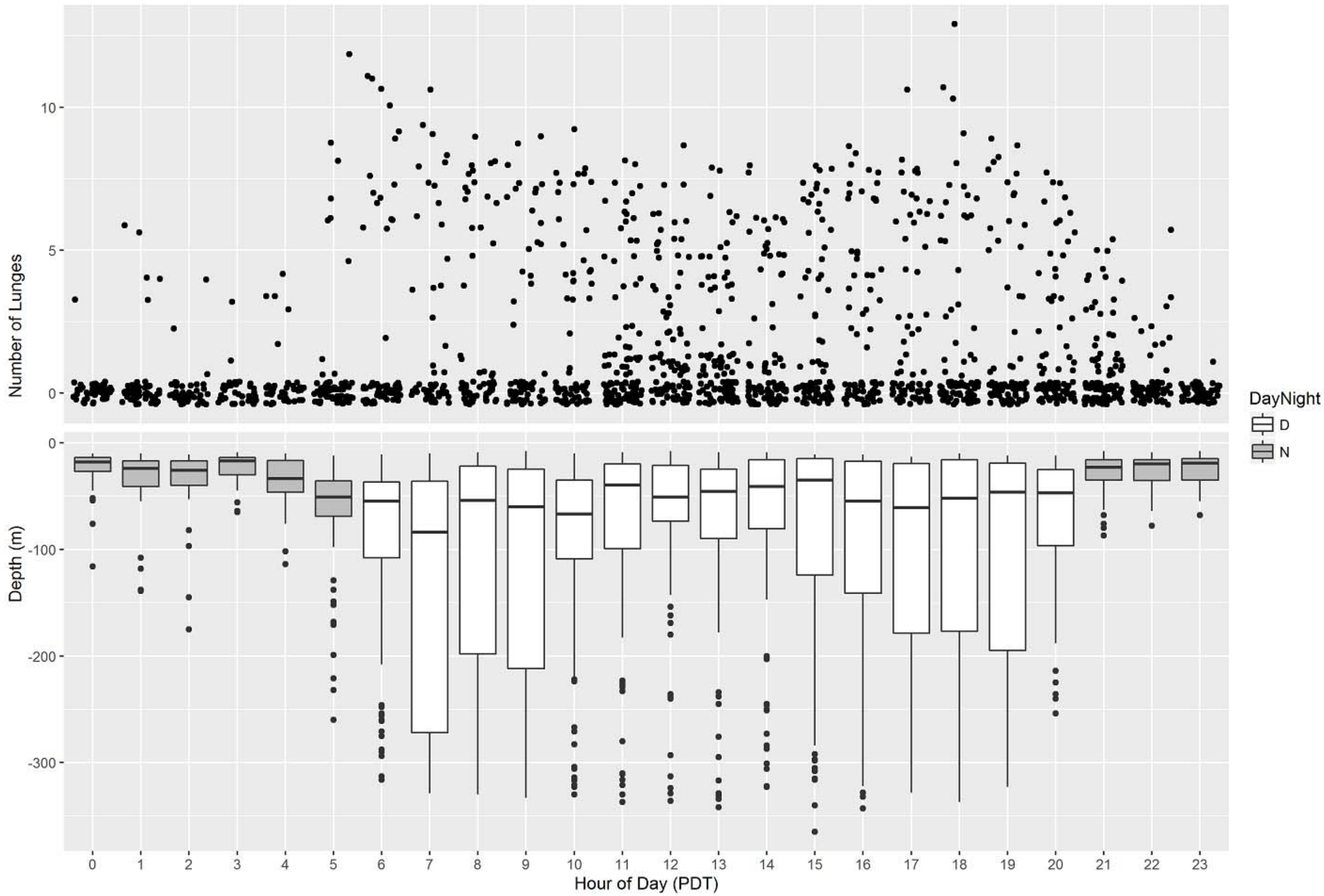

Figure 78. Number of lunges per dive (upper panel) and maximum dive depth (lower panel) of an ADB-tagged fin whale tracked off southern California during July 2015 (n = 1). Data are presented by hour of day to better visualize diel variability and the data in the top panel are jittered to avoid overplotting.

A total of 59 feeding bouts was identified from the fin whale ADB data (**Table 33**). The number of bouts made per whale ranged from 13 to 25. The median bout consisted of 19 dives over 2.7 h (range = 4–142 dives and 0.3–19.6 h respectively). Bouts were temporally distinct with a median of 3.1 h between bouts (range = 1.0–61 h) and a median size of 4.1 km^2 (range = 0.002–317.1 km^2). The median duration of feeding bouts recorded by the recovered data archives were longer for Tag #2015_5654 compared to the 2014 tags while also containing deeper dives with a higher proportion of feeding versus non-feeding dives per bout (**Table 33**). The distribution of feeding bout duration was bimodal, with a strong peak near 2 h and a secondary peak at close to 15 h (**Figure 79**). The average number of feeding lunges per dive increased with increasing duration of a feeding bout ($p < 0.001$, $R^2 = 0.43$, linear regression, **Figure 80**).

Table 33. Summary of dives occurring during feeding bouts made by three ADB-tagged fin whales tagged off southern California in August 2014 and July 2015. Feeding bouts are sequences of dives with no more than 60 minutes between dives with feeding lunges. Unknown sex whales are cases where no biopsy sample was collected.

Tag #	Sex	Year		Bout Duration (h)	# Dives	Mean Max Dive Depth (m)	Mean Dive Duration (minutes)	Mean Lunges per Dive	Dives With No Lunges	Tortuosity	Area of Bout (km^2)	Time to Next Bout (h)	Dist to Next Bout (km)
2014_5685	Male	2014	Median	2.5	12	63.0	9.2	0.9	5.0	1.0	1.95	3.1	12.7
# Bouts = 25			Min	0.8	4	18.8	2.7	0.4	0.0	0.5	0.00	1.1	2.1
			Max	14.6	88	174.7	15.9	3.0	16.0	1.0	193.55	61.2	81.1
2014_5838	Female	2014	Median	1.9	19	59.3	4.7	0.4	16.0	0.7	3.35	2.2	1.3
# Bouts = 13			Min	0.3	6	17.2	1.4	0.2	3.0	0.1	0.00	1.0	0.0
			Max	19.6	142	167.2	7.6	2.8	78.0	1.0	317.05	10.1	18.9
2015_5654	Unknown	2015	Median	3.4	22	98.7	8.6	3.3	2.0	0.6	7.64	7.5	10.2
# Bouts = 21			Min	0.7	4	28.4	1.7	0.4	0.0	0.1	0.22	1.1	0.0
			Max	15.7	119	247.5	11.7	5.2	55.0	1.0	132.33	47.8	111.4

KEY: dist = distance; h = hour(s); km = kilometer(s); km^2 = square kilometer(s); Locs = locations; m = meter(s); max = maximum; min = minimum; # = number

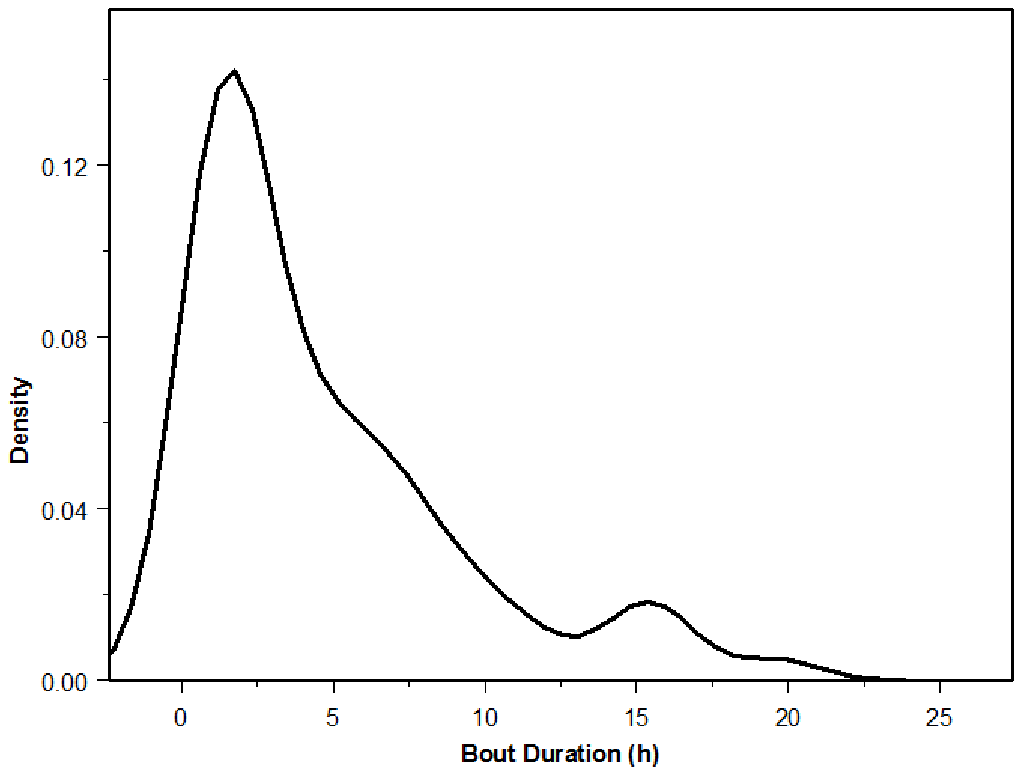

Figure 79. Density plot of feeding bout duration for ADB-tagged fin whales in 2014–2015.

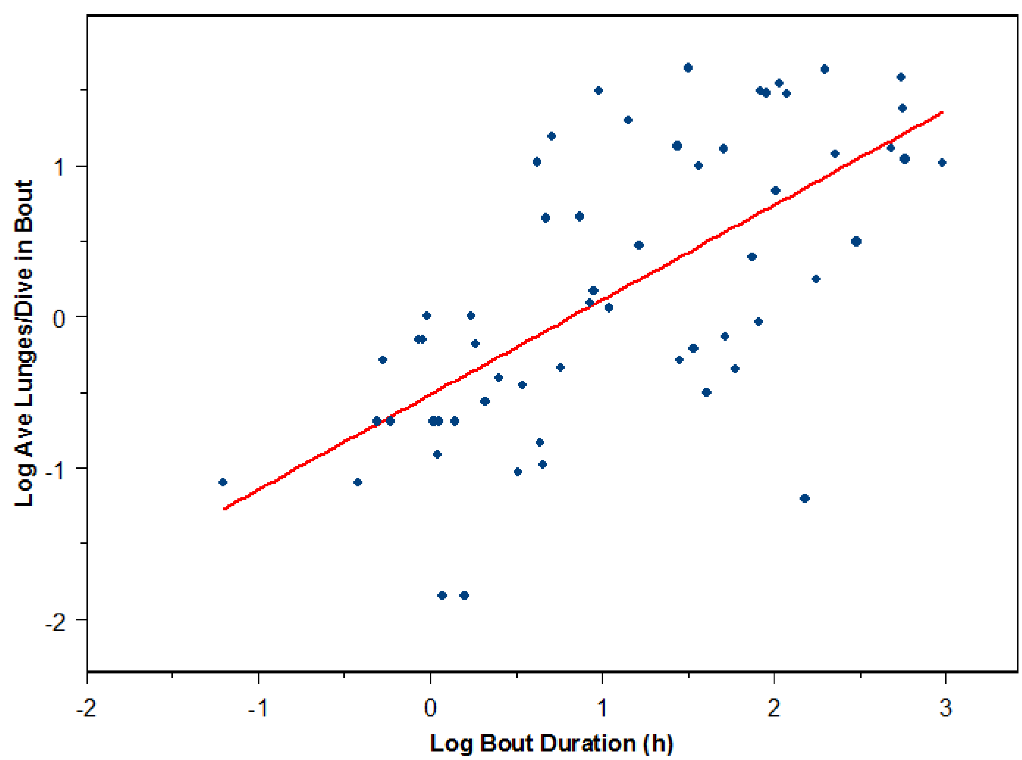

Figure 80. A comparison of the average number of feeding lunges made per dive within a feeding bout to the duration of that bout. Red line is a linear fit through the data. Data are from fin whales tracked with ADB tags off southern California during the summer of 2014 and 2015.

3.2.5 DM Tag Analysis

DM tags were deployed on nine fin whales off central California from late July to early August 2016. No transmissions were received from one tag. Median tracking duration of the rest was 28.7 d (range = 1.3–104.3 d; **Table 34**), and the tags provided a median of 1,670 dive summaries (range = 8–3,964) and 125 Argos locations (range = 7–374). Tagged whales generally occupied the waters over the continental slope from Monterey Bay to Point Arena with the exception of one whale (Tag #23030) which travelled north to an area east of Haida Gwaii, British Columbia, in the Hecate Strait and remained there for 39 d until its tag stopped transmitting.

Table 34. Summary statistics of DM tags deployed on fin whales off central California in July 2016.

Tag #	Sex	Tag type	Deployment Date	# Days Tracked	Mean Locs per Day	Distance (km)	# Dives Transmitted	Filtered Locs
831*	Unknown	DM	29-Jul-16	0	-	-	-	-
5655	Unknown	DM	28-Jul-16	104.30	3.6	5,805	2,164	374
5700	Female	DM	29-Jul-16	58.9	4.6	2,729	3,790	272
5726	Male	DM	29-Jul-16	31.2	3.7	1,385	1,601	114
5743	Female	DM	30-Jul-16	24.1	5.6	1,238	1,738	135
10829	Female	DM	29-Jul-16	26.2	2.4	951	766	62
10839	Unknown	DM	28-Jul-16	7.1	4.9	229	182	35
23030	Male	DM	28-Jul-16	55.8	6.4	4,427	3,964	359
23035	Unknown	DM	3-Aug-16	1.3	5.3	45	8	7
			Sum	**317.5**		**15,981.1**	**1,4213**	**1,298**
			Median	**28.7**	**4.8**	**1,311**	**1,670**	**125**

KEY: DM = Telonics RDW-665 Dive-Monitoring tag; km = kilometer(s); Locs = Locations; # = number; * No transmissions were received for Tag# 831. This tag is not included in summary statistics.

Dive depths reported by all tags showed a diel trend with fewer lunges and shallower dives occurring at night (mean = 2.6 lunges versus 4.6 lunges and mean = 33 m depth versus 87 m depth; **Figure 81**) although there were not always large differences. Daytime dive depths were highly variable within and across individuals with the majority of dives limited to 150 m or less in depth. Spatial distribution of dive depths was relatively consistent across the study area with slightly shallower average maximum dive depths occurring off Monterey Bay, California (**Figure 82)**. Feeding effort was also relatively consistent across the study area with the most effort occurring from Monterey Bay to Point Arena and in the Hecate Strait east of Haida Gwaii, Canada (**Figure 83**). Fin whale tracks overlapped the most near the tagging area, however at least 2–3 individuals occupied much of the study area (**Figure 83 right panel**).

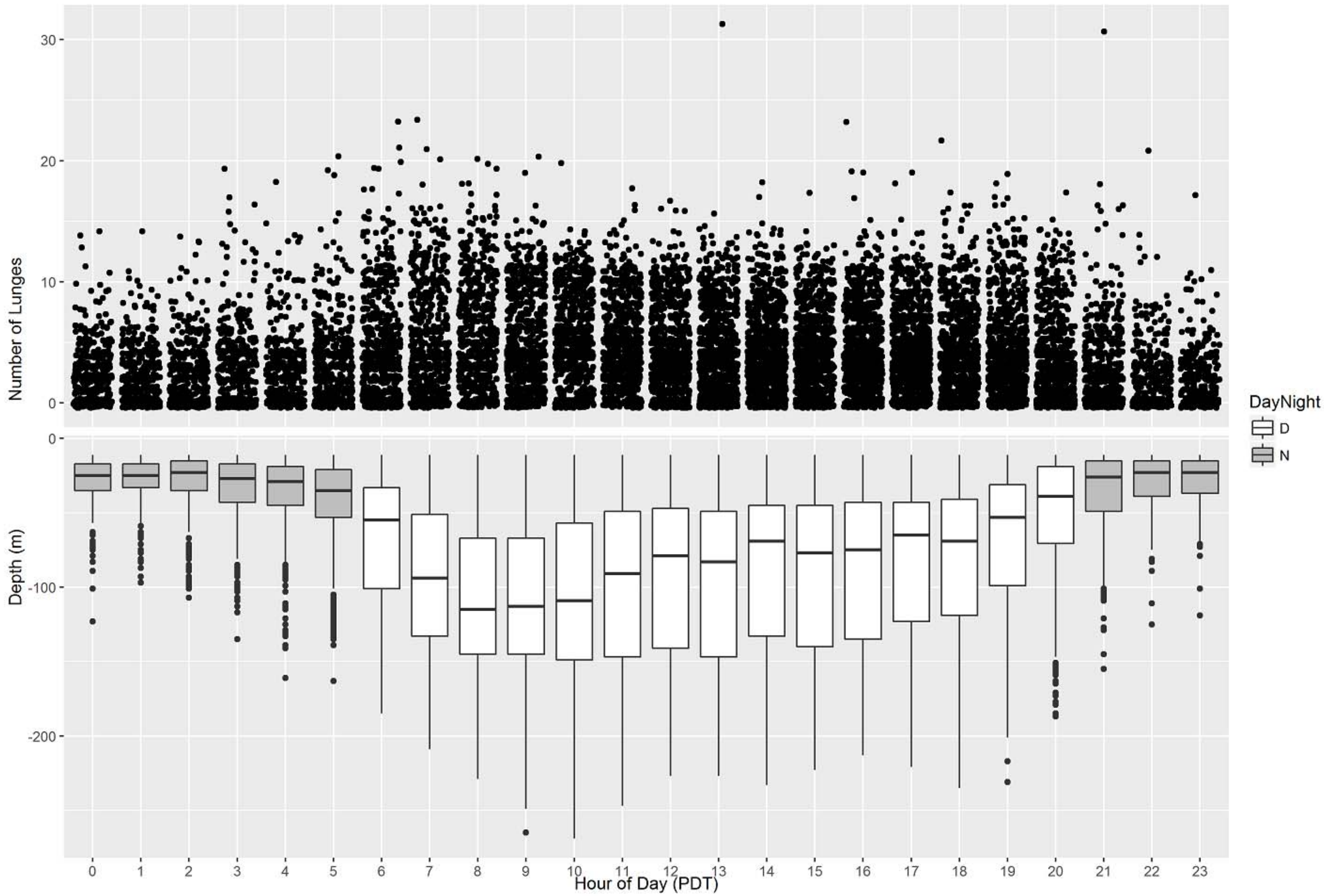

Figure 81. Number of lunges per dive (upper panel) and maximum dive depth (lower panel) of DM-tagged fin whales tracked off central California during July–August 2016. Data are presented by hour of day to better visualize diel variability and the data in the top panel are jittered to avoid overplotting.

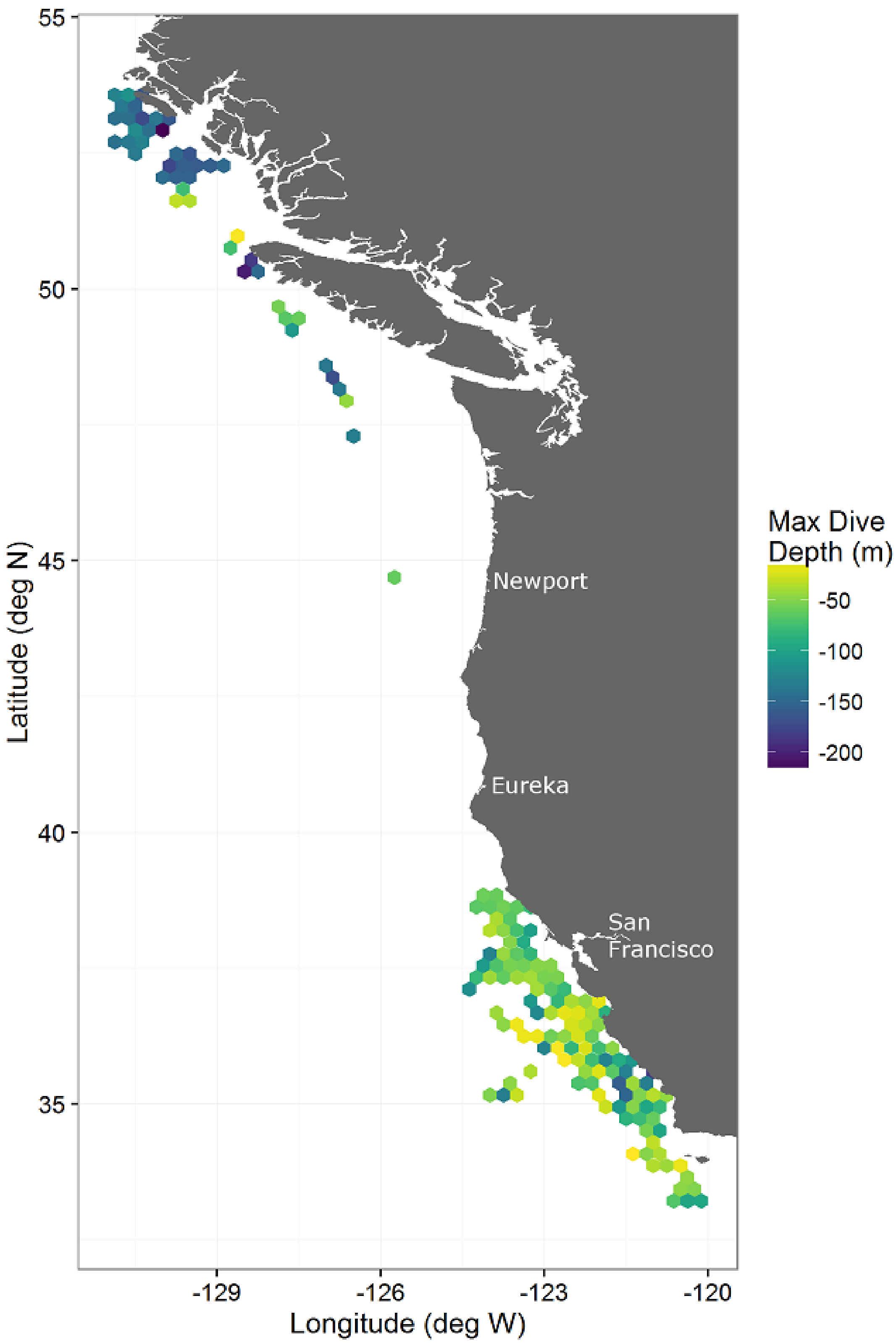

Figure 82. A 0.25-degree hexagonal grid showing the average daytime maximum dive depth reported by DM-tagged fin whales tagged in August 2016.

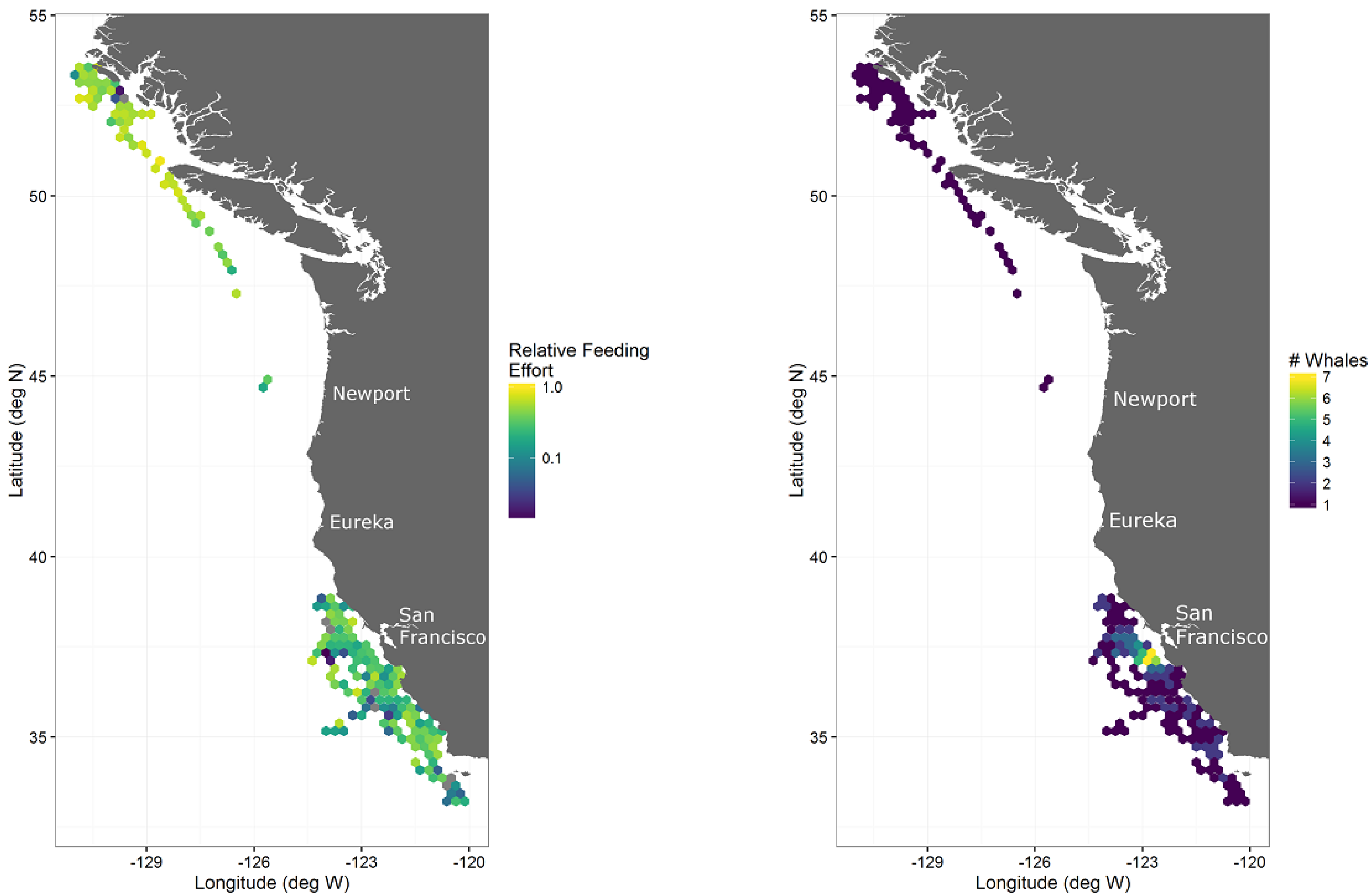

Figure 83. Left panel: A 0.25-degree hexagonal grid showing the average relative feeding effort (lunges/h) reported by DM-tagged fin whales tagged in August 2016. Right panel: The number of whales occupying each grid cell.

3.2.6 Body Condition Assessment and Tagging Rates

In 2016, fourteen fin whales were tagged during approaches to 160 whales (9 percent; **Table 14**). Two percent of fin whales approached were in poor body condition and were not considered candidates for tagging (**Table 14**). No fin whales approached in 2014 and 2015 were in poor body condition (**Table 14**).

3.2.7 Behavioral Responses to Tagging

Only one of the 14 tagged fin whales responded to the tagging/biopsy process, giving a moderate tail flick and diving upon tagging.

3.2.8 Wound Healing

Only one fin whale tagged in 2016 (Tag #5719) was seen again during our field efforts, 1 d after tagging. No signs of swelling were present. No fin whales tagged in the two previous seasons (2014 and 2015) were resighted in 2016.

3.2.9 Photo-ID

A total of 2,849 photos of fin whales was taken during the 2016 cruise, resulting in IDs for 42 individuals. Two fin whales identified in previous seasons (37 IDs in 2014 and 34 IDs in 2015) were resighted in 2016, which resulted in a 2.8 percent resight rate. Photo-IDs were obtained of all 14 tagged fin whales. Eight IDs included both left- and right-side photographs, five had right-side photos only, and one had only a left-side photo.

3.2.10 Ecological Relationships—2016

The SSMs generated regularized daily locations for 12 fin whale tags in 2016, resulting in 458 estimated locations, of which 11 occurred on land and 54 had unacceptable estimation uncertainty (**Table 35**). The geographic extent of these tracks covered approximately 11 degrees of longitude (130.9–120°W) and 20 degrees of latitude (33.2–53.5°N) (**Figure 84**). The majority of the 393 accepted locations occurred in CCAL (89.8 percent), followed by ALSK (10.2 percent). The GUCA, NPPF, NPTG, PNEC and PQED provinces were not occupied by fin whales in 2016 (**Table 35 and Figure 84**).

Table 35. Number of accepted SSM locations (and percentage) inside each province for fin whales in each year. Also provided are the number of locations that fell on land and the number of locations excluded from the analyses because their high estimation uncertainty. Unclassified locations correspond to the end-of-track locations, which do not receive a behavioral mode classification by the SSM. This number can be lower than the number of tracks because of the exclusion of locations on land and those with high estimation uncertainty. The number of SSM tracks is indicated (n).

