Final Report

Baleen (Blue and Fin) Whale Tagging in Southern California in Support of Marine Mammal Monitoring Across Multiple Navy Training Areas

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Photo Credit:

A fin whale (*Balaenoptera physalus*) (upper left) and blue whale (*Balaenoptera musculus*) (upper right) from the air in southern California, summer 2015. A fin whale (bottom) surfaces in southern California, summer 2014. Photographs taken by Roxanne Parker (upper two) and Craig Hayslip (bottom) under National Marine Fisheries Service Permit 14856 issued to Dr. Bruce Mate.

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14. ABSTRACT
A 2-year tagging and tracking study was conducted on eastern North Pacific blue whales (Balaenoptera musculus) and fin whales (Balaenoptera physalus) to determine their movement patterns, occurrence, and residence times within Navy training and testing areas along the U.S. West Coast. Tagging occurred off the coast of southern California in August and September 2014, and in July 2015. Twenty-four blue whales (20 location-only tags, 4 ADB tags) and six fin whales (3 location-only, 3 ADB) were tagged between Mugu Canyon, west of Malibu, and San Diego in August and September, 2014. Twenty-two blue whales (18 location-only, 4 ADB), 11 fin whales (9 location-only, 2 ADB), one blue/fin hybrid whale (location-only), and one Bryde’s whale (location-only) were tagged off the west end of San Miguel Island and near Mugu Canyon in July 2015. Both blue and fin whales were quite widespread in their tracked distribution, with locations over the 2 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 (formerly the Queen Charlotte Islands) 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, and in whales’ use of Navy training ranges and Biologically Important Areas (BIAs) for blue whales.Blue whales had locations in the SOCAL, PT MUGU, and NWTRC in both years, but locations in W237 of the NWTRC occurred in 2014 only. Blue whales were not found in the GOA training range in either year. Fin whales had locations in the SOCAL, PT MUGU, and NWTRC ranges in both years, but locations in area W237 occurred in 2015 only. The GOA training range had no fin whale locations in either year. PT MUGU was the most

heavily used training range by fin whales in both years, with 100 percent of tagged whales spending time there. The blue/fin hybrid spent 18 d of its 28-d tracking period within the PT MUGU training range, with locations there in both July and August. It was not located in any other training range. The Bryde's whale had locations in both PT MUGU and SOCAL, with PT MUGU being the most heavily used area, with a residency of 60 d, compared to 22 d in SOCAL.

ADB-tagged blue whales were tracked for a median of 22.4 d, and seven of eight tags were recovered for data download. Tagged blue whales made deeper dives during the day when most foraging activity also occurred. The whales generally foraged in relatively small (median 7.6 square kilometers) areas for time periods ranging from less than 1 to 20.5 h (median = 4.5 h). Five ADB-tagged fin whales were tracked for a median of 14.4 d, and two of the tags were recovered for data download. The shorter tracking duration compared to blue whales was due to the tags being shed by the whales more rapidly. Diel variability in dive depths and foraging behavior similar to blue whales was recorded by the tags. The limited number of recovered tags makes conclusions difficult, but 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. Male whales of both species (n = 3 of 10 whales of known sex) made long, clock-wise circuits of southern California waters with little foraging, while female tracks were generally more clustered and indicative of foraging 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.

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. From a biogeographic perspective, the majority of the state-space models 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 in 2015). For fin whales, the vast majority of locations occurred in CCAL, but the Alaska Downwelling Coastal Province was also visited in 2015. In terms of movement behavior, blue whales displayed extensive area-restricted searching behavior while in CCAL (consistent with foraging activities in small areas). The opposite was the case for fin whales, as they appeared to spend more time in transiting behavior (consistent with long-range movements between foraging areas) and less time in area-restricted searching behavior in 2015 than in 2014. These inter-annual differences corresponded well with the strong climatic perturbations that took place in 2013–2015 (the "Warm Blob" off the west coast of North America) and in 2015–2016 (El Niño, which originated in the equator but also affected the west coast of North America in late 2015 and early 2016). Relationships with oceanographic and seafloor relief variables within CCAL indicated that, compared to blue whales, fin whales generally used areas that had cooler sea surface temperature (SST) and somewhat lower phytoplankton chlorophyll-a concentration, and that were found farther away from the shelf break and the shoreline. The relationships with oceanographic and seafloor relief variables were also helpful in characterizing the habitat used by the Bryde's whale tracked in 2015 in southern California waters. This animal was generally found in significantly warmer waters and with lower chlorophyll-a concentrations than any of the other species tracked in 2015. It also occurred in shallower depths, over slopes that were steeper and that faced more southward.

Tissue samples collected from the tagged blue and fin whales were used for DNA profiling. Of the sampled 31 blue whales, 13 were females and 18 were males. 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. Of the 14 samples collected from whales 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, first sampled off California on 22 September 2004, providing an 11-year record of genotype recapture. Of the 12 sampled fin whales, 6 were females and 6 were males. To investigate population structure, we compared the mtDNA haplotype frequencies of the 12 tagged fin whales to a reference dataset of 397 samples available through collaborative agreement with the Southwest Fisheries. The haplotype frequencies of the tagged fin whales were similar to those from the Southern California Bight but differed significantly from several of the other proposed strata, including California/Oregon/Washington and the Gulf of California.

15. SUBJECT TERMS

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Executive Summary

Oregon State University's Marine Mammal Institute conducted a 2-year 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 California in August and September 2014, and in July 2015. Two types of tags were used: location-only tags, providing long-term tracking information via the Argos satellite system, and Advanced Dive Behavior (ADB) tags, providing short-term, fine-scale dive profile information and geographic positioning system (GPS)-quality locations.

Twenty-four blue whales (20 location-only tags, 4 ADB tags) and six fin whales (3 location-only, 3 ADB) were tagged between Mugu Canyon, west of Malibu, and San Diego in August and September, 2014. Twenty-two blue whales (18 location-only, 4 ADB), 11 fin whales (9 location-only, 2 ADB), one blue/fin hybrid whale (location-only), and one Bryde's whale (location-only) were tagged off the west end of San Miguel Island and near Mugu Canyon in July 2015. One tag from the 2015 deployments was still transmitting on 29 February 2016, when the data were summarized for this report (although not analyzed beyond 29 February 2016, this tag stayed attached for 252.4 days (d), through 1 April 2016. Transmissions were received from all but one tag, with tracking periods ranging from 0.7 to 283.8 days (d). Average tracking duration for the longer-term location-only tags was 76.3 days (d) (standard deviation [SD] = 64.3 d) for blue whales and 77.9 d (SD = 60.0 d) for fin whales, for the 2 years combined. Tracking durations were 28.1 d and 86.7 d for the blue/fin hybrid and the Bryde's whale, respectively.

Both blue and fin whales were quite widespread in their tracked distribution, with locations over the two 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 (formerly the Queen Charlotte Islands) 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, and in whales' use of Navy training ranges and Biologically Important Areas (BIAs) for blue whales. Blue whales were distributed farther north and had significantly larger HRs and CAs in 2014 than in 2015. The opposite was true for fin whales, with their distribution extending farther north in 2015 and their HRs and CAs being significantly larger in 2015 than in 2014.

Blue whales had locations in the Southern California Range Complex (SOCAL), Point Mugu Range Complex (PT MUGU), and Northwest Training Range Complex (NWTRC) in both years, but locations in Warning Area 237 of the NWTRC (W237) of the NWTRC occurred in 2014 only. Blue whales were not found in the Gulf of Alaska (GOA) training range in either year. SOCAL was the most heavily used area in 2014, whereas PT MUGU was the most heavily used area in 2015. Seasonality was similar in both ranges between the 2 years, with locations occurring in July through November, but inter-annual distribution was markedly different. In PT MUGU, HRs and CAs were more widespread and residency was longer in 2015 than in 2014. In SOCAL, blue whale locations were far more concentrated in the nearshore waters of the northeast

corner of the range, compared to a more widespread distribution in 2015. Fewer blue whales traveled into the NWTRC range in 2015 than in 2014, but seasonal occurrence and residency were similar between years, with locations occurring there from August through November. Only one blue whale (tagged in 2014) had locations in area W237, in September, October, and November, with a total residency of 19 d.

Seasonal use of blue whale BIAs was similar between the two years of the study (August through October in 2014 and July through October in 2015), but distribution within the areas was quite different. The San Diego and Santa Monica Bay to Long Beach BIAs were the two most heavily used in 2014, whereas the Santa Barbara Channel and San Miguel and Pt. Conception/Arguello were the two most heavily used in 2015. With the exception of the Santa Barbara and San Miguel BIA in 2015 (median residency of 8 d), median residency in BIAs was quite low (less than 1 d).

Fin whales had locations in the SOCAL, PT MUGU, and NWTRC ranges in both years, but locations in area W237 occurred in 2015 only. The GOA training range had no fin whale locations in either year. PT MUGU was the most heavily used training range by fin whales in both years, with 100 percent of tagged whales spending time there. Inter-annual differences were evident, however, with more widespread HRs and CAs, longer residency, and slightly earlier occurrence in 2015 than in 2014. The SOCAL range was more heavily used in 2014 than in 2015, both in terms of number of fin whales with locations there and time spent in the area. Seasonal use of SOCAL was similar between the 2 years, with locations occurring there in most months during which fin whales were tracked. The number of fin whales having locations in the NWTRC range was greater in 2015 than in 2014, as was the spatial extent of HRs and CAs, but the median time spent there was the same in both years. The larger sample size of tagged whales in 2015 versus 2014 likely played a role in differences in NWTRC use between years. Only two fin whales (tagged in 2015) spent time in area W237; one just passing through the area, and the other spending 22 d there, in August and early September.

The blue/fin hybrid spent 18 d of its 28-d tracking period within the PT MUGU training range, with locations there in both July and August. It was not located in any other training range. The Bryde’s whale had locations in both PT MUGU and SOCAL, with PT MUGU being the most heavily used area, with a residency of 60 d, compared to 22 d in SOCAL.

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 foraged in relatively small (median 7.6 square kilometers) areas for time periods ranging from less than 1 to 20.5 h (median = 4.5 h). The duration of a foraging bout was correlated to the number of feeding lunges made per dive during the bout, suggesting the whales quickly left less productive prey patches. Individual variability in diving behavior was also recorded, as some tagged whales made deeper dives during foraging bouts than others, and, in two instances, one tagged whale foraged at over twice the depth of another whale when they were within 1 kilometer of each other.

Five ADB-tagged fin whales were tracked for a median of 14.4 d, and two of the tags were recovered for data download. The shorter tracking duration compared to blue whales was due to the tags being shed by the whales more rapidly. The two recovered tags recorded 1,180 and 1,695 dives, and a total of 95 and 1,591 GPS locations, respectively. The three non-recovered tags transmitted dive summary information for 279 to 406 dives and 12 to 14 GPS locations via the Argos system. Diel variability in dive depths and foraging behavior similar to blue whales was recorded by the tags. The limited number of recovered tags makes conclusions difficult, but 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. Male whales of both species (n = 3 of 10 whales of known sex) made long, clock-wise circuits of southern California waters with little foraging, while female tracks were generally more clustered and indicative of foraging 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.

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 (SSMs) 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 patterns on the distribution and movement behavior of the tracked whales.

Blue whales had the largest geographic range of the species tracked during this study, with a span of 50 degrees of latitude (0–50°N), while fin whales had a smaller geographic range spanning 22 degrees of latitude (30–52°N). However, there were marked inter-annual differences in the pattern of occupation in both species, with blue whales ranging farther north and west in 2014 and ranging farther south and east in 2015, while fin whales ranged farther north and west in 2015 than in 2014. 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 in 2015). For fin whales, the vast majority of locations occurred in CCAL, but the Alaska Downwelling Coastal Province was also visited in 2015.

In terms of movement behavior, blue whales displayed extensive area-restricted searching behavior while in CCAL (consistent with foraging activities in small areas), but it was reduced in 2014 compared to 2015. The opposite was the case for fin whales, as they appeared to spend more time in transiting behavior (consistent with long-range movements between foraging areas) and less time in area-restricted searching behavior in 2015 than in 2014. These inter-annual differences corresponded well with the strong climatic perturbations that took place in 2013–2015 (the “Warm Blob” off the west coast of North America) and in 2015–2016 (El Niño, which originated in the equator but also affected the west coast of North America in late 2015 and early 2016). However, the opposite responses by blue and fin whales to these perturbations strongly suggest that these two species are ecological counterparts in many respects, despite the large overlap in range off the west coast of North America.

Relationships with oceanographic and seafloor relief variables within CCAL indicated that, compared to blue whales, fin whales generally used areas that had cooler sea surface temperature (SST) and somewhat lower phytoplankton chlorophyll-*a* concentration, and that were found farther away from the shelf break and the shoreline. The inter-annual differences observed in apparent response to climatic perturbations were reflected in these variables, as blue whales were found closer to shore in areas with cooler SST in 2015 than in 2014. Although fin whales also occurred in waters with cooler SST in 2015, these areas were found farther from shore. Their apparent higher foraging success in 2014 may have been related to fin whales successfully exploiting a region of enhanced open-ocean upwelling driven by strong wind-stress curl off central California. These environmental relationships suggest that while in CCAL (outside of southern California, where they 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.

The relationships with oceanographic and seafloor relief variables were also helpful in characterizing the habitat used by the Bryde's whale tracked in 2015 in southern California waters. This animal was generally found in significantly warmer waters and with lower chlorophyll-*a* concentrations than any of the other species tracked in 2015. It also occurred in shallower depths, over slopes that were steeper and that faced more southward. This evidence suggests that Bryde's whales exploit a habitat with distinct characteristics despite the apparent spatial overlap with blue and fin whales.

Tissue samples collected from the tagged blue and fin whales were used for DNA profiling, including sex identification, sequencing of mitochondrial deoxyribonucleic acid (mtDNA) control region haplotypes, and genotyping at 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.

All 31 samples of blue whales were represented by unique multi-locus genotypes with an average probability of identity of 7.6×10^{-15} (i.e., there was a very low probability of a match by chance). Of the 31 individuals, 13 were females and 18 were males. Of the 9 mtDNA haplotypes resolved in the tagged blue whales from 2014–15, 6 matched to the 15 haplotypes represented in reference database from the eastern North Pacific (n = 76 individuals), resulting in a total of 18 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 14 samples collected from whales 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, first sampled off California on 22 September 2004, providing an 11-year record of genotype recapture.

All of the12 tagged fin whales were represented by unique multi-locus genotypes with an average probability of identity of 3.7 $x10^{-18}$ (i.e., there was a very low probability of a match by chance). Of the 12 individuals, 6 were females and 6 were males. To investigate population structure, we compared the mtDNA haplotype frequencies of the 12 tagged fin whales to a reference dataset of 397 samples available through collaborative agreement with the Southwest Fisheries Science Center. The haplotype frequencies of the tagged fin whales were similar to those from the Southern California Bight but differed significantly from several of the other proposed strata, including California/Oregon/Washington and the Gulf of California. Given the evidence of fine-scale population structure, there would be considerable benefit to further integration of information from the available reference samples of fin whales, including microsatellite genotyping and sex for individual identification and population assignment procedures.

Additional tagging efforts in July 2016 will add valuable information to the results obtained in the first 2 years of this multi-year study. Such information will contribute greatly to a more thorough understanding of the variation, both between individual animals and between years, in the distribution and behavior of whales in this dynamic environment. This will help provide a more complete description of blue and fin whale movement and use of the Navy training and testing areas along the U.S. West Coast. With this information, the Navy will be better equipped in their efforts to minimize effects of military activities on blue and fin whales.

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Acronyms and Abbreviations

ADB	Advanced Dive Behavior
ALSK	Alaska Downwelling Coastal Province
ASPECT	slope aspect
BIA	Biologically Important Area
BLAST	Basic Local Alignment Search Tool
bp	base pairs
°C	degree(s) Celsius
CA	core area
CHL	chlorophyll-*a* concentration
cm	centimeter(s)
d	day(s)
DISTSHELF	distance to the shelf break
DISTSHORE	distance to the nearest shoreline
DNA	deoxyribonucleic acid
EEZ	Exclusive Economic Zone
ERDDAP	Environmental Research Division Data Access Program
g	gram(s)
GLM	generalized linear model
GOA	Gulf of Alaska
GPS	geographic positioning system
h	hour(s)
HR	home range
ID	identification
km	kilometer(s)
km^2	square kilometer(s)
LC	location class
LED	light-emitting diode
m	meter(s)
mg	milligram(s)
mg m^{-3}	milligram(s) per cubic meter
min	minute(s)
MMI	Marine Mammal Institute
MSA	minimum specific acceleration
mtDNA	mitochondrial deoxyribonucleic acid
Navy	U.S. Navy
NMFS	U.S. National Marine Fisheries Service
NPFF	North Pacific Transition Zone Province
NWTRC	Northwest Training Range Complex
W237	Warning Area 237 of the NWTRC
OSU	Oregon State University
PSAE	Pacific Subarctic Gyre-East Province
PT MUGU	Point Mugu Range Complex
R/V	research vessel
s	second(s)
SD	standard deviation
SLOPE	slope or depth gradient
SOCAL	Southern California Range Complex
SPOT5	Smart Positioning or Temperature Transmitting Tag, Version 5
SSM	State Space Model
SST	sea surface temperature
U.S.	United States
WEKM	vertical upwelling velocity

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1. Introduction

The United States (U.S.) Navy (Navy) conducts training and testing activities in several areas of the eastern North Pacific Ocean, including the Gulf of Alaska Temporary Maritime Activities Area (GOA), the Northwest Training Range Complex (NWTRC), Naval Undersea Warfare Center Keyport Range Complex (together known as the Northwest Training and Testing Study Area), and the Southern California Training Range Complex (SOCAL) portion of the Hawaii-Southern California Training and Testing Study Area. This region also supports endangered populations of both blue (*Balaenoptera musculus*) and fin whales (*Balaenoptera physalus*), whose migratory movements and seasonal feeding distributions may take them within the boundaries of the Navy training and testing areas. The blue whale is the largest of all whale species, reaching lengths of up to 33 meters (m). Their blue steel-gray color, with mottling on the back and sides, and the relatively small dorsal fin are characteristic of the species. Fin whales are the second largest species, reaching up to 24 m in the northern hemisphere. They have a narrow head compared to the broad, rounded head of the blue whale. The most distinctive features are the prominent, swept-back dorsal fin and the asymmetrical coloration of the body, with a white right lip and a chevron pattern on the back between the flippers, on an otherwise black or dark brownish background (see cover photos). Fin whales tend to be social, sometimes forming groups of two to seven whales and even associating with blue whales. Both species are considered open-ocean inhabitants, although they may come close to shore to feed in areas adjacent to deep water (Leatherwood et al. 1988, Reeves et al. 2002, Jefferson et al. 2008, Calambokidis et al. 2009).

In 2015 Oregon State University's Marine Mammal Institute (OSU/MMI) conducted a second year of tagging operations in support of the Navy's marine mammal studies in the offshore waters of SOCAL and NWTRC. The focus of these studies is to address key science objectives the Navy has committed to completing as part of regulatory requirements promulgated from the National Marine Fisheries Service. In particular, this multi-year project is designed to address the following questions:

1. "What are the movement patterns, occurrence, and residence time/patterns/area restricted searches of blue (*Balaenoptera musculus*) and fin (*Balaenoptera physalus*) 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?" The Pt. Mugu Sea Range (PT MUGU) is also included in these analyses for the benefit of the Navy air testing community.
2. "What are the residency time/patterns of blue whales within National Marine Fisheries Service-designated blue whale Biologically Important Areas (BIAs) along the U.S. West Coast that intersect with the Navy training and testing areas?"
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, Pacific Decadal Oscillation, El Niño/La Niña events, etc.) that can help explain blue and fin whale affinity for any identified areas of high residency/area restricted search/kernel home ranges (HRs) along the U.S. West Coast?"

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

A. Determine blue and fin whale distribution and habitat use through deployment of long-term location-only satellite tags to refine our understanding of short- and long-term movement patterns and, most importantly, to generate metrics for defining residency times, HRs and core areas (CAs), area restricted searches, 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 Advanced Dive Behavior (ADB) tags, with sampling resolution of 1 Hertz. This technology will enable us to determine how large-whale behavior changes over time and to better characterize "normal" behavior for individuals and throughout a population.

C. Identify ecological relationships that will help explain/predict spatial and temporal movement patterns from bathymetric and satellite-determined measurements like sea surface temperature, frontal zones, phytoplankton chlorophyll-*a* 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 loci composition, individual identification, population structure, and interspecific introgressive hybridization.

This Final Report presents detailed analyses of the 2015 blue and fin whale tracking results, including deployment specifics and tracking information through 29 February 2016, as well as a cumulative analysis of blue and fin whale tracking results for 2014 and 2015 combined. It includes maps of whale tracks, HRs, and CAs of highest use for both 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 both years of the study. This report also includes analyses of the dive characteristics data obtained from the ADB tags and a comparison of these results between 2014 and 2015. It 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, including sex determination, individual identification, as well as species and stock identification.

2. Methods

2.1 Field Efforts

Field work took place off the coast of southern California during two 3-week cruise legs in 2014 and one 5-week cruise in 2015, aboard the Research Vessel (R/V) *Pacific Storm*. This 26-m ship 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 and for tag-recovery operations. Leg 1 of the 2014 cruise took place 2 to 22 August 2014, departing from Santa Barbara Harbor. Leg 2 of the 2014 cruise took place 23 August to 12 September 2014, departing from Marina Del Rey. Tagging efforts were conducted on 15 days (d) during the first cruise leg and on 7 d during the second leg. Aerial observations to locate whales and direct the tagging boat into position were conducted on a total of 14 d over the entire 6-week field effort. The 2015 cruise took place from 6 July to 8 August 2015, departing from Marina Del Rey and returning to Half Moon Bay. Tagging efforts were conducted on 17 d and tag-recovery efforts were conducted on 6 d. Aerial observations to locate whales and direct the tagging boat into tagging position were conducted for 6 d over the 5-week field effort.

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 and will be compared to existing ID catalogs for blue (maintained by Cascadia Research Collective, Olympia, Washington) and fin whales (maintained by Greg Schorr and Erin Falcone of Marine Ecology & Telemetry Research, Seabeck, Washington). Candidates 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. Wildlife Computers' Smart Positioning or Temperature Transmitting Tag, version 5 (SPOT5) and Mk10-PATF (ADB) 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 125-pound force per square inch in the applicator's 70-cubic centimeter pressure chamber.

2.2 Tagging

2.2.1 Satellite Tags

The SPOT5 tags were composed of a main body, a penetrating tip, and an anchoring system. The design of this tag and its main components are shown schematically in **Figure 1**. The main body consisted of a certified Argos transmitter, housed in an epoxy-filled stainless steel cylinder (2.02 centimeters [cm] in diameter × 21.3 cm in length). A flexible whip antenna and a saltwater conductivity switch were mounted on the distal endcap of this cylinder, while a penetrating tip was screwed onto the other end. The antenna/switch endcap had two perpendicular stops, approximately 0.6 cm in diameter and extending approximately 1.5 cm laterally to prevent tags from embedding too deeply on deployment or migrating inward after deployment. The penetrating tip consisted of a Delrin® nose cone, into which was pressed a ferrule shaft with four double-edged blades. The anchoring system

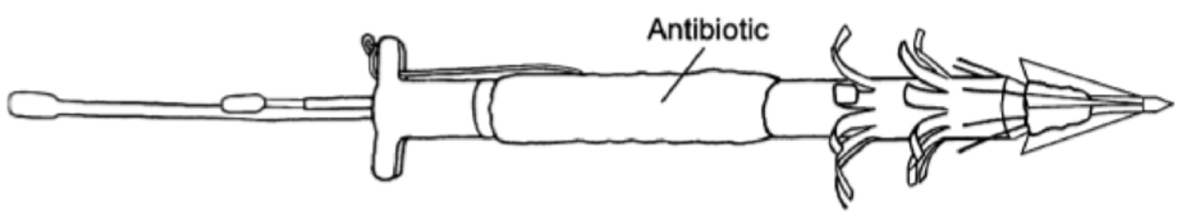

Figure 1. Schematic of the design of the location-only tag, such as the SPOT5 used in this project, showing the main body, the antenna/saltwater conductivity switch endcap, the penetrating tip, the anchoring system, and the antibiotic coating. Taken from Mate et al. (2007).

consisted 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 was 209.5 grams (g). Tags were partially coated with a broad-spectrum antibiotic (gentamicin sulfate) mixed with a long-dispersant methacrylate. This allowed for a continual release of antibiotic into the tag site for a period of up to 5 months. This tag is designed for nearly complete implantation under the whale's skin and is 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 SPOT5 tag reports percentage of time at the surface and percentage of time in user-specified temperature ranges. 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 may be 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).

The design of the ADB tag and its main components are shown schematically in **Figure 2**. The ADB tag consisted of a certified Argos transmitter and a Wildlife Computers Time-Depth Recorder, with a three-axis accelerometer and magnetometer, cast in an epoxy tube (2.0 cm in diameter and 11.5 cm long). A FastLoc® geographic positioning system (GPS) receiver, encased in syntactic foam (10.0-cm diameter dome with a maximum height of 4.0 cm), was attached to one end of the epoxy tube. Three light-emitting diode (LED) lights were mounted on top of the syntactic foam to facilitate relocation of the tag. The tubular portion of the tag was slid into a cylindrical stainless steel tag housing (2.6 cm in diameter and 14.5 cm long) for deployment. A circular stainless steel plate, or collar, was welded onto the distal end of the housing to protect the syntactic foam during deployment. A penetrating tip and anchoring system, similar to that of the SPOT5 tags, was mounted onto the cylindrical end of the tag housing. The cylindrical portion of the tag housing was designed for implantation beneath the whale's skin while the plate and syntactic foam GPS receiver sat atop the whale's back. The ADB tag and housing weighed approximately 470 g (approximately 240 g for the tag and approximately 230 g for the housing). A plastic "D-ring" was mounted on the bottom of the syntactic foam with a corrodible wire. This "D-ring" passed through a slot in the stainless steel plate and was secured on the backside of the plate with a screw. After a pre-determined time, an electrical current was activated within the tag, oxidizing the corrodible wire, whereupon the

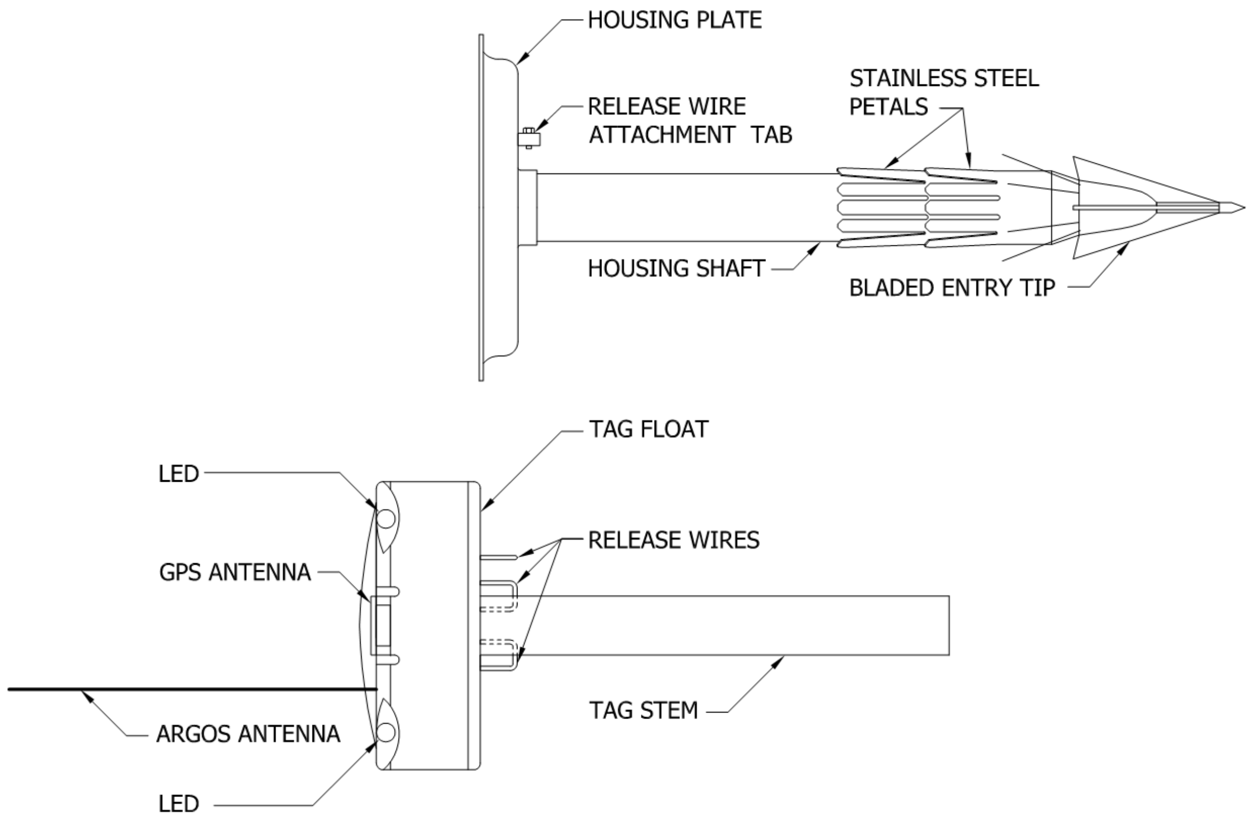

Figure 2. Schematic of the design of the Advanced Dive Behavior (ADB) tag used in this project. Taken from Mate et al. (in prep).

tag was ejected from the housing and floated to the surface for recovery (Mate et al. in prep). For this study, the electro-mechanical connections between the tags and their housings were programmed to release the tags on 1 August 2015. This allowed one week for tag recovery during the 5-week project.

The ADB tags were programmed to collect a GPS-quality FastLoc® location every 7 minutes (min) or as soon thereafter as the whale surfaced from a dive. Dive depth was recorded every 1 second (s) with 2-m vertical resolution. Body orientation (from the accelerometer) and magnetic compass heading (from the magnetometer) were also recorded at 1-s intervals. These data were all archived onboard the tag and accessible only when the tag was recovered. Qualifying dives (those greater than 2 min in duration and 10 m in depth) were also summarized for transmission through the Argos system along with GPS locations recorded by the tag. Three dive summary histograms were created for qualifying dives every 6 h during tag operation. The histograms summarized the percentage of time spent at different depths (%TADHist), the maximum dive depths (MaxDiveDeptHist), and maximum dive durations (DiveDurHist). Separate summary messages (behavior messages) describing individual qualifying dives were also generated by recording dive duration, maximum dive depth, dive shape (U-, V-, or square-shaped- and whether the U- or V-shaped dives were skewed right, left or centered) and the subsequent surfacing duration. Up to four consecutive summarized dives were transmitted in each behavior message (Wildlife Computers PAT-MK10 User Guide [30 Nov 2015] http://wildlifecomputers.com/wp-content/uploads/manuals/MK10-User-Guide.pdf). A single Argos message from the tag could send either one GPS location, one histogram summary, or one behavior message (summarizing four dives). One of two versions of firmware was installed in the ADB tags, each using a different version of the FastLoc® GPS acquisition program (FastLoc® v. 1 or v. 3).

2.2.2 Argos and GPS Tracking

Tagged whales were tracked using the Argos satellite-based system that assigns a location 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 error 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 the MMI to remove locations occurring on land. Remaining Argos locations were further filtered by LCs and speeds. 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. If a speed between two locations exceeded 12 km/h, one of the two locations was removed, with the location resulting in a shorter overall track length being retained.

It is important to note here that the Argos locations from the tags deployed in 2014 were initially filtered differently than those from tags deployed in 2015. For tags deployed in 2014, locations of class B, when derived from only one transmission, were removed from analyses. We have since determined that these locations provide valuable information despite having potentially large error radii around them. The 2014 data presented here have been recalculated to incorporate these class B locations into further location filtering and subsequent analyses. Results may appear slightly different from those presented in the Preliminary Summary and Final Report from the 2014 tagging study, however these differences are minor.

The ADB tags provide both Argos and GPS locations. For the latter, the tag's GPS receiver records a snapshot of the radio signals produced by overhead GPS satellites. Snapshots are processed onboard the tag and converted to a compressed format that is optimized for transmission over Argos. Snapshots (either downloaded from Argos or from the archived tag memory after recovery) are then processed using Fast-GPS Solver, part of the Wildlife Computers Data Analysis Package. The Fast-GPS Solver calculates locations from snapshots using ephemeris information (the known GPS satellites' positions in the sky) downloaded from the internet, along with the previous known location of the tag (the solution from one snapshot can be used as a seed location of another snapshot). The Fast-GPS Solver does not use any statistical movement model or location smoothing, nor does it produce an estimate of location error analogous to LC. Testing on previous ADB tag generations showed that 83 percent of FastLoc® location errors were less than 100 m when compared to a handheld GPS (max = 455 m, Mate et al. in prep.) and 95 percent of locations with four satellites have been shown to have errors < 810 m (Bryant 2007). All GPS and Argos locations were combined for each ADB tag to make one composite track (with both location types) and then filtered by the OSU/MMI to remove locations occurring on land. Argos locations were not retained if they were received within 20 min of GPS locations. Remaining locations were further filtered by speed using the 12 km/hr criterion described above.

2.2.3 Location Analysis

2.2.3.1 CALCULATION OF DISTANCE FROM SHORE

Minimum and maximum great-circle distances to the closest point on land were computed for each whale location, using the NEAR ARC Tool function in ESRI® ArcMap v.10.0. Vancouver Island, British Columbia, Canada, was used as the land reference for whale locations west of the island.

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. Four blue whale BIAs overlapped completely or partially with the SOCAL area: Santa Monica Bay to Long Beach; San Nicolas Island; Tanner-Cortes Bank; and San Diego. Two blue whale BIAs overlapped with the PT MUGU area: Santa Barbara Channel and San Miguel, and Point Conception/Arguello. Numbers of blue whale locations and corresponding percentages were also computed for these six BIAs. The other three blue whale BIAs 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 and GPS 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 (SSM)

A Bayesian switching state-space model (SSM) developed by Jonsen et al. (2005) was applied to the unfiltered Argos locations (after removal of Z-class locations) for each SPOT5 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 SSM 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. 2010). 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. 2010). As in Bailey et al. (2010) 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 HR 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.

2.2.4 ADB Analysis

To establish a baseline orientation for the position of the tag on the whale, a series of three temporally close FastLoc® GPS locations were identified from each whale’s track where the whale was travelling 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 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 & Tyack 2003, Simon et al. 2012). Once the tag data were rotated to the whale’s reference frame, the Minimum Specific Acceleration (MSA) and Jerk metrics were calculated from the accelerometer data as described in Simon et al. (2012) to identify lunge-feeding events in the data record. MSA identifies the acceleration beyond standard earth’s gravity that the whale is experiencing, and Jerk measures the rate at which the whale is changing orientation. Lunge-feeding events in rorquals are characterized by near-coincident peaks in both MSA and Jerk as the whale typically accelerates, then decelerates rapidly and rolls as it opens its mouth to engulf prey (Goldbogen et al. 2006, Simon et al. 2012). Peaks in Jerk were more distinct than MSA in the ADB data, so the Jerk metric was used to identify lunges. In order to better identify peaks in Jerk a 0.15-Hz low-pass filter was applied to the data to remove high-frequency signals associated with fluking by the whale. 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 foraging dives (dives with at least one detected lunge) in order to obtain an objective criterion to distinguish between series of related foraging dives. Sequences of dives defined by this criterion were isolated and labeled ‘foraging bouts.’ Dive summary statistics were calculated for each foraging bout, and minimum convex polygons were created using the corresponding locations to assess the spatial extent of each foraging bout and the overall scale of foraging effort by comparing the area of each foraging bout and the distance between foraging bouts.

It is important to note that the criteria used in this report are slightly different from those used in the Preliminary Summary Report submitted in January 2016. All previous data were re-analyzed using the newer criteria, so some numbers reported will be different from those in the Preliminary Summary.

2.3 Ecological Relationships

The daily locations generated by the SSM were used to describe whale distribution using an objective framework rooted in regional ecology. For this purpose, we followed Longhurst's (1998, 2006) biogeochemical province designations. 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 last year's report (Mate et al. 2015). Digital boundaries for these provinces were obtained as shapefiles from Vlaams Instituut voor de Zee (2009; version 2). 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 last year's report (Mate et al. 2015), the boundaries of two of these provinces were slightly modified 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, since 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. SSM locations that occurred on land were excluded from this assessment. To minimize the impact of locations with large estimation uncertainty on the analyses we also excluded locations with 95 percent credible limits exceeding 1 degree in longitude and/or in latitude.

In order to provide an environmental context to the tracking observations we obtained relevant variables for each accepted SSM location from remotely sensed measurements collected by oceanographic satellites and from digital elevation models of seafloor relief available through the web service Environmental Research Division Data Access Program (ERDDAP), hosted by the National Marine Fisheries Service's (NMFS's) Southwest Fisheries Science Center in Santa Cruz, California (http://coastwatch.pfeg.noaa.gov/erddap/index.html). This process was automated using the R package "xtractomatic" (Mendelssohn 2015), a collection of functions that permit client-side access to the data sets served by ERDDAP (**Table 1**). The oceanographic variables extracted included: vertical upwelling velocity (or Ekman pumping, WEKM), sea surface temperature (SST), and phytoplankton chlorophyll-*a* concentration (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

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), 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	Metop-A ASCAT*	8 d†	0.25 deg (27.28 km)
Sea surface temperature (SST)	°C	agssta8day	POES AVHRR	8 d†	0.1 deg (11.11 km)
Chlorophyll-*a* concentration (CHL)	$mg\ m^{-3}$	mbchla8day	Aqua MODIS	8 d†	0.025 deg (2.78 km)
Depth (DEPTH)	m	ETOPO180	ETOPO1	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.

for each SSM location. Two other potentially informative oceanographic variables, sea surface height and sea surface salinity, were not accessible through xtractomatic at the time of preparation of this report due to changes in data distribution policies (R. Mendelssohn and C. Wilson, pers. comm.), although they are expected to become available soon and we look forward to incorporating them in future analyses.