	2014 (n = 5)	**2015 (n = 10)**	**2016 (n = 12)**
Longitudinal range	9.7 degrees (125.8–116.1°W)	16.1 degrees (133.1–117.0°W)	10.9 degrees (130.9–120°W)
Latitudinal range	12.2 degrees (30.1–42.3°N)	21.8 degrees (30.8–52.6°N)	20 degrees (33.2–53.5°N)
Province			
ALSK	NA	51 (10.3%)	40 (10.2%)
CCAL	261 (100%)	446 (89.7%)	353 (89.8%)
GUCA	NA	NA	NA
NPPF	NA	NA	NA
NPTG	NA	NA	NA
PNEC	NA	NA	NA
PQED	NA	NA	NA
Accepted locs.	261 (100%)	497 (100%)	393 (100%)
Unclassified locs.	5	7	10
Excluded locs.	12	56	54
Land locs.	29	11	11
Total locs.	302	564	458

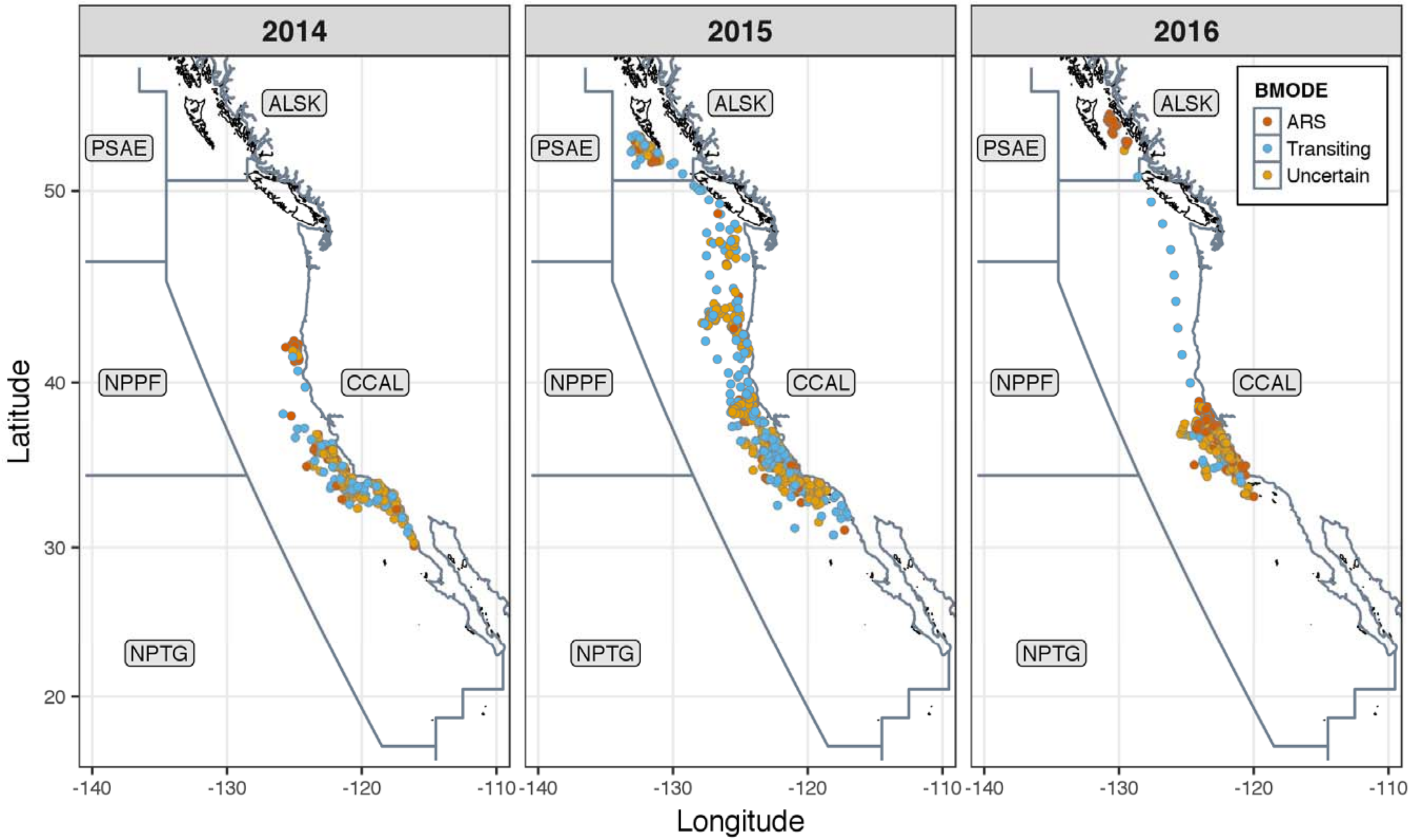

Figure 84. Accepted SSM locations for fin whales colored by behavioral mode for each year in the study. Five of the Longhurst biogeographic provinces in the region occupied by tagged fin whales are outlined.

The behavioral classification for each location for all tracks is shown in the map in **Figure 84**. The number and proportion of locations classified by behavioral mode in CCAL is reported in **Table 36**. Of 344 SSM locations, 120 (34.9 percent) were classified as ARS, 191 (55.5 percent) were classified as uncertain, and 33 (9.6 percent) were classified as transiting (**Table 36**).

Table 36. Number of classified SSM locations (and percentage) in CCAL for each behavioral mode for fin whales in each year. The number of SSM tracks is indicated (n).

Behavioral Mode	2014 (n = 5)	2015 (n = 10)	2016 (n = 12)
Transiting	50 (19.5%)	157 (35.8%)	33 (9.6%)
Uncertain	158 (61.7%)	230 (52.4%)	191 (55.5%)
ARS	48 (18.8%)	52 (11.8%)	120 (34.9%)
Classified locs.	256 (100%)	439 (100%)	344 (100%)

Details of the environmental variables examined are provided in **Table 1**. Summary statistics for these variables obtained for the SSM locations are reported for CCAL only (**Tables 18 and 19**), as this was the only biogeographic province consistently occupied by all species and in all years. In 2016, average WEKM was 1.1e-06 m s^{-1}, average SST was 15.4°C, and average CHL was 1.47 mg m^{-3} (**Table 18**). The values at each location for these environmental variables are shown in the maps in **Figures 85 through 87**.

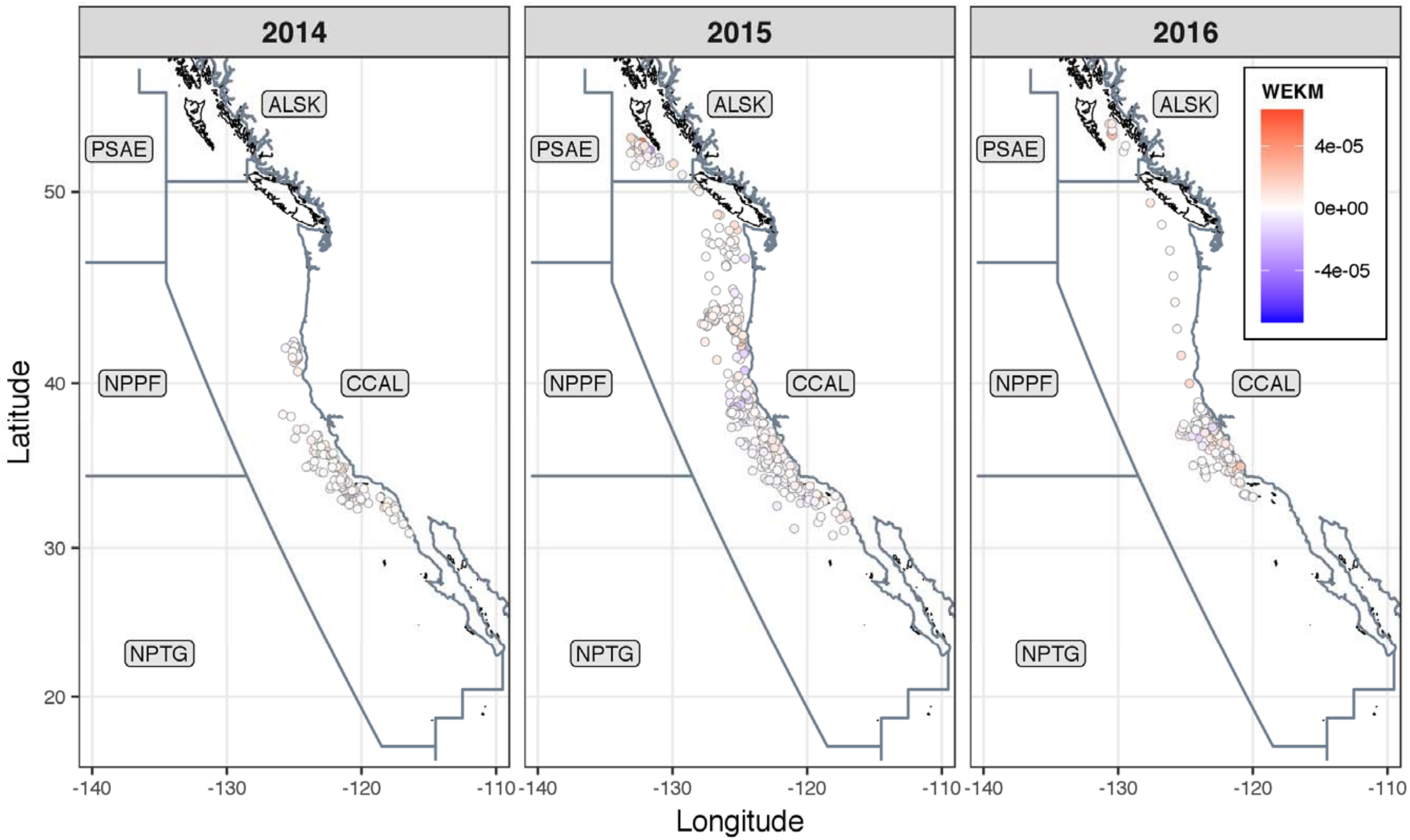

Figure 85. Map representation of vertical upwelling velocity (WEKM, m s^{-1}) values obtained from satellite remote sensing around each fin whale location for each year in the study. The Longhurst biogeographic provinces are indicated.

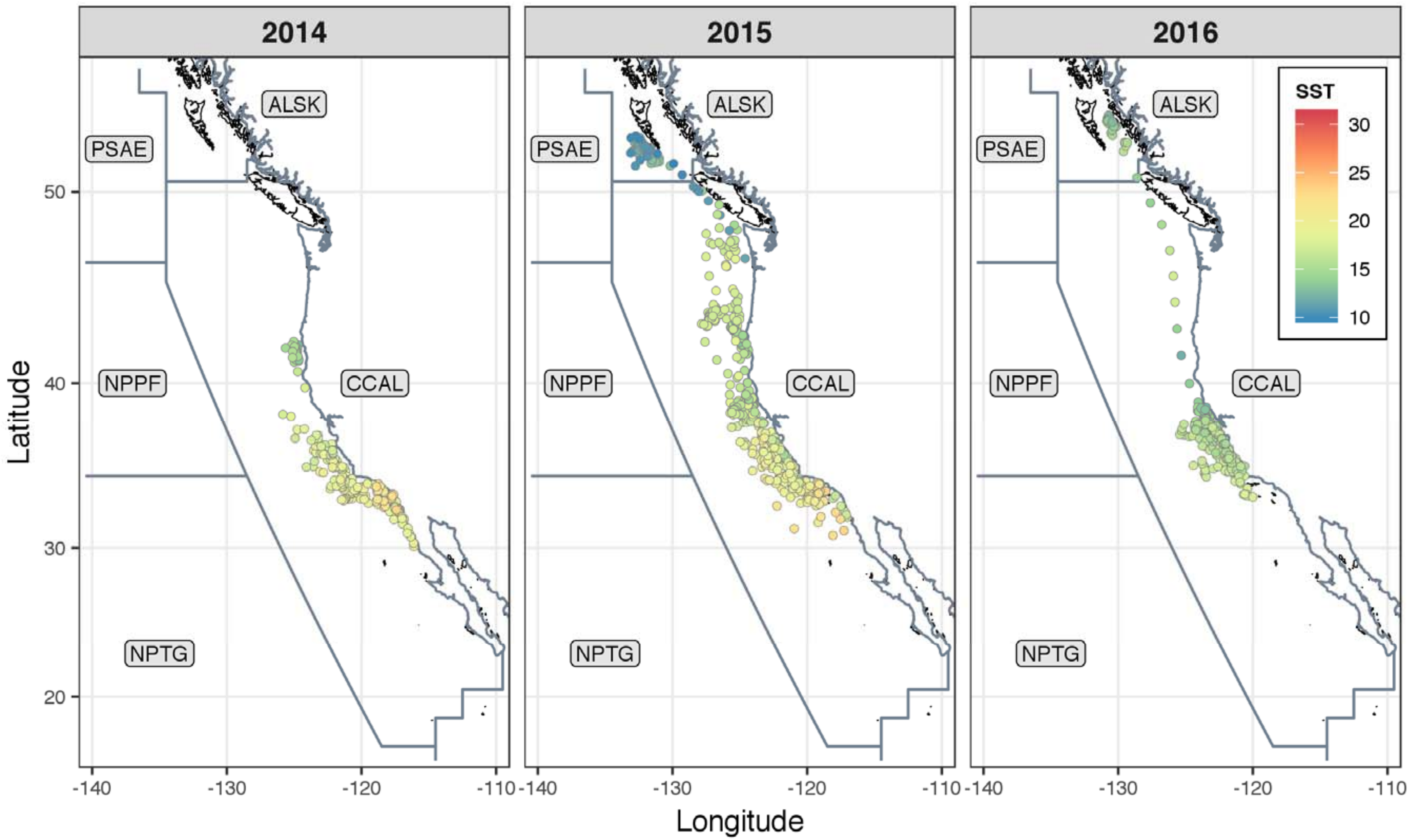

Figure 86. Map representation of sea surface temperature (SST, °C) values obtained from satellite remote sensing around each fin whale location for each year in the study. The Longhurst biogeographic provinces are indicated.

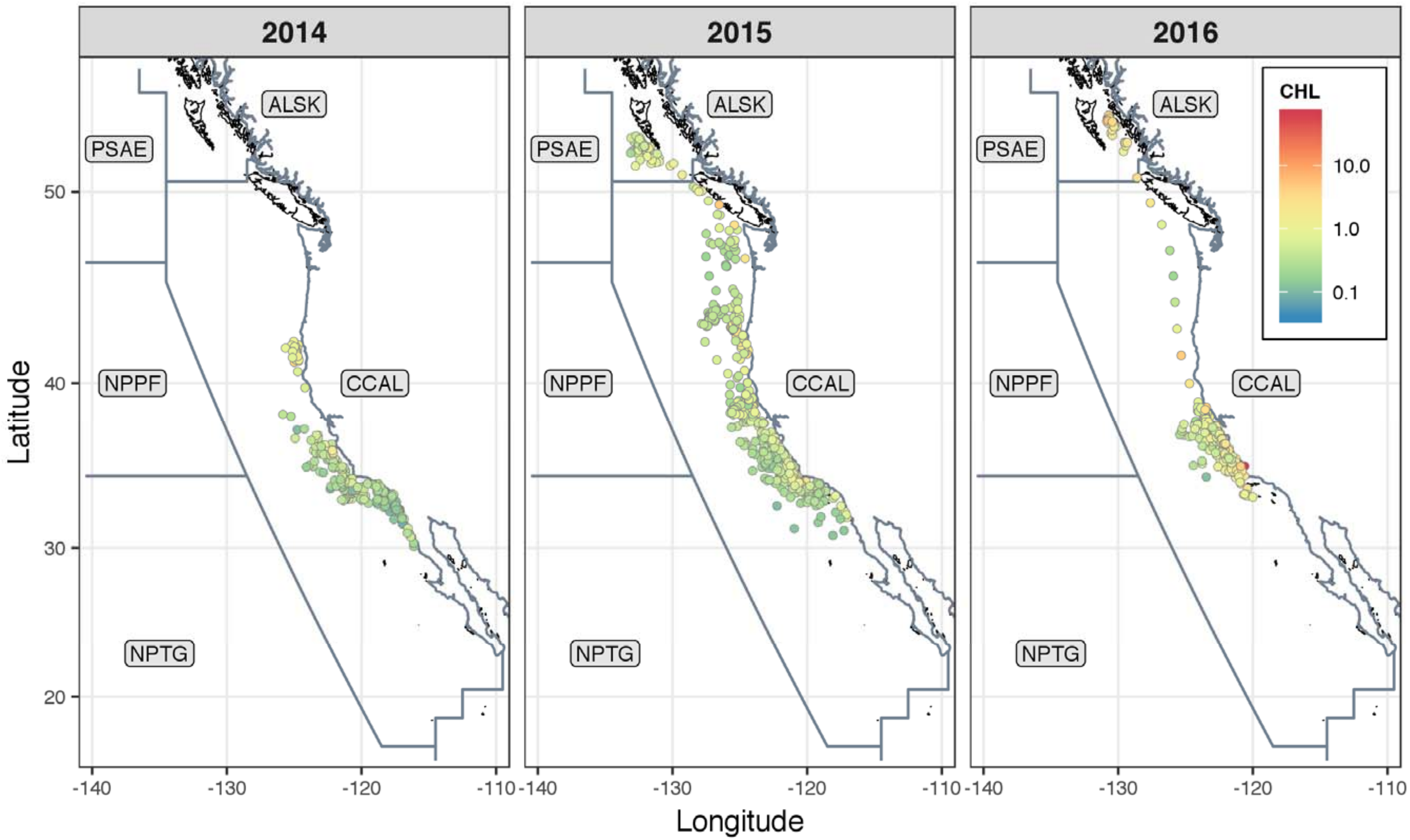

Figure 87. Map representation of chlorophyll-*a* concentration (CHL, mg m^{-3}) values obtained from satellite remote sensing around each fin whale location for each year in the study. The Longhurst biogeographic provinces are indicated.

In terms of seafloor characteristics, in 2016 fin whales occurred in areas with an average DEPTH of 1,492.32 m, average DISTSHELF of 35.37 km, and average DISTSHORE of 60.87 km. The average SLOPE in these areas was 47.59 m km^{-1} and faced toward the southwest (average ASPECT = 232°) (**Table 19**). The values at each location for these seafloor relief variables are shown in the maps in **Figures 88 through 92**.

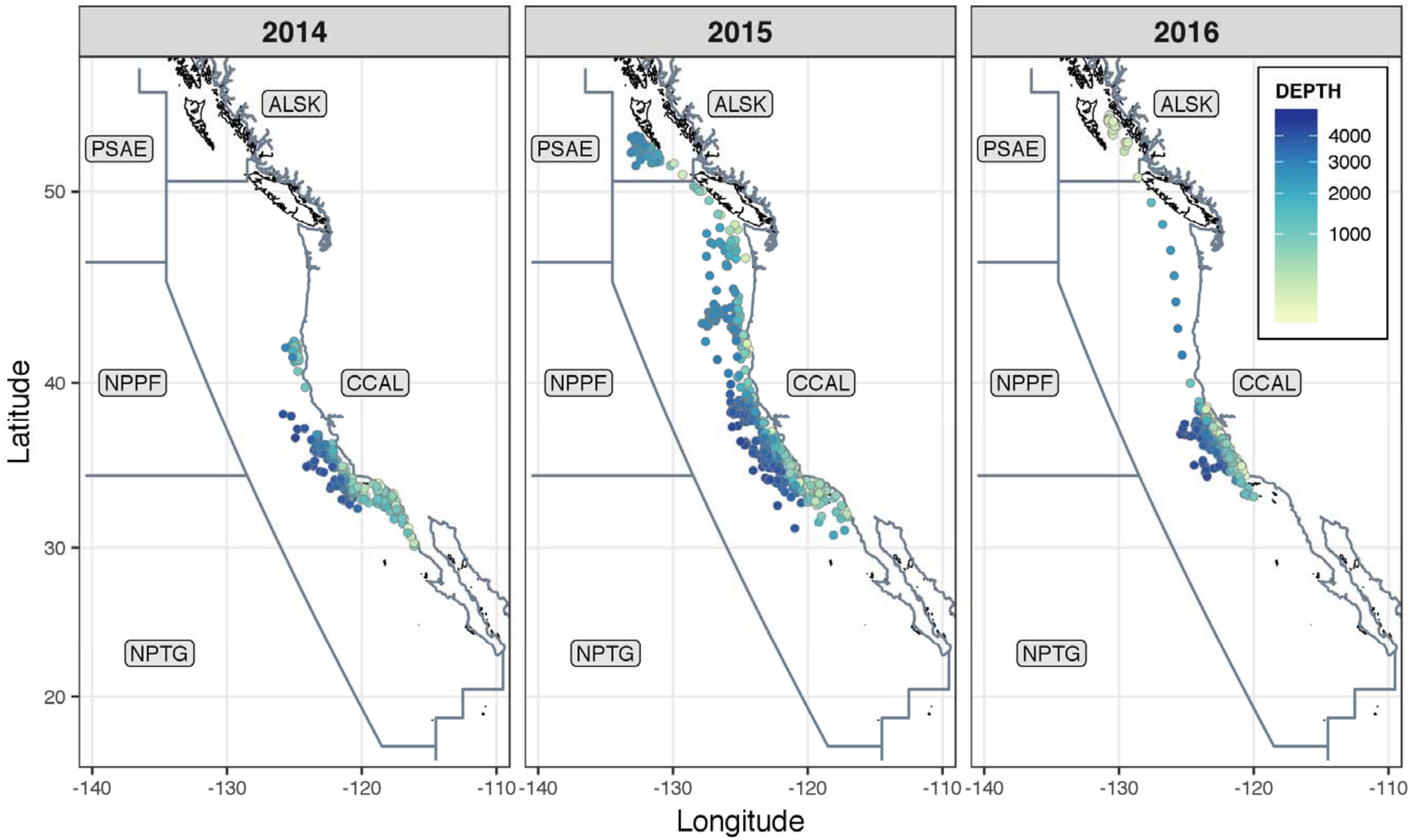

Figure 88. Map representation of seafloor depth (DEPTH, m) values obtained from ETOPO1 around each fin whale location for each year in the study. The Longhurst biogeographic provinces are indicated.

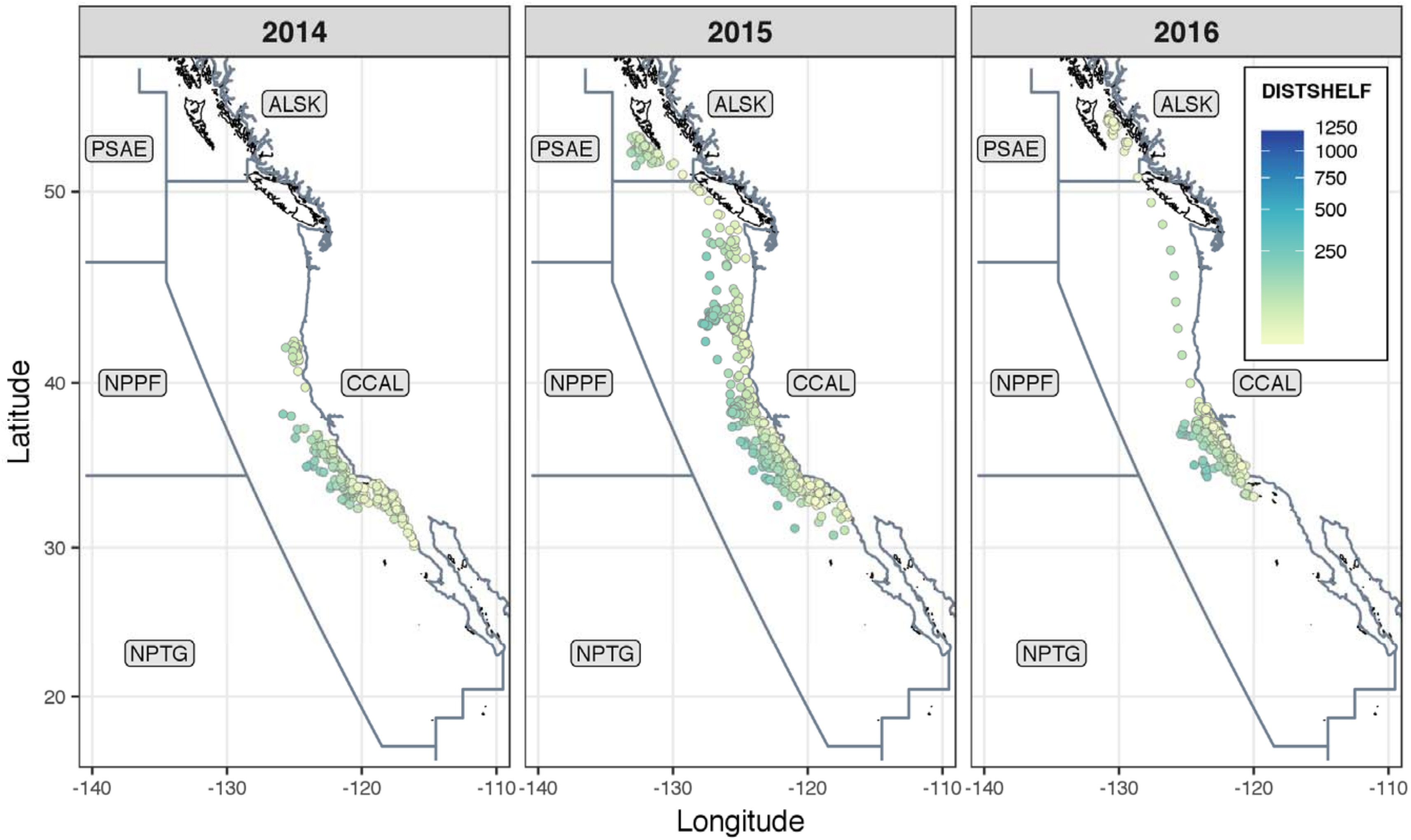

Figure 89. Map representation of distance to the 200 m isobath (DISTSHELF, km) values obtained from ETOPO1 around each fin whale location for each year in the study. The Longhurst biogeographic provinces are indicated.

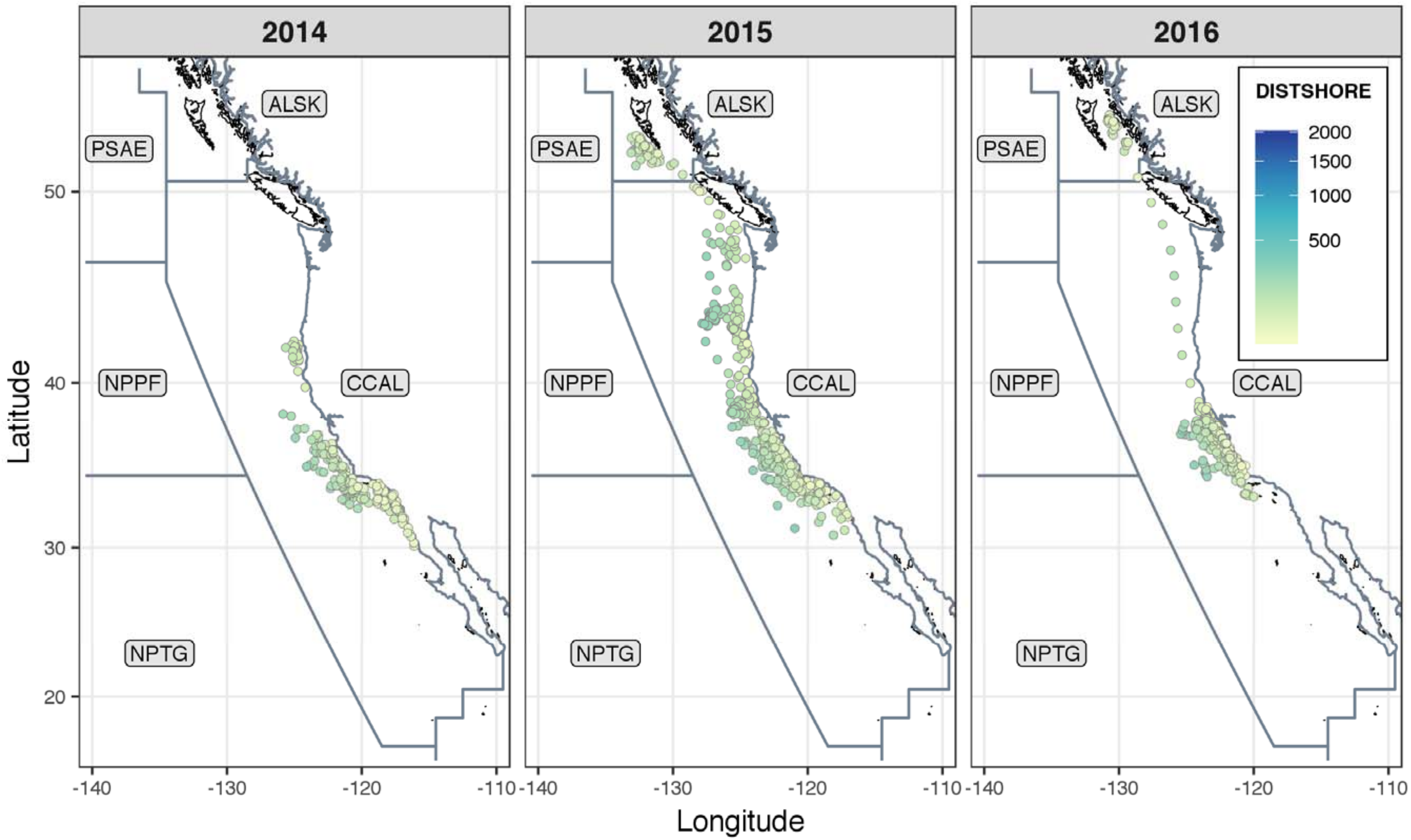

Figure 90. Map representation of distance to the shoreline (DISTSHORE, km) values obtained from ETOPO1 around each fin whale location for each year in the study. The Longhurst biogeographic provinces are indicated.