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 95 percent 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). 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.

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 (LeDuc et al. 2007; Attard et al. 2015; Sremba et al. 2012; Archer et al. 2013), downloaded from GenBank® and from samples collected during previous tagging efforts. New haplotypes were confirmed by reverse sequencing from a new 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 submitted 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 whales was investigated by developing a reference database of published mtDNA sequences and by initiating collaboration with other holders of unpublished data. It was not possible to include nuclear microsatellite loci in the stock analyses because of differences in loci used by other investigators and the difficulties of standardizing allele sizes across laboratories (Morin et al. 2010). The mtDNA haplotypes of the tagged whales were compared to the 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 unpublished results from samples of blue whales from the eastern North Pacific and published reports of mtDNA haplotypes 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.

3. Results

3.1 Blue Whales

3.1.1 2014 Location Tracking

Twenty-four tags were deployed on blue whales (20 SPOT5, 4 ADB) between 3 August and 12 September 2014. All tags were deployed off southern California, between Mugu Canyon (west of Malibu) and San Diego. Locations were received from 23 of these tags, providing tracking periods ranging from 0.7 to 283.8 d (**Table 2**). The average tracking duration for SPOT5 tags was 64.0 d (standard deviation [SD] = 69.3 d, median = 39.8 d) and for ADB tags was 19.0 d (SD = 0.6 d, median = 18.9 d). There was a great deal of individual variation among blue whale tracks, both in terms of distance to shore (from less than 1 and up to 996.7 km, median = 59 km) and latitudinal movement along the coastline (from 6.7 to 50.5°N; **Figure 3 and Table 3**). The continental shelf edge between Dume and Mugu canyons (where all of blue whales were tagged during the first leg of the cruise) and Santa Monica Canyon were heavily used throughout August. There was also extensive movement north and south from the tagging area by some whales during this same period, with two reaching Cape Mendocino in northern California and three others crossing into Mexican waters by the third week of August. There was extensive movement off San Diego as well, where whales were tagged during the second leg of the cruise. By the end of September, the blue whales were spread out between the area off Magdalena Bay in southern Baja California and the tip of the Olympic Peninsula in Washington. By mid-October all whales were traveling south, with the northernmost departure point at the northern tip of Vancouver Island, British Columbia. By mid-November, all five whales still being tracked were south of the U.S./Mexico border, with three of them having crossed south of the Mexico/Guatemala border. Only two tags continued to transmit after mid-December; both of those whales spent the months of December, January, and February in the Costa Rica Dome upwelling area. One of these whales was tracked for another 5 months, remaining in the Costa Rica Dome area until 10 May 2015, at which point it began its northward migration. After a 45-d migration the whale crossed the U.S./Mexico border on 23 June. The whale then spent almost 2 weeks just west of the Tanner-Cortes Bank BIA in southern California before heading north again and was last located west of Pt. Conception on 13 July. In total, this whale (Tag #2014_10827) was tracked for 283.8 d.

The two most heavily used Navy training areas for tagged blue whales were SOCAL and PT MUGU, with 18 blue whales having locations in SOCAL and 14 having locations in PT MUGU (**Table 4, Figures 4 and 5**). Four blue whales had locations within the NWTRC area, but only one of these four had locations within Warning Area 237 of the NWTRC (W237) (**Figures 6 and 7**). None of the tagged blue whales were tracked within the GOA area. Seventy-five percent of all blue whale locations were less than 84 km from shore (median = 59 km), but maximum distances from land in Navy training ranges was 668 km within SOCAL, 219 km in PT MUGU, 322 km in the NWTRC, and 98 km in area W237. Blue whale locations occurred in SOCAL during 6 months of the year (June, July, August, September, October, and November), during five months in PT MUGU (July, August, September, October, and November), and during four months in the NWTRC (August, September, October, and November). Locations inside area W237 occurred only in September, October, and November.

Table 2. Deployment and performance data for satellite-monitored radio tags deployed on blue whales in southern California, 2014. In the Sex column, F = female, M = male, and U = unknown sex, because no biopsy sample was collected. See Section 3.2.2 for location filtering method.

Tag #	Sex	Tag Type	Deployment Date	Most Recent Location	# Days Tracked	# Filtered Locations	# GPS/Argos Locations	Total Distance (km)
847	F	SPOT5	03-Aug-14	26-Nov-14	115.5	372	0 / 372	9,719
5641	F	SPOT5	02-Aug-14	6-Nov-14	95.6	446	0 / 446	6,151
5784*	U	SPOT5	07-Aug-14	23-Aug-14	15.8	1	0 / 1	903
5826*	U	SPOT5	11-Sep-14					
5840	M	SPOT5	05-Aug-14	12-Aug-14	7.2	22	0 / 22	368
5921	M	SPOT5	09-Sep-14	14-Feb-15	157.7	369	0 / 369	8,191
5922	U	SPOT5	12-Sep-14	3-Nov-14	52.1	160	0 / 160	2,284
5923	M	SPOT5	08-Aug-14	5-Sep-14	27.5	114	0 / 114	1,652
10826	U	SPOT5	09-Sep-14	23-Oct-14	43.3	157	0 / 157	2,746
10827	U	SPOT5	12-Sep-14	23-Jun-15	283.8	676	0 / 676	17,840
10829	U	SPOT5	12-Sep-14	6-Oct-14	23.9	81	0 / 81	1,884
10830	U	SPOT5	10-Aug-14	11-Aug-14	0.7	3	0 / 3	57
10833	M	SPOT5	11-Sep-14	16-Oct-14	34.8	130	0 / 130	1,989
10834	M	SPOT5	08-Aug-14	18-Nov-14	101.6	397	0 / 397	6,805
10836	U	SPOT5	13-Aug-14	6-Dec-14	115.3	397	0 / 397	6,883
10839	U	SPOT5	11-Sep-14	6-Oct-14	24.6	71	0 / 71	2,121
10840	F	SPOT5	08-Aug-14	13-Aug-14	4.5	16	0 / 16	195
23029	M	SPOT5	05-Aug-14	26-Aug-14	21.0	73	0 / 73	776
23030	U	SPOT5	12-Sep-14	2-Nov-14	51.0	75	0 / 75	4,653
23031	M	SPOT5	05-Aug-14	14-Sep-14	39.8	103	0 / 103	3,029
Mean		**SPOT5**			**64.0**	**193**		**4,297**
Median		**SPOT5**			**39.8**	**114**		**2,515**
5644^{+}	F	ADB	4-Aug-14	23-Aug-14	18.9	454	182 / 272	1,937
5650^{+++}	M	ADB	4-Aug-14	23-Aug-14	19.0	2324	2,277 / 47	1,715
5655^{+}	F	ADB	6-Aug-14	26-Aug-14	19.8	1017	796 / 221	2,008
5803^{+++}	F	ADB	4-Aug-14	23-Aug-14	18.2	2570	2,530 / 40	2,045
Mean		**ADB**			**19.0**	**1,591**		**1,926**
Median		**ADB**			**19.0**	**1,671**		**1,973**

KEY: ADB = Advanced Dive Behavior; km = kilometer(s); GPS = geographic positioning system; SPOT5 = Smart Positioning or Temperature Transmitting Tag, Version 5; # = number; *broken antenna; $^{+}$Tag is FastLoc®, Version.1; $^{+++}$Tag is FastLoc®, Version.3

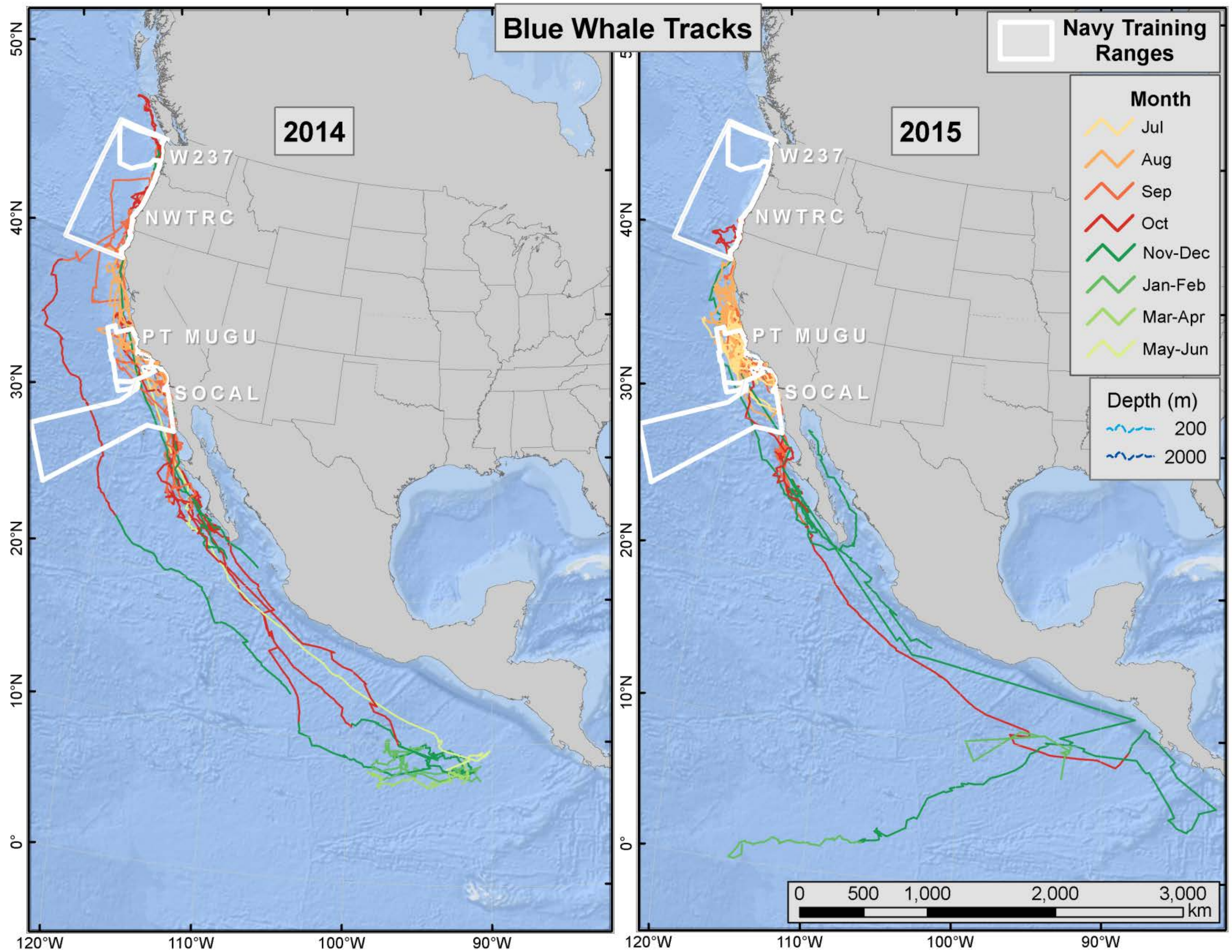

Figure 3. Satellite-monitored radio tracks for blue whales tagged off southern California in August and September, 2014 (left panel; 20 SPOT5 tags, 4 ADB tags), and July, 2015 (right panel; 18 SPOT5 tags, 4 ADB tags).

Table 3. Great-circle distances to nearest point on land for blue whales tagged off southern California, 2014. The number of locations includes filtered locations (see Section 3.2.2 for filtering method) plus deployment location.

Tag #	Tag Type	# Locations	Median (km)	Mean (km)	SD (km)	Minimum (km)	Maximum (km)	Deploy Location Distance (km)
847	SPOT5	374	262.7	314.1	258.54	0.4	680.6	9.5
5641	SPOT5	448	34.2	38.1	26.98	0.9	166.9	8.7
5840	SPOT5	24	26.5	44.0	36.78	6.1	130.3	7.1
5921	SPOT5	371	532.1	409.5	247.20	8.5	826.7	9.0
5922	SPOT5	162	60.0	58.0	29.70	4.9	139.7	11.5
5923	SPOT5	116	147.9	141.6	65.40	0.4	274.7	8.3
10826	SPOT5	159	69.9	84.6	69.47	1.0	233.3	9.7
10827	SPOT5	678	656.9	522.9	296.95	3.8	996.7	7.9
10829	SPOT5	83	88.1	104.0	83.71	2.2	265.4	8.1
10830	SPOT5	5	6.7	6.9	1.92	4.8	10.0	6.3
10833	SPOT5	132	59.5	76.7	65.57	7.9	255.7	10.6
10834	SPOT5	399	48.9	53.7	41.33	1.3	229.1	15.3
10836	SPOT5	399	57.8	72.5	44.26	1.1	222.0	6.9
10839	SPOT5	73	109.0	109.7	72.33	0.9	234.7	11.4
10840	SPOT5	18	8.4	11.1	10.23	0.6	43.7	8.6
23029	SPOT5	75	6.7	9.6	7.45	2.1	32.0	6.4
23030	SPOT5	77	113.9	149.7	142.42	2.3	651.7	12.8
23031	SPOT5	105	77.9	75.1	52.14	1.6	230.4	7.1
5644^{+}	ADB	455	10.8	18.0	17.79	0.2	86.0	7.9
5650^{+++}	ADB	2325	13.9	38.4	43.92	2.0	137.0	9.1
5655^{+}	ADB	1018	8.4	9.9	5.05	0.0	42.4	9.1
5803^{+++}	ADB	2572	16.0	28.4	26.32	1.7	113.7	7.2
Mean				**108.0**		**2.5**	**272.9**	**9.0**
Median			**58.7**			**1.7**	**225.6**	**8.7**

KEY: ADB = Advanced Dive Behavior; km = kilometer(s); SD = standard deviation; SPOT5 = Smart Positioning or Temperature Transmitting Tag, Version 5; # = number; $^{+}$Tag is FastLoc®, Version.1; $^{+++}$Tag is FastLoc®, Version.3

Table 4. Percentage of filtered locations (Locs) and time spent inside the SOCAL, PT MUGU, NWTRC and W237 areas for blue whales tagged off southern California, 2014. See Section 3.2.2 for location filtering method.

		Filtered Locations														
Tag #	Tag Type	Total		SOCAL			PT MUGU			NWRTC			W237			
		# Locs	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days
847	SPOT5	372	115.5	5	5	5.5	3	3	3.1	24	21	24.1			
5641	SPOT5	446	95.6				9	8	7.4	41	40	38.5	20	20	19.5
5784*	SPOT5		24.8												
5826*	SPOT5		0.0												
5840	SPOT5	22	7.2	55	51	3.7									
5921	SPOT5	369	157.8	1	1	1.5									
5922	SPOT5	160	52.1	6	5	2.7									
5923	SPOT5	114	27.5	15	13	3.5	59	60	16.5						
10826	SPOT5	157	43.3	9	8	3.3									
10827	SPOT5	676	304.2	7	6	17.6	3	5	15.6						
10829	SPOT5	81	23.8	21	23	5.5									
10830	SPOT5	3	0.7												
10833	SPOT5	130	34.8	15	15	5.2									
10834	SPOT5	397	102.8	18	17	17.1	11	14	14.6						
10836	SPOT5	397	115.3	3	4	4.1	8	7	7.6	52	45	52.3			
10839	SPOT5	71	24.6	44	40	9.7	34	37	9.0						
10840	SPOT5	16	4.5				6	3	0.2						
23029	SPOT5	73	21.0	8	9	1.9	37	39	8.1						
23030	SPOT5	75	51.0	20	11	5.6									
23031	SPOT5	103	39.8	10	9	3.8	51	44	17.4						
5644[+]	ADB	454	18.9	39	38	7.1	10	10	1.9						
5650[+++]	ADB	2,324	18.9	34	39	7.3	14	17	3.2						
5655[+]	ADB	1,017	19.8	45	45	8.9	8	7	1.4						
5803[+++]	ADB	2,571	18.2				17	15	2.8	<1	4	0.7			

KEY: ADB = Advanced Dive Behavior; SPOT5 = Smart Positioning or Temperature Transmitting Tag, Version 5; # = number; * broken antenna; [+]Tag is FastLoc®, Version.1; +[++]Tag is FastLoc®, Version.3

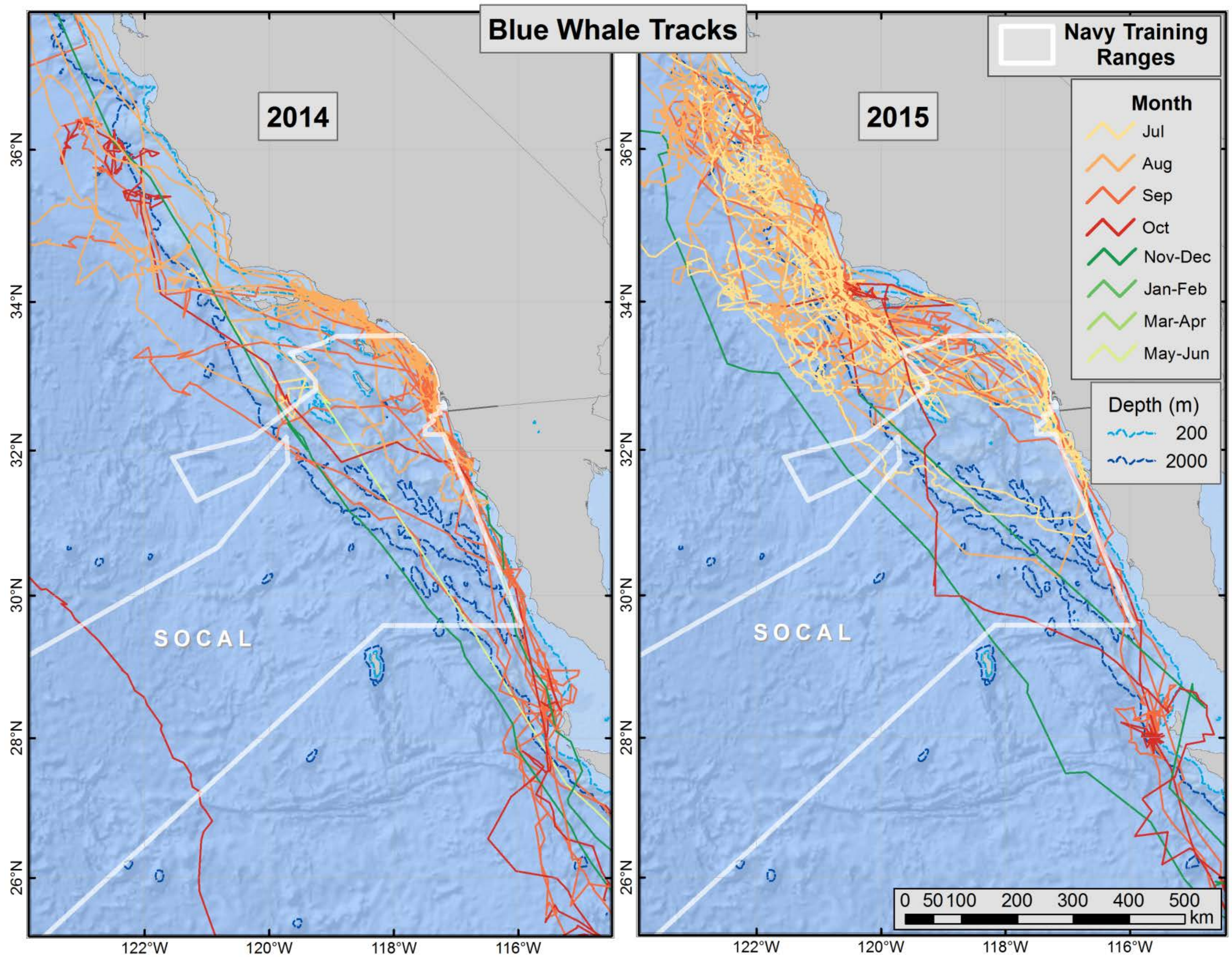

Figure 4. Satellite-monitored radio tracks in SOCAL for blue whales tagged off southern California in August and September 2014 (left panel; 15 SPOT5 tags, 3 ADB tags) and July 2015 (right panel; 12 SPOT5 tags, 2 ADB tags).

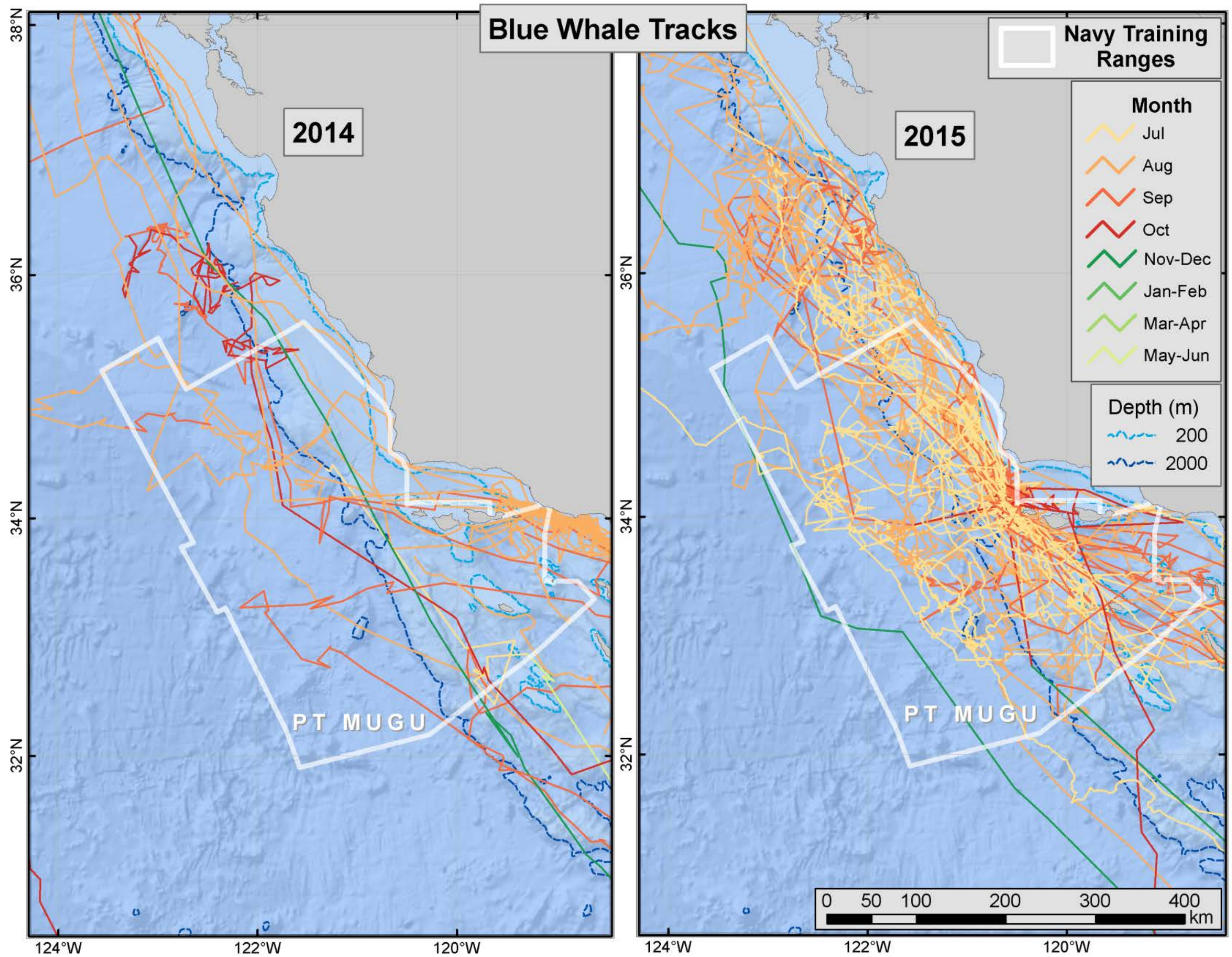

Figure 5. Satellite-monitored radio tracks in PT MUGU for blue whales tagged off southern California in August and September 2014 (left panel; 10 SPOT5 tags, 4 ADB tags) and July 2015 (right panel; 18 SPOT5 tags, 4 ADB tags).

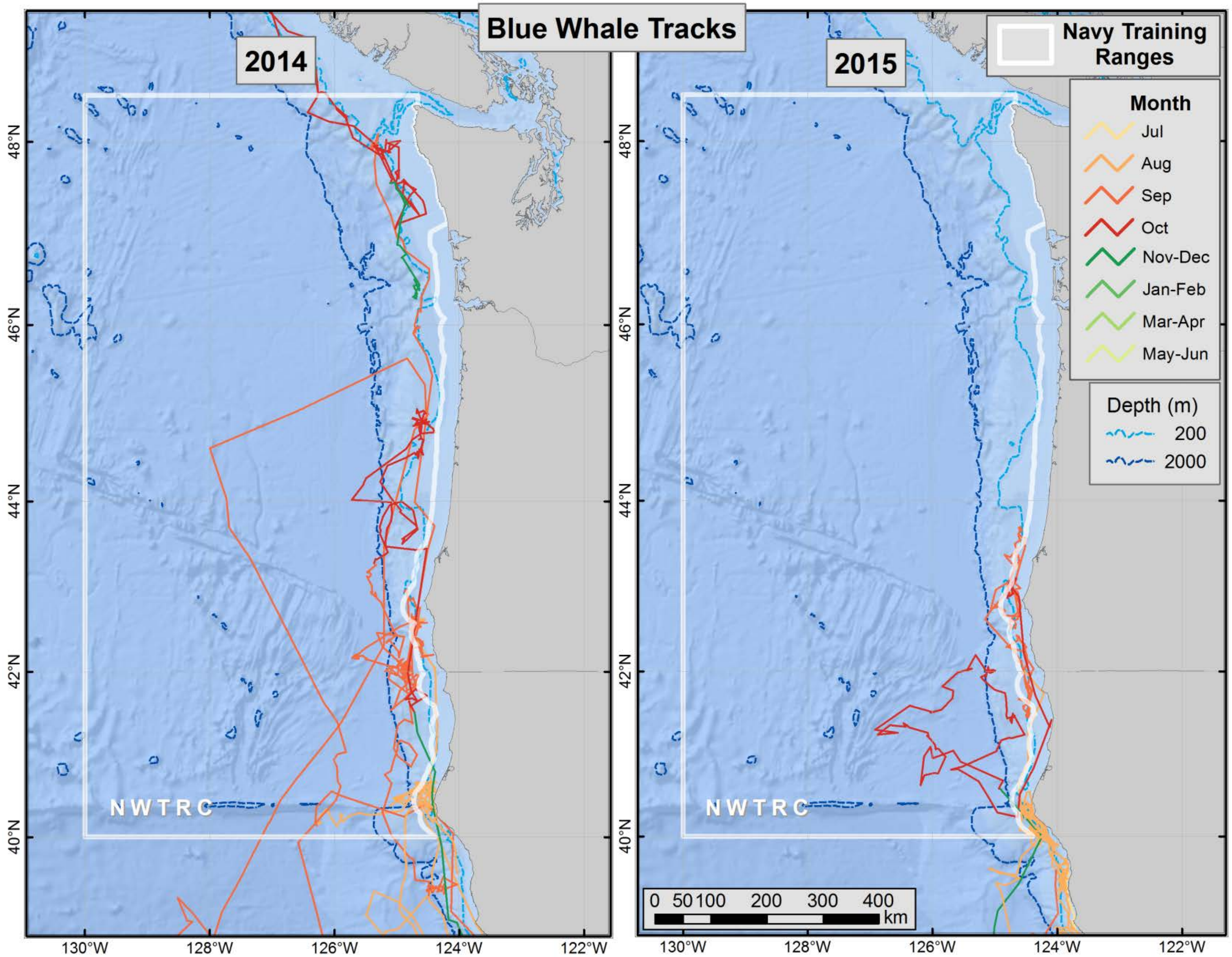

Figure 6. Satellite-monitored radio tracks in NWTRC for blue whales tagged off southern California in August and September 2014 (left panel; 3 SPOT5 tags, 1 ADB tag) and July 2015 (right panel; 2 SPOT5 tags).

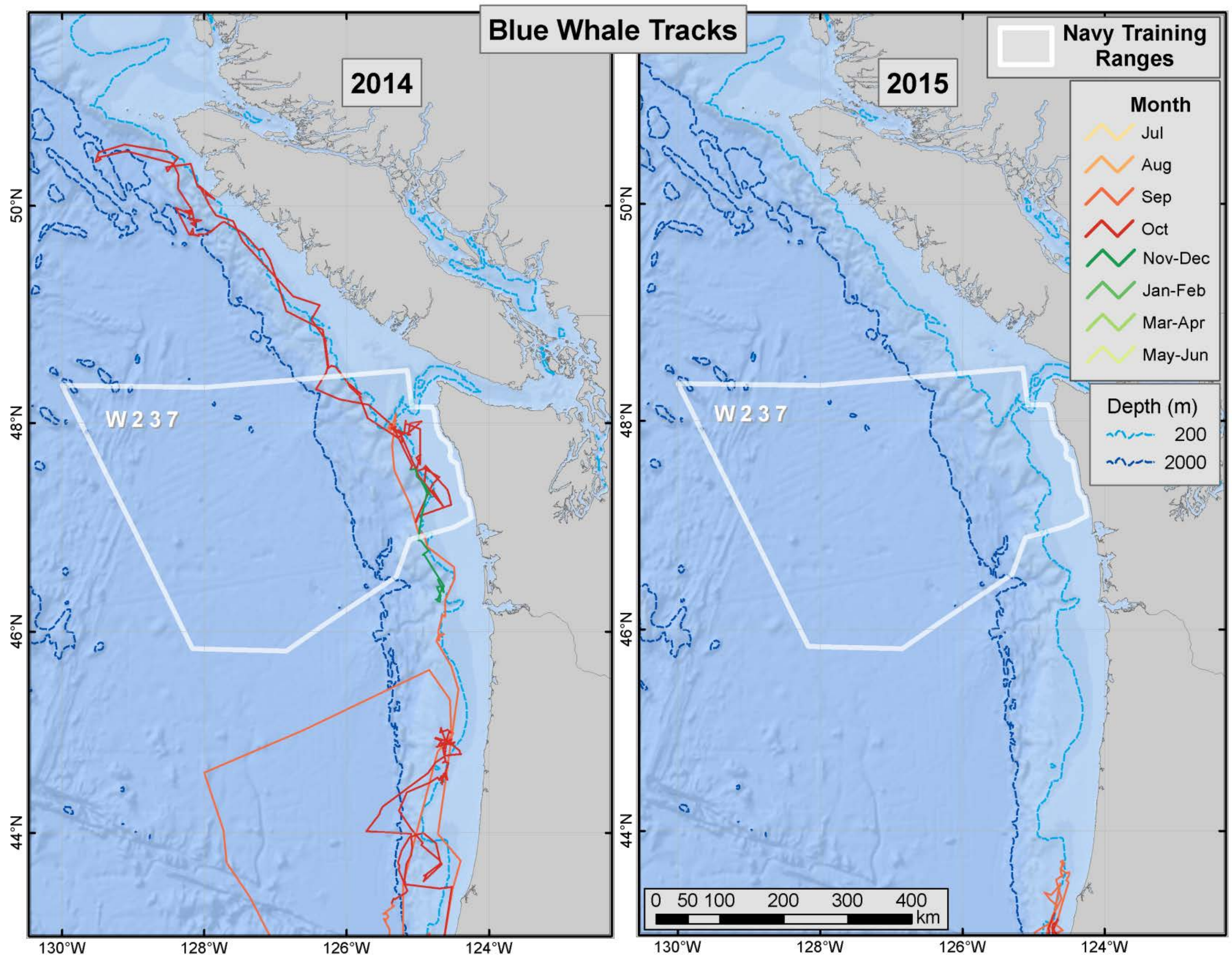

Figure 7. Satellite-monitored radio tracks in area W237 for blue whales tagged off southern California in August and September 2014 (left panel; 1 SPOT5 tag) and July 2015 (right panel; 0 tags).

For the 18 blue whales with locations in SOCAL, time spent there ranged from 1 to 50 percent of their total tracking periods (**Table 4**), representing 2 to 18 d in this Navy area. The 14 blue whales in PT MUGU spent from <1 to 17 d there, which represented from 3 to 60 percent of their total tracking periods. Time spent in the NWTRC ranged from 4 to 45 percent of total tracking periods for the four blue whales with locations there (<1 to 52 d). One of these whales spent 20 percent of its total tracking period, or 19 d, within area W237.

The amount of time spent in BIAs by tagged blue whales ranged from <1 to 14 percent of their total tracking periods. The two most heavily used BIAs (of the six overlapping Navy training ranges), in terms of number of whales having locations there, were Santa Monica Bay to Long Beach and San Diego (**Table 5**, **Figures 8 and 9**). Ten blue whales had locations in the Santa Monica Bay to Long Beach BIA, spending 1 to 14 percent of their total tracking time there, or <1 to 7 d. This represented 1 to 15 percent of the total number of locations for these 10 whales. Fourteen blue whales had locations in the San Diego BIA, spending <1 to 11 percent of their total time there, or <1 to 3 d. For these 14 whales, this represented <1 to 11 percent of their total number of locations. Both the Santa Barbara Channel and San Miguel BIA and the Pt. Conception/Arguello BIA had locations for 4 blue whales, each representing from <1 to 2 percent of the whales' total tracking periods and from <1 to 2 percent of their total number of locations (**Figures 10 and 11**). The track of one blue whale (Tag #2014_10839) crossed the San Nicolas Island BIA, for an estimated 7.3 h, but no locations were received from within the BIA itself (**Figure 12**). Another blue whale (Tag #2014_10827) spent 2 d in the Tanner-Cortes Bank BIA (**Figure 13**), representing <1 percent of its total tracking time and <1 percent of its total number of locations. All of the blue whale locations within these six BIAs occurred in August or September.

Five blue whales provided enough locations to calculate HRs and CAs within waters of the U.S. Exclusive Economic Zone (**Table 6, Figures 14 and 15**). HR sizes ranged from 50,179 to 176,028 square kilometers (km^2) (mean = 145,301.6 km^2; SD = 56,328.84 km^2) and covered the entire U.S. West Coast. The densest location of HRs occurred in the Southern California Bight, from Santa Barbara to Los Angeles out to approximately 70 km from shore, where HRs overlapped for all five blue whales. There were several other areas with overlapping HRs for four blue whales, including near Cordell Bank off Point Reyes, and areas west of Monterey Bay, Pt. Conception, and the Channel Islands. CAs ranged in size from 13,854 to 45,654 km^2 (mean = 32,639.2 km^2, SD = 12,915.23 km^2), extending from the California/Mexico border to the tip of the Olympic Peninsula in Washington. The area of highest use, with overlapping CAs for all five blue whales, was between Pt. Dume and Mugu canyons and seaward to approximately 30 km from shore.

3.1.2 2015 Location Tracking

Twenty-two tags were deployed on blue whales (18 SPOT5, 4 ADB) between 7 and 16 July 2015. All blue whale tags but one were deployed off the west coast of San Miguel Island in southern California, with the exception being deployed just south of Pt. Mugu. Locations were received from all 22 of these tags, providing tracking periods ranging from 4.2 to 212.5 d (**Table 7**). Average tracking duration was 88.8 d (SD = 58.2 d, median = 64.5 d) for SPOT5 tags and 26.9 d (SD = 2.2 d, median = 26.5 d) for ADB tags. Blue whales tagged in 2015 ranged widely along the California coast (**Figure 3**). By the end of July, locations extended from off

Table 5. Percentage of filtered locations (Locs) and time spent inside the Biological Important Areas (BIAs) for blue whales tagged off southern California, 2014. See Section 3.2.2 for location filtering method.

		Filtered Locations																				
		Total		Santa Monica			San Diego			San Nicolas			Tanner Cortes			Santa Barbara			Pt Conception			
Tag #	Tag Type	# 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
847	SPOT5	372	115.5													<1	<1	0.3	1	<1	0.3
5641	SPOT5	446	95.6	1	1	1.3													<1	<1	0.2
5784*	SPOT5		24.8																		
5826*	SPOT5		0.0																		
5840	SPOT5	22	7.2	9	8	0.6															
5921	SPOT5	369	157.8				1	1	1.0												
5922	SPOT5	160	52.1				6	5	2.7												
5923	SPOT5	114	27.5	1	1	0.2	1	1	0.3												
10826	SPOT5	157	43.3				3	2	0.7												
10827	SPOT5	676	304.2				<1	<1	1.3				<1	1	1.7						
10829	SPOT5	81	23.8				2	2	0.5												
10830	SPOT5	3	0.7																		
10833	SPOT5	130	34.8				8	10	3.4												
10834	SPOT5	397	102.8	7	6	6.5	3	3	3.0							1	1	1.0	<1	<1	0.4
10836	SPOT5	397	115.3				2	2	2.3												
10839	SPOT5	71	24.6							<1	1	0.3									
10840	SPOT5	16	4.5																		
23029	SPOT5	73	21.0	5	5	1.0															
23030	SPOT5	75	51.0				7	3	1.7												
23031	SPOT5	103	39.8	4	4	1.6	1	2	0.8							2	2	0.7			
5644^{+}	ADB	454	18.9	15	14	2.6	6	5	1.0												
5650^{+++}	ADB	2,324	18.9	4	4	0.8	1	1	0.1												
5655^{+}	ADB	1,017	19.8	7	10	1.9	11	11	2.1												
5803^{+++}	ADB	2,571	18.2	11	11	2.0										1	1	0.2	2	2	0.3
Mean/Median				6.4/6.0	6.3/5.5	1.8/1.5	3.7/2.5	3.4/2.0	1.5/1.1							1.0/0.9	1.1/1.2	0.6/0.2	0.7/0.4	0.7/0.3	0.3/0.3

KEY: ADB = Advanced Dive Behavior; SPOT5 = Smart Positioning or Temperature Transmitting Tag, Version 5; # = number; * broken antenna; $^{+}$Tag is FastLoc®, Version.1; +$^{++}$Tag is FastLoc®, Version.3.