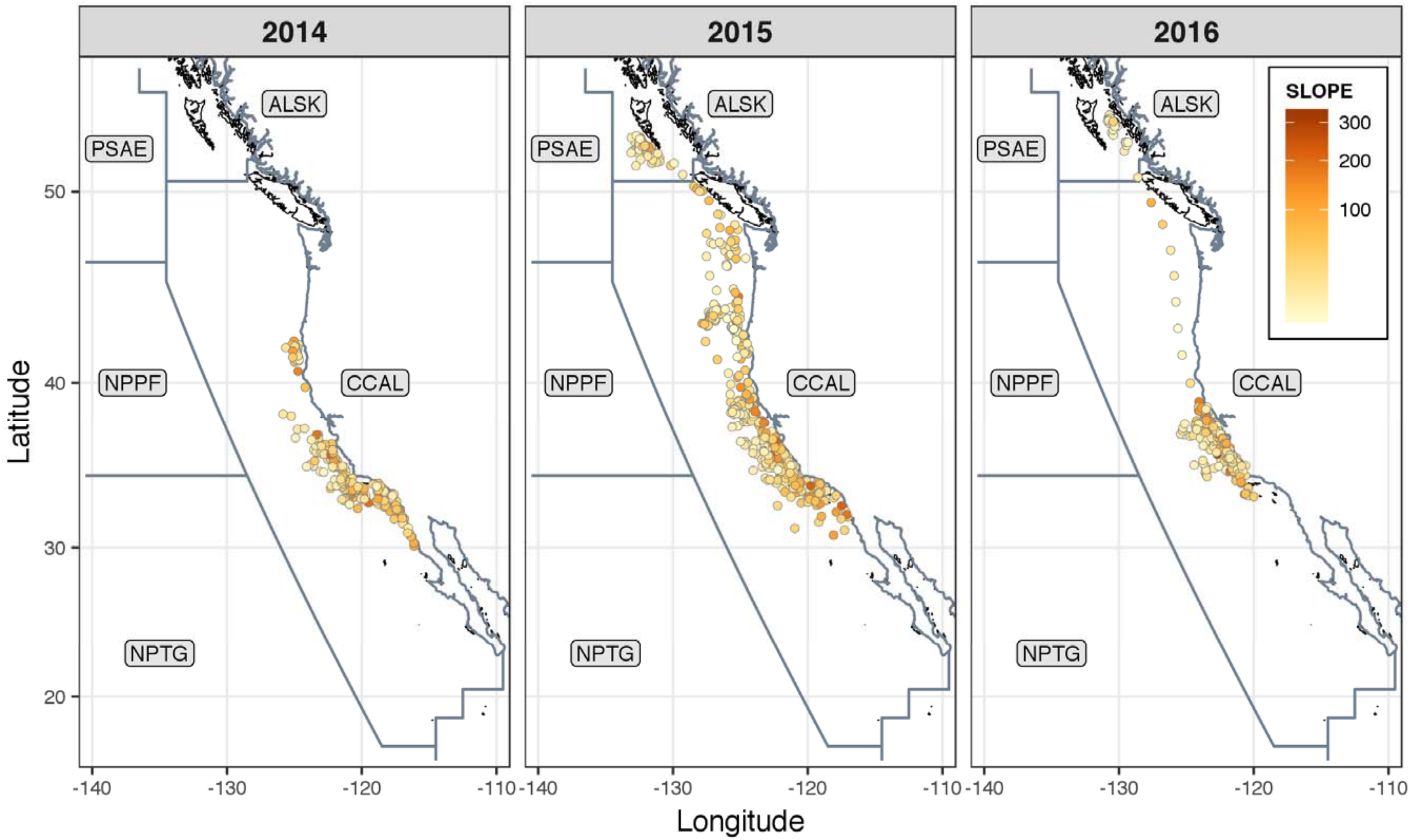

Figure 91. Map representation of seafloor slope (SLOPE, m km^{-1}) values obtained from ETOPO1 around each fin whale location for each year in the study. The Longhurst biogeographic provinces are indicated.

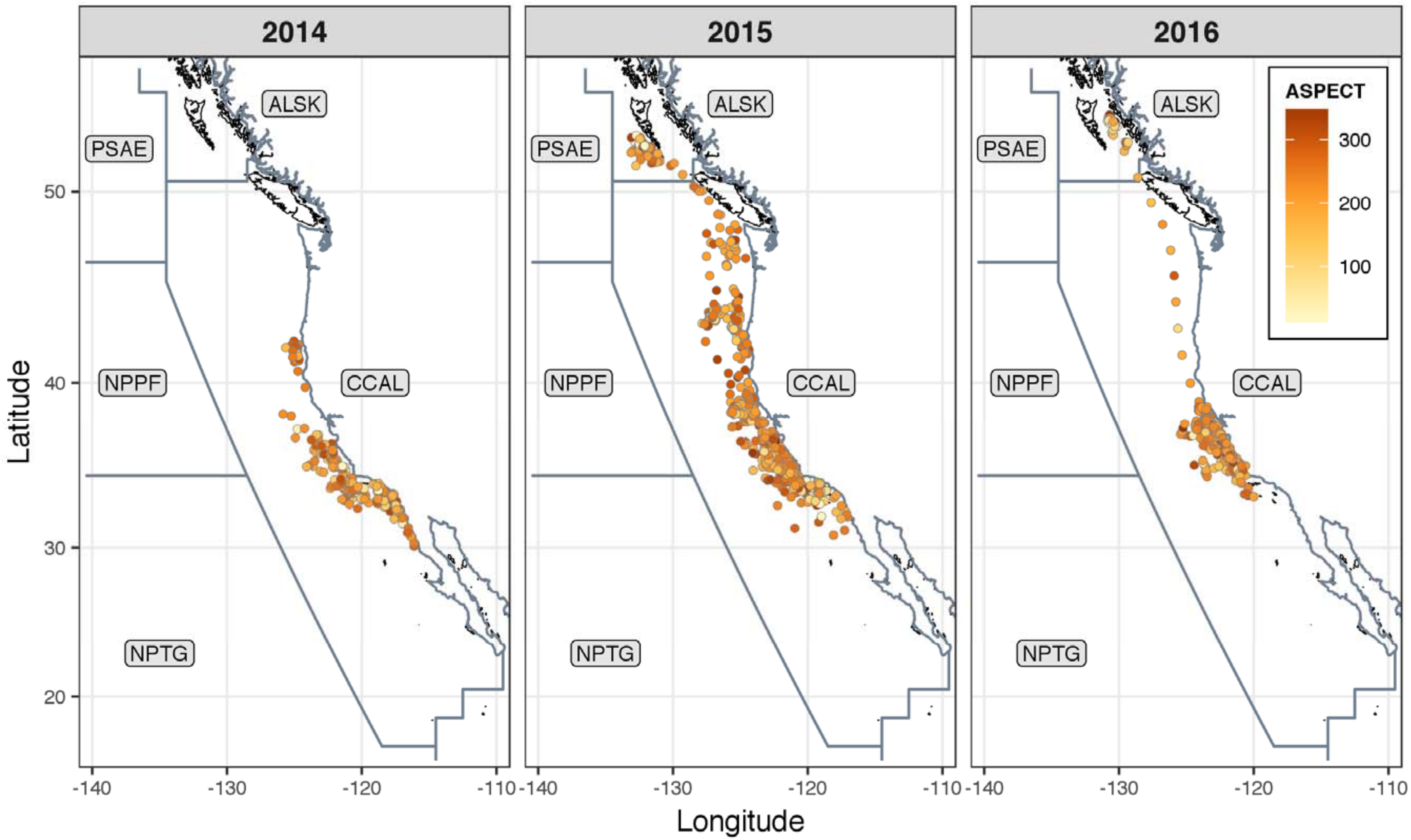

Figure 92. Map representation of seafloor slope aspect (ASPECT, degrees) values obtained from ETOPO1 around each fin whale location for each year in the study. The Longhurst biogeographic provinces are indicated.

3.2.11 Ecological Relationships—Interannual Comparisons

The number of tracked fin whales in the three years was smaller and more variable than that of blue whales (n = 5 in 2014, n = 10 in 2015, and n = 12 in 2016) (**Table 35**). The longitudinal range of these tracks was smallest in 2014 and 2016 (9.7 and 10.9 degrees, respectively), and it was greatest in 2015 (16.1 degrees). The latitudinal range was restricted and shifted to the south in 2014 (12.2 degrees; 30.1–42.3°N), while in 2015 and 2016 it was larger (21.8 and 20 degrees, respectively) and shifted to the north, reaching Haida Gwaii and Hecate Strait off British Columbia (**Table 35 and Figure 84**).

In contrast to blue whales, fin whales were only present in two of the eight biogeographic provinces of the eastern North Pacific considered here, CCAL and ALSK (**Table 35**). Their proportional occupation of these provinces was virtually identical in 2015 and 2016 (CCAL: 89.7 and 89.8 percent of locations, respectively; ALSK: 10.3 and 10.2 percent, respectively), while in 2014 they were restricted to CCAL (**Table 35 and Figure 84**).

The behavioral classification in CCAL was based on 256 SSM locations in 2014, 439 locations in 2015, and 344 locations in 2016. The proportion of locations classified as ARS was lowest (11.2 percent of locations) in 2015, intermediate (18.8 percent) in 2014, and highest (34.9 percent) in 2016. The proportion of locations classified as transiting was highest (35.8 percent) in 2015, intermediate in 2014 (19.5 percent), and lowest in 2016 (9.6 percent). Locations considered uncertain made up the remainder (61.7 percent in 2014, 52.4 percent in 2015, and 55.5 percent in 2016) (**Table 36**).

In terms of oceanographic characteristics in CCAL, fin whales were found in areas with average positive upwelling velocities (WEKM) in all three years, but they were weaker by an order of magnitude in 2015 (6.1e-07 m s^{-1}) than in 2014 or 2016 (1.0e-06 and 1.1e-06 m s^{-1}, respectively). Average SST was warmest in 2014 and 2015 (18.8 and 17.6°C, respectively), and coolest in 2016 (15.40°C). Average CHL was low in 2014 and 2015 (0.56 and 0.64 mg m^{-3}, respectively) and higher in 2016 (1.47 mg m^{-3}) (**Table 18**). The values at each location for these environmental variables are shown in the maps in **Figures 85 through 87**, and their distributional properties are shown in the violin plots in **Figures 93 through 95**.

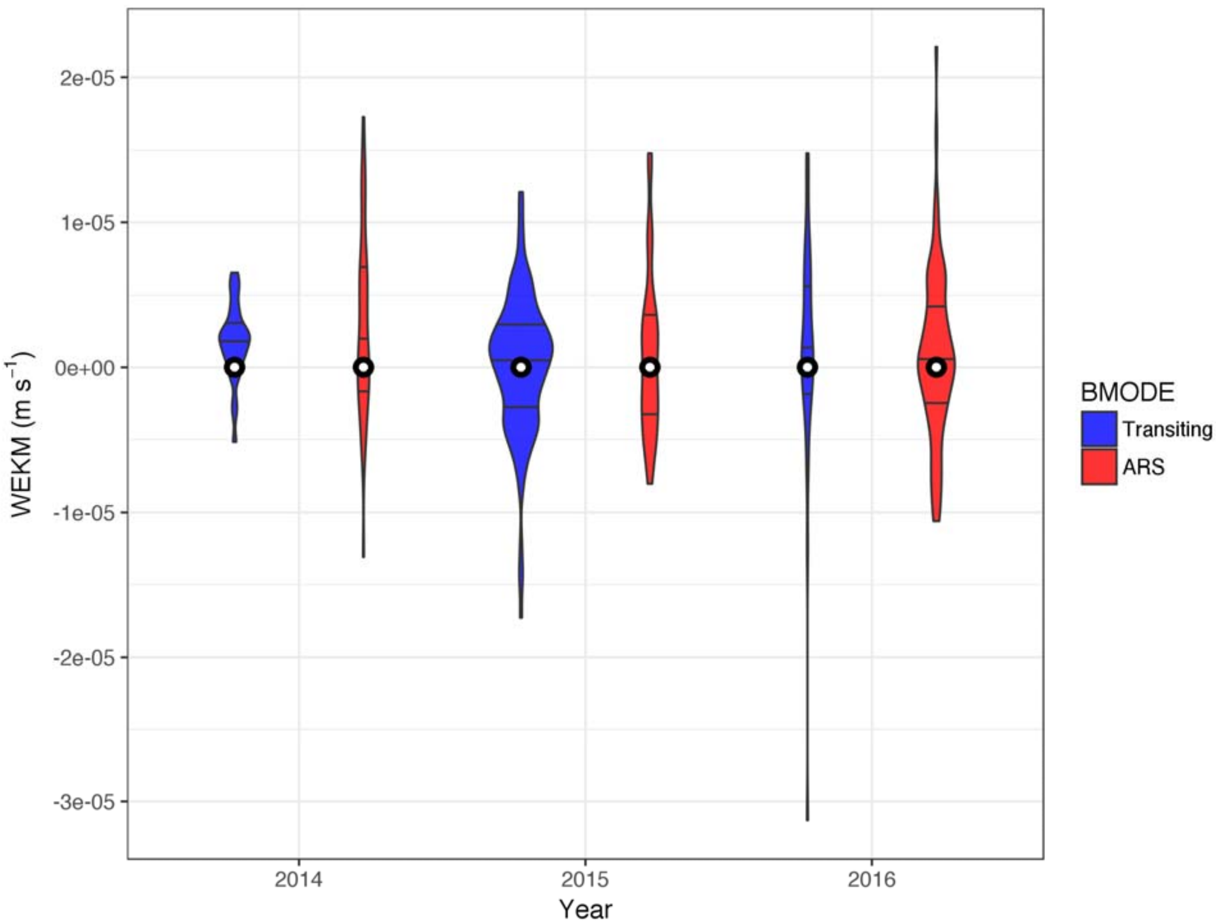

Figure 93. Paired violin plots of vertical upwelling velocity (WEKM, m s^{-1}) values in CCAL for fin whale locations classified as transiting and ARS for each year in the study. Horizontal lines inside each violin indicate the quartiles of the data distribution and white circle with black outline indicates the median.

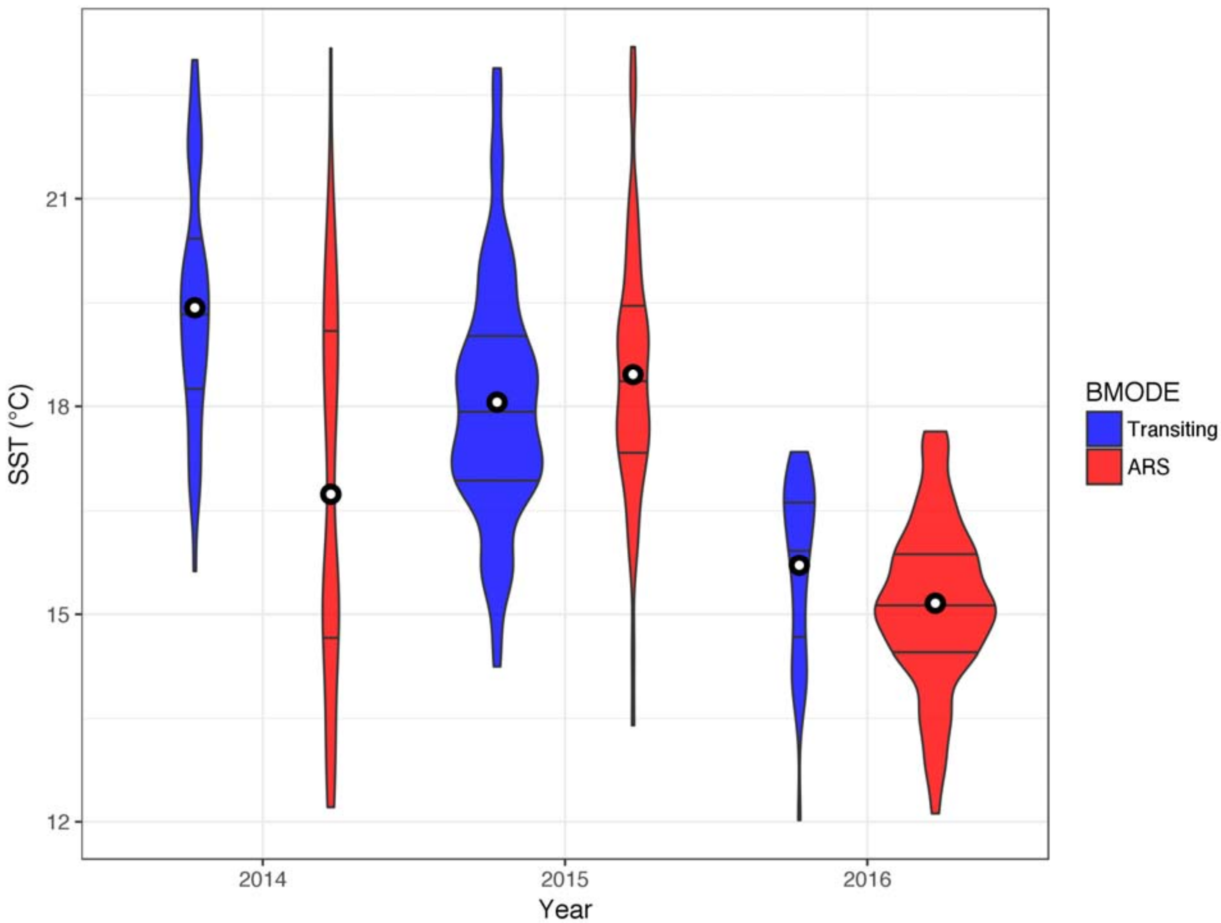

Figure 94. Paired violin plots of sea surface temperature (SST, °C) values in CCAL for fin whale locations classified as transiting and ARS for each year in the study. Horizontal lines inside each violin indicate the quartiles of the data distribution and white circle with black outline indicates the median.

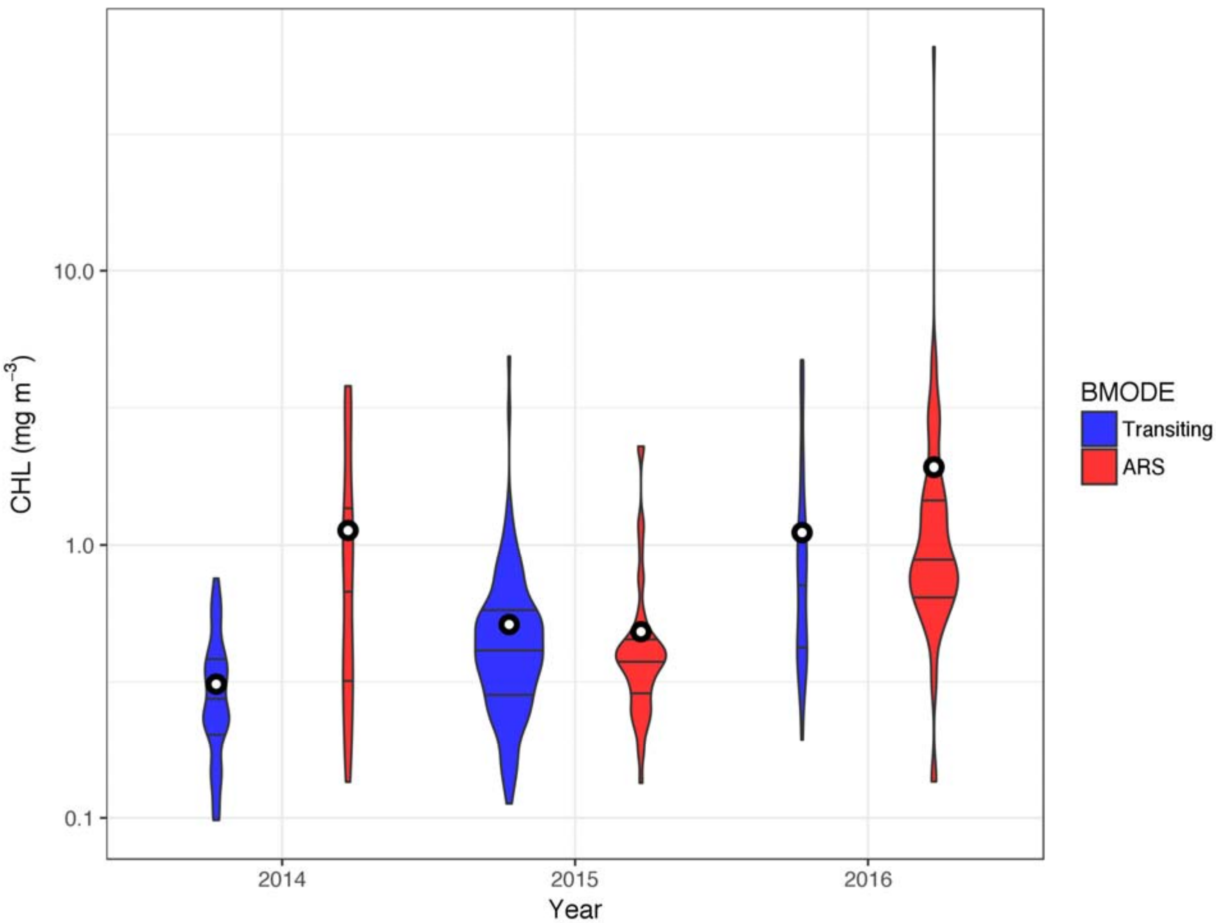

Figure 95. Paired violin plots of chlorophyll-*a* concentration (CHL, mg m^{-3}) values in CCAL for fin whale locations classified as transiting and ARS for each year in the study. Horizontal lines inside each violin indicate the quartiles of the data distribution and white circle with black outline indicates the median. Note that data were log-transformed to improve visualization.

In terms of seafloor characteristics in CCAL, in 2015 fin whales occurred in areas that on average were deeper (DEPTH = 2145.73 m) and further away from the shelf break (DISTSHELF = 62.11 km) and the shore (DISTSHORE = 90.30 km) than in 2014 (DEPTH = 1696.44 m, DISTSHELF = 45.14 km, DISTSHORE = 62.45 km) or 2016 (DEPTH = 1,492.32 m, DISTSHELF = 35.37 km, DISTSHORE = 60.87 km). However, average SLOPE (50.14 m km^{-1} in 2014, 42.85 m km^{-1} in 2015, and 47.59 m km^{-1} in 2016) and average ASPECT (212.11° in 2014, 223.74° in 2015, and 232.00° in 2016) values remained similar in all three years (**Table 19**). The values at each location for these seafloor relief variables are shown in the maps in **Figures 88 through 92**, and their distributional properties are shown in the violin plots in **Figures 96 through 100**.

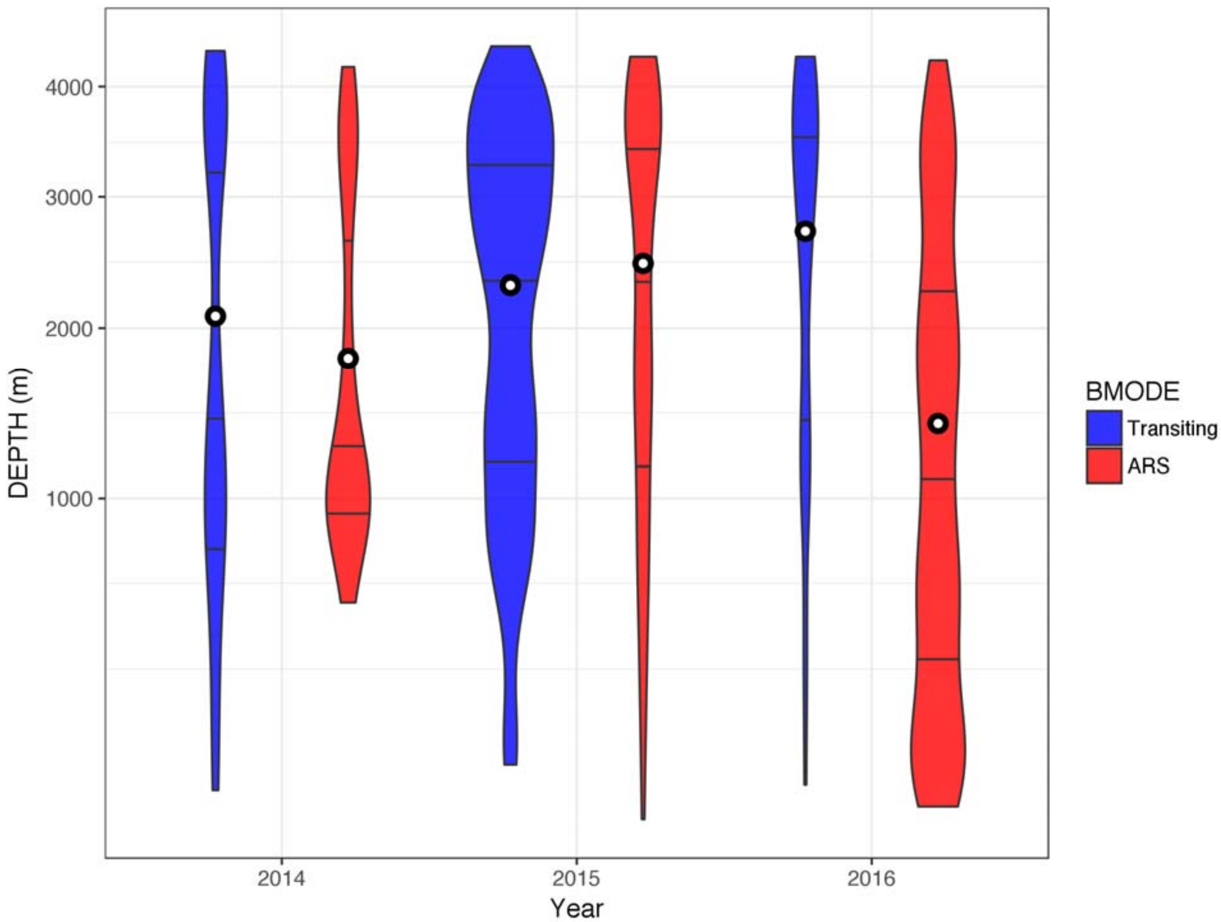

Figure 96. Paired violin plots of seafloor depth (DEPTH, m) values in CCAL for fin whale locations classified as transiting and ARS for each year in the study. Horizontal lines inside each violin indicate the quartiles of the data distribution and white circle with black outline indicates the median. Note that data were square-root-transformed to improve visualization.

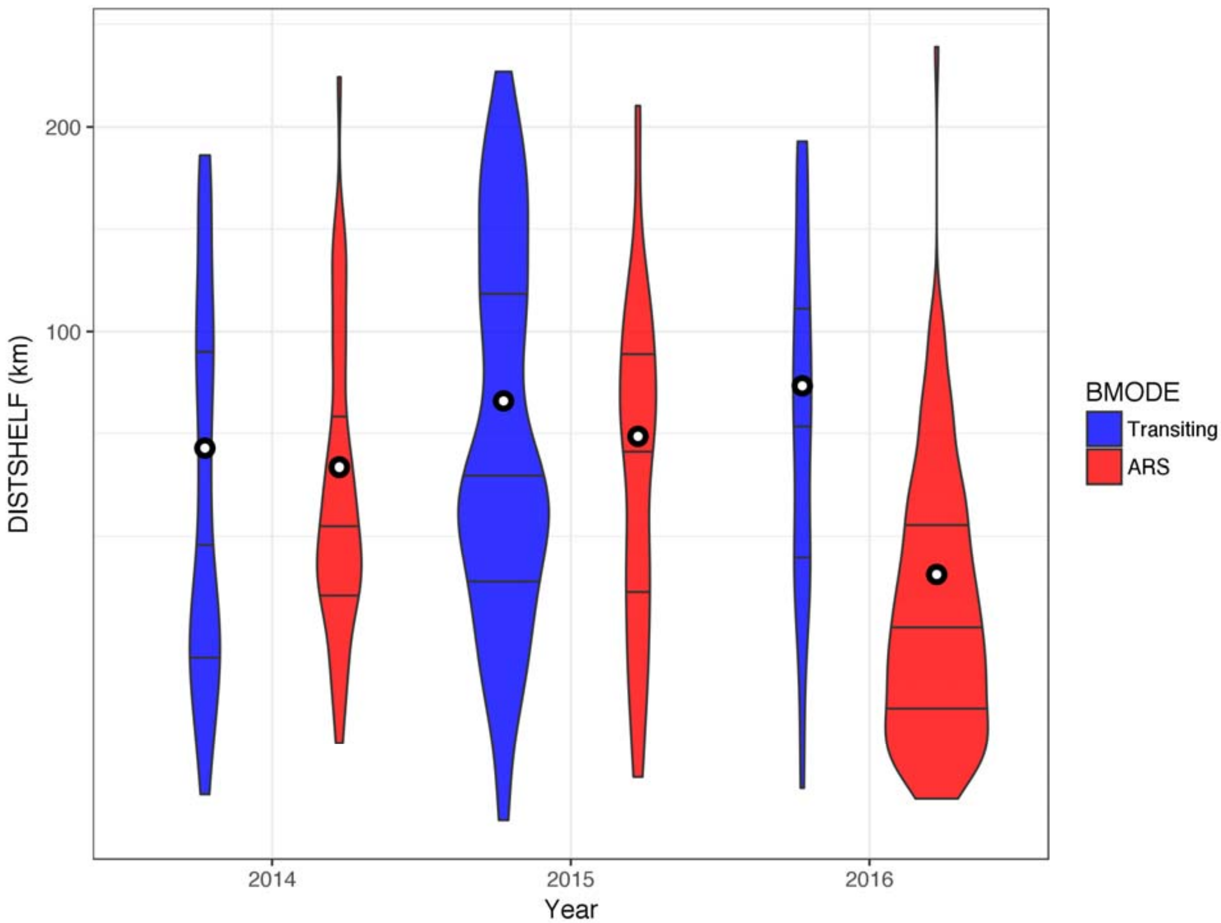

Figure 97. Paired violin plots of distance to the 200 m isobath (DISTSHELF, km) values in CCAL for fin whale locations classified as transiting and ARS for each year in the study. Horizontal lines inside each violin indicate the quartiles of the data distribution and white circle with black outline indicates the median. Note that data were square-root-transformed to improve visualization.

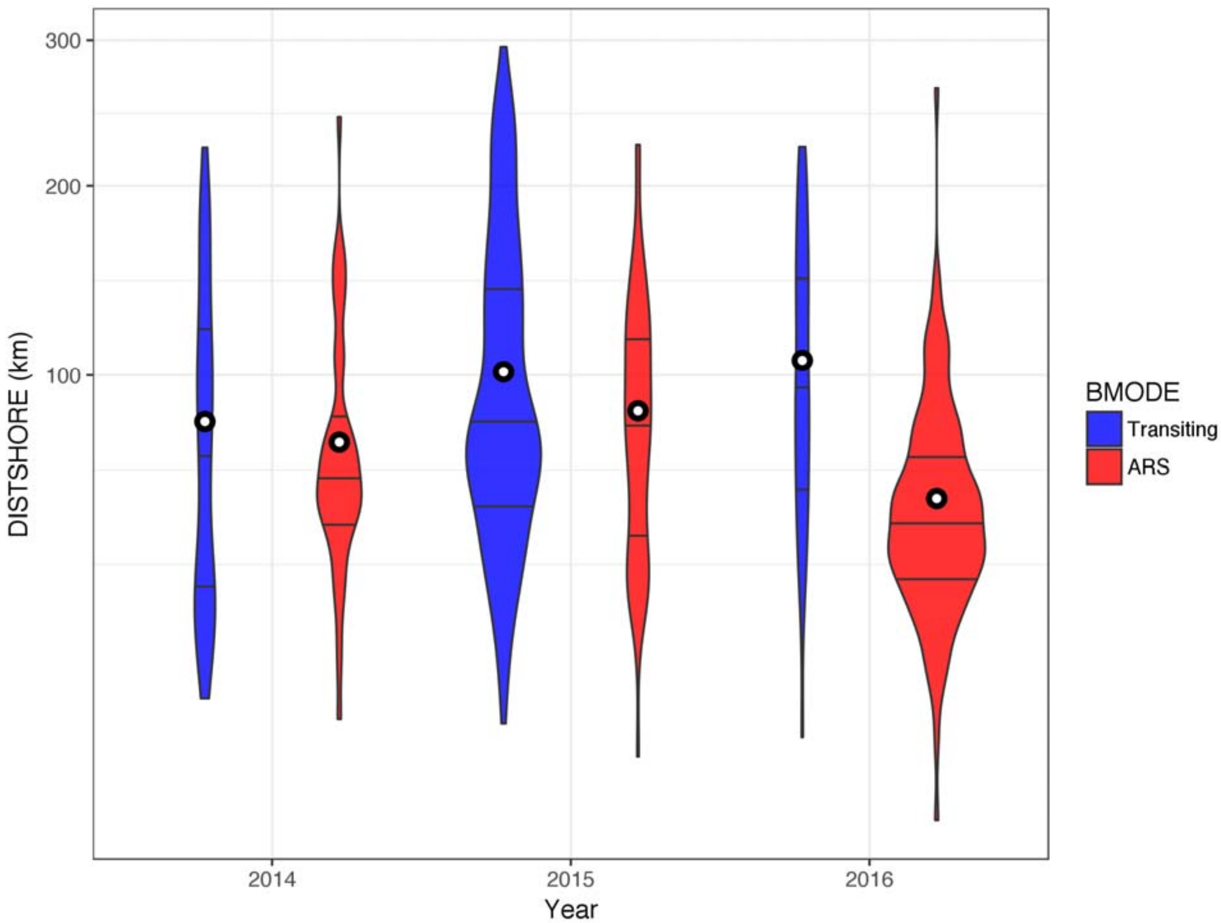

Figure 98. Paired violin plots of distance to the shoreline (DISTSHORE, km) values in CCAL for fin whale locations classified as transiting and ARS for each year in the study. Horizontal lines inside each violin indicate the quartiles of the data distribution and white circle with black outline indicates the median. Note that data were square-root-transformed to improve visualization.

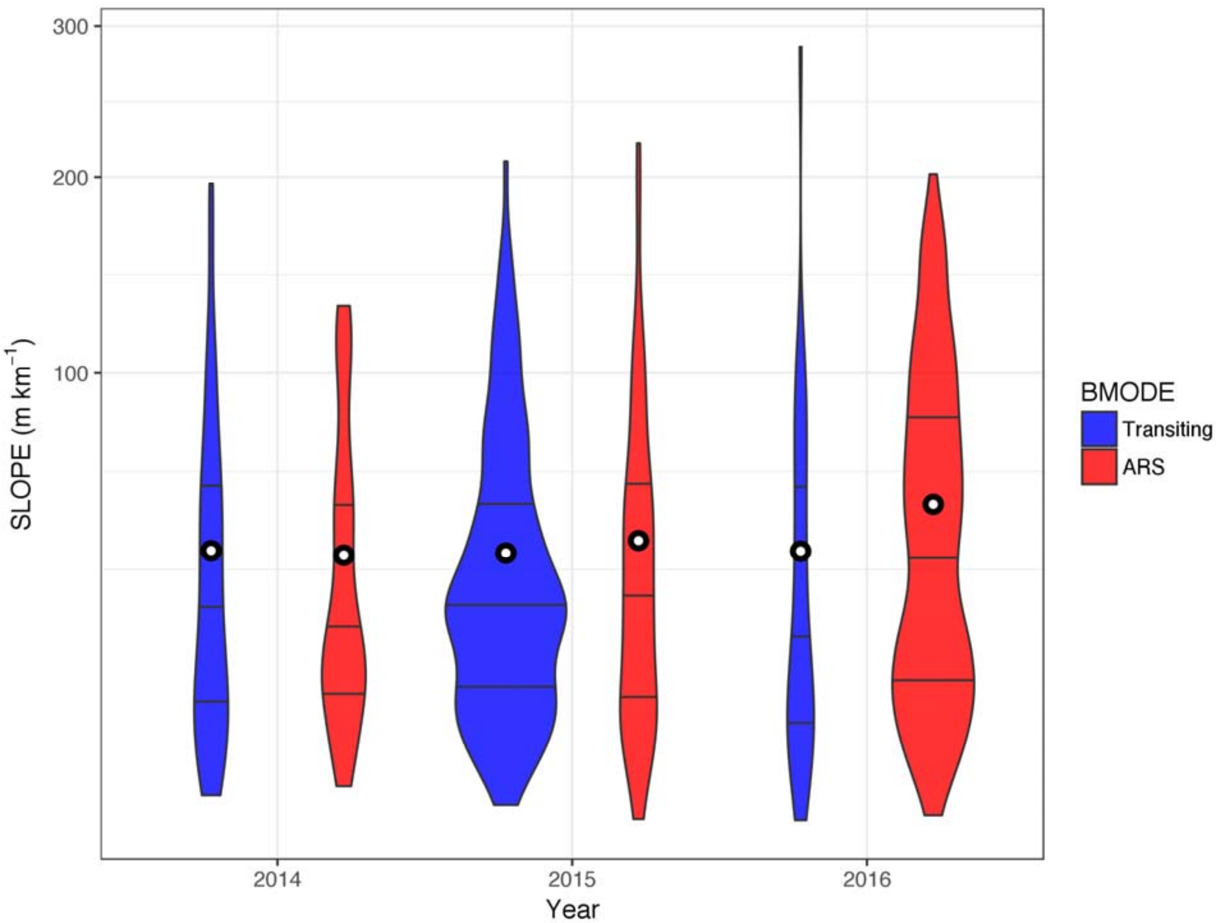

Figure 99. Paired violin plots of seafloor slope (SLOPE, m km^{-1}) values in CCAL for fin whale locations classified as transiting and ARS for each year in the study. Horizontal lines inside each violin indicate the quartiles of the data distribution and white circle with black outline indicates the median. Data were square-root-transformed to improve visualization.

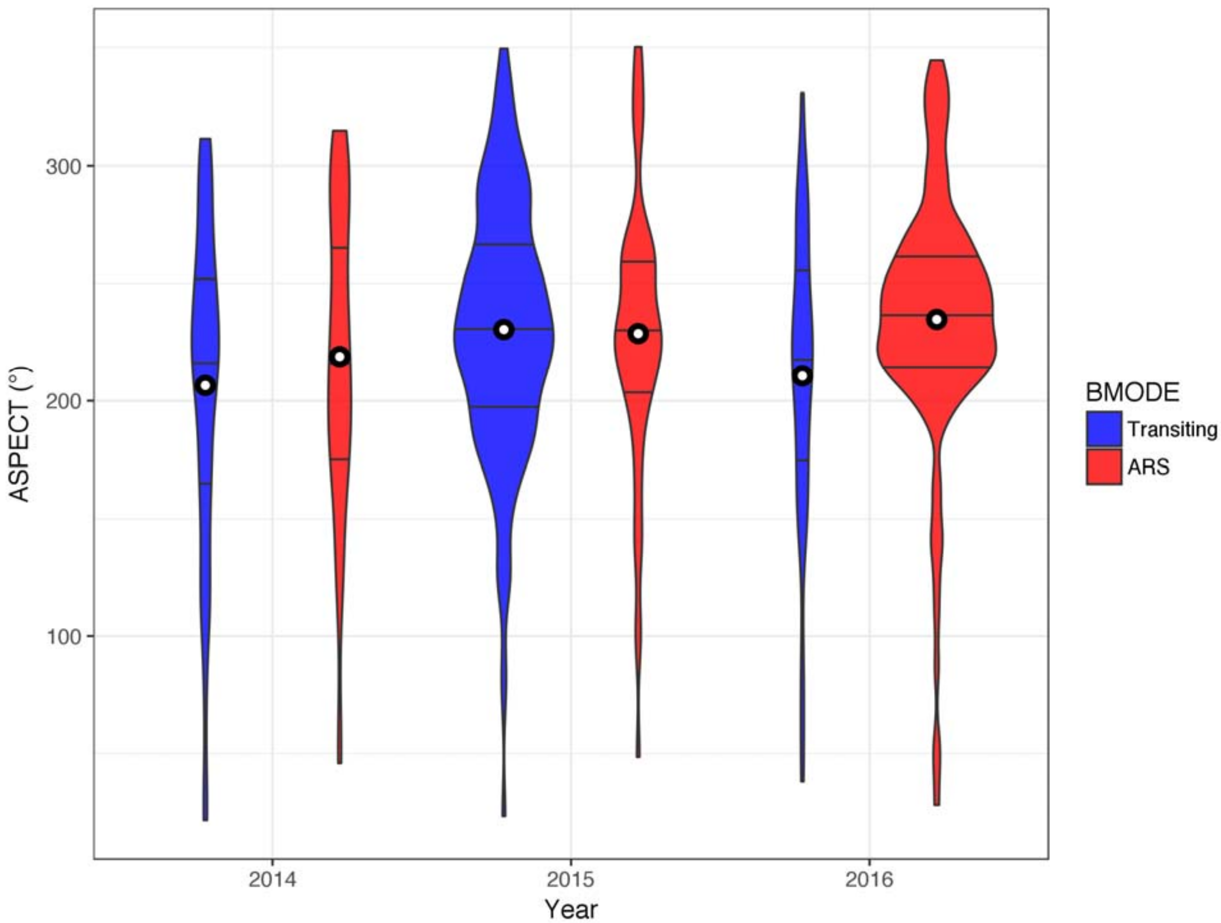

Figure 100. Paired violin plots of seafloor slope aspect (ASPECT, degrees) values in CCAL for fin whale locations classified as transiting and ARS for each year in the study. Horizontal lines inside each violin indicate the quartiles of the data distribution and white circle with black outline indicates the median.

An examination of the ONI, PDO (**Figure 59**), and other interannual climatic perturbations during the three years of this study was presented in **Section 3.1.6** concerning blue whales. These results apply to fin whales as well, and the reader is referred to that section for the climatic context.

3.2.12 Genetics and Species Identification

In 2014, skin biopsy samples were collected from five of the tagged whales considered to be fin whales based on field observations (Mate et al. 2016). All samples provided DNA profiles sufficient for subsequent analyses and initial comparison of mtDNA sequences with reference sequences confirmed species identification. In 2015, skin biopsy samples were collected from nine of the tagged whales initially considered to be fin whales based on field observations (Mate et al. 2016). All samples provided DNA profiles sufficient for subsequent analyses. Initial comparison of mtDNA sequences showed disagreement with field identification of two samples. Based on submission of mtDNA control region sequences to *DNA-surveillance* and a BLAST search of GenBank®, sample Bph15CA002 was identified as a blue whale and sample Bph15CA006 was identified as a Bryde's whale *Balaenoptera brydei/edeni*. Subsequent review of photographic records agreed with the molecular identification of Bph15CA006 as a Bryde's whale. For sample Bph15CA002, we used a structure analysis with a reference dataset of genotypes from North Pacific blue and fin whales to confirm a high likelihood that the individual is a blue/fin whale hybrid (Mate et al. 2016, Steiger et al. 2009). Given the maternal inheritance of mtDNA and the biparental inheritance of the microsatellite loci, we can also confirm that the parents of the hybrid were a blue whale mother and fin whale father.

In 2016, skin biopsy samples were collected from six of the tagged whales considered to be fin whales based on field observations (**Figure 101**). All samples provided DNA profiles sufficient for subsequent analyses and initial comparison of mtDNA sequences with reference sequences confirmed species identification.

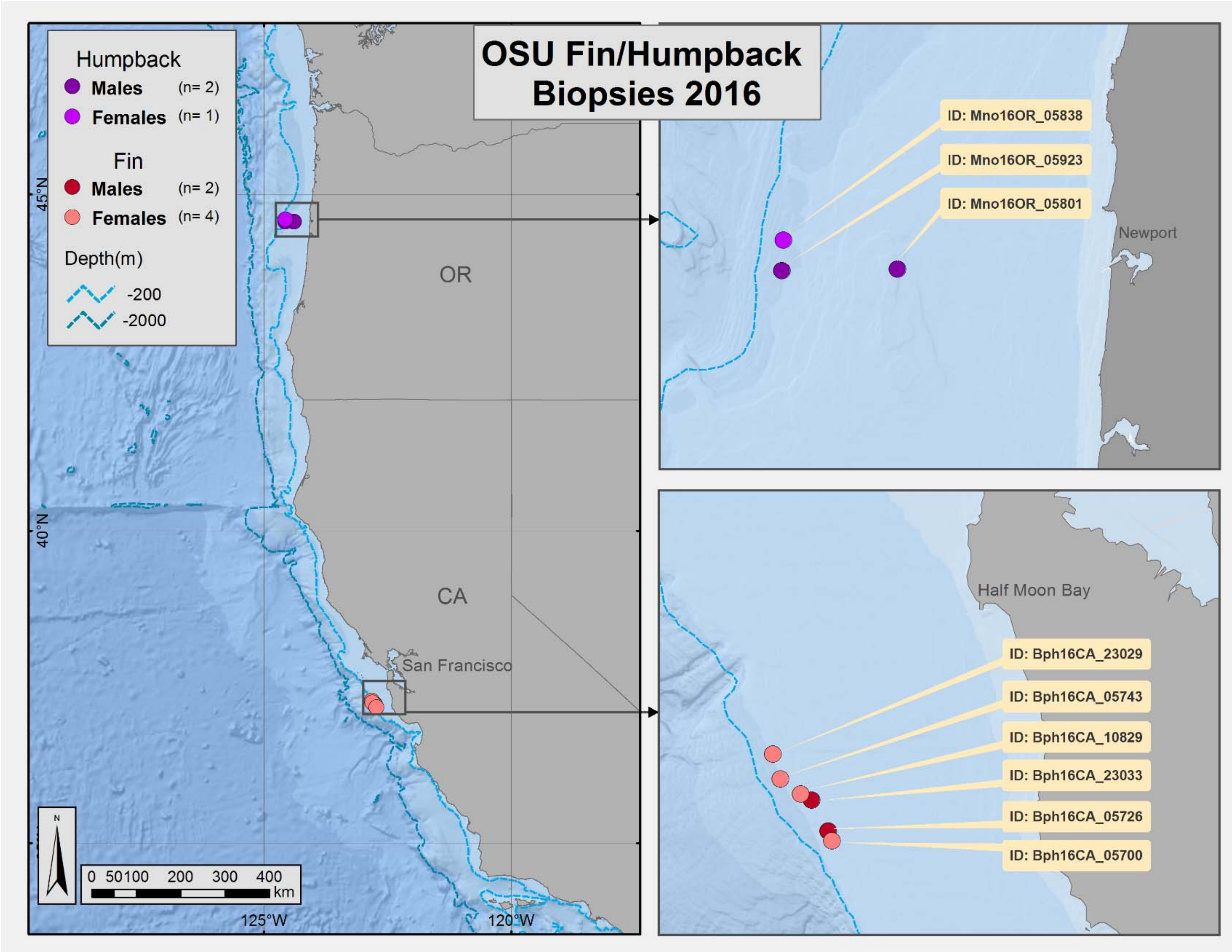

Figure 101. The location of biopsy sample collections from fin and humpback whales tagged in 2016.

3.2.12.1 SEX DETERMINATION

The blue/fin whale hybrid (Bph15CA002) was identified as a male and the Bryde's whale (Bph15CA006) was identified as a female. Of the 18 fin whales, 8 were male and 10 were female.

3.2.12.2 INDIVIDUAL IDENTIFICATION

All 18 tagged fin whales were represented by unique multi-locus genotypes and the probability of identity for the 17 loci was very low, 8.8×10^{-21} (i.e., there was a very low probability of a match by chance). Consequently, we are confident that the 18 unique multi-locus genotypes represented 18 individuals, i.e., there were no replicate samples among the fin whales tagged in 2014–2016. This was consistent with sex and mtDNA haplotypes, as provided in the full DNA profiles. There is only one other sample of a previously tagged fin whale in the reference collection for the Marine Mammal Institute. The DNA profile of this individual, tagged in 2006 (Bphy06Ca001) did not match to any of those from the 18 fin whales tagged in 2014–2016.

Given the interest in the blue/fin whale hybrid, we reviewed the DNA profile of a previous blue/fin whale hybrid conducted in collaboration with researchers from Cascadia Research Collective, as reported by Steiger et al. (2009). The comparison of the DNA profiles confirmed a match with this individual, first sampled on 22 September 2004, providing an 11-year resighting record. In keeping with the collaborative agreement with Cascadia Research Collective, the information on this 'genotype recapture' was shared with John Calambokidis on 22 September 2015, and then with HDR, Naval Facilities Engineering Command Pacific and Commander, U.S. Pacific Fleet by email on 24 September 2015.

3.2.12.3 STOCK IDENTIFICATION

The haplotype frequencies of the 2016 tagged whales were first compared to those of the combined 2014–2015 tagged whales. This comparison indicated a weak but significant difference in haplotype frequencies and thus the 2016 dataset was not pooled with the previous years for subsequent analyses.

In collaboration with the Southwest Fisheries Science Center, we compared the mtDNA haplotype frequencies of the 12 fin whales tagged in 2014–2015 and the six tagged in 2016 to a reference dataset of 397 samples as described by Archer et al. (2013). The 397 samples represented 52 mtDNA haplotypes based on sequence variation in the first 412 bp of the control region. For this consensus length, the 18 tagging samples represented 10 haplotypes, all of which were found in the reference database.

Based on the ongoing analyses of this reference dataset, we compared the haplotype frequencies of the 12 fin whales tagged in 2014–2015 and the six tagged in 2016 to those of seven *a priori* population strata (**Figure 102**). Despite the small sample sizes for these comparisons, the haplotype frequencies of the tagged fin whales from all years showed significant differences from several of the other strata, including California/Oregon/Washington and the Gulf of California, but not the Southern California Bight (**Table 37**).

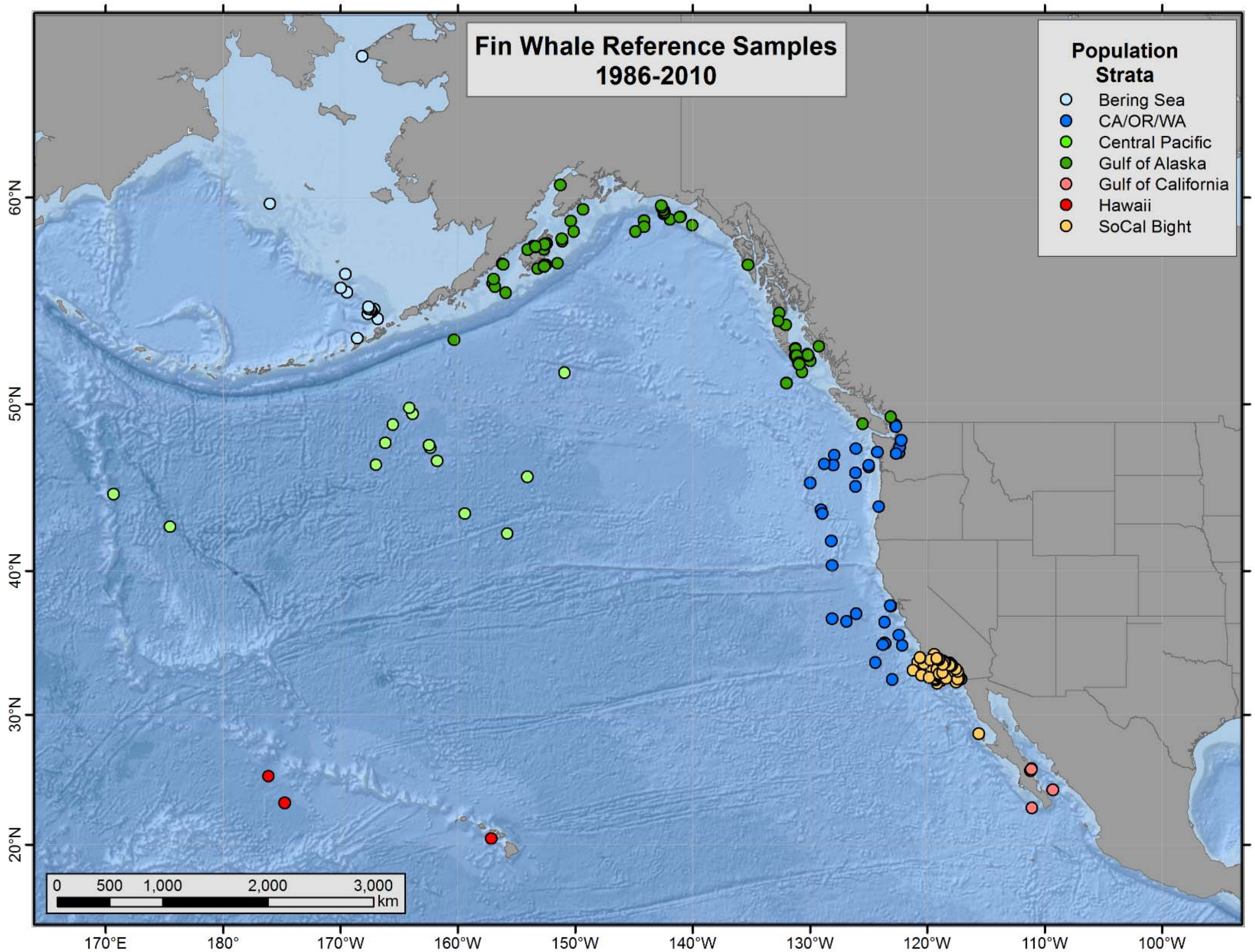

Figure 102. The seven population strata of the reference dataset (n = 397) used in the test of differentiation for the mtDNA haplotypes of the tagged fin whales (n = 12). Note that these seven a priori strata are under review as part of a larger study of fin whale population structure in the North Pacific (courtesy of F.I. Archer, NMFS/Southwest Fisheries Science Center, La Jolla).

Table 37. Pairwise tests of differentiation (FST) for mtDNA haplotype frequencies from the tagged fin whales and seven population strata in the North Pacific (Archer et al. 2012). Pairwise tests with significant differences are shown in bold.

Stratum 1	n 1	2014–2015			2016		
		n 2	F_{ST}	P	n2	F_{ST}	P
Southern California Bight	143	12	0.013	0.213	6	0.066	0.054
Gulf of California	33	12	**0.354**	**0.001**	**6**	**0.655**	**0.001**
California/Oregon/Washington	57	12	**0.056**	**0.005**	**6**	**0.051**	**0.044**
Central Pacific	14	12	0.044	0.078	6	**0.083**	**0.028**
Gulf of Alaska	124	12	**0.062**	**0.002**	**6**	**0.046**	**0.041**
Hawaii	4	12	0.083	0.145	6	0.000	0.556
Bering Sea	22	12	**0.071**	**0.002**	**6**	0.028	0.191
2014	5				**6**	**0.212**	**0.015**
2015	7				**6**	0.095	0.131

3.3 Humpback Whale

3.3.1 Tracking Analysis—2016

Two DM tags were deployed on humpback whales on 15 September 2016 (**Table 38**), off the coast of Newport, Oregon. A third DM tag was launched from the tag applicator, but did not properly deploy and was lost. One of these whales (Tag #5838) was tracked for 7.3 d, spending the majority of its time on Heceta Bank off the central Oregon coast before being last located off Coos Bay, Oregon, on 22 September (**Figure 103**). Most locations for this whale were over the continental shelf. The second humpback whale was tracked for 18.9 d, traveling from its tagging location to an area just north of Cape Mendocino in that time, with 1- to 4-d stopovers at the continental shelf edge near Stonewall Bank, Heceta Bank, the shelf edge off Coos Bay, and the shelf waters off Point St. George and Trinidad, California (**Figure 103**).

Table 38. Deployment and performance data for satellite-monitored radio tags deployed on humpback whales off central Oregon, 2016. See Section 2.2.2 for location filtering method. Deployment dates reflect UTC dates.