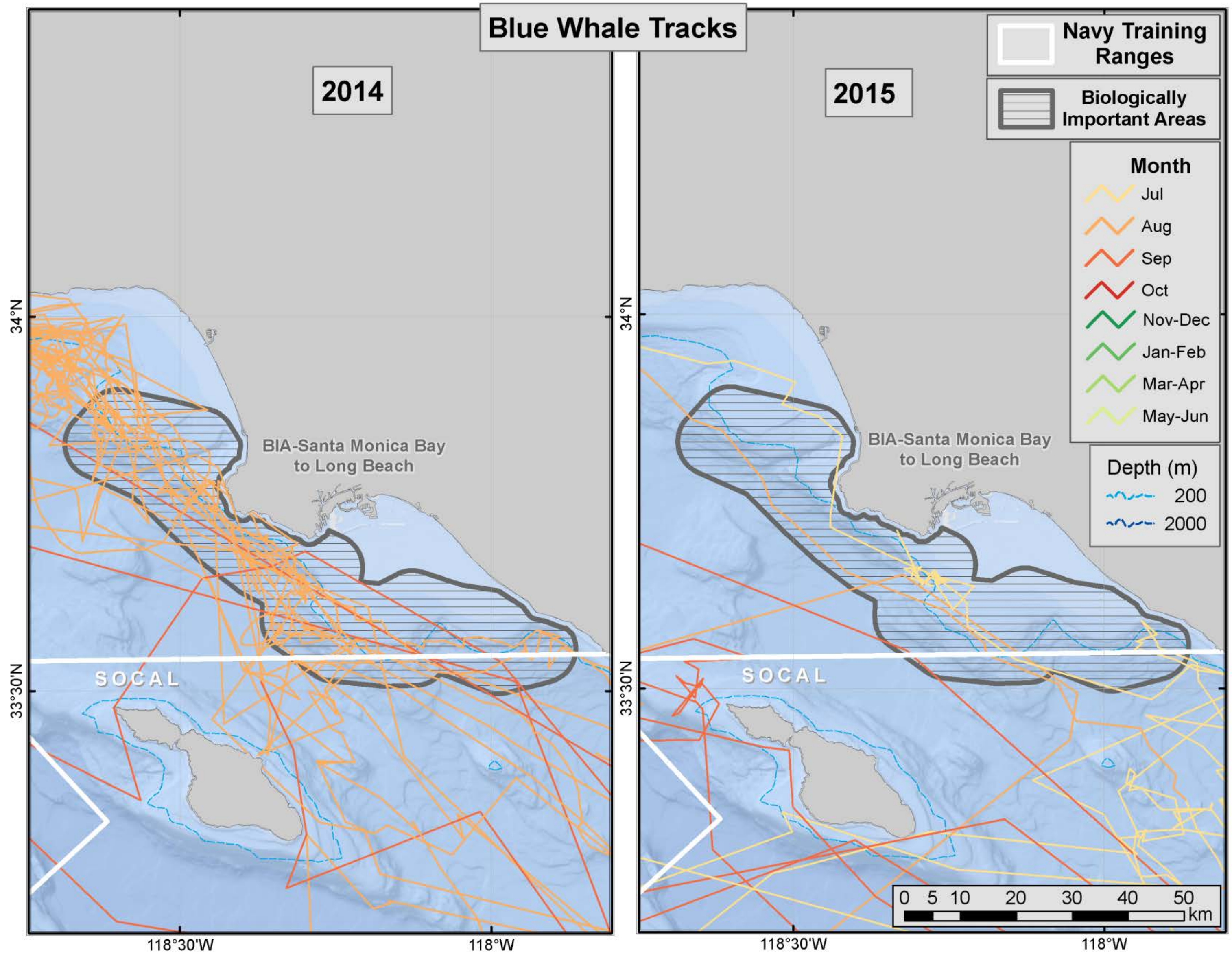

Figure 8. Satellite-monitored radio tracks in the Santa Monica Bay to Long Beach BIA for blue whales tagged off southern California in August and September 2014 (left panel; l6 SPOT5 tags, 4 ADB tags) and July 2015 (right panel; 2 SPOT5 tags, 1 ADB tag).

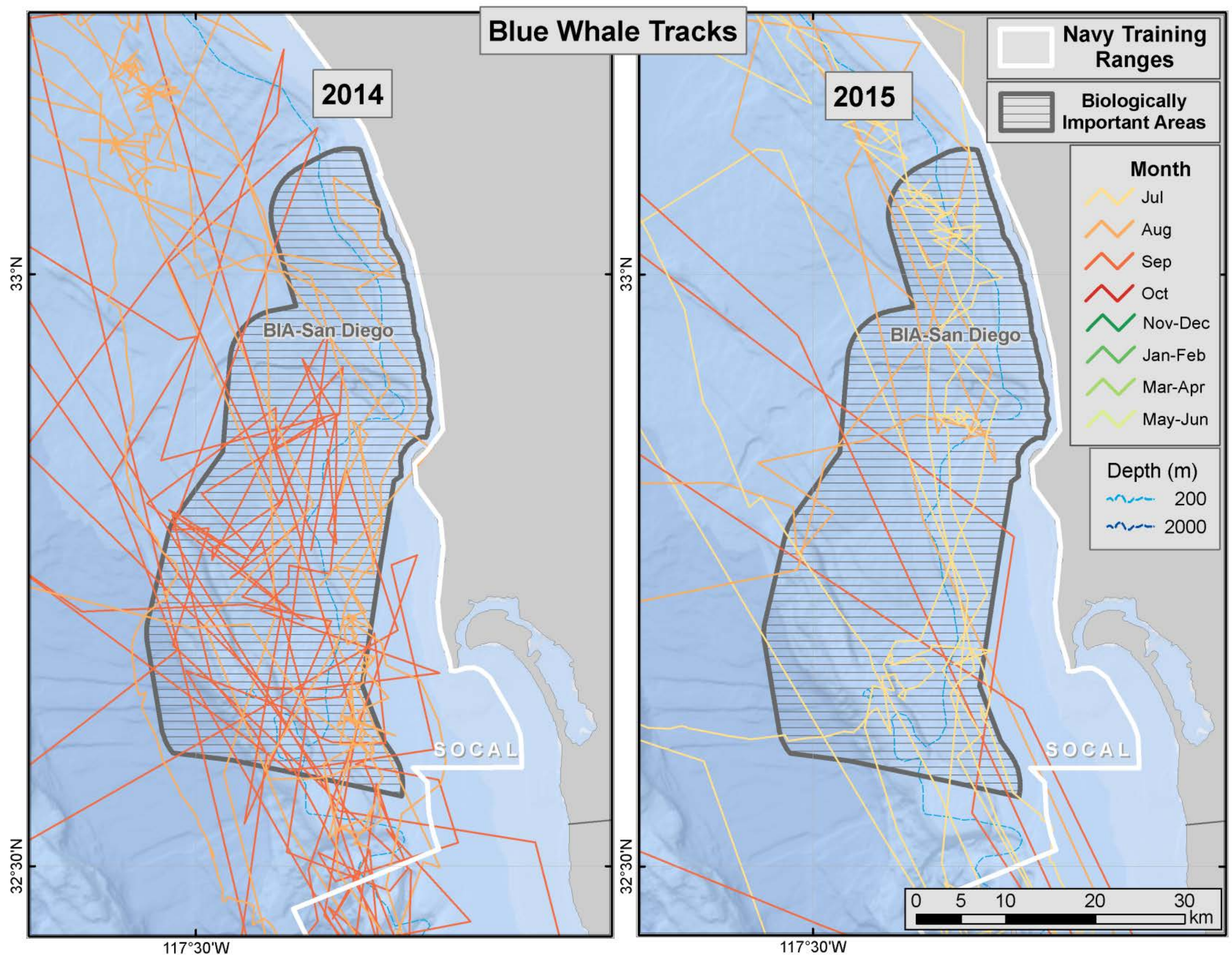

Figure 9. Satellite-monitored radio tracks in the San Diego BIA for blue whales tagged off southern California in August and September 2014 (left panel; 11 SPOT5 tags, 3 ADB tags) and July 2015 (right panel; 7 SPOT5 tags, 2 ADB tags).

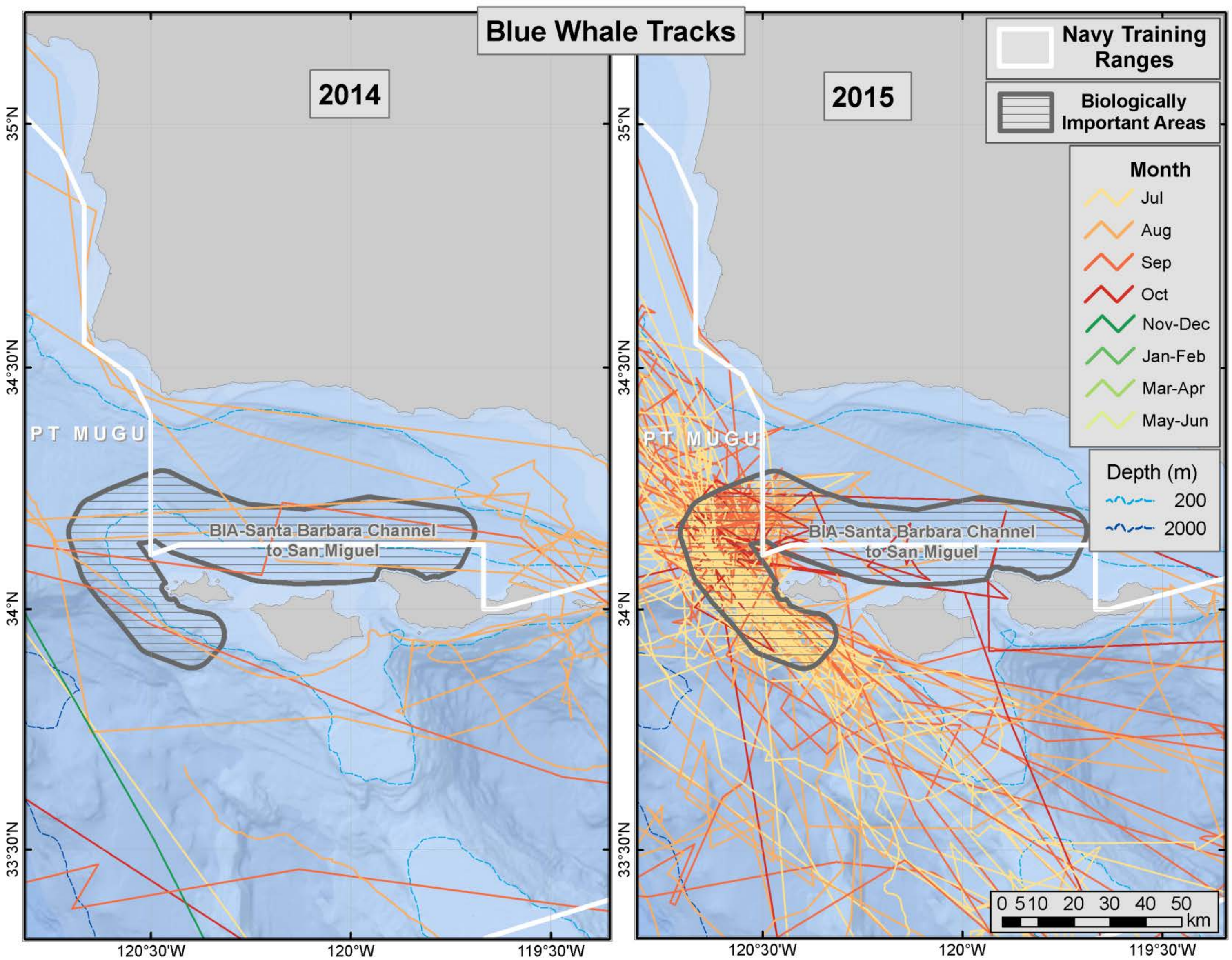

Figure 10. Satellite-monitored radio tracks in the Santa Barbara Channel and San Miguel BIA for blue whales tagged off southern California in August and September 2014 (left panel; 3 SPOT5 tags, 1 ADB tag) and July 2015 (right panel; 17 SPOT5 tags, 3 ADB tags).

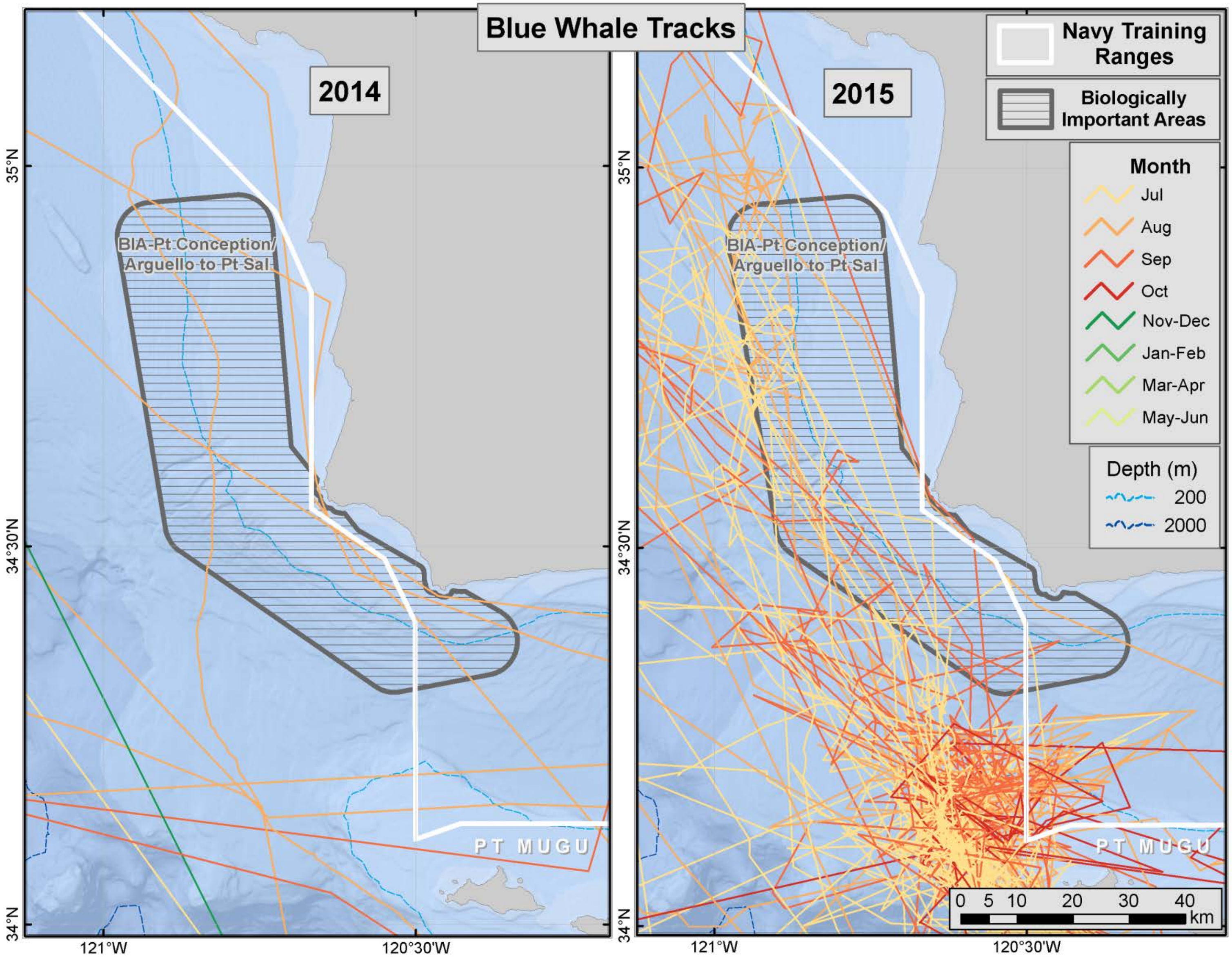

Figure 11. Satellite-monitored radio tracks in the Point Conception/Arguello BIA for blue whales tagged off southern California in August and September 2014 (left panel; 3 SPOT5 tags, 1 ADB tag) and July 2015 (right panel; 14 SPOT5 tags, 2 ADB tags).

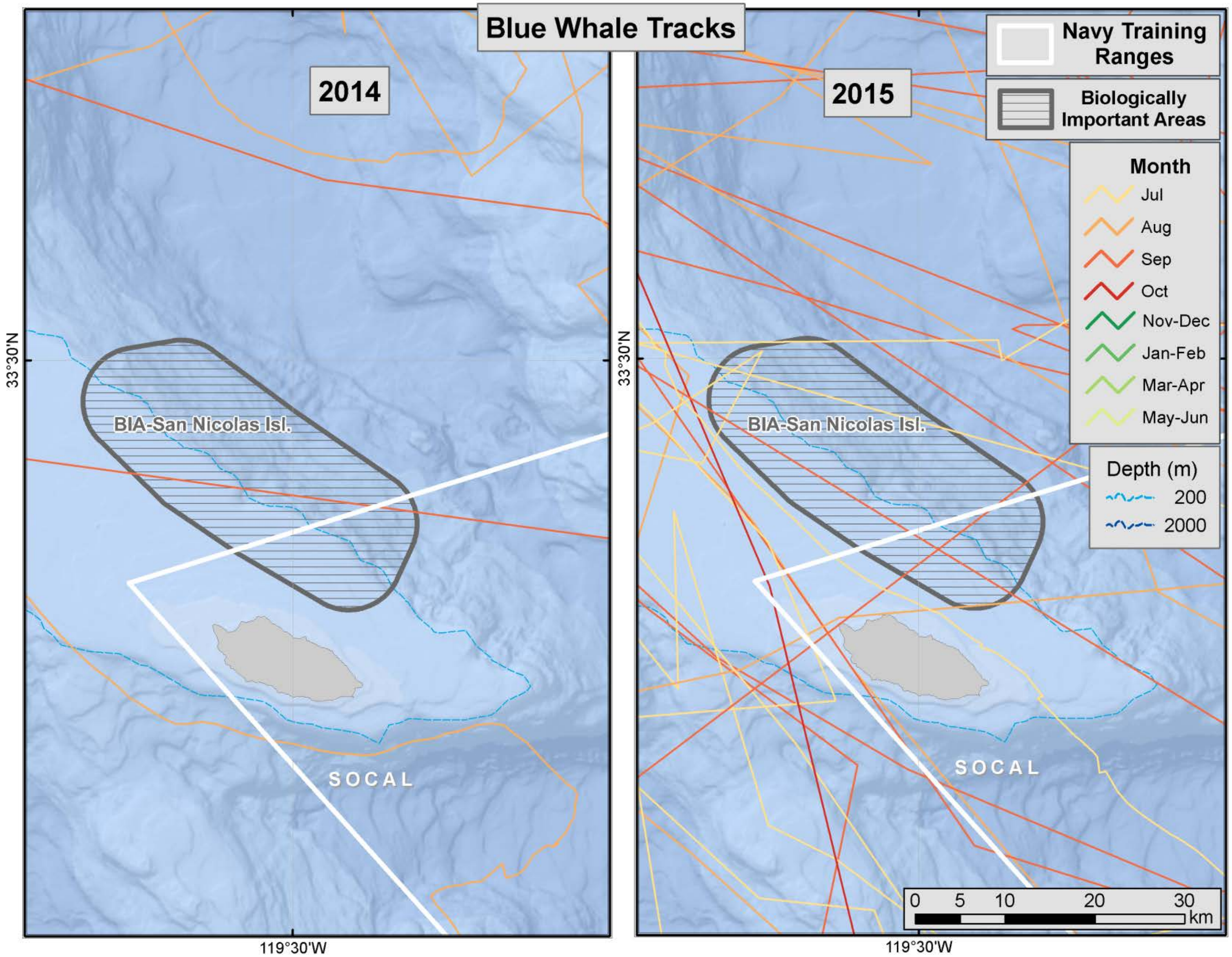

Figure 12. Satellite-monitored radio tracks in the San Nicolas Island BIA for blue whales tagged off southern California in August and September 2014 (left panel; 1 SPOT5 tag) and July 2015 (right panel; 3 SPOT5 tags).