Tag #	Sex	Tag Type	Deployment Date	Most Recent Location	# Days Tracked	# Filtered Locations	Total Distance (km)
5838	Female	DM	15-Sep-16	23-Sep-16	7.3	36	381
5923	Male	DM	15-Sep-16	4-Oct-16	18.9	82	920
	Mean	**DM**			**13.1**	**59**	**651**
	Median	**DM**			**13.1**	**59**	**651**

KEY: DM = Telonics RDW-665 Dive-Monitoring tag; km = kilometer(s); # = number

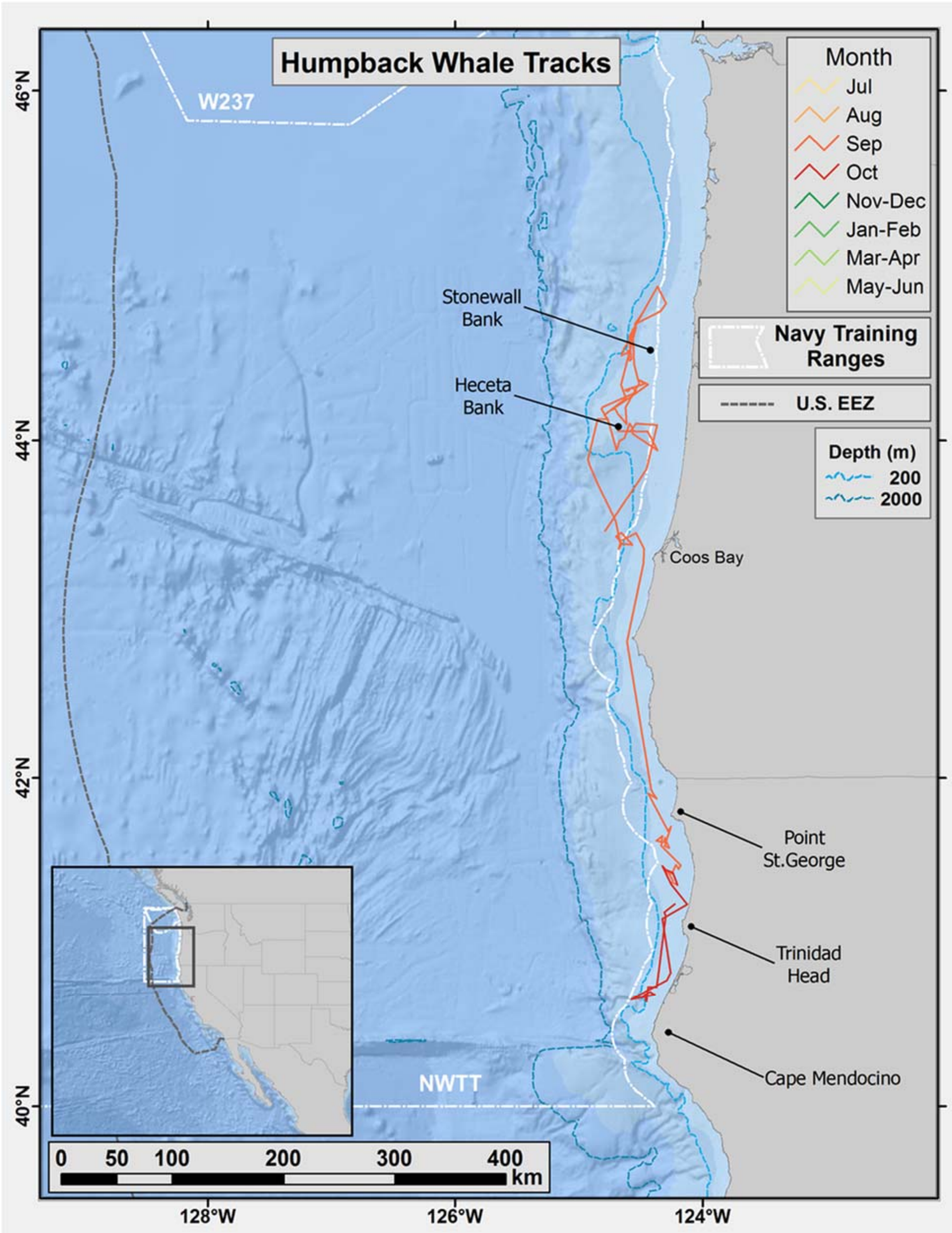

Figure 103. Satellite-monitored radio tracks for two humpback whales tagged off central Oregon in September 2016 (2 DM tags).

Almost all (97 percent) of the locations for whale Tag #5838 were within the NWTT, representing 90 percent of its total tracking period (7 d; **Table 39 and Figure 103**). For whale Tag #5923, only the locations north of Coos Bay, Oregon, were far enough offshore to be within the NWTT. Thirty-five percent of the locations for this latter whale were within the NWTT, representing 25 percent of its tracking period, or 5 d (**Table 39 and Figure 103**). Distances to shore in NWTT averaged 40 km (SD = 2.1 km, maximum = 63 km) (**Table 40**). Humpback whale locations within the NWTT occurred only in September. Neither of the tagged humpback whales was tracked in any other Navy training range.

Table 39. Percentage of filtered locations and time spent inside the SOCAL, PT MUGU, NWTT, and W237 areas for humpback whales tagged off central Oregon, 2016. See Section 2.2.2 for location filtering method.

Tag #	Tag Type	Total		SOCAL			PT MUGU			NWTT			W237		
		# Locs	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days
5838	DM	37	7.3	0	0	0	0	0	0	97	90	6.6	0	0	0
5923	DM	82	18.9	0	0	0	0	0	0	35	25	4.8	0	0	0
	Mean	**59**	**13.1**	**-**	**-**	**-**	**-**	**-**	**-**	**66**	**58**	**5.7**	-	-	-
	Median	**59**	**13.1**	**-**	**-**	**-**	**-**	**-**	**-**	**66**	**58**	**5.7**	-	-	-

KEY: DM = Telonics RDW-665 Dive-Monitoring tag; Locs = Locations; # = number

Table 40. Geodesic distances to nearest point on shore in Navy training ranges for humpback whales tagged off central Oregon, 2016 (including mean, median, and maximum distance to shore). The number of locations includes filtered locations (see Section 2.2.2 for filtering method) plus deployment location (when the deployment location occurred in a Navy range.

Tag #	Tag Type	SOCAL				PT MUGU				NWTT				W237			
		n	Mean	Median	Max	n	Mean	Median	Max	n	Mean	Median	Max	n	Mean	Median	Max
5838	DM	0	-	-	-	0	-	-	-	35	39	38	56	0	-	-	-
5923	DM	0	-	-	-	0	-	-	-	28	42	41	63	0	-	-	-
	Mean		**-**	**-**	**-**		**-**	**-**	**-**		**40**	**40**	**60**		-	-	-
	Median		**-**	**-**	**-**		**-**	**-**	**-**		**40**	**40**	**60**		-	-	-

KEY: DM = Telonics RDW-665 Dive-Monitoring tag; n = number of locations.

3.3.2 DM Tag Analysis

The two DM tags on humpback whales provided 563 and 1,032 dive summaries, respectively (**Table 41**). Dive depths were generally limited to the upper 100 m of the water column with Tag #5838 making dives as deep as approximately 150 m (**Figure 104**). Tag #5923 made substantially shallower dives, rarely exceeding 80 m in depth, however when it did, it made the deepest dives of the two whales, diving as deep as 225 m (**Figure 105**). Dives from Tag #5838 showed a diel trend with fewer lunges and shallower dives occurring at night, but no trend was evident in the dive data received from Tag #5923 (**Figures 104 and 105**). Daytime dive depths made by Tag #5923 were deeper off central Oregon compared to northern California (**Figure 106**) but no such comparison can be made for Tag #5838 as the tag stopped transmitting while the whale was off central Oregon.

Table 41. Summary statistics of DM tags deployed on humpback whales off central Oregon in September 2016.

Tag #	Sex	Tag type	Deployment Date	# Days Tracked	Mean Locs per Day	Distance (km)	# Dives Transmitted	Filtered Locs
5838	Female	DM	15-Sep-16	7.3	4.9	381	563	36
5923	Male	DM	15-Sep-16	18.9	4.5	931	1,032	85
			Mean	**13.1**	**4.7**	**656**	**798**	**81**
			Median	**13.1**	**4.7**	**656**	**798**	**81**

KEY: DM = Telonics RDW-665 Dive-Monitoring tag; km = kilometer(s); Locs = Locations; # = number

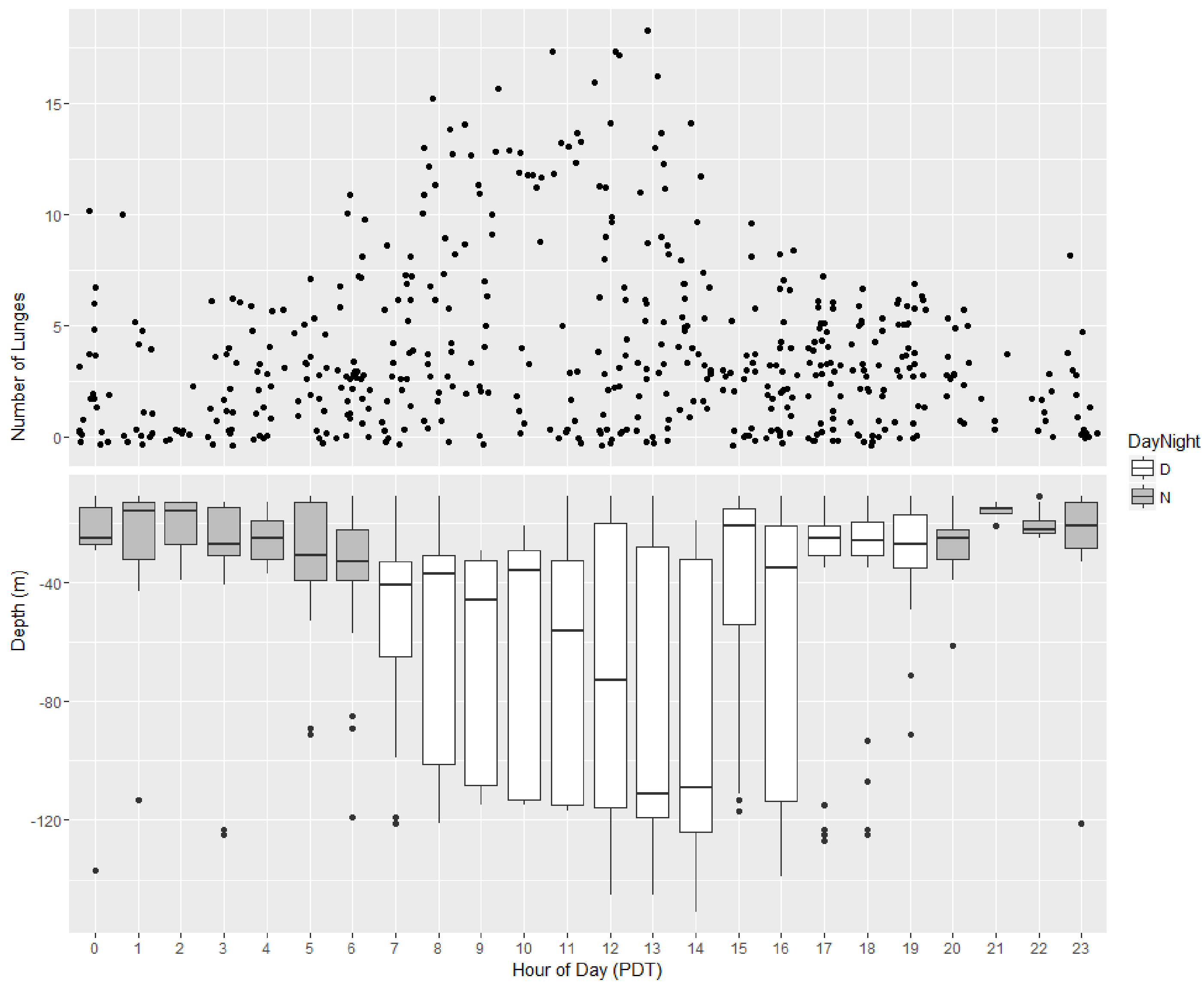

Figure 104. Number of lunges per dive (upper panel) and maximum dive depth (lower panel) of a DM-tagged humpback whale (Tag #5838) tracked off central Oregon during September 2016. Data are presented by hour of day to better visualize diel variability and the data in the top panel are jittered to avoid overplotting.

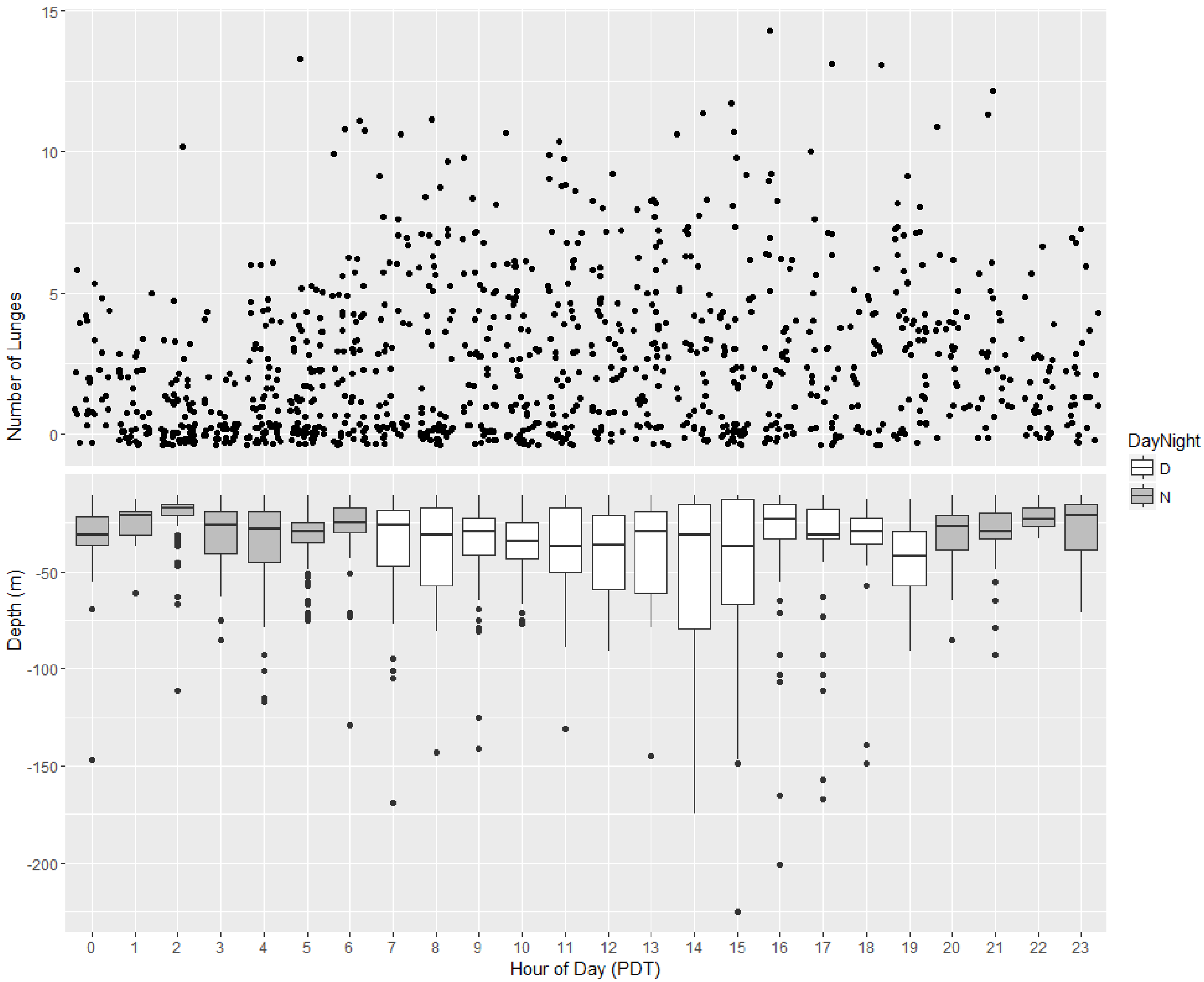

Figure 105. Number of lunges per dive (upper panel) and maximum dive depth (lower panel) of a DM-tagged humpback whale (Tag #5923) tracked off central Oregon during September 2016. Data are presented by hour of day to better visualize diel variability and the data in the top panel are jittered to avoid overplotting.

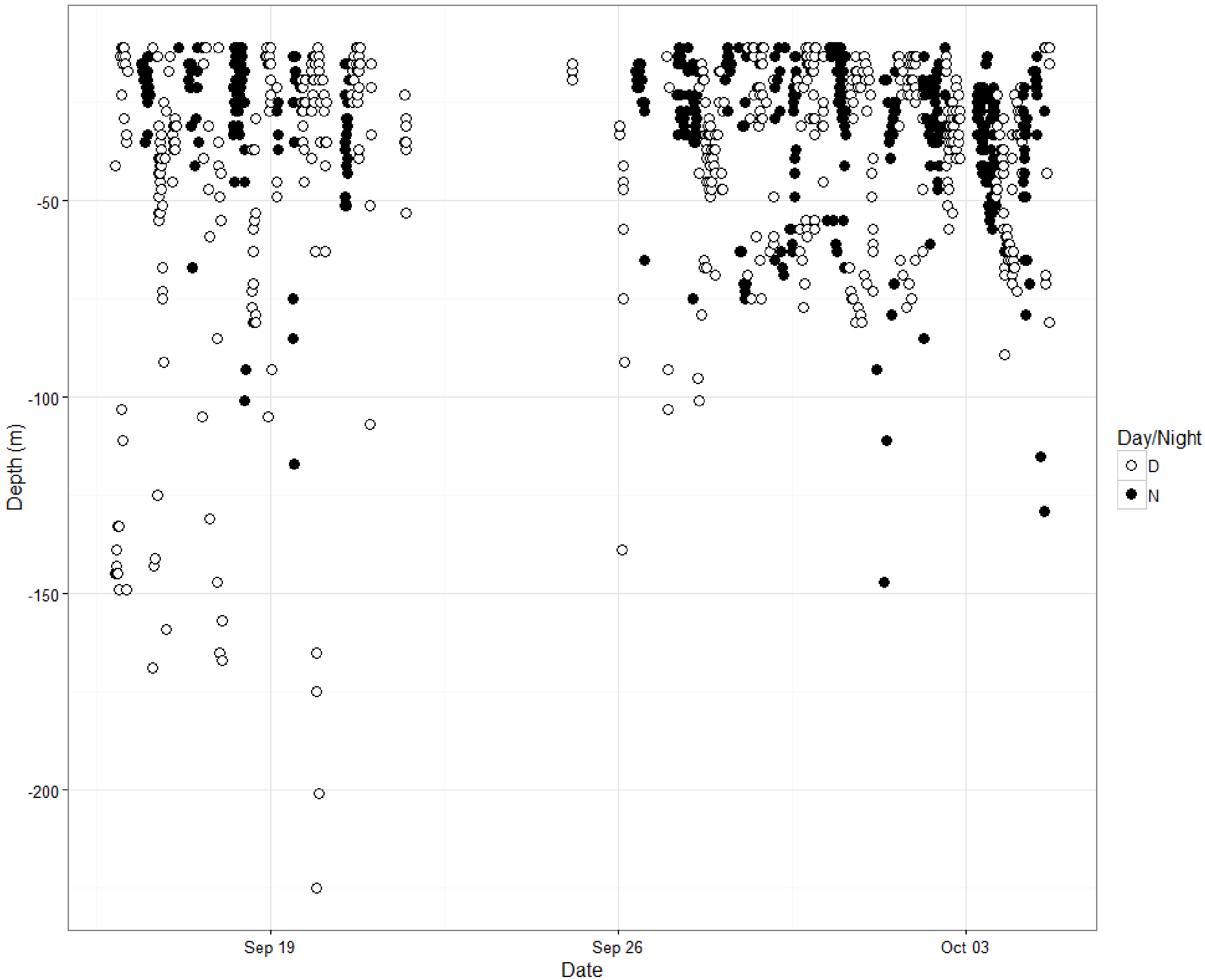

Figure 106. Maximum dive depth of a DM-tagged humpback whale (Tag #5923) tracked off central Oregon and northern California during September–October 2016. The whale was located off central Oregon until 25 September when it moved to northern California. The data gap in the middle of the record is likely due to an issue with the tag's saltwater conductivity sensor (see section 2.2.5).

3.3.3 Body Condition Assessment and Tagging Rates

In 2016, two humpback whales were tagged during approaches to 39 whales (5 percent; **Table 14**). No humpbacks appeared in poor body condition (**Table 14**).

3.3.4 Behavioral Responses to Tagging

Both of the tagged humpback whales exhibited short-term startle responses to the tagging/biopsy process. In each case, the response consisted of a moderate tail flick upon tagging.

3.3.5 Wound Healing

No tagged humpback whales from 2016 were resighted after tagging, so determination of wound healing could not be made.

3.3.6 Photo-ID

A total of 670 photos of humpback whales was taken during the 2 days of tagging off Oregon in 2016, from which 15 were determined to be unique individuals. No ID photographs were obtained from the tagged whales because they did not raise their flukes at any time during our encounters with them. Fluke photos are the current standard of identification for humpback whales.

3.3.7 Ecological Relationships - 2016

The SSMs generated regularized daily locations for 2 humpback whale tags in 2016, resulting in 27 estimated locations, of which 2 occurred on land (**Table 42**). The geographic extent of these tracks covered approximately 0.6 degrees of longitude (124.8–124.2°W) and 4 degrees of latitude (40.7–44.8°N) (**Figure 107**). All 25 accepted locations occurred in CCAL (100 percent). The ALSK, GUCA, NPPF, NPTG, PNEC and PQED provinces were not occupied by the tagged humpback whales in 2016 (**Table 42 and Figure 107**).

Table 42. Number of accepted SSM locations (and percentage) inside each province for humpback whales in 2016. Also provided are the number of locations that fell on land and the number of locations excluded from the analyses because their high estimation uncertainty. Unclassified locations correspond to the end-of-track locations, which do not receive a behavioral mode classification by the SSM. This number can be lower than the number of tracks because of the exclusion of locations on land and those with high estimation uncertainty. The number of SSM tracks is indicated (n).

	2016 (n = 2)
Longitudinal range	0.6 degrees (124.8–124.2°W)
Latitudinal range	4 degrees (40.7–44.8°N)
Province	
ALSK	NA
CCAL	25 (100%)
GUCA	NA
NPPF	NA
NPTG	NA
PNEC	NA
PQED	NA
Accepted locs.	25 (100%)
Unclassified locs.	2
Excluded locs.	0
Land locs.	2
Total locs.	27

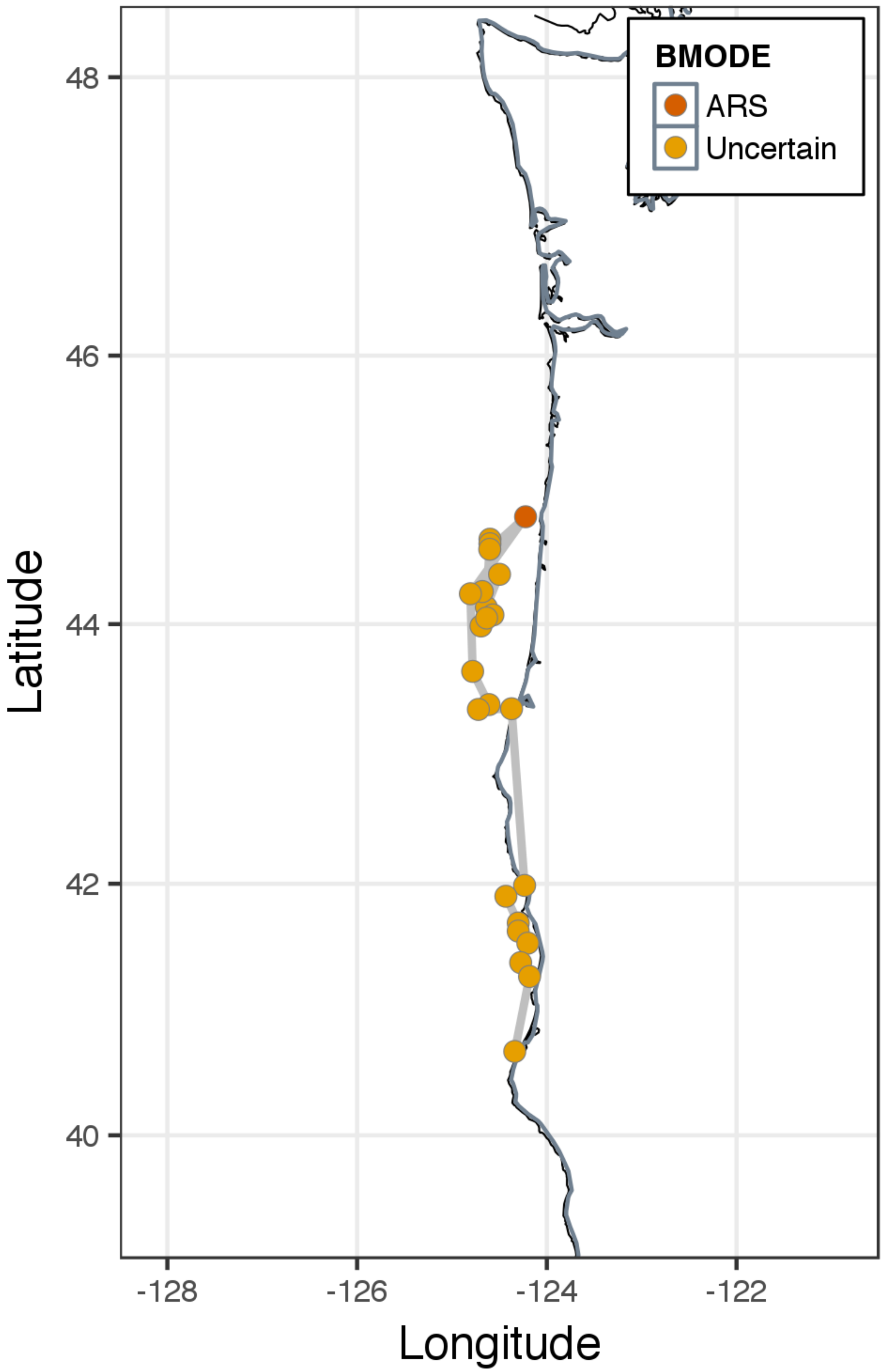

Figure 107. Accepted SSM locations colored by behavioral mode for the two humpback whales tagged off Oregon in 2016.

The behavioral classification for each location for all tracks is shown in the map in **Figure 107**. The number and proportion of locations classified by behavioral mode in CCAL is reported in **Table 43**. Of 23 SSM locations, 1 (4.3 percent) was classified as ARS, 22 (95.7 percent) were classified as uncertain, and none (0 percent) were classified as transiting (**Table 43**).

Table 43. Number of classified SSM locations (and percentage) in CCAL for each behavioral mode for humpback whales in 2016. The number of SSM tracks is indicated (n).

Behavioral mode	2016 (n = 2)
Transiting	NA
Uncertain	22 (95.7%)
ARS	1 (4.3%)
Classified locs.	23 (100%)

Details of the environmental variables examined are provided in **Table 1**. Summary statistics for these variables obtained for the SSM locations are reported in **Tables 18 and 19**. Average WEKM was -3.8e-07 m s^{-1}, average SST was 13.36°C, and average CHL was 6.78 mg m^{-3} (**Table 18**). The values at each location for these environmental variables are shown in the maps in **Figures 108 through 110**.