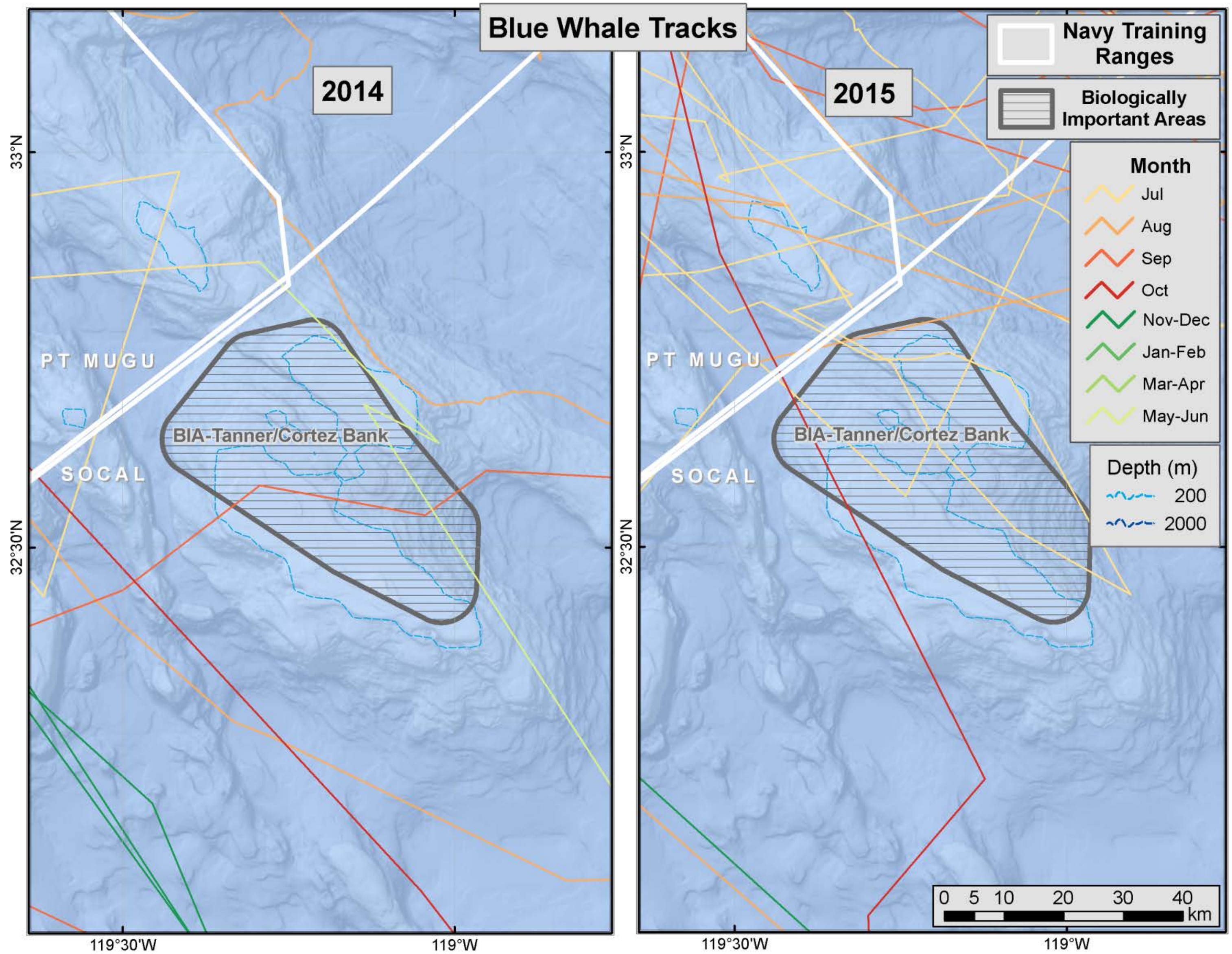

Figure 13. Satellite-monitored radio tracks in the Tanner-Cortes Bank BIA for blue whales tagged off southern California in August and September 2014 (left panel; 1 SPOT5 tag) and July 2015 (right panel; 4 SPOT5 tags).

Table 6. Sizes of HRs and CAs of use in the U.S. EEZ calculated from State Space Modeled (SSM) locations for five blue whales tagged off southern California, 2014.

Tag #	# SSM Locations	Sex	HR Size (km^2)	CA Size (km^2)
Blue Whales				
847	56	F	171,044	25,423
5641	77	F	176,028	37,065
10834	76	M	50,179	13,854
10836	90	U	190,022	41,199
23031	36	M	139,235	45,654
Mean			**145,301.6**	**32,639.2**

Key: km^2 = square kilometer(s).

Note: The U.S. EEZ is located 370.4 km (200 nautical miles) from shore.

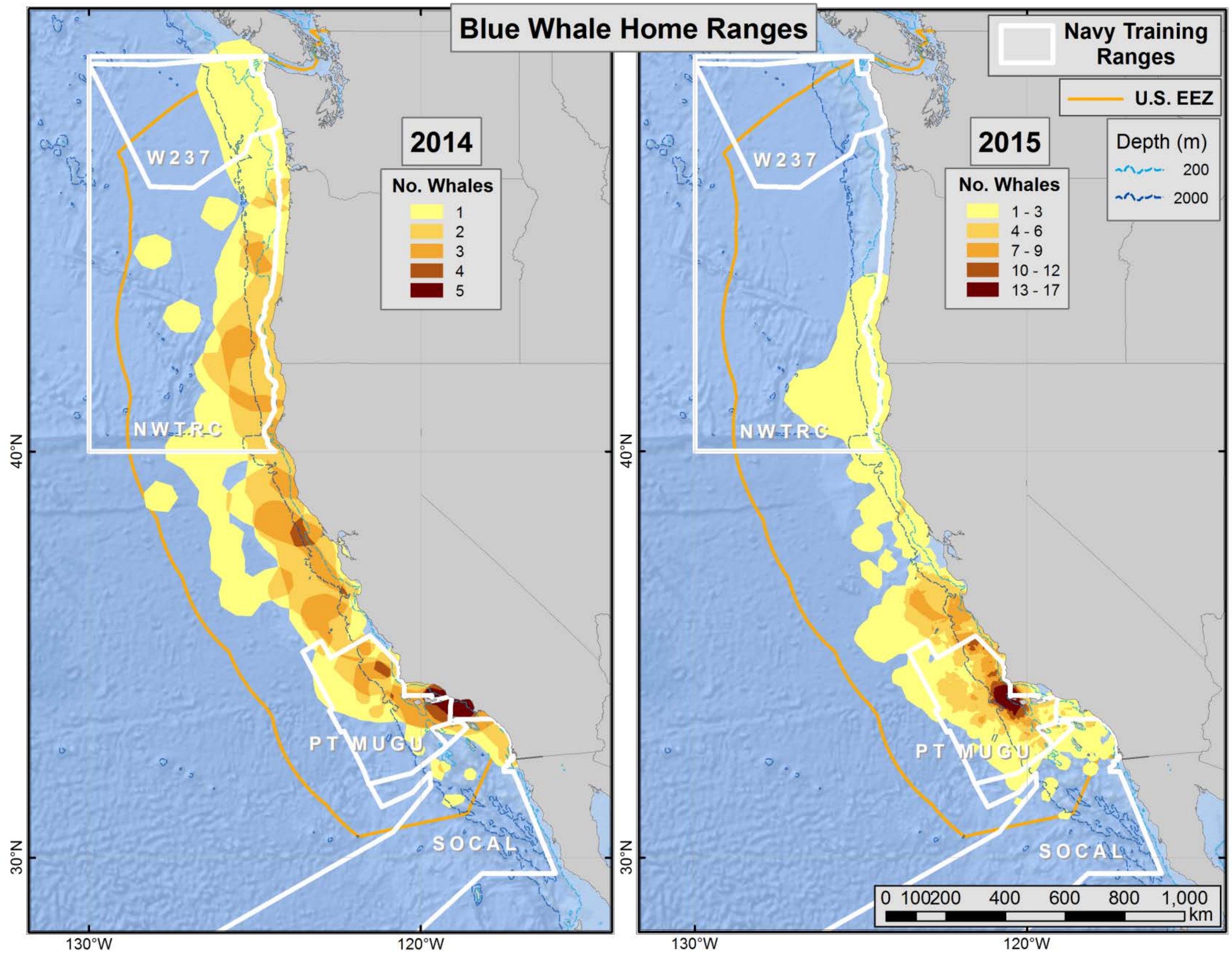

Figure 14. HRs in the U.S. EEZ for blue whales tagged off southern California in 2014 (left panel; 5 whales) and 2015 (right panel; 17 whales). Shading represents the number of individual whales with overlapping HRs.

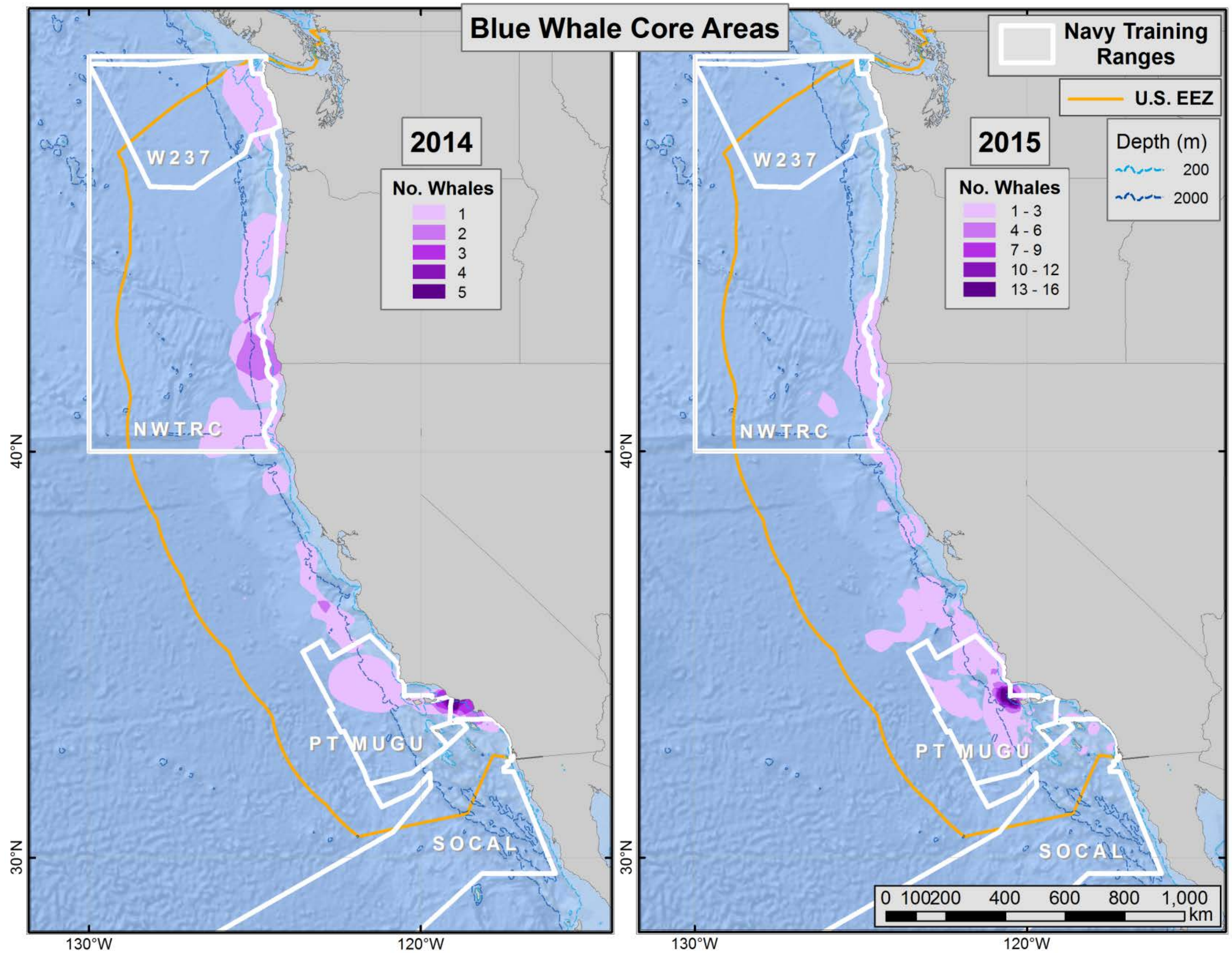

Figure 15. CAs of use in the U.S. EEZ for blue whales tagged off southern California in 2014 (left panel; 5 whales) and 2015 (right panel; 17 whales). Shading represents the number of individual whales with overlapping HRs.

Table 7. Deployment and performance data for satellite-monitored radio tags deployed on blue whales in southern California, 2015. In the Sex column, F = female, M = male, and U = unknown sex, because no biopsy sample was collected. See Section 3.2.2 for location filtering method.

Tag #	Sex	Tag Type	Deployment Date	Most Recent Location	# Days Tracked	# Filtered Locations	# GPS/Argos Locations	Total Distance (km)
825	F	SPOT5	10-Jul-15	26-Jan-16	199.9	538	0 / 538	16,010
831	U	SPOT5	9-Jul-15	2-Sep-15	54.6	177	0 / 177	4,217
849	U	SPOT5	9-Jul-15	30-Sep-15	84.0	299	0 / 299	5,285
1385	M	SPOT5	9-Jul-15	9-Sep-15	62.0	260	0 / 260	2,261
5640	M	SPOT5	16-Jul-15	22-Dec-15	158.8	620	0 / 620	9,815
5678	M	SPOT5	9-Jul-15	11-Dec-15	154.8	556	0 / 556	8,722
5700	U	SPOT5	8-Jul-15	4-Oct-15	87.8	352	0 / 352	3,960
5701	F	SPOT5	16-Jul-15	3-Sep-15	48.9	197	0 / 197	3,037
5726	U	SPOT5	8-Jul-15	4-Sep-15	57.7	118	0 / 118	2,560
5736	F	SPOT5	9-Jul-15	13-Jul-15	4.2	17	0 / 17	191
5801	M	SPOT5	10-Jul-15	15-Aug-15	35.3	15	0 / 15	675
5823	U	SPOT5	10-Jul-15	8-Feb-16	212.5	147	0 / 147	10,791
5838	M	SPOT5	17-Jul-15	26-Aug-15	40.6	160	0 / 160	2,272
5840	F	SPOT5	17-Jul-15	18-Sep-15	63.2	187	0 / 187	2,222
5841	F	SPOT5	9-Jul-15	3-Sep-15	56.2	254	0 / 254	3,081
10839	U	SPOT5	16-Jul-15	20-Sep-15	65.8	210	0 / 210	3,536
23031	F	SPOT5	16-Jul-15	23-Nov-15	129.7	403	0 / 403	6,912
23033	M	SPOT5	8-Jul-15	29-Sep-15	83.0	338	0 / 338	4,356
Mean		**SPOT5**			**88.8**	**270**		**4,995**
Median		**SPOT5**			**64.5**	**232**		**3,748**
838+++	F	ADB	7-Jul-15	2-Aug-15	25.9	541	71 / 470	2,157
840+	U	ADB	8-Jul-15	2-Aug-15	24.8	1,675	1,633 / 42	1,521
4177+++	M	ADB	8-Jul-15	5-Aug-15	27.2	1,598	1,520 / 78	2,336
5650+++	M	ADB	8-Jul-15	7-Aug-15	29.8	2,547	2,443 / 104	2,495
Mean		**ADB**			**26.9**	**1,590**		**2,127**
Median		**ADB**			**26.5**	**1,636**		**2,247**

KEY: ADB = Advanced Dive Behavior; km = kilometer(s); GPS = geographic positioning system; SPOT5 = Smart Positioning or Temperature Transmitting Tag, Version 5; # = number; +Tag is FastLoc®, Version.1; +++Tag is FastLoc®, Version.3

Mendocino, northern California, to Camalú, Baja California, 230 km south of the California/Mexico border, and from near shore out to 350 km. By the end of August, locations extended as far north as Cape Mendocino, with the densest areas of use ranging from the western end of the Channel Islands to the waters off Monterey Bay. Monterey Bay and Point Conception continued to be areas with numerous locations throughout September. One blue whale had also reached the southern Oregon coast by this time, with locations off Cape Blanco and Coos Bay. Two other blue whales headed south in September, spending time off Vizcaino Bay along the central Baja California coast. Five tags continued to transmit into late October, and by the end of that month one tag was located off the Oregon/California border, one was located in the Santa Barbara Channel, two made it south of San Ignacio Lagoon in Baja California, and one was off Guatemala. By mid-November, all five blue whales were south of the U.S./Mexico border—three were located between San Ignacio Lagoon and Magdalena Bay, one was off Acapulco, and one was approximately 500 km off Costa Rica. Four tags continued to transmit into December and beyond. One of these whales was last located just south of Magdalena Bay on 10 December. One whale traveled into the Gulf of California and was last located in the northern part of the Gulf on 22 December. The other two whales spent the remainder of their tracking periods off Central America, with one (Tag #2015_825) being last located on 26 January far offshore near the equator (0.1ºN, 114ºW), approximately 3,300 km west-southwest of Costa Rica, and the other (Tag #2015_5823) being last located on 8 February in the region of the Costa Rica Dome, approximately 970 km west of Costa Rica.

The most heavily used Navy training area for tagged blue whales in 2015 was PT MUGU, with all 22 blue whales having locations there (**Figure 5; Table 8)**. SOCAL was the second most heavily used training area for blue whales, with 14 whales having locations there (**Figure 4**). Two blue whales had locations in NWTRC, but none of these were within area W237 (**Figures 6 and 7**). None of the tagged blue whales were tracked within the GOA training area. Seventy-five percent of all blue whale locations were less than 117 km from shore (median = 63 km; **Table 9**), but the maximum distances to shore for blue whale locations in the Navy training ranges were 254 km for PT MUGU, 303 km for SOCAL, and 230 for the NWTRC. Blue whale locations occurred in both PT MUGU and SOCAL in 5 of the 8 months in which blue whales were tracked (July, August, September, October, and November). Locations in the NWTRC occurred in August, September, October, and November.

Time spent by blue whales in PT MUGU ranged from 13 to 100 percent of their total tracking periods, or 3.3 to 77.0 d (**Table 10**). For the 14 blue whales with locations in SOCAL, time spent there ranged from 2 to 39 percent of their total tracking periods, or 1.4 to 16.7 d. Of the two blue whales with locations in the NWTRC one spent 1 percent of its tracking period there, or 0.5 d, and the other spent 26 percent of its time there, or 40.3 d.

The amount of time spent in BIAs by tagged blue whales ranged from <1 to 82 percent of their total tracking periods. 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 Pt. Conception/Arguello BIA (**Table 10, Figures 10 and 11**), with 21 and 16 blue whales having locations in the two areas, respectively. Time spent in the Santa Barbara Channel and San Miguel BIA ranged from 1 to 82 percent of total tracking periods, or <1 to 50 d. This represented 1 to 78 percent of the total number of locations for the 21 whales

Table 8. Percentage of filtered locations (Locs) and time spent inside the SOCAL, PT MUGU, NWTRC and W237 areas for blue whales tagged off southern California, 2015. See Section 3.2.2 for location filtering method.

		Filtered Locations														
		Total		SOCAL			PT MUGU			NWRTC			W237			
Tag #	Tag Type	# Locs	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days
825	SPOT5	538	201.7	10	8	16.7	27	17	34.2						
831	SPOT5	177	54.6	12	13	7.3	63	58	31.9						
849	SPOT5	299	84.0	2	5	3.9	45	47	39.4						
1385	SPOT5	260	62.0				87	88	54.3						
5640	SPOT5	620	158.8	4	4	7.0	38	34	54.5						
5678	SPOT5	556	154.8	1	2	3.2	19	16	24.6	27	26	40.3			
5700	SPOT5	352	87.8	9	9	7.9	84	88	77.0						
5701	SPOT5	197	48.8	6	8	3.9	90	85	41.5						
5726	SPOT5	118	57.8				35	39	22.5						
5736	SPOT5	17	4.2				100	100	4.2						
5801	SPOT5	15	35.3				60	45	16.0						
5823	SPOT5	147	227.0	1	5	10.4	49	24	53.8						
5838	SPOT5	160	40.7	22	24	9.7	71	70	28.6						
5840	SPOT5	187	63.2				99	97	61.5						
5841	SPOT5	254	56.2				35	32	17.7	1	1	0.5			
10839	SPOT5	210	65.8	7	7	4.9	47	43	28.0						
23031	SPOT5	403	129.8	5	5	7.0	47	39	50.7						
23033	SPOT5	338	83.0	1	2	1.4	28	31	25.4						
838[+++]	ADB	541	25.9	43	39	10.2	15	13	3.3						
840[+]	ADB	1,675	24.8				100	100	24.8						
4177[+++]	ADB	1,598	27.2	31	31	8.3	54	47	12.7						
5650[+++]	ADB	2,547	29.9				18	14	4.3						

KEY: ADB = Advanced Dive Behavior; SPOT5 = Smart Positioning or Temperature Transmitting Tag, Version 5; # = number; [+]Tag is FastLoc®, Version.1; [+++]Tag is FastLoc®, Version.3.

Table 9. Great-circle distances to nearest point on land for blue whales tagged off southern California, 2015. The number of locations includes filtered locations (see Section 3.2.2 for filtering method) plus deployment location.

Tag #	Tag Type	# Locations	Median (km)	Mean (km)	SD (km)	Minimum (km)	Maximum (km)	Deploy Location Distance (km)
825	SPOT5	539	144.9	485.9	679.36	0.1	2379.6	39.7
831	SPOT5	178	81.2	89.2	58.70	0.4	279.6	45.4
849	SPOT5	296	21.2	25.0	19.95	0.5	130.2	40.5
1385	SPOT5	253	37.3	39.4	12.97	18.6	146.0	44.2
5640	SPOT5	623	73.8	86.2	43.06	5.3	218.5	43.8
5678	SPOT5	557	38.0	63.6	63.28	0.4	311.1	43.4
5700	SPOT5	339	63.8	69.4	35.05	14.3	182.2	40.2
5701	SPOT5	198	48.8	55.1	25.33	8.0	128.1	43.7
5726	SPOT5	119	36.2	39.3	19.71	5.1	110.7	40.1
5736	SPOT5	19	60.1	56.5	11.88	34.7	77.9	44.2
5801	SPOT5	16	40.2	53.3	46.79	4.6	169.6	39.9
5823	SPOT5	148	65.2	143.4	178.94	6.0	811.1	41.9
5838	SPOT5	158	43.3	51.0	32.04	1.7	145.5	45.6
5840	SPOT5	188	107.5	99.5	55.28	5.4	194.2	45.7
5841	SPOT5	258	147.4	138.9	74.14	0.7	296.4	45.4
10839	SPOT5	211	63.1	74.6	42.45	5.2	151.8	39.1
23031	SPOT5	433	69.3	79.3	56.13	0.3	289.5	42.6
23033	SPOT5	339	58.2	60.1	28.61	1.2	129.8	40.1
838+++	ADB	542	9.7	12.3	8.30	0.0	77.2	5.5
840+	ADB	1676	140.0	116.6	50.61	16.0	187.0	40.3
4177+++	ADB	1599	79.4	96.4	78.10	0.0	289.4	39.7
5650+++	ADB	2548	69.4	67.2	26.17	8.6	150.0	39.8
Mean				**91.0**		**6.2**	**311.6**	**40.5**
Median			**63.5**			**4.9**	**175.9**	**41.2**

KEY: ADB = Advanced Dive Behavior; km = kilometer(s); SD = standard deviation; SPOT5 = Smart Positioning or Temperature Transmitting Tag, Version 5; # = number; +Tag is FastLoc®, Version.1; +++Tag is FastLoc®, Version.3

Table 10. Percentage of filtered locations (Locs) and time spent inside the Biological Important Areas (BIAs) for blue whales tagged off southern California, 2015. See Section 3.2.2 for location filtering method.

Filtered Locations																					
		Total		Santa Monica			San Diego			San Nicolas			Tanner Cortes			Santa Barbara			Pt Conception		
Tag #	Tag Type	# 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
825	SPOT5	538	201.7	<1	<1	0.3	<1	<1	0.1							5	3	5.9	1	1	2.6
831	SPOT5	177	54.6				1	<1	0.3				1	<1	0.2	7	6	3.3	2	1	0.5
849	SPOT5	299	84.0				<1	<1	0.3							12	15	12.3	13	12	10.1
1385	SPOT5	260	62.0													78	82	50.5	<1	<1	<0.1
5640	SPOT5	620	158.8				<1	<1	0.2							7	7	10.3			
5678	SPOT5	556	154.8													10	8	12.8	<1	<1	0.4
5700	SPOT5	352	87.8										0	<1	<0.1	22	25	21.9	1	1	0.8
5701	SPOT5	197	48.8				1	1	0.4	0	<1	0.1				12	11	5.4	3	3	1.3
5726	SPOT5	118	57.8													14	13	7.8	3	2	0.9
5736	SPOT5	17	4.2													41	45	1.9			
5801	SPOT5	15	35.3													33	4	1.4	20	29	10.1
5823	SPOT5	147	227.0													24	12	27.2	1	<1	0.5
5838	SPOT5	160	40.7				10	7	3.0							34	35	14.4	1	1	0.4
5840	SPOT5	187	63.2													8	5	3.5	2	2	1.3
5841	SPOT5	254	56.2													1	1	0.4			
10839	SPOT5	210	65.8	<1	<1	0.1	<1	<1	0.2				3	2	1.5	23	18	11.7			
23031	SPOT5	403	129.8							<1	<1	0.4	0	<1	0.1	18	16	20.8	<1	<1	0.5
23033	SPOT5	338	83.0							0	<1	0.1				15	19	15.9	<1	<1	0.1
838[+++]	ADB	541	25.9	12	10	2.7	16	14	3.5												
840[+]	ADB	1,675	24.8													18	13	3.3	18	2	0.5
4177[+++]	ADB	1,598	27.2				3	2	0.6							6	4	1.0			
5650[+++]	ADB	2,547	29.9													1	1	0.3	1	1	0.3
Mean/Median				4.2/0.5	3.5/0.2	1.0/0.3	3.3/0.5	2.9/0.5	1.0/0.3		0.3/0.2	0.2/0.2	1.7/1.7	0.7/0.2	0.5/0.2	18.5/13.6	16.3/12.0	11.0/7.8	4.3/1.4	3.4/1.0	1.9/0.5

KEY: ADB = Advanced Dive Behavior; SPOT5 = Smart Positioning or Temperature Transmitting Tag, Version 5; # = number; [+]Tag is FastLoc®, Version.1; [+++]Tag is FastLoc®, Version.3

located there. Time spent in the Pt. Conception/Arguello BIA ranged from <1 to 29 percent of total tracking periods, or from <1 to 10 d. For the 16 whales with locations in this BIA, this represented from <1 to 20 percent of the total number of locations. Five blue whales had locations within the San Diego BIA (representing from 1 to 16 percent of their total number of locations) and 4 more had tracks going through the area, but no locations there (**Figure 9**). Time spent in the San Diego BIA ranged from <1 to 14 percent of total tracking periods for these nine whales, or <1 to 3 d. Three blue whales had locations within the Santa Monica to Long Beach BIA, representing <1 to 12 percent of their total number of locations and <1 to 10 percent of their total tracking periods (or <1 to 3 d; **Figure 8**). Two blue whales had locations within the Tanner-Cortes Bank BIA (representing 1 and 3 percent of their total number of locations, respectively) and the tracks of two others crossed the area, representing <1 to 2 percent of their total tracking periods, or <1 to 1 d (**Figure 13**). One blue whale had locations in the San Nicolas Island BIA (representing <1 percent of its total number of locations), with tracks for two others crossing the area (**Figure 10**). This represented <1 percent of the total tracking periods for these three whales, or <1 d each. Blue whale use of the BIAs in 2015 extended from July to October, but only the Santa Barbara Channel and San Miguel BIA had blue whale locations in it during all four of those months. The Pt. Conception/Arguello and the San Diego BIAs had blue whale locations in them during July, August, and September. Each of the remaining BIAs had blue whale use in only two months; July and August for Santa Monica to Long Beach, July and September for San Nicolas Island, and July and October for Tanner-Cortes Bank.

All but one of the SPOT5 tags on blue whales (17 of 18) provided enough locations to calculate HRs and CAs within the EEZ waters of the United States (**Table 11, Figures 14 and 15**). HR sizes ranged from 1,373 to 166,519 km^2 (mean = 48,604.9 km^2; SD = 39,950.24 km^2) and covered the entire California and southern Oregon coasts. The densest location of HRs occurred in the western end of the Channel Islands and north to Point Conception, out to approximately 90 km from shore, where HRs overlapped for 13 to 17 blue whales. The next two densest locations of HRs occurred approximately 100 km west of Morro Bay and approximately 45 km west of Vandenberg Air Force Base, just north of Point Conception, where HRs overlapped for 10 to 12 blue whales. CAs ranged in size from 361 to 33,887 km^2 (mean = 10,625.3 km^2, SD = 9,574.92 km^2), extending from the California/Mexico border to Coos Bay in southern Oregon. The area of highest use, with overlapping CAs for 13 to 16 blue whales, was the area at the western end of the Channel Islands.

The sizes of blue whale HRs and CAs were significantly higher in 2014 than 2015, with a mean HR of 145,301.6 km^2 in 2014 and 48,604.9 km^2 in 2015 (generalized linear model [GLM] $p = 0.0003$; Levene's test for equality of variances, $p = 0.63$; Kolmogorov-Smirnov test for normality, $p = 0.12$), and mean CAs of 32,639.2 km^2 in 2014 compared to 10,625.3 km^2 in 2015 (GLM, $p = 0.0006$; Levene's test for equality of variances, $p = 0.45$; Kolmogorov-Smirnov test for normality, $p = 0.15$). There was no relationship between the number of SSM locations used in the analysis and the size of either HRs or CAs (linear regression, $p > 0.23$).

Table 11. Sizes of HRs and CAs of use in the U.S. EEZ calculated from State Space Modeled (SSM) locations for 17 blue whales tagged off southern California, 2015.

Blue Whales				
Tag #	**# SSM Locations**	**Sex**	**HR Size (km^2)**	**CA Size (km^2)**
825	52	F	51559	9286
831	50	U	99655	32062
849	77	U	58834	10122
1385	62	M	1373	361
5640	76	M	55178	12156
5678	126	M	166519	33887
5700	88	U	22843	4612
5701	48	F	23263	6203
5726	58	U	38552	9486
5801	36	M	13674	2195
5823	117	U	59654	10189
5838	40	M	19071	3907
5840	64	F	16376	3952
5841	57	F	88189	23225
10839	49	U	38565	7317
23031	89	F	39461	8539
23033	83	M	33517	3133
Mean			**48604.9**	**10625.3**

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

3.1.3 ADB Tracking

Eight blue whales were tagged with ADB tags from 2014 to 2015 and tracked for a median of 22.4 d, though median tracking duration was approximately 7 d longer in 2015 compared to 2014 (**Table 12**). In 2014 three of the tags reached their programmed release dates while still attached to the whales. The other 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 16 and 17**). 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.

Table 12. ADB tag deployment summary information for tags deployed on blue whales off southern California in August 2014 and July 2015.

Species	Tag #	Recovered?	Duration (d)	# Dives	# GPS locations	Dives/day	GPS Locs/day	Total Distance (km)
2014								
Blue Whale	5644^{+}	Yes	19	1392	185	73.263	9.7	1,454.00
Blue Whale	5650^{+++}	Yes	20	3004	2297	150.2	115	1,708.20
Blue Whale	5655^{+}	Yes	19.8	4089	799	206.52	40.3	1,563.40
Blue Whale	5803^{+++}	Yes	18.3	2789	2539	152.4	139.1	2,032.90
	Median		19.4	2896.5	1548.0	151.3	77.7	1635.8
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**	**9663.0**	**5444.0**	**361.4**	**200.2**	**8800.9**

KEY: d = day(s); GPS = geographic 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.

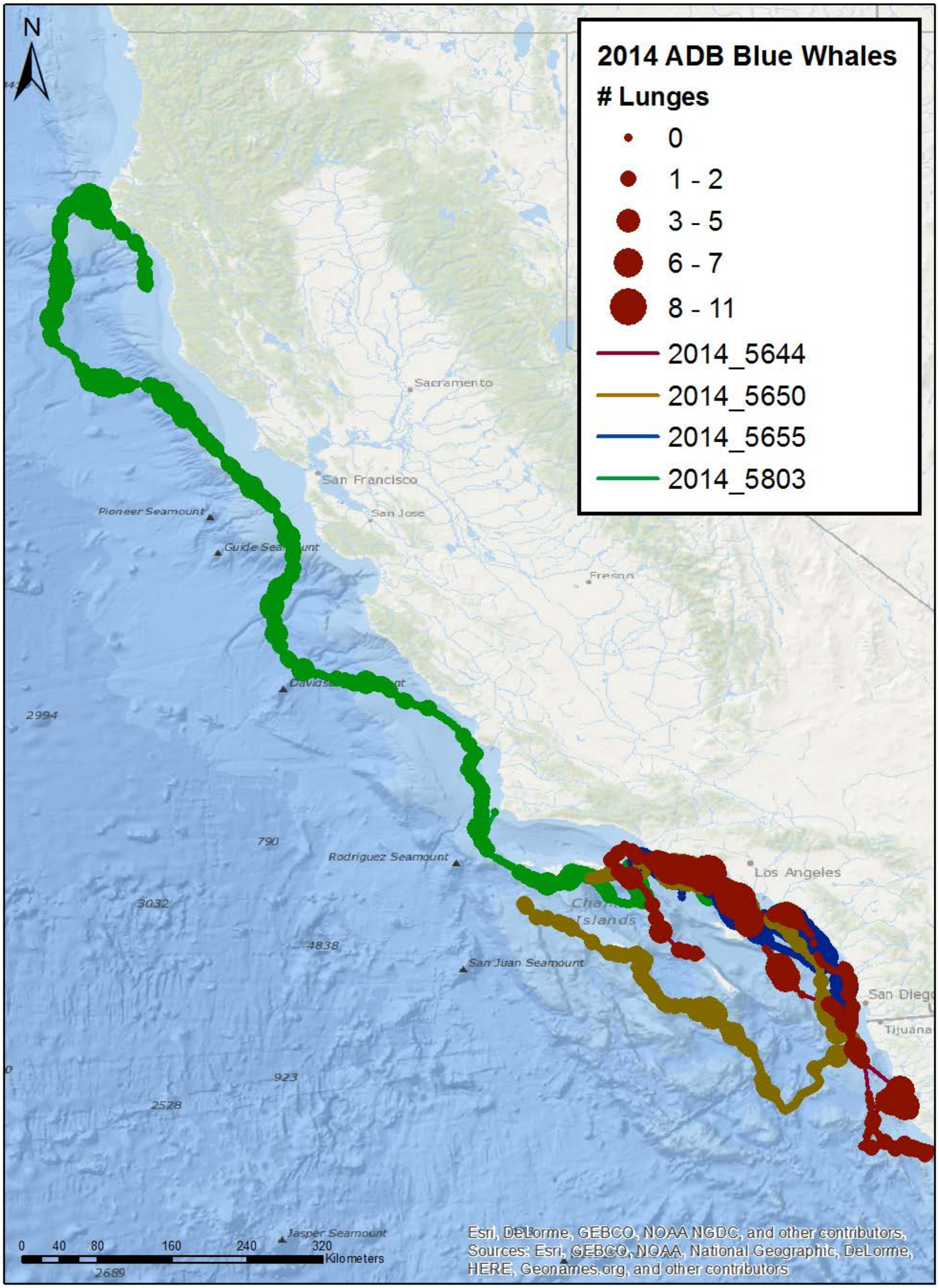

Figure 16. Tracks of four ADB-tagged blue whales off southern California in August 2014. Size of the circles represents the number of feeding lunges that occurred during a dive at that location.