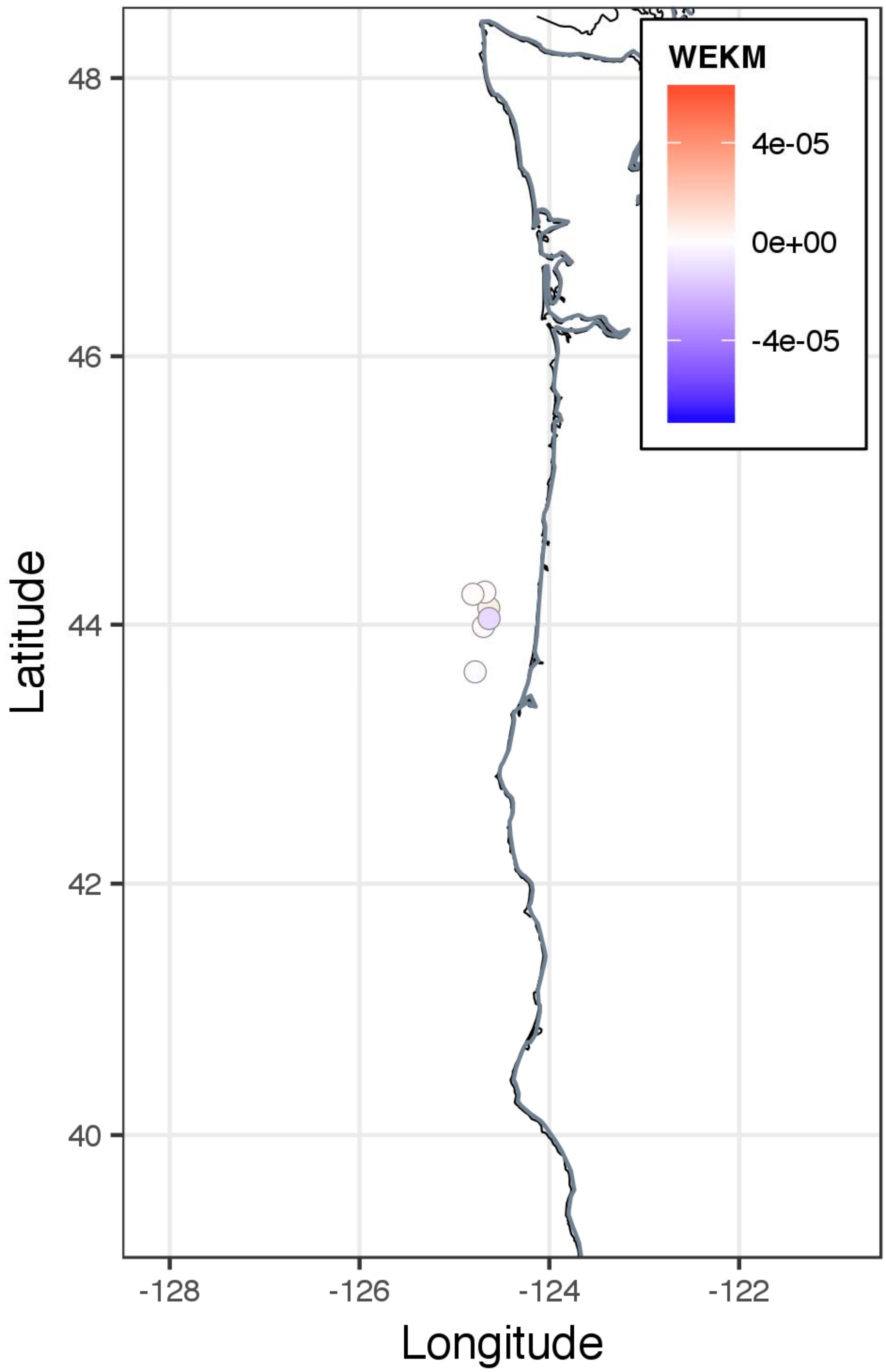

Figure 108. Map representation of vertical upwelling velocity (WEKM, m s^{-1}) values obtained from satellite remote sensing for the two humpback whales tagged off Oregon in 2016.

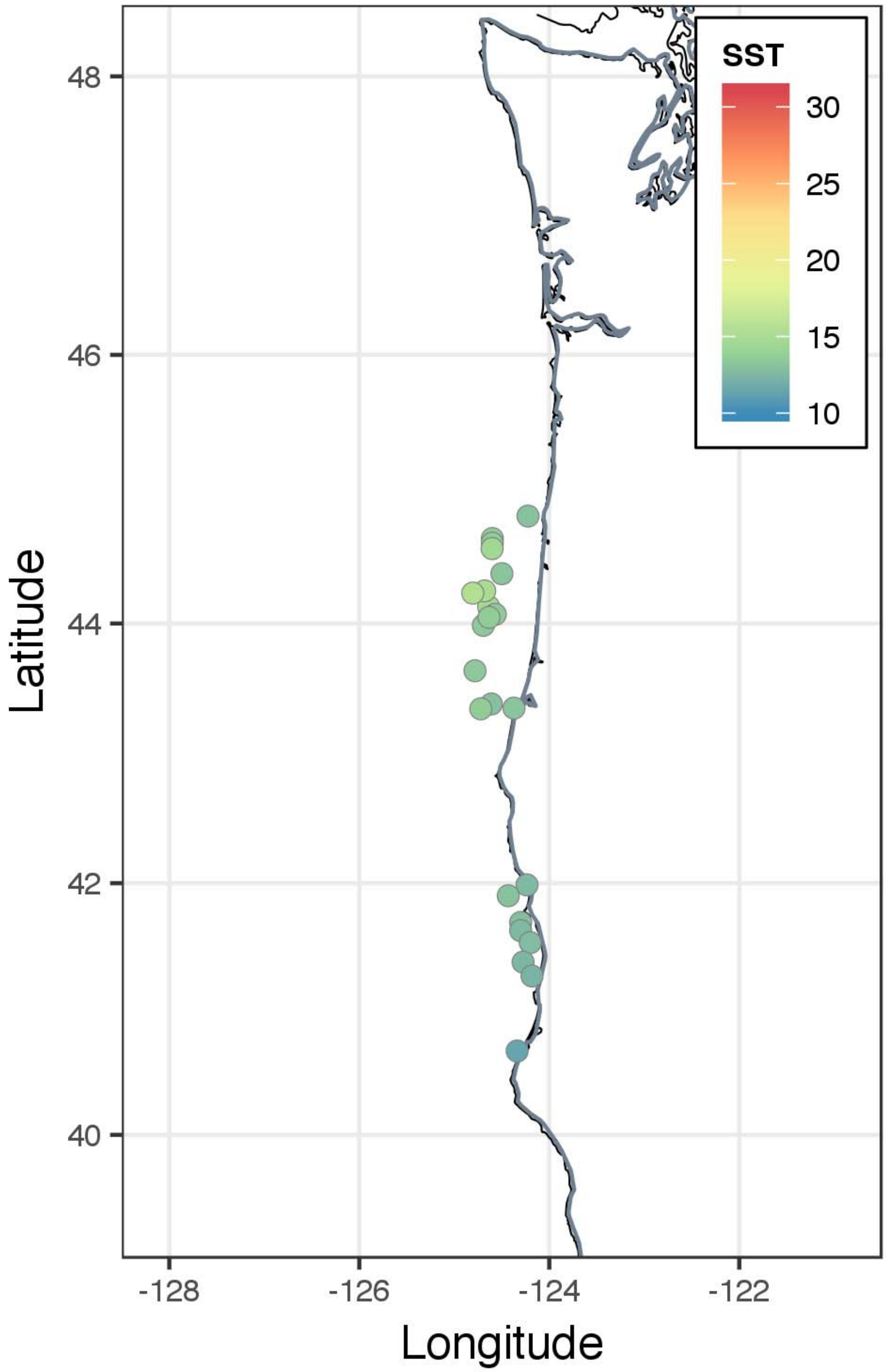

Figure 109. Map representation of sea surface temperature (SST, °C) values obtained from satellite remote sensing for the two humpback whales tagged off Oregon in 2016.

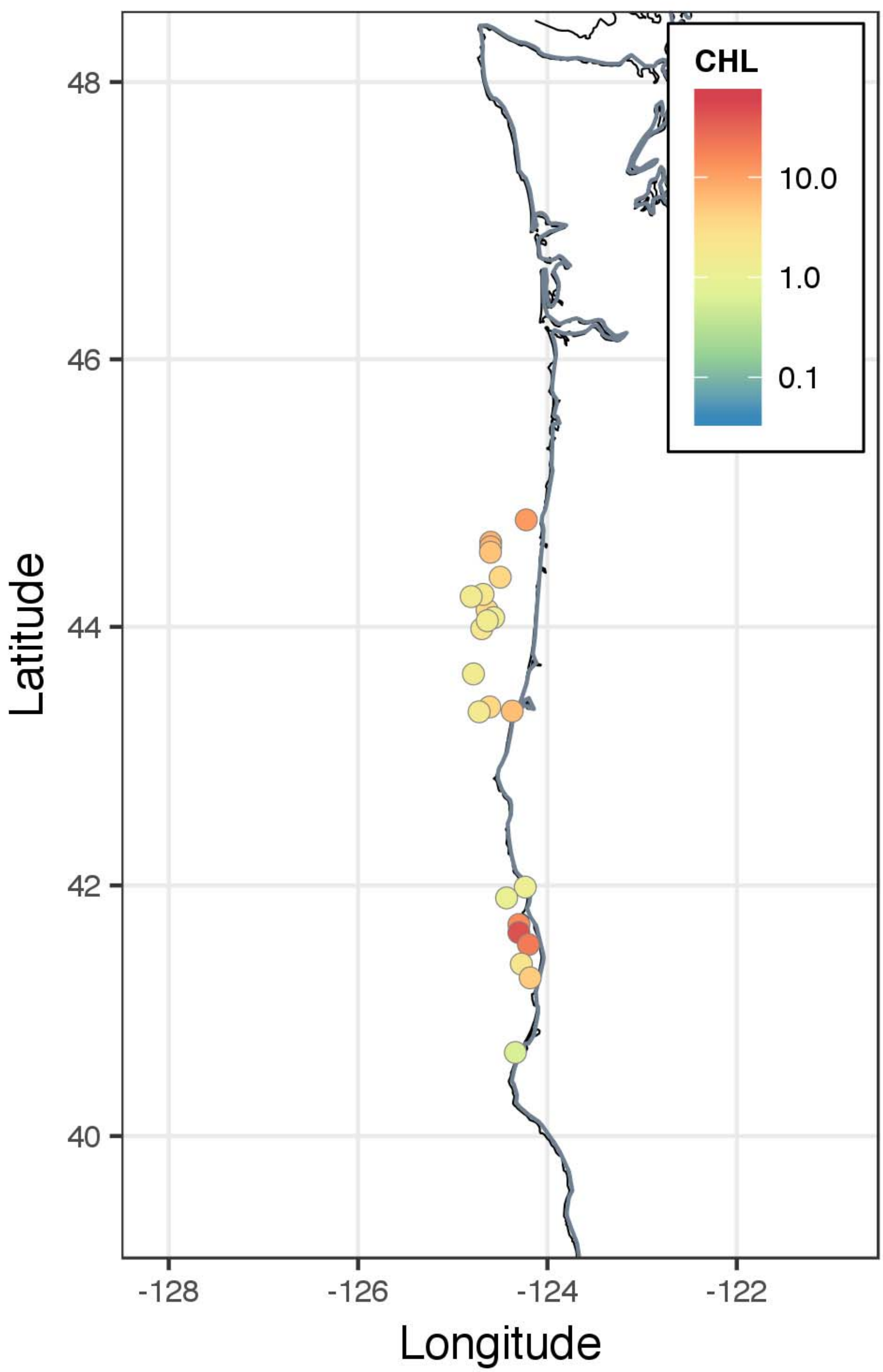

Figure 110. Map representation of chlorophyll-*a* concentration (CHL, mg m^{-3}) values obtained from satellite remote sensing for the two humpback whales tagged off Oregon in 2016.

In terms of seafloor characteristics, humpback whales occurred in areas with an average DEPTH of 143.2 m, average DISTSHELF of 12.24 km, and average DISTSHORE of 27.46 km. The average SLOPE in these areas was 7.69 m km^{-1} and faced toward the west (average ASPECT = 258.34°) (**Table 19**). The values at each location for these seafloor relief variables are shown in the maps in **Figures 111 through 115**.

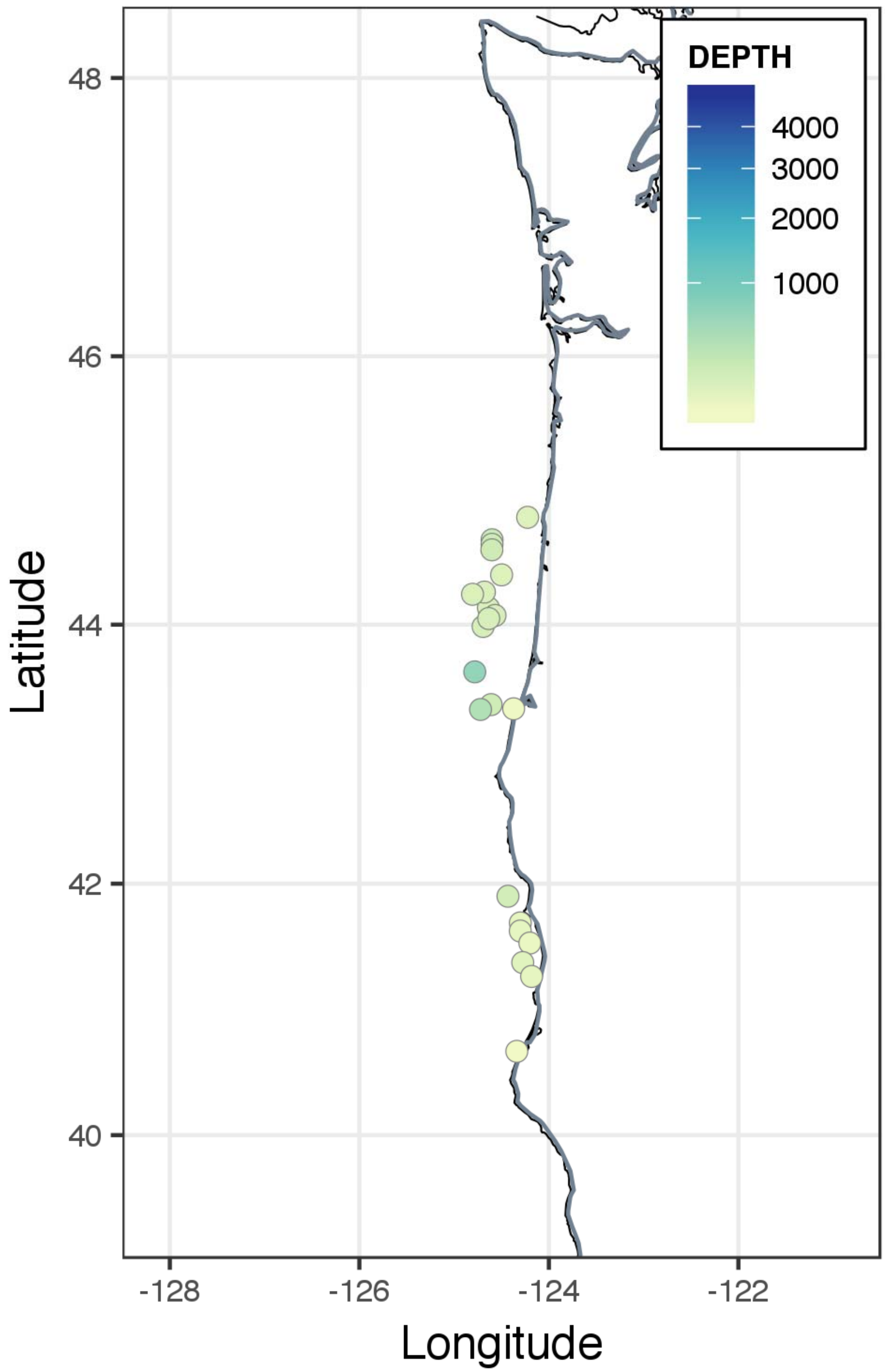

Figure 111. Map representation of seafloor depth (DEPTH, m) values obtained from ETOPO1 for the two humpback whales tagged off Oregon in 2016.

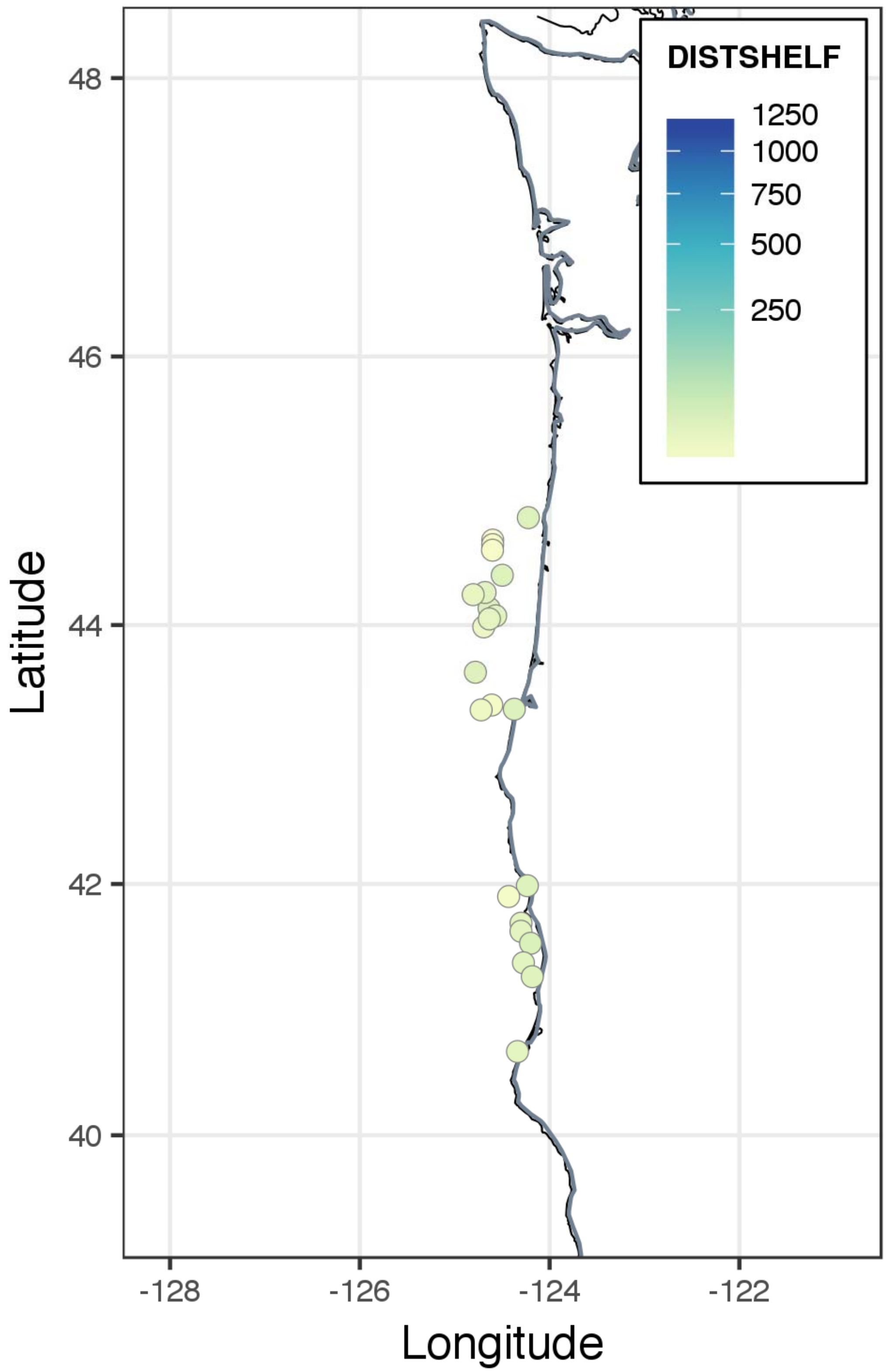

Figure 112. Map representation of distance to the 200 m isobath (DISTSHELF, km) values obtained from ETOPO1 for the two humpback whales tagged off Oregon in 2016.

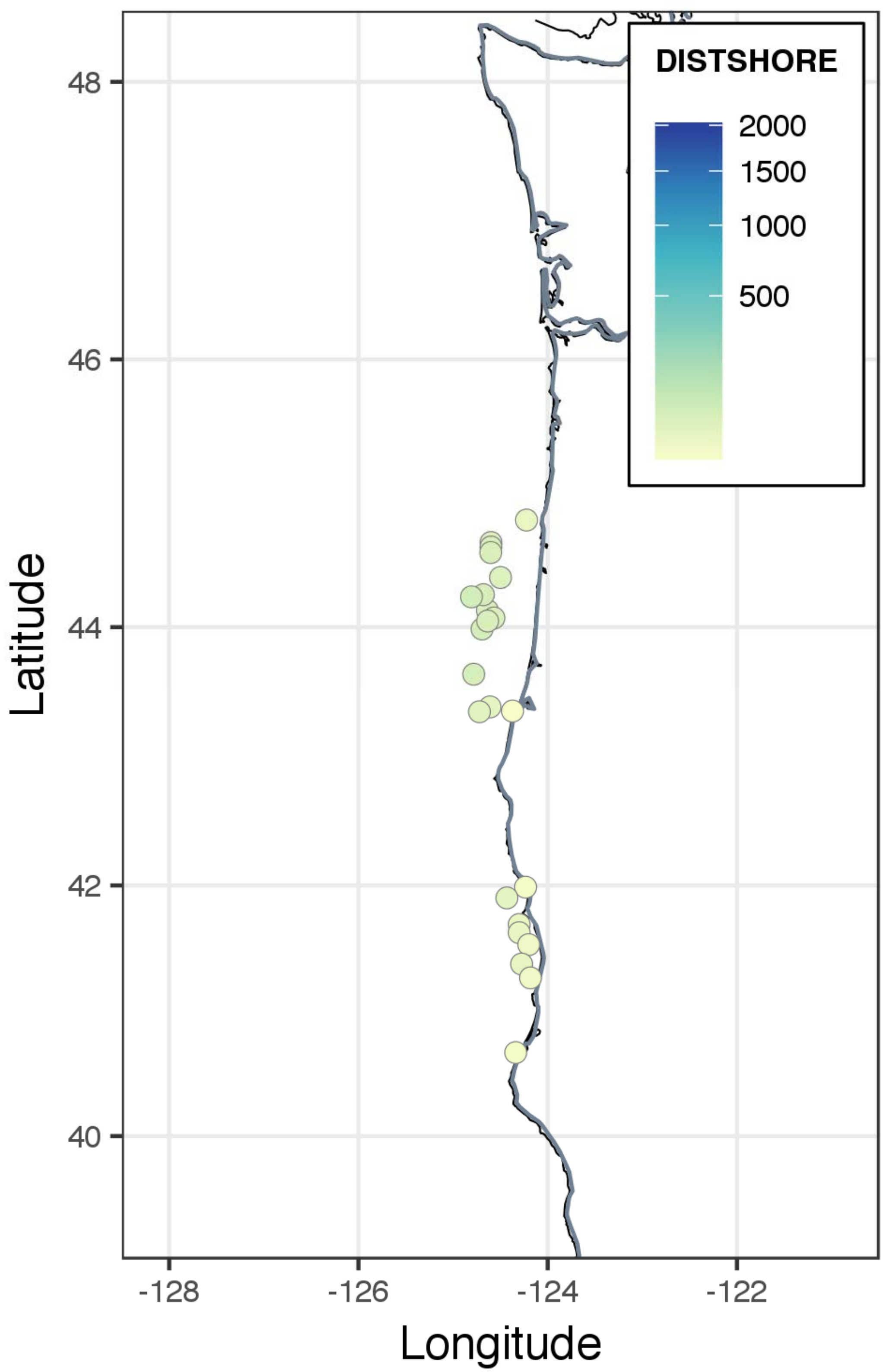

Figure 113. Map representation of distance to the shore (DISTSHORE, km) values obtained from ETOPO1 for the two humpback whales tagged off Oregon in 2016.

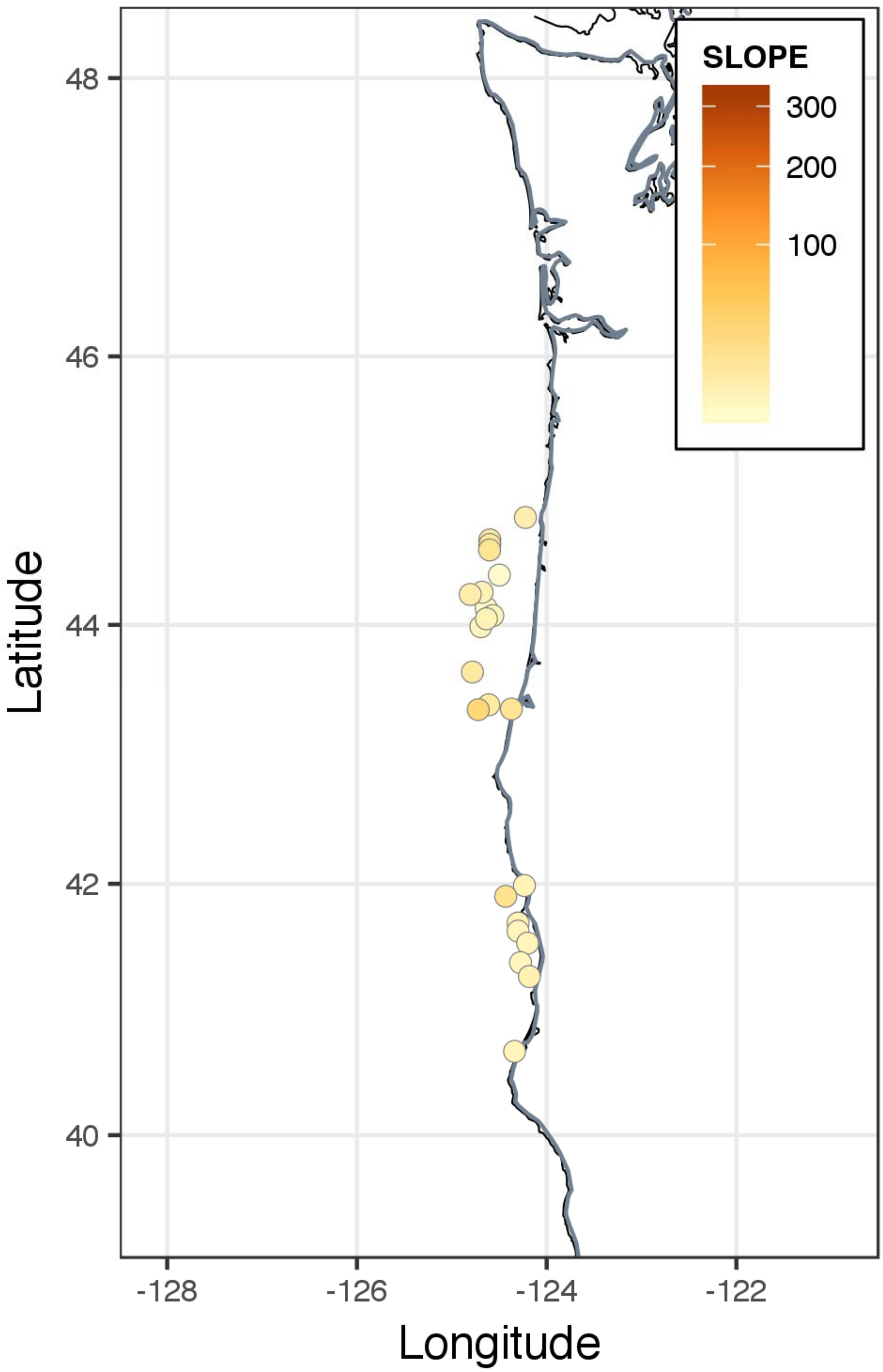

Figure 114. Map representation of seafloor slope (SLOPE, m km^{-1}) values obtained from ETOPO1 for the two humpback whales tagged off Oregon in 2016.

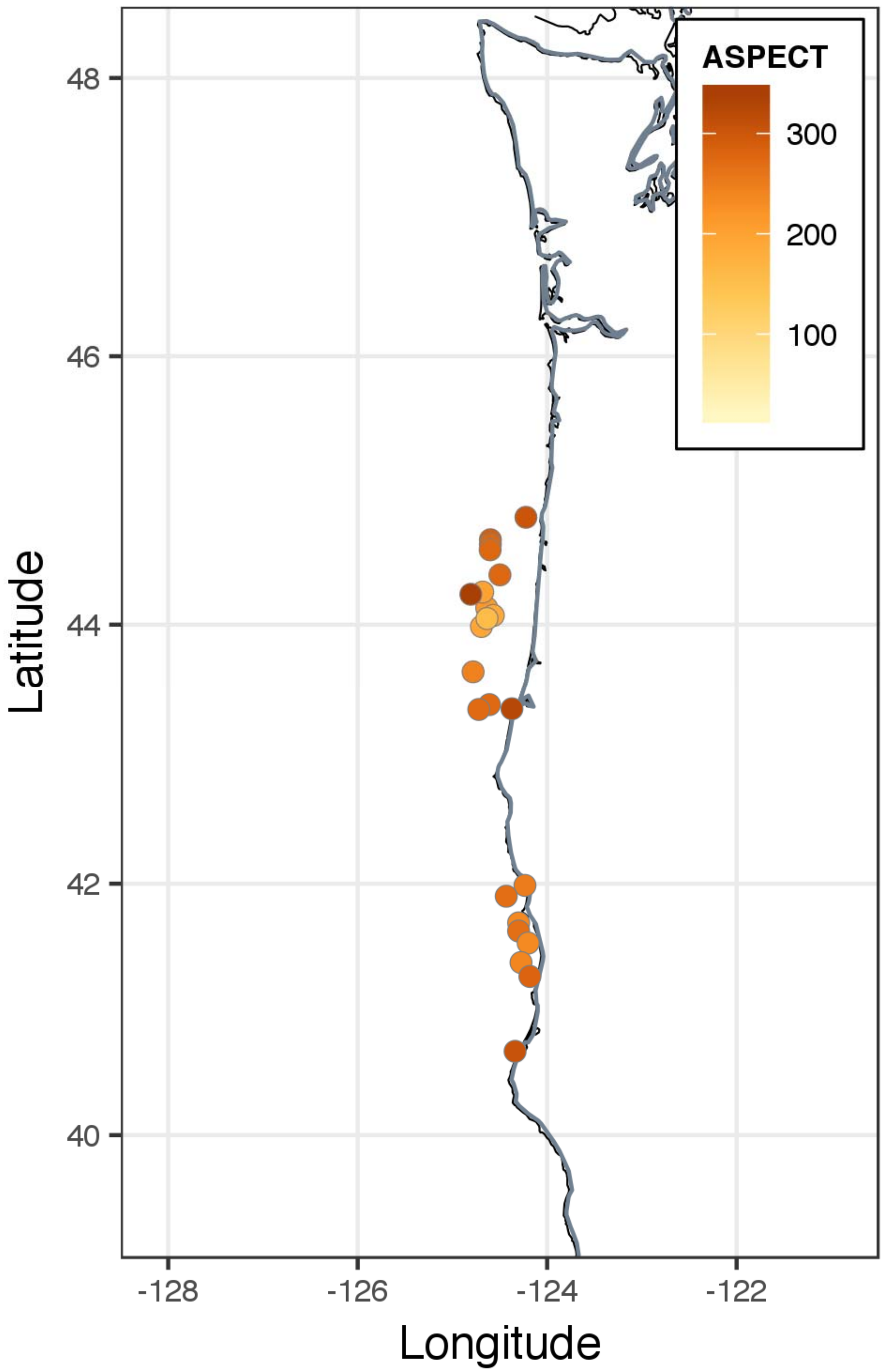

Figure 115. Map representation of seafloor slope aspect (ASPECT, degrees) values obtained from ETOPO1 for the two humpback whales tagged off Oregon in 2016.

An examination of the ONI, PDO (**Figure 59**), and other interannual climatic perturbations during the three years of this study was presented in **Section 3.1.6** concerning blue whales. These results apply to humpback whales as well, and the reader is referred to that section for the climatic context in 2016.

3.3.8 Genetics and Species Identification

In 2016, skin biopsy samples were collected from the two tagged whales and the third whale for which tagging was unsuccessful, all of which were considered humpback whales based on field observations (**Figure 101**).

All samples provided DNA profiles sufficient for subsequent analyses and comparison of mtDNA sequences with reference sequences confirmed species identification.

3.3.8.1 SEX DETERMINATION

The three humpback whale samples (one of which came from the whale that was unsuccessfully tagged) represented one female and two males (**Table 38**).

3.3.8.2 INDIVIDUAL IDENTIFICATION

All three humpback whale samples were represented by unique multi-locus genotypes and the probability of identity for the 16 loci was very low, 6.2×10^{-12} (i.e., there was a very low probability of a match by chance). This was consistent with sex and mtDNA sequence as provided by the full profile.

The DNA profiles of the three humpback whales tagged in 2016 were compared to a reference database of 1,805 humpback whales from all known North Pacific breeding and feeding grounds as described in Baker et al. (2013). There were no matches between these two datasets.

3.3.8.3 STOCK IDENTIFICATION

The three tagged humpback whales resolved two haplotypes previously identified in North Pacific humpback whales. A sample size of three is not large enough for statistical analysis; however, a qualitative comparison was conducted between the mtDNA haplotypes found in the tagged dataset and those found in four feeding grounds in the eastern North Pacific (**Table 44**; Baker et al. 2013). The mtDNA haplotypes of the three tagged humpback whales showed a greater affinity with those from feeding grounds along the coast from Oregon to southeastern Alaska than to those from California.

Table 44. The frequency and identity of 19 mtDNA haplotypes for humpback whales from feeding grounds of the eastern North Pacific, including three from the 2016 tagging. California (CA), South British Columbia/Washington (SBC/WA) and Southeast Alaska /North British Columbia (SEA/BC) data comes from analysis of samples collected during the SPLASH project (Baker et al. 2013) and prior. The Oregon (OR) dataset is a combination of 3 individuals sampled during SPLASH (Baker et al. 2013) and 11 humpback whales sampled earlier (pre-SPLASH).

mtDNA haplotype	GenBank code	CA	OR	SBC/WA	SEA/NBC	2016 Tagged Whales
A-	KF477245	1	2	11	184	
A+	KF477244	8	2	14	85	2
A3	KF477246	5				
A4	KF477247				1	
E1	KF477249	24	4	7	1	
E2	KF477256				14	1
E3	KF477257	2				
E4	KF477258	8	2	8		
E5	KF477259	2				
E6	KF477260	3		1		
E7	KF477261	2	2	7		
E10	KF477250	3	1	1		
E13	KF477253	5		1		
F1	KF477265	5				
F2	KF477266	43	1	1	2	
F3	KF477271	4				
F4	KF477268	1				
F6	KF477267	3				
F8	KF477270	1				
Total individuals		**122**	**14**	**51**	**294**	**3**

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4. Discussion

This report details the results of three years of tracking data for blue and fin whales tagged in southern California waters, as well as one season of tracking data for humpback whales tagged off the Oregon coast. The resulting tracks and dive behavior data provide valuable information regarding the timing, distribution, and behavior of these species within Navy training ranges in the eastern Pacific and NMFS-identified BIAs for blue whales, and allow for the examination of baleen whale movements in relation to oceanographic conditions. The biopsy samples collected provided sex determination for tagged whales and individual identifications, as well as stock structure information.

As in 2014 and 2015, blue whales continued to be more numerous and easier to approach than fin whales in 2016, with the result that more tags were applied to blue whales than fins (19 blue whales versus 14 fin whales). Only two tags were successfully deployed on humpback whales off Oregon, due principally to inclement weather conditions off the Oregon coast in late summer/fall, resulting in only 2 d of workable tagging opportunities. Mean tracking duration for the three years combined was slightly longer for blue whales (77.9 d) than for fin whales (55.9 d), but not significantly so. The two humpback whales tagged in 2016 had a mean tracking duration of 13.1 d.

4.1 Blue Whale

4.1.1 Tracking Analysis

The tracking results from blue whales tagged in 2016 continue to expand our knowledge of the long-term movements, distribution, and dive behavior of these whales in the eastern North Pacific, supplementing information from past years on blue whale occurrence and use of Navy training and testing ranges. As in 2014 and 2015, the majority of the blue whale locations were within the distribution of blue whales described in previous studies (Calambokidis et al. 2009, 2015, Bailey et al. 2009, Irvine et al. 2014). In 2016, tagging activities were conducted in both southern (11 whales tagged) and central (eight whales tagged) California waters due to a scarcity of "tagable" (i.e., in good body condition) whales in southern California. These two areas, separated by approximately 425 km constitute the two primary hotspots of aggregation for blue whales during the summer and fall (Irvine et al. 2014). The tagging in the two areas in 2016 afforded us the opportunity to look at possible differences in movement patterns and habitat use between the two areas during the same year.

With a few exceptions, the movements of blue whales tagged in the two areas were quite different. All but one of the ten blue whales tagged in southern California remained in waters south of Point Sur on the central California coast (the one exception was whale Tag #836 that traveled as far north as the California/Oregon border). Only three of the eight blue whales tagged in central California spent time in southern California waters during their tracking periods. For whales that were tracked for only a short period of time the different tagging locations and the time of year may have been the reason for this spatial separation, but only four of the 18 whales had tracking durations less than 5 d. Tracking durations for the remaining 14 whales were all greater than 44 d, which was ample time for the whales to range widely had they been so inclined. While some whales were tagged almost three weeks apart, tracking durations were long enough to ensure sufficient overlap in tracking periods between the two tagging groups. The photo-ID results lend support to the idea of spatial group differentiation, as only one whale photographed off central California had been seen in the previous 2 years, when we operated in southern California only, compared to six (of the seven resights) photographed in southern California in 2016.

While the spatial separation and photo-ID results from 2016 suggested the possibility of distinct groups of blue whales in southern versus central California, the examination of tracks of all blue whales tagged by OSU from 1994 to 2016 appeared to refute this idea. Despite some interannual and individual variation in movements over the 22-year period, overall feeding area distribution and migratory destinations were similar between whales tagged in southern and central California. The differences noted between the two tagging groups in 2016 may have been the result of increased productivity in both locations, allowing blue whales to remain in more localized areas, rather than some intrinsic variability between the groups leading to feeding area separation.

Differences also existed between the three tagging years in this study (2014, 2015, and 2016), in latitudinal range of blue whales, in total distances traveled, and in sizes and locations of home ranges and core areas. The significantly longer distances traveled and larger home ranges and core areas in 2014 than in either 2015 or 2016 were likely the result of poorer productivity in the California Current System in 2014 (during the 2013–2015 heat wave; Leising et al. 2015, McClatchie et al. 2016), requiring blue whales to range farther to find food. Unlike humpback whales, which have been shown to switch their dominant prey type (from euphausiids to fish or vice versa) in response to changing oceanographic conditions and prey availability (Fleming et al. 2016), blue whales are almost completely stenophagous (euphausiid-eating). They may need to travel in search of other sources of euphausiids in times of low euphausiid abundance (Hazen et al. 2012), rather than switching to a different prey type. Fleming et al. (2016) noted that blue whales were distributed more widely throughout the California Current System and farther north in 2004 to 2006 when there was a delay in seasonal summer upwelling (compared to other years) and poor euphausiid recruitment in nearshore feeding areas. Calambokidis et al. (2009) also pointed to changes in oceanographic conditions and inadequate feeding conditions in California to explain recent shifts in blue whale habitat to include areas off British Columbia and Alaska. Burtenshaw et al. (2004) reported increased calling duration of vocalizing blue whales off Washington and Vancouver Island in 1998 and 1999 than in other years of their study, and suggested this was due to increased prey availability or increased northern movements by whales. The northern extent of blue whale locations in this study in 2014 was off the northern tip of Vancouver Island, compared to central Oregon for both 2015 and 2016 blue whales, when upwelling conditions were more prevalent (Leising et al. 2015, McClatchie et al. 2016).

PT MUGU was the most heavily used Navy training range by blue whales for the three years of study combined, both in terms of total numbers of whales having locations there (50 of 63 tracked whales) and in residence time (overall mean of 26.2 d). This is not surprising, as this range encompasses one of the main hotspots of blue whale occurrence in California (the western end of the Santa Barbara Channel), as identified by overlapping core areas for tagged blue whales in this study and in Irvine et al. (2014). SOCAL was also used by a high number of blue whales in this study (37 of 63 tracked whales), and was the most heavily used range in 2014. Differences in blue whale use of Navy training ranges between different tagging years was likely driven by differing oceanographic conditions. In 2014, blue whales used inshore, more southern waters of the Southern California Bight when there was a collapse of the typical upwelling at Point Conception (Leising et al. 2015). The NWTT area was used by a small number of blue whales (9 of 63) over the three-year study, but those that were located there spent an average of 23.2 d in the area, resulting in more extensive overlap of HRs and CAs with this range than with SOCAL. In both 2014 and 2016, 17 percent of tracked blue whales spent time in NWTT, which suggests that the area is not just used by blue whales in times of reduced productivity. Only one of 63 tracked blue whales had locations in area W237 of the NWTT, however, spending 19.5 d in the area in 2014. Area W237 area may only be used by a small number of blue whales and only in times of reduced productivity, as whales range farther north in search of food. While the number of tagged blue whales occurring in the NWTT and W237 are not high, the lengthy residencies highlight the importance of both of these areas as northern feeding habitat for some blue whales.

Blue whale locations occurred in PT MUGU from July to December, in SOCAL from July to November, in NWTT from August to December, and in W237 from September to November. The predominance of summer and fall locations of tagged blue whales in Navy training ranges off the U.S. West Coast reflects the seasonality typical of most baleen whales, in which individuals migrate poleward to feeding areas in the summer and fall. Two blue whales in this study were tracked returning to U.S. waters after migrating south for the winter, and provided additional locations in SOCAL in March and June, and in PT MUGU in March and April. These results indicate that springtime use of Navy ranges, and southern ranges in particular, may be common, whereas winter occurrence in the ranges is rare.

As with the Navy training ranges, there were also some striking differences in blue whale use of BIAs between 2014 and the other two tagging years. The San Diego and the Santa Monica Bay to Long Beach BIAs were the most heavily used in 2014, whereas the Santa Barbara Channel and San Miguel Island and the Point Conception/Arguello BIAs were the most heavily used in 2015 and 2016. This preference for the more southeasterly and coastal BIAs in 2014 coincided with the decrease of upwelling mentioned above around Point Conception that year (Leising et al. 2015). Despite these interannual differences, overall the Santa Barbara Channel and San Miguel Island BIA appears to be the most important BIA to blue whales of the six that overlap Navy training ranges, in terms of number of whales using the area, time spent there (with a maximum residency of 63.3 d), and number of overlapping core areas. The shelf breaks, island slopes, and nearby seamounts at the west end of the Channel Islands support dense aggregations of euphausiids as a result of increased turbulence, mixing, and increased surface nutrients, and contribute to the importance of this area for blue whales (Fiedler et al. 1998, Burtenshaw et al. 2004). The remaining two BIAs, San Nicolas Island and Tanner/Cortez Banks, were used only minimally by blue whales in 2016, as was the case in 2014 and 2015, suggesting that these areas are of much less importance to blue whales than the other BIAs. The majority of our tracking results are from summer and fall, however, and perhaps these latter BIAs see more blue whale use in the spring.

4.1.2 ADB Tag Analysis

The ADB tag data offer an unprecedented ability to observe how the diving behavior of blue whales changes at high spatial and temporal resolution, and allow us to see how consistent those behaviors are across individuals. The high degree of variability in the number of GPS locations recorded by the tags appears to have been related to the different versions of the Fastloc® software running the tags, but even the tags that recorded the fewest locations provided significantly more and better quality, locations than would be expected from an Argos-style tag.

Once the ADB-tagged whales departed the tagging area none stayed in one area for any period of time. Their behavior would best be described as searching with occasional bouts of foraging. This suggests that prey was patchy and possibly even scarce in southern California waters, and the tagging location may have occurred within the only significant concentration of prey in that area during the tracking period. ADB-tagged whales in 2015 used areas substantially farther offshore than whales tagged in 2014 except Tag #2015_838. While it may be coincidental, it should be noted that this whale was tagged close to shore near Point Mugu, California, where the 2014 whales were tagged, while the other three whales were tagged at the west end of the Santa Barbara Channel. The sample size is too limited for any conclusions; however, it does hint that different individuals may preferentially use different portions of the southern California waters. If this were the case, such whales would be more likely to occur in nearshore Navy training areas, and would be at higher risk of repeated exposure compared to whales in other parts of southern California.

One whale in each year (Tag #2014_5650 and #2015_4177) made a clockwise circuit through most of the southern California waters with few, if any, stops to forage. In both years the whales passed through areas where other tagged whales were foraging, suggesting that either 1) the whales were not able to find the prey being consumed by other tagged whales, 2) the prey was so ephemeral that it had already been depleted by the time the whale passed through, 3) the existing prey concentrations were not sufficient for the whale to expend the effort of feeding due to previous satiation or individual differences in feeding thresholds, or 4) feeding was not the primary driver of the whales' behavior. Blue whales have been shown to adjust their dive behavior and number of lunges made per dive based on the density of prey in the area (Goldbogen et al. 2015, Hazen et al. 2015). It is therefore not unreasonable to hypothesize that the criteria for an 'acceptable' density of prey for a whale to feed on may vary between individuals and may even be related to the whale's body condition. However, there is also a possible explanation that this behavior is not related to foraging, as both whales making the circuit through southern California waters were male. While these are results from a very limited sample, it is possible that their movements were related to reproductive, rather than foraging, behavior. Little is known about blue whale reproductive behavior and the timing of its occurrence. Whales have been observed engaged in rapid pursuit behavior, indicative of pre-courtship behavior, off southern California (OSU field observations), so it is possible that courtship, or at least searching for a potential mate, may begin much earlier than previously thought, and was the reason for the whales' circuits in southern California waters and the relatively limited foraging effort.

The general dive behaviors recorded by the ADB tags, showing that the whales tended to dive deeper and feed more during the day, are consistent with the published literature (Calambokidis et al. 2007, Doniol-Valcroze et al. 2011); however, the observed variability between tagged individuals indicates that feeding behavior in blue whales is more complex at the scales sampled by these tags than previously documented. While there was a clear diel pattern observed in the data, a non-negligible proportion of feeding dives occurred at night, when the whales are generally thought to be resting or otherwise not engaged in feeding. While it is not unknown for blue whales to feed at night (Doniol-Valcroze et al. 2011), there is relatively little information about it in the literature. These data offer the chance to see where the nightime feeding was occurring and what kind of behavior led up to the nightime feeding events. A number of the nightime feeding events recorded by the ADB tags occurred in the hours just prior to sunrise or after sunset. Dive profiles from those time periods show the bottom depth of recorded dives ascending or descending in the water column. This phenomenon has been shown to be the result of the whale following the diel vertical migration of the deep-scattering layer as it either ascends or descends in the water column (Fiedler et al. 1998, Calambokidis et al. 2007, Doniol-Valcroze et al. 2011). It may be that, if prey is dense enough, the whale can continue to feed at night, after the prey has migrated up the water column.

Feeding bouts were generally of intermediate duration, although there was substantial variability between individuals. Overall, most feeding bouts were approximately 2 h long, and bout duration was correlated to the number of lunges per dive that occurred within a feeding bout. Blue whales have been shown to adjust their behavior and number of lunges made per dive based on the density of prey in the area (Goldbogen et al. 2015, Hazen et al. 2015), so the correlation between bout duration and number of lunges per dive indicates that the whales quickly left lower-density prey patches, and that they stayed longer and fed more intensely in higher-density patches. However, while the sample size is very small, female blue whales generally fed for longer periods of time than male whales across both years. This may be an indication that female blue whales have greater energetic requirements than males, although it also is likely an indirect expression of the circuits made by two male ADB-tagged blue whales around southern California waters where they engaged in limited feeding. If males have lower energetic requirements than females, that may allow some to sacrifice energetic gain while on the feeding grounds in order to start courtship behavior earlier. This would suggest there may be an additional social component driving blue whale behavior while on the feeding grounds, and that female blue whales remain in an area for longer time periods than males.

The spatial distribution of feeding bouts was highly variable within and between individuals, though the results suggest that blue whales typically feed in areas 2.6 km^2 in size. It is likely that some of the larger feeding bout areas were the result of an insufficient number of locations to define the true extent of the area being used for feeding. Longer-duration feeding bouts were also relatively linear at times, which would inflate the calculated area. Feeding bouts were generally more numerous and overlapped more frequently earlier in the tracks, especially in 2014, suggesting the whales were feeding on large concentrations of prey when first tagged and then were encountering smaller, more dispersed patches of prey later in the track. The relatively linear nature of many feeding bouts was surprising, as whales would be expected to turn in order to feed within a patch, thereby creating a cluster of locations over the prey patch. Some of the feeding bouts extended across > 20 km, which far exceeds the spatial scale of euphausiid patches off central California (1.8 to 7.4 km) described using overlap with euphausiid-feeding seabirds (Santora et al. 2011). It is therefore possible that the more linear foraging bouts may represent the whales feeding on sequential smaller patches of prey rather than one very large prey patch.

The results of this study indicate that, on a broad scale, blue whale behavior is generally similar across individuals, with the whales mostly foraging during the day at a range of depths, likely dependent on the depth and concentration of prey. However, at a finer scale, there are differences between individuals in both overall diving behavior and the diving behavior during foraging bouts, with some whales consistently making deeper foraging dives and/or longer duration foraging bouts. Without knowing the structure of the prey field being exploited, it is difficult to be sure how much these differences are related to the individual versus whales exploiting prey in different areas. Blue whales are thought to preferentially feed on the adult stage of euphausiids (Fiedler et al. 1998, Croll et al. 2005), which have been found to occupy deeper parts of the water column (Bollens et al. 1992, Lavaniegos 1996). It is possible the observed differences represent different foraging strategies across individuals or possibly that different individuals have different energetic requirements that allow some whales to forage less intensively on lower prey concentrations (i.e., less dense prey at shallower depths), different age classes, or different prey species, while others expend more effort and forage deeper where prey is denser. Further effort is needed to resolve these questions.

4.1.3 DM Tag Analysis

DM tags offered the ability to document blue whale diving and feeding behavior over substantially longer time periods than were previously possible, allowing for better insight into where and how much feeding occurs off the U.S. West Coast. The number of lunges detected per dive by the tags was higher than expected, suggesting there were non-feeding dives included in the number. However, the diel pattern of more lunges and deeper dives reported during the day by DM tags matches closely with what was documented by ADB tags deployed in 2014–2015. This suggests that the number of lunges detected by DM tags is useful as a relative measure of feeding 'effort' rather than a direct measure of the number of feeding lunges that occurred during a dive.

Feeding effort was variable across the study area with the areas of highest effort occurring near the tagging areas (San Miguel Island and near San Francisco) as well as offshore of Point Conception. The two tagging areas are known to be highly productive upwelling regions where whales regularly occur (Fiedler et al. 1998, Santora et al. 2011). While the high occupancy of those areas by tagged whales may be related in part to tags having been deployed there, tagged whales remained in the areas for weeks or even months after tagging, and the high levels of reported feeding effort for those areas shows they were productive. The low levels of occupancy of the rest of the study area indicate that, once whales departed the tagging areas, other consistently productive places to feed were limited at best. With that said, relative feeding effort was high across a large area offshore of Point Conception and to the southwest of San Miguel Island. This suggests that some whales could feed well in other areas, but that the prey may have been more dispersed, forcing the whales to move continuously, rather than remaining in one fixed area. The two most dominant euphausiid species off the U.S. West Coast are *Thysanoessa spinifera,* typically found nearshore and out to the shelf edge, and *Euphausia* *pacifica,* which is typically found in waters > 200 m depth (Brinton 1962) although they both occur in some nearshore areas Monterey Bay and the west end of the Channel Islands (Croll et al. 1998, 2005, Fiedler et al. 1998). Blue whales are known to feed on both species (Croll et al. 1998, 2005, Fiedler et al. 1998) and there is evidence they selectively target the larger *T. spinifera* when both are available (Fiedler et al. 1998). The difference in tagged whales remaining in consistently productive areas like the tagging areas, versus feeding offshore may therefore be related to the euphausiid composition in each region. The tagging areas likely offer both *T. spinifera* and *E. pacifica*, while the whales feeding further offshore are likely finding lower species variety, density, or both.

While the overall depth of dives reported by DM tags in 2016 was similar to those reported by ADB tags in 2014–2015, the spatial distribution of daytime dive depths indicated there were regional differences in the depth at which DM-tagged whales were feeding. Daytime dive depths for DM-tagged blue whales were deepest at the high-feeding-effort area near San Miguel Island off southern California. High-feeding-effort areas to the north coincided with shallower daytime dive depths. This may be related to regional differences in prey species composition, or represent a difference in the daytime behavior of prey species that is related to each region's topography and physical oceanographic structure.

One DM-tagged blue whale (Tag #5790; **Figure 23**) made a round trip from San Miguel to an area south of San Clemente Island. This is notable because the whale was male and recorded almost no lunges during the trip, similar to what was recorded by ADB tagged blue whales in 2014 (Tag #2014_5650) and 2015 (Tag #2015_4177). However, some caution should be used when making this assessment as the track is suggestive of the whale searching a new area for food before returning to a known supply. In either case, the track is a good indicator that DM tags can detect changes in a whale's behavior over relatively fine scales, which may make them useful for future studies of the effects of sound on their behavior.

4.1.4 ADB–DM Tag Comparison

Direct comparisons between ADB tag and DM tag data were complicated, as the DM tag data were not a continuous record and feeding has to be interpreted as 'effort' rather than a specific number of feeding lunges. However, general trends across the two tag types can be compared and offer generally strong similarities. Data from both tag types suggest there are a few very productive feeding areas year after year, typically nearshore. When not feeding there, whales meander to different areas with varying degrees of feeding success. In 2015, two whales traveled to different offshore areas (southwest of San Miguel Island, and west of Big Sur and Monterey Bay) after leaving the tagging area. They moved continuously, meandering in a manner that would appear to be searching for prey; however, lunge data from the tags revealed that the whales were feeding extensively across these areas. Those offshore areas were also areas of high relative feeding effort for DM-tagged whales in 2016. This suggests that blue whales may have multiple feeding modes, either focusing on spatially persistent, highly productive areas that are mostly driven by bottom topography and currents (i.e., west of San Miguel Island (Fiedler et al. 1998) or the area off San Francisco (Santora et al. 2011)), or broader, offshore areas where prey is apparently abundant but more dispersed, causing the whales to move more. This would have important implications as it means many whales may be consistently found in some localized areas, making them more subject to possible anthropogenic impacts, but also more easily avoided. Other whales feeding in a more dispersed manner would be less likely to be exposed due to the more limited numbers, but harder to avoid as they are occupying a larger area.

4.1.5 Ecological Relationships

The 60 SSM blue whale tracks analyzed in the three years of this study (2014, 2015, and 2016) covered a large but interannually variable geographic extent (20 to 44 degrees of longitude and 26 to 44 degrees of latitude), with a presence in seven of the eight biogeographic provinces of the eastern North Pacific considered here (**Figure 42**). No tagged blue whales were tracked to PSAE during this study, although one blue whale was tracked there by OSU in 2007 (Mate et al. 2015). Conversely, during this study one blue whale was tracked to ALSK (2014) and one to PQED (2015–2016) for the first time (**Figure 42, Table 16**). These large-scale shifts within the range are likely in response to the strongly anomalous oceanographic conditions that occurred during the study, including warm anomalies associated with the marine heat wave of 2013–2015 (Bond et al. 2015, Leising et al. 2015, Di Lorenzo and Mantua 2016, McClatchie et al. 2016) and with the 2015–2016 El Niño event (Jacox et al. 2016, Levine and McPhaden 2016), and cold anomalies associated with the 2016–2017 La Niña event. Dramatic biotic changes were documented across the food web and throughout the study area in response to these events, which likely had an impact on the abundance, distribution, species composition, and nutritional value of the euphausiids upon which blue whales forage.

Specifically, within CCAL, the province with highest occupation (73-95 percent), interannual differences were observed in blue whale behavior and in several of the environmental variables examined in this study that reflect these anomalous oceanographic conditions. Blue whale ARS activity went from very low in 2014 (11 percent), as animals spent most of their time transiting in offshore waters, to very high in 2016 (51 percent), as animals spent most of their time foraging. The little ARS activity in 2014 occurred in the warmest SST recorded during the study (median = 24°C), compared to the more predominant ARS activity that was recorded in cooler waters in 2015 (median = 19°C) and even more so in 2016 (median = 16.6°C) (**Figure 52**). Correspondingly, CHL values where ARS activity took place steadily increased from 2014 (median = 0.21 mg m^{-3}) through 2015 (median = 0.45 mg m^{-3}) and 2016 (median = 1.16 mg m^{-3}) (**Figure 53**). During 2016, ARS activity took place in shallower waters (median = 305 m), in the vicinity of the shelf break (median = 5.5 km), and closer to shore (median = 28.4 km) than in the previous years (**Figures 54 through 56**).

These trends are consistent with documented biotic changes in the California Current in response to the anomalies that occurred during the study period. The 2013–2015 heat wave led to unprecedented and lasting alterations to the ecosystem due to the widespread cessation of upwelling (Leising et al. 2015, Du et al. 2016, McCabe et al. 2016, McClatchie et al. 2016, Daly et al. 2017, Gómez-Ocampo et al. 2017), and to greatly reduced blue whale foraging success in 2014. In contrast, the 2015-2016 El Niño, while being one of the strongest on record (at least in terms of the magnitude of the SST anomalies in the Niño 3.4 region), only had modest biotic effects in the CCAL ecosystem (Leising et al. 2015, Jacox et al. 2016, McClatchie et al. 2016). Strong upwelling pulses at several coastal locations in spring–summer 2015 were responsible for maintaining an overall moderate productivity at this time (Leising et al. 2015, Jacox et al. 2016), such that during the 2015 tracking period environmental conditions were slightly improved and blue whale foraging success was somewhat higher than in 2014. Finally, in 2016 La Niña conditions were conducive to elevated biological productivity and blue whale foraging success was greatest.

The background to these interannual changes was a warm phase of the PDO that started in January 2014 and that continues through the present time. These PDO phase or "regime" shifts occur every 20 to 30 years (Mantua et al. 1997, Zhang et al. 1997, Mantua and Hare 2002), and in the California Current ecosystem they are accompanied by profound and widespread changes in community structure and function, from phytoplankton to top predators (e.g., Du et al. 2015, Brinton and Townsend 2003, Peterson and Keister 2003, Ainley and Hyrenbach 2010, Keister et al. 2011, Koslow et al. 2013). For blue whales, Calambokidis et al. (2009) documented an apparent correlation between range expansions and contractions and PDO cool and warm phases, respectively. Given this evidence, with the 2014 switch to a PDO warm phase, in the next decade we might expect blue whale range to shift (and possibly to contract), and their movement patterns to change as they respond to changes in euphausiid composition and abundance in the eastern North Pacific.

Finally, we note that while blue whales generally had distinct preferences for all the environmental and seafloor relief variables we examined (**Figures 51 through 58**), several of the variables showed no noticeable differences between years. Such was the case for seafloor slope and slope aspect (SLOPE and ASPECT, respectively). Because interannual differences were noticeable for the related variables depth (DEPTH) and distance to the shoreline (DISTSHOR), this suggests that SLOPE and ASPECT have a limited range of variability throughout CCAL, making them less useful as habitat predictors in the face of changing environmental conditions. This was also the case with vertical upwelling velocity (WEKM), although this variable typically spans several orders of magnitude and has a long-tailed distribution, so it is possible that WEKM requires further transformation and removal of outliers before it can be used as a predictor. In addition, the horizontal scale over which WEKM operates (determined by the curl of the wind stress field over the open ocean) tends to be much greater than the horizontal scale at which variables like sea surface temperature (SST) and chlorophyll-*a* concentrations (CHL) change in CCAL. In this regard, the horizontal scales of SST and CHL variability are more closely matched with the scale of blue whale movement (as determined by the SSM) in CCAL.

4.1.6 Genetics

The genetic analyses to date have provided new information on the diversity of mtDNA haplotypes for blue whales in the eastern North Pacific, as well as the sex and individual identity of tagged individuals. The 'DNA profiles' (i.e., microsatellite genotypes, mtDNA haplotypes, and sex) of 43 tagged whales have been reconciled with those available from archived samples with OSU and with a subset of available samples from the Cascadia Research Collective. This provides a catalogue or 'DNA register' of more than 100 individual blue whales, most of which have associated information from tagging or photo-ID.

There were no significant differences in mtDNA haplotype frequencies between the tagged blue whales from 2014–2016 and the reference database for the eastern North Pacific. Although this comparison provided reasonable confidence that the two samples do not represent distinct stocks, we cannot discount the potential for more subtle spatial heterogeneity or fine-scale population structure in this geographic region. Our analysis of stock structure was also limited by the absence of samples from other putative stocks in the North Pacific, particularly the western North Pacific stock (Monnahan et al. 2014). Without more representative sampling, it is difficult to construct analyses for alternate stock structure hypotheses.

Although we confirmed differentiation of the eastern North Pacific blue whales from other populations or subspecies in the Southern Hemisphere, there was considerable sharing of mtDNA haplotypes, particularly with the eastern South Pacific. The sharing of common haplotypes at relatively high frequencies is evidence of recent divergence or ongoing genetic exchange between the hemispheres. The documented migration of a female blue whale from the Chilean feeding ground to the Galapagos Islands, just south of the equator (Torres-Florez et al. 2015), also suggests the potential for genetic exchange by individual movement or by male-mediated 'gametic exchange.' This possibility could be tested further by collaboration on developing a standardized set of nuclear markers (e.g., microsatellites or Single Nucleotide Polymorphisms) for further comparison of the two populations.

4.1.7 Concluding Thoughts (Integration of Tagging, Ecological, and Genetic Information)

The 60 SSM blue whale tracks analyzed in the three years of this study (2014, 2015, and 2016) add to the collection of 104 blue whale tracks that OSU had previously obtained in the eastern North Pacific between 1994 and 2008 (Bailey et al. 2009, Irvine et al. 2014, Mate et al. 2015). Combined, these data sets now span more than two decades and present a unique opportunity for a more complete examination of blue whale responses to interannual and decadal variability. Over this time period, the PDO went from a warm phase (prior to 1999) to a cool phase (1999–2013) and back to a warm phase (2014–present). Multiple El Niño and La Niña events occurred (see **Section 3.1.6.**), and other anomalous events that disrupted North Pacific ecosystems were recorded (a subarctic intrusion in 2002 [Murphree et al. 2003], delayed upwelling in 2005 [Schwing et al. 2006], collapsed upwelling in 2009 [Bjorkstedt et al. 2010, Melin et al. 2010]).

In addition, the collection of biopsy samples and identification photographs in southern and central California during the three years of this study present opportunities for further integration with external genetic collections and photo-identification catalogs. An integration of these data sets would be a valuable resource for future estimates of abundance by genotype capture-recapture (Carroll et al. 2013) and further investigation of population structure (similar to that now available for humpback whales in the North Pacific [Baker et al. 2013]), including looking into fine-scale genetic structure of blue whales in the North Pacific (Costa-Urrutia et al. 2013). Finally, stable isotopic analysis of the biopsy samples collected would yield further insight into their seasonal movement patterns (Busquets-Vass et al. 2017) and their interannual/decadal responses to climate variability (Fleming et al. 2016).

4.2 Fin Whale

4.2.1 Tracking Analysis

As with the blue whales, the tracking data obtained from fin whales in 2016 add to our sample sizes from the previous 2 years, providing a richer data set of information on long-term movements and dive behavior of fin whales in the eastern North Pacific as well as increasing our understanding of occurrence and use of Navy training and testing ranges. Very few fin whales were encountered in southern California in 2016, so all tagging took place off the central California coast. The resulting fin whale locations from the 2016 tagging matched well with fin whale distribution identified in other studies (Falcone et al. 2011, Calambokidis et al. 2015).

The overall latitudinal range of tagged fin whales in 2016 was very similar to that in 2015, with the northern-most extent being off the islands of Haida Gwaii, British Columbia in both years. This was much farther north than for fin whales tagged in 2014, for which the northern-most location was off Cape Blanco in southern Oregon. Interannual differences in oceanographic conditions affecting prey distribution may have been a contributing factor in these patterns, but another important contributor is the different samples sizes between years, with twice as many fin whales being tagged in both 2015 and 2016 than in 2014. Despite similar northern extremes in 2015 and 2016, distances traveled by fin whales were significantly different in 2015 from in 2016, with the former being longer than the latter. Significant differences between years also existed in the size of fin whale home ranges and core areas, with 2015 have the largest areas. Larger home ranges and core areas and longer distances traveled in 2015 than in 2014 is just the opposite pattern that was found for blue whales in those two years. This is not surprising, however, as fin whales are typically found farther from shore over the continental slope and deeper waters than blue whales and consume both euphausiids and fish (Calambokidis et al. 2015), so may quite likely respond to times of low productivity differently. The constriction of home ranges and core areas for fin whales off central California in 2016 and shorter distances traveled suggest even better oceanographic conditions in that area that year, perhaps with higher concentrations of prey that were more localized and persistent.

PT MUGU was the most heavily used Navy training range for fin whales in all three tagging years, in terms of number of whales having locations there as well as home ranges and core areas occurring there. SOCAL was the second most heavily used training range in terms of number of fin whales as well as home range and core area overlap in 2014, but the NWTT area was the second most heavily used range in 2015. No fin whales tagged in 2016 had locations in SOCAL, and only one fin whale crossed through the NWTT in 2016. Two whales had locations in area W237 of the NWTT in 2015, and one in 2016, but the latter only passed through the area briefly on its way further north. PT MUGU and SOCAL encompass some of the areas of highest density for fin whales identified previously by both visual surveys and habitat-based density models (Falcone et al. 2011, Calambokidis et al. 2015). NWTT also encompasses areas with high predicted density for fin whales (Becker et al. 2016) and while numbers of fin whales in this study using this range and W237 were relatively low, time spent there was quite high for some whales (maximum of 57.4 d for NWTT and 22.3 d for W237) and much higher than in other ranges in 2014 and 2015. As with blue whales, these northern ranges appeared to be important feeding habitat for some fin whales in some years.

Fin whale use of NWTT and W237 occurs primarily in late summer and fall, whereas fin whales can be found in PT MUGU in summer, fall, and winter, and in SOCAL in all seasons. The occurrence of fin whale locations in SOCAL in January, February, and March, as well as in the summer and fall support the evidence of previous studies that fin whales have a year-round presence off southern California (Caretta et al. 1995, Forney and Barlow 1998, Širović et al.

2013, 2015). This is also supported by the fact that fin whales tracked in this study did not engage in a typical uni-directional migration south of California in winter.

The fin whales tagged in 2016 provide further evidence, along with that from 2014 and 2015, to refute the idea of regional subpopulations of fin whales in the eastern North Pacific, with little movement between regions. Even with the shorter distances traveled by fin whales in 2016, two of the animals visited more than one of the regions delineated by Falcone et al. (2011); one having locations in three regions (northern California, Oregon and Washington, and British Columbia and Southeast Alaska), and one having locations in two regions (northern California and southern California). Nine of the 12 fin whales tracked with longer-term implantable tags in 2014 and 2015 visited more than one region, and most of these whales spent time in three or more regions. In addition, these inter-regional movements occurred within the same year and in many cases involved movements back and forth between the regions, contrary to photo-ID studies, for which very few whales were seen in more than one region and none were seen in different regions in the same year (Falcone et al. 2011).

4.2.2 ADB Tag Analysis

The ADB tag data offer the first detailed look at how the diving behavior of a fin whale changes spatially and temporally at high resolution. The relatively small number of recorded GPS locations by Tag #2014_5685 was likely due to a combination of the tag using older Fastloc® v.1 software and a slightly lower tag placement on the back of the whale, meaning it may not have always cleared the water during a surfacing, possibly interrupting a Fastloc® attempt. The recent return of tag #2014_5838 was a substantial addition to the fin whale ADB dataset; however the disproportionately large number of dives recorded by the tag over a relatively short period of time (1,030 dives over 4.9 d vs. ~1,300 dives over 15 d for other tags) is puzzling. It appears to be the result of one afternoon and evening spent making almost exclusively very short duration (~ 2 min duration) shallow dives (< 20 m deep) despite this occurring in an area where the whale fed for three days. While other ADB-tagged fin whales made shallower dives at night, they typically were at least twice the duration and to depths of at least 30 m. The other nighttime dives of Tag #2014_5838 also matched this pattern suggesting the very shallow dives, and their occurrence in the afternoon and night, were a change from typical behavior.

While the general dive behaviors recorded by the ADB tags are consistent with known rorqual behavior (Calambokidis et al. 2007, Doniol-Valcroze et al. 2011), there was substantial variability in the amount of feeding effort recorded between the recovered tags, with Tag #2014_5685 recording remarkably little feeding effort during a clockwise loop through southern California waters. Tag #2014_5685 passed through an area where Tag #2014_5838 was recorded feeding without stopping. This pattern was discussed in **Section 4.1.1.** It is especially surprising that the whale passed through this area without stopping as so little feeding effort was observed during the tracking period and suggests there may be an alternative explanation. Tagged whale #2014_5685 was identified as male from a biopsy sample collected during tagging and the other two fin whales tagged with ADB tags in 2014 were female. While the sample size is very small, it suggests that there may be a reproductive aspect driving the behavior of Tag #2014_5685 rather than solely a search for food as described in **Section 4.1.1**.

Three of the five ADB-tagged fin whales left southern California waters after tagging and traveled north. The portions of those tracks in southern California were indicative of the whales searching for prey as there were numerous clusters of locations and the movements covered a wide area. Once the whales departed, their behavior was more characteristic of directed travel, somewhat similar to migration, where the tracks were relatively linear and there was little evidence of extended feeding. This appears to suggest that fin whales use southern California waters only briefly during the summer, and that their preferred destination is farther to the north. This idea is supported by data from acoustic recordings that found that fin whale calling activity, while occurring year-round in southern California, is at a minimum during early to mid-summer (Širović et al. 2015). It is unknown if the lack of feeding north of southern California is due to a lack of available prey or because the whales were travelling to a specific destination. Both ADB-tagged fin whales in 2015 stopped briefly in the same place off San Simeon, California, suggesting they may exploit prey patches when encountered while travelling north.

Feeding appeared to have been located near areas of steep bottom topography, which have been shown to both increase and concentrate prey (Genin 2004, Croll et al. 2005). Short- to intermediate-duration feeding bouts were most numerous, though the whales also made very long-duration feeding bouts. The duration of the bouts was correlated to the number of feeding lunges made per dive during the bouts. Other large baleen whale species have been shown to adjust their behavior and number of lunges made per dive based on the density of prey in the area (Goldbogen et al. 2015, Hazen et al. 2015), so the correlation between bout duration and number of lunges per dive indicates the whales left lower-density prey patches and stayed longer, and foraged more intensely, in higher-density patches.

4.2.3 DM Tag Analysis

DM tags offered the ability to document fin whale diving and feeding behavior over substantially longer time periods than were previously possible, allowing for better insight into where and how much feeding occurs off the U.S. West Coast. The number of lunges detected per dive by the tags was higher than expected, suggesting there were non-feeding dives included in the number. However, the diel pattern of more lunges and deeper dives reported during the day by ADB tags deployed in 2014–2015 is consistent with what was documented by DM tags, although magnitude of the diel difference in feeding was more limited. This suggests that the number of lunges detected by DM tags is useful as a relative measure of feeding 'effort' rather than a direct measure of the number of feeding lunges that occurred during a dive. The difference in the magnitude of the diel difference of feeding between ADB and DM tags may be related to geography, as all fin whale ADB tags were deployed in southern California and all fin whale DM tags were deployed off central California.

Feeding effort was relatively uniform at a moderate level across the U.S. West Coast with small patches of limited effort far offshore. The highest feeding effort was recorded by Tag #23030, which travelled up to the Hecate Strait and fed there for 39 days. This is surprising, especially as the tagged whales apparently visited highly productive regions like the Gulf of the Farallones (Dorman et al. 2015), Monterey Bay (Croll et al. 2005), and the western Santa Barbara Channel (Fiedler et al. 1998), without generating elevated feeding effort in any of them. As prey distribution and abundance are primary drivers of baleen whale distribution over a broad scale (Croll et al. 2005, Friedlaender et al. 2006), this would seem to indicate that they were able to find sufficient prey throughout the study area and/or, with the exception of Tag #23030 in the Hecate Strait, preferentially did not limit themselves to feeding for an extended period of time in one area. Daytime dive depths reported by DM-tagged whales in 2016 was also similar across the study area with the exception of Tag #23030 in the Hecate Strait, suggesting the whales were feeding on similar prey throughout the areas used off the U.S. West Coast.

4.2.4 ADB–DM Tag Comparisons

Direct comparisons between ADB tag and DM tag data were complicated as the DM tag data were not a continuous record and feeding has to be interpreted as relative 'effort' rather than a specific number of feeding lunges. It is difficult to determine if the elevated number of nighttime lunges reported by DM tags, and proportionally fewer daytime lunges compared to ADB tags are due to less feeding effort made by DM-tagged fin whales. Comparisons are further complicated for fin whales as the tags were deployed in different locations and there was only limited overlap of the areas used so feeding behavior may differ between the two regions. Three ADB-tagged whales moved north into areas used by DM-tagged fin whales; however, two of those tags were not recovered, so feeding data are not available, and little feeding was recorded by the last tag during that portion of the track. ADB-tagged whales from 2014 and 2015, as well as a DM-tagged whale fed in the area south of San Miguel Island and west of San Nicolas Island, suggesting it may be an important area; however, none of the whales spent an extended period of time there despite feeding success. The northward movement of three of five ADB-tagged fin whales, the directed nature of the movements, and the limited number of DM-tagged fin whales that traveled south, may indicate that fin whales preferentially occupy areas north of southern California during the summer.

4.2.4.1 CONCLUSIONS/BLUE–FIN COMPARISON

Both blue and fin whales were tagged with ADB tags allowing for a comparison of behavior between species, though the smaller number of recovered ADB tags attached to fin whales (n = 3 versus n = 7 for blue whales) makes definitive comparisons problematic. The overall behavior trends of deeper dives and more lunges during the day that were observed in blue whales were also recorded in the fin whale data, although fin whales recorded higher numbers of lunges per dive than blue whales. This is supported by the literature as a species-specific difference between fin and blue whales, but not as a mechanism to limit inter-species competition (Friedlaender et al. 2015). Feeding-bout duration was correlated to the number of feeding lunges per dive for both species, suggesting that, despite the difference in feeding lunges executed per dive, they employed similar feeding strategies during the tracking periods. Blue whales may have used two different feeding modes, either feeding in a few, highly localized and productive areas of limited size, or feeding across large areas without staying in one place for long. Fin whales appeared to generally follow the latter practice of feeding across large areas. While they were tagged in highly localized and productive areas apparently favored by the blue whales, they generally left within days of being tagged, while blue whales in some cases remained for weeks to months. This suggests that, while interspecific differences in the number of feeding lunges may not be related to competition, the two species may behave differently over longer temporal scales in order to partition their use of similar resources.

It is interesting to note that tagged whales of both species traveled linearly to specific destinations despite apparently passing feeding opportunities along the way. ADB Tag #5803, a blue whale, departed southern California waters and traveled north to Cape Mendocino, despite encountering sufficient prey along the way to make multiple dives with 5–7 lunges per dive. DM Tag #23030, a fin whale, traveled from the tagging area, where many whales of both species were feeding extensively, to an area in the Hecate Straight. These tracks, and others where the tags stopped during a segment of linear travel, suggest the intriguing possibility that some individuals may favor specific places and remember them from year to year.

Another interesting result was the possible difference in behavior between male and female whales of both species while in southern California waters. With one exception, male ADB-tagged whales of both species made large clockwise circuits across southern California waters while engaging in a limited amount of feeding. Female whales produced more clustered tracks and substantially more feeding, at times in places crossed by the male whales without feeding. The behavior was also documented by a DM tag on a male blue whale in 2016, although the interpretation is slightly less clear. It appears that there may be an additional factor besides the pursuit of prey driving male behavior in both species while in southern California, likely related to courtship or the search for a possible mate. This inter-sexual difference in behavior has the added implication that it caused the male whales to spend less time in any one area compared to female whales. That all four whales traveled in the same direction (clockwise) around southern California waters is also of interest; while at present there is no explanation for it, the pattern may be related to how whale aggregations move through the area at this time of the year.

4.2.5 Ecological Relationships

The geographic extent covered by the 27 fin whales tracked in the three years of this study (2014, 2015, and 2016) was smaller than that of the blue whales, but it also displayed marked interannual variability (10 to 16 degrees of longitude and 12 to 22 degrees of latitude) (**Table 33**). Also, while blue whales migrated in late fall and winter from CCAL to lower-latitude provinces (PNEC, GUCA, PQED), fin whales moved northward and remained in CCAL or visited ALSK (**Figure 84, Table 35**). And, in contrast to blue whales, in 2015 fin whales ranged farther west and north than in the other two years (**Figure 84**).

Interannual differences in fin whale behavior in CCAL suggested very low foraging success in 2015 (11 percent ARS activity), relative to the other two years (19 percent in 2014 and 35 percent in 2016). In contrast, blue whale foraging success in 2015 (during El Niño) was higher than in 2014 (during the heat wave). Examination of SST and CHL values where ARS activity occurred provides clues for this interspecific difference in foraging success: while in 2015 blue whales foraged in areas with lower SST and higher CHL than in 2014, fin whales occurred in areas with similar SST (**Figures 52 and 94**) and CHL levels (**Figures 53 and 95**) in the two years. In contrast, in 2016, the two species foraged in habitats with cooler SST and elevated CHL (during La Niña), and both had the highest levels of ARS. Also, while fin whales occurred in relatively deeper, more offshore waters than blue whales in all years (**Figures 54 and 96**), in 2016 there was a tendency for both species to forage in shallower waters that were closer to the shelf break (**Figures 55 and 97**).

Together, these results suggest that the anomalous warm events of 2014 and 2015 had different impacts on blue and fin whales. Being found generally further offshore in most of

CCAL, fin whales appeared to have fared worse (based on ARS and transiting activity) than blue whales during the 2015–2016 El Niño event. Strong upwelling pulses occurred at several coastal locations in spring–summer 2015 that supported high biological productivity at these sites (Leising et al. 2015, Jacox et al. 2016) and, being found closer to shore, blue whales may have benefited from this supply in the otherwise unfavorable conditions prevalent further offshore.

These environmental relationships suggest that while in CCAL (but outside of southern California, where they overlap spatially and may share the same prey resources), blue whales rely on the high but episodic productivity of coastal upwelling ecosystems, while fin whales may be more reliant on offshore upwelling processes that are more susceptible to disruption from climatic events. Thus, despite partial spatial and environmental overlap, fin and blue whales have distinct ecological optima that likely reflect different prey resource utilization in much of their range. In the North Pacific, the diet of fin whales includes both euphausiids and pelagic schooling fish (Tershy and Wiley 1992, Aguilar 2009), while blue whales only feed on euphausiids (Fiedler et al. 1998, Croll et al. 2005).

As with the blue whale, with the 2014 shift to a warm PDO phase, in the next decade we might expect fin whale range and movement patterns in CCAL to change, given that pelagic schooling fish abundance and composition strongly respond to decadal variability, with numerically dominant species like sardines and anchovies respectively alternating during warm and cool phases (Chavez et al. 2003, Rykaczewski and Checkley 2008).

4.2.6 Genetics

The genetic analyses to-date identified the hybrid origin of one of the tagged whales (Tag #2015_10831) and, through a collaborative relationship with Cascadia Research Collective, documented a previous biopsy sampling of this individual (a male) in 2004 during photo-ID surveys conducted under NMFS/Southwest Fisheries Science Center funding (Steiger et al. 2009). The genetic analyses also confirmed identification of a Bryde's whale, initially identified in the field as a fin whale. Initial analysis indicates that this individual represented the '*brydei'* subspecies or type, as described by Yoshida and Kato (1999).

The analysis of fin whale stock structure was limited by the relatively small number of samples from tagged whales but benefitted from comparison to a large reference database of mtDNA haplotypes from throughout the eastern and central North Pacific. Other limitations include the absence of sex identification and compatible nuclear genetic markers in the reference database (e.g., microsatellites were used for tagging and single nucleotide polymorphisms for only a subset of the reference database (Archer et al. 2013). There is also unexplored potential for an influence of seasonal migration on the geographical strata used for the comparisons of population structure. With these caveats, however, the observed differences in mtDNA haplotypes among the *a priori* strata are strong evidence of spatial heterogeneity in the genetic structure of this species in the eastern and central North Pacific. In particular, the haplotype frequencies of the tagged whales from 2014–2015 showed the greatest similarity to the reference dataset from the Southern California Bight, despite the documented movement of these individuals northward along the coast into the CA/OR/WA stratum. The 2016 samples, however, were sampled further north and differed in haplotype frequency from those collected in

2014–2015. Surprisingly, the 2016 sample also showed a weak but significant differentiation from several of the geographic strata despite the small sample sizes.

4.2.7 Concluding Thoughts (Integration of Tagging, Ecological, and Genetic Information)

The fin whale tracking data collected over the three years of this study have provided a wealth of new information about this poorly known species. Even though the species shares a substantial part of its range with the blue whale in the California Current, the environmental and dive data indicate that it has a distinct ecology, with particular responses to climatic fluctuations that we are just beginning to understand. The addition of a third year of data in 2016 led us to a revised (and more complete) interpretation of fin whale habitat associations and their range of responses to strongly contrasting environmental conditions (cf. Mate et al. 2016). This highlights the importance (and rewards) of continued monitoring of this enigmatic species.

There would be considerable benefit to further integration of information from the available reference biopsy samples of fin whales, including microsatellite genotyping and sex for individual identification and population assignment procedures. Alternate hypotheses for population structure are also likely to benefit from further integration of genetic identity with seasonal movement, as revealed by satellite tagging, and perhaps differences in vocalizations as evidence of breeding stocks (Širović et al. 2013). Additionally, stable isotopic analysis of the biopsy samples collected would further help answer these questions (Busquets-Vass et al. 2017).

4.3 Humpback Whale

4.3.1 Tracking Analysis

The tracking data obtained from humpback whales tagged off Oregon in 2016 provides valuable insight into their localized movements on their feeding grounds in the northern part of the California Current. Inclement weather off the Oregon coast in September and October 2016 restricted our tagging opportunities to just 2 days, and only two humpback whales were tagged. Additionally, in our experience, satellite tags do not last as long on humpback whales as they do on other baleen whale species (Mate et al. 2007). Very little detailed information exists for the population segment that uses Oregon waters, however, so while the results from this study are limited to the relatively short duration tracking periods for two animals, they are still valuable in informing our knowledge of this group of whales. Several areas of importance were identified along the Oregon and northern California coast, including Stonewall and Heceta banks and an area off Coos Bay, Oregon, as well as the continental shelf between Point St. George and Cape Mendocino in northern California.

The eastern boundary of the Navy's NWTT occurs at approximately 22 km (12 nautical miles) off the coast of Oregon and northern California. Tagged humpback whales in this study occurred within the boundary of the NWTT while north of Coos Bay, Oregon, where shallower continental shelf waters extended further than 22 km offshore. In southern Oregon and northern California where the shelf is narrower, humpback whale locations were not within the NWTT, as the whales seemed to prefer shallower continental shelf waters. The absence of humpback locations in other Navy training ranges is due to the small sample size and short tracking durations obtained in 2016. Future tagging of humpback whales off Oregon and southern California would be helpful in assessing humpback occupancy and use of other training ranges, especially in areas where those ranges overlap with continental shelf waters.

4.3.2 DM Tag Analysis

The two DM-tagged humpback whales appear to have behaved very differently, with the whale carrying Tag #5923 showing little evidence of diel variability in its diving behavior, while the whale carrying Tag #5838 showing a strong diel difference in both dive depths and the number of lunges recorded. However, Tag #5923 left the tagging area off central Oregon after one week, and prior to departure, it exhibited very similar depth range for dives, as well as a diel trend, with deeper dives occurring at night. Humpback whales feed on both euphausiids and fish (Clapham et al. 1997, Fleming et al. 2016) so the change in behavior as Tag #5923 moved south from the tagging area may be an indication that it changed to a different prey species. While the data from these two tags is relatively limited it demonstrates that DM tags are capable of documenting humpback whale behavior and how it changes over time.

4.3.3 Ecological Relationships

The short tracking period (7 and 19 d) and the small geographic extent (0.6 degrees of longitude by 4 degrees of latitude) covered by the two humpback whales tagged off Oregon in 2016 prevent us from drawing robust ecological inferences. Further, as a result of the low number of Argos locations acquired during the tracking period, the SSM failed to assign most locations to a behavioral mode (96 percent were considered uncertain), which often occurs with tracks of short duration (Bailey et al. 2008).

Generally, however, compared to blue and fin whales, humpback whale habitat off Oregon and northern California on average occurred in areas characterized by downwelling (-3.8e-07 m s^{-1}), colder SST (13.4°C), and much higher CHL levels (6.78 mg m^{-3}). The two humpback whales were found in much shallower depth (143.2 m), over seafloor with very gentle slope (7.69 m km^{1}), and closer to shore (27.5 km).

The pattern of occupation off Oregon by the two tracked humpback whales was consistent with the distribution reported by Tynan et al. (2005) for a visual survey in August 2000, with animals using both the broad shelf at Heceta Bank and the coastal waters near upwelling centers like Cape Blanco (Tynan et al. 2005) or between Point St. George and Trinidad Head (this study).

In terms of decadal variability, the shift to a warm PDO regime in 2014 will likely have implications for humpback whales in the next decade. Based on stable isotopes, Fleming et al. (2016) recently reported that in the California Current humpback whales shift from a diet composed mainly of euphausiids to one dominated by schooling fish during cool and warm regimes, respectively.

4.3.4 Genetics

The genetic analysis of the three humpback whales is not sufficient for any statistical comparisons but does provide some initial evidence of affinities to regional feeding divisions based on qualitative comparison to the large reference dataset available from SPLASH (Baker et al. 2013) and pre-SPLASH. Although previous analyses of the SPLASH dataset grouped the

Oregon coast with California, this included only three whales sampled on the Oregon coast. The inclusion of additional pre-SPLASH samples, shown in **Table 20**, suggests the potential for some differentiation of Oregon from whales feeding off California and, thus, some revision of the SPLASH boundaries. If so, the 'A+' and 'E2' haplotypes of the three whales from this study showed a greater affinity with the frequencies of haplotypes from Oregon, Washington, Southern British Columbia and southeastern Alaska. It is also notable that the density of humpback whales along the coast of Oregon has been lower than regions to the north or to the south (Calambokidis et al. 2008) and that this might be changing due to either local recovery or expansion of adjacent population units. Further tagging could provide evidence to address these alternate scenarios.

4.3.5 Concluding Thoughts (Integration of Tagging, Ecological, and Genetic Information)

This was the first time that humpback whales have been satellite-tracked off Oregon. Although only two tags were deployed successfully, the movements of the animals and associated environmental conditions have provided preliminary information about the habitat preferences of this species compared to those of blue and fin whales in the California Current. The genetic composition analysis has further suggested a greater stock affinity with haplotypes from Oregon, Washington, Southern British Columbia and southeastern Alaska, rather than with whales feeding off California (DPS 6), as is currently assumed by NMFS (Bettridge et al. 2015, DOC-NOAA 2016, DOI-FWS 2016). Together, this information is starting to fill an important knowledge gap for an area that has been poorly studied. Future comparison with humpback whale tracking data previously collected by OSU off central California (2004 and 2005), in combination with analyses of biopsy samples and comparison of photo-identification catalogs will yield further insight into their seasonal movement patterns and their interannual/decadal responses to climate variability.

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