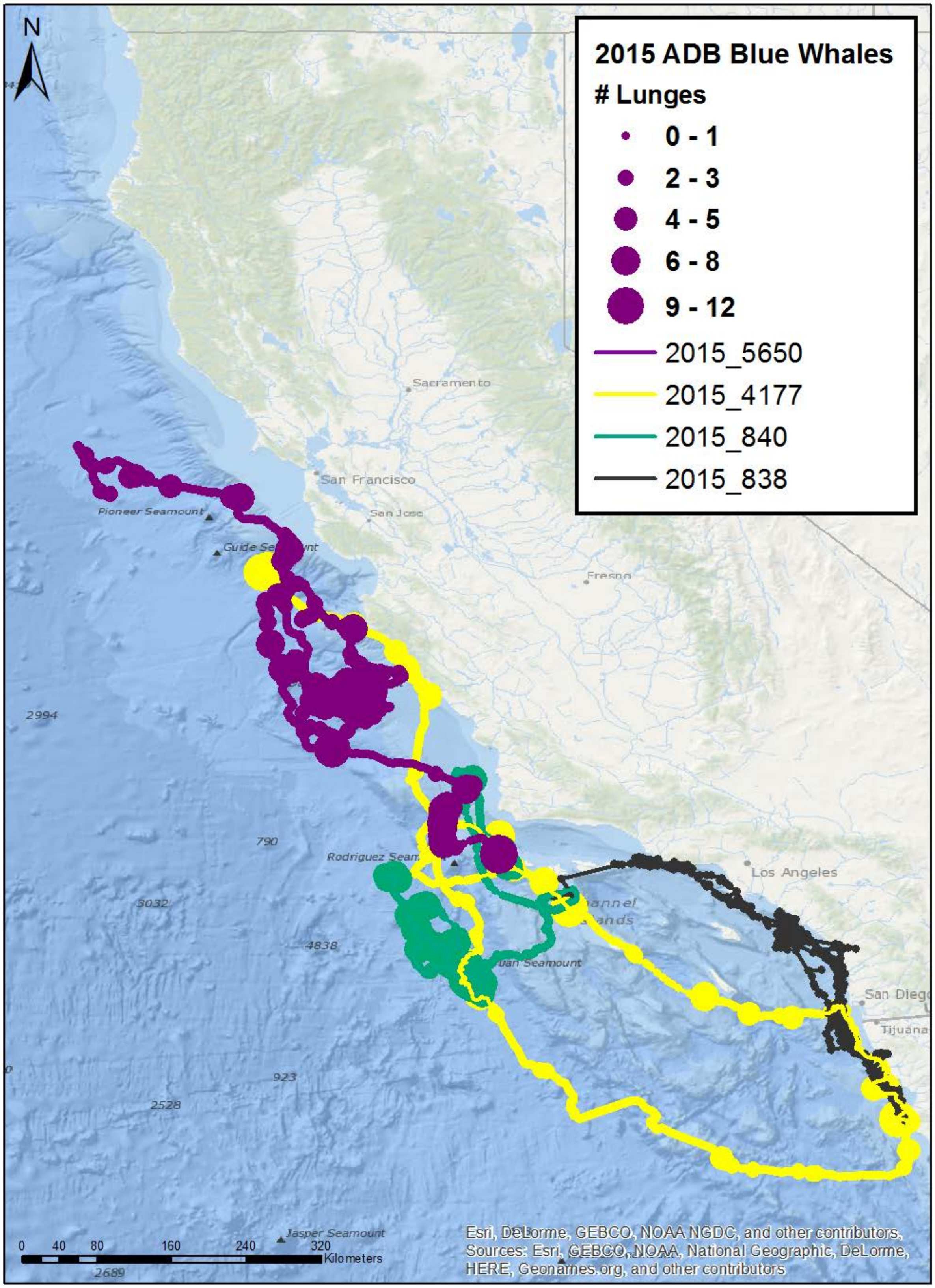

Figure 17. Tracks of four ADB-tagged blue whales off southern California in July 2015. Size of the circles represents the number of foraging lunges that occurred during a dive at that location. Tag #2015_838 was not recovered so no foraging data were available.

The seven recovered ADB tags each recorded more than 1,300 dives > 10 m in depth, with a median of 151 dives/d (**Table 12**). 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 12**). Feeding lunges were detected in low-passed data record for all whales as spikes in Jerk calculated from the accelerometer data (**Figure 18**) and coincided well with dives containing distinctive vertical excursions during the bottom portion of the dive that are characteristic of lunge-feeding events (Croll et al. 2001).

ADB-tagged blue whales generally made deeper dives during the daytime than at night (**Figure 19**); 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. Foraging 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 (**Figure 20**). High rates of foraging activity occurred near the tagging location, with periodic clusters of foraging activity recorded after departure from the tagging area (**Figures 16 and 17**).

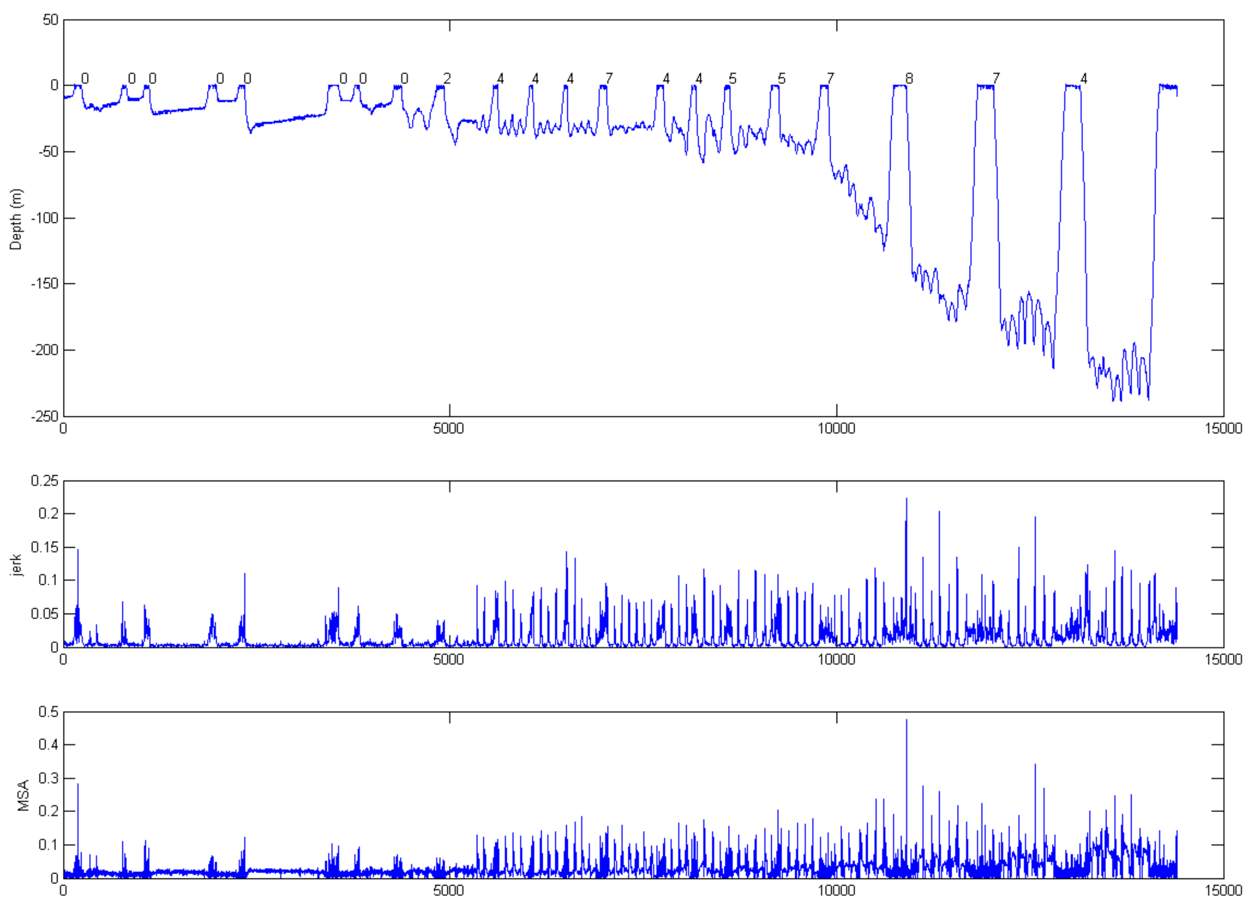

Figure 18. An example dive profile (top) of an ADB-tagged blue whale off southern California in August 2014. The numbers represent the number of lunges detected during each dive by peaks in the Jerk (middle plot) and MSA (bottom plot) calculated from accelerometer data.

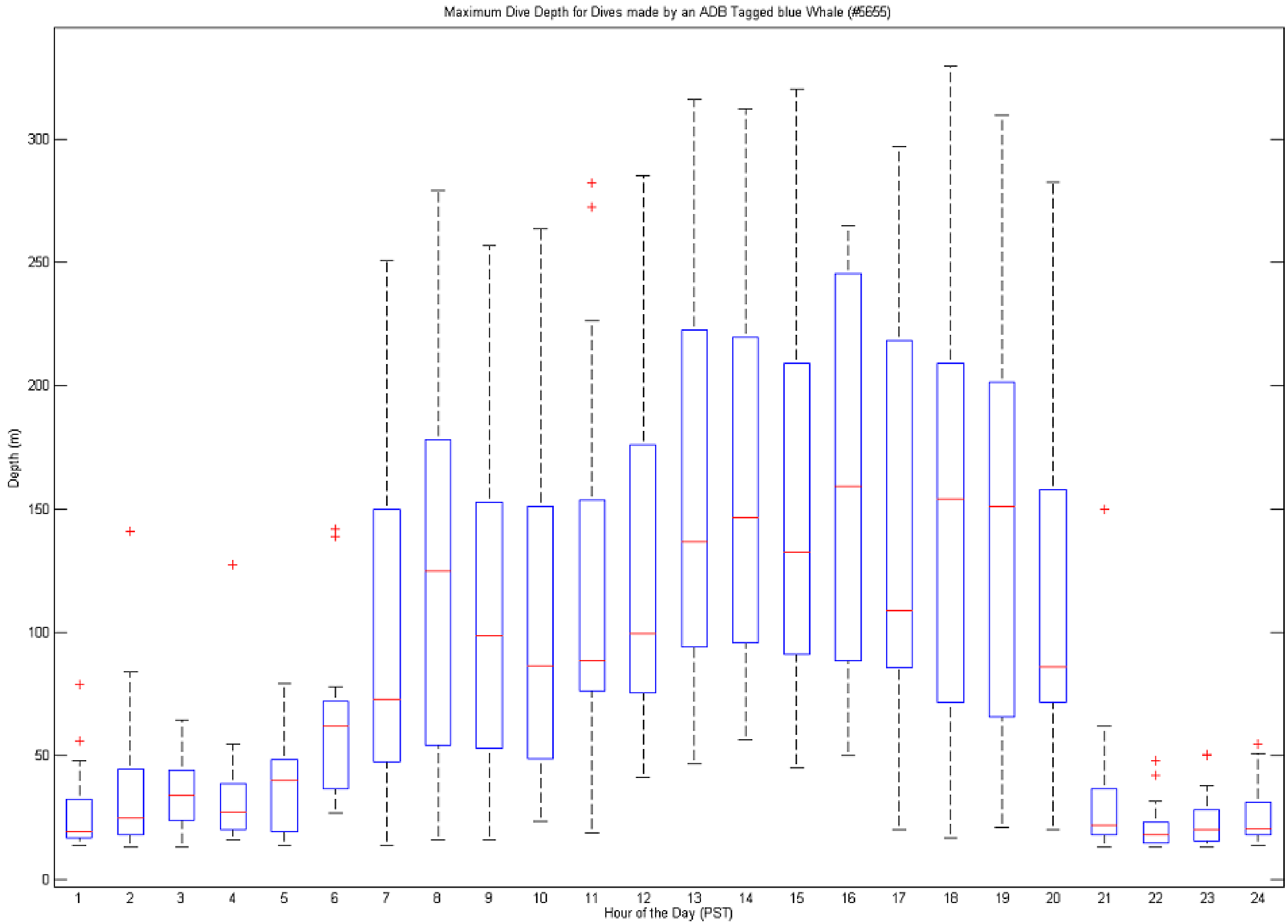

Figure 19. The distribution of maximum dive depths for dives made by ADB-tagged blue whale Tag #2015_5655 tagged off southern California during each hour of the day.

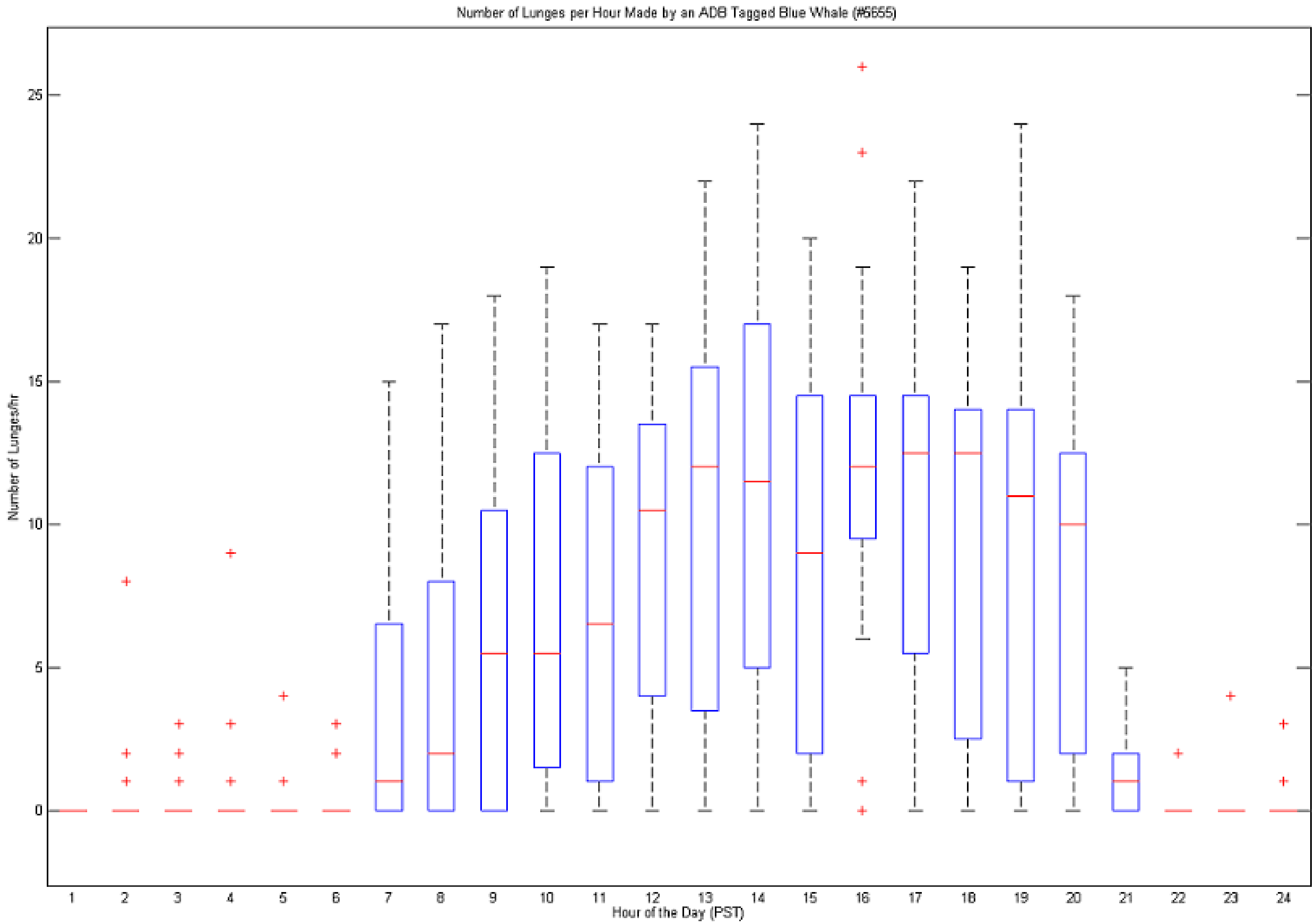

Figure 20. The distribution of dive durations for dives made by ADB-tagged blue whale Tag #2014_5655 during each hour of the day.

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 13**) and overall daytime dive depths were highly variable for all whales. The location, duration, and intensity (i.e., number of lunges per dive) of foraging effort varied by individual and were generally located near areas of high bottom slope (**Figures 16 and 17**). Foraging bouts identified from the data were temporally distinct (median = 8.1 h apart) and generally small in area (median = 7.6 km^2), with a median foraging bout containing 26 dives over 4.5 h (**Table 13**). 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 foraging bout areas is likely an overestimate as the bouts were relatively linear in many cases and GPS locations were somewhat sparse in others. Foraging bout duration was generally short (approximately 2 h) with a smaller number of long-duration bouts (**Figure 21**). Average number of foraging lunges per dive within bouts varied substantially and was correlated to the duration of a foraging bout ($p < 0.001$, $R^2 = 0.31$ from linear regression; **Figure 22**). Dive depths during foraging bouts varied widely with one whale (Tag #2015_840) foraging at a median depth almost twice that of others (**Table 13**). The fraction of non-foraging dives was ≥39 percent for all but one whale (Tag #2015_840). This whale also made the longest duration foraging bouts of all ADB-tagged blue whales (**Table 13**) suggesting it foraged almost continuously during daylight hours for many days. The same whale foraged for multiple days in an area near a seamount. However, another ADB-tagged whale (Tag #2015_4177) passed through the same area within 1 day of Tag #2015_840 and did not forage there at all (**Figure 23**).

The very high number of GPS locations recorded by Tag #2014_5650 and Tag #2014_5803 allowed for comparisons of diving behavior between the two individuals when they were in close proximity, providing an opportunity to see if the overall trends held up at a finer scale when the whales were occupying the same space (**Figures 24 through 27**). Tag #2014_5650 and Tag #2014_5803 were in close proximity nine times across a 9-day period. Those periods of overlap included both foraging and non-foraging behavior (**Table 13**). Dive depths and durations were approximately equal during overlap periods with no foraging lunges, though the whale carrying Tag #2014_5803 generally made deeper dives than Tag #2014_5650. However, on two occasions during overlap periods with foraging recorded, the whale carrying Tag #2014_5803 dove over twice as deeply as Tag #2014_5650, and in one instance, was foraging when the whale with Tag #2014_5650 was not. There appears to be additional variability within close proximity events as demonstrated by overlap bout number 6 (**Table 14)**. During the first 2 hours of the overlap period, the whales appear to have been behaving similarly after coming closer than 0.5 km from each other (**Figures 24 and 25**), with both whales making foraging dives to a similar depth. An hour later the whale carrying Tag #2014_5803 was feeding deeper in the water column than the whale carrying Tag #2014_5650 (**Figures 26 and 27**).

3.1.4 Behavioral Responses to Tagging

Eight of the 24 tagged blue whales in 2014 exhibited short-term startle responses to the tagging/biopsy process and one of these whales also responded to the biopsy darting process when approached on a subsequent surfacing (**Table 15**). Only one of the 22 tagged blue whales in 2015 exhibited short-term startle responses to the tagging/biopsy process (**Table 15**).

Table 13. Summary of dives occurring during foraging bouts made by seven ADB-tagged blue whales tagged off southern California in August 2014 and July 2015. Foraging bouts are sequences of dives with no more than three dives in a row with no recorded foraging lunges.

Tag #	Sex	Year		Bout Duration (h)	# Dives	Mean Max Dive Depth Foraging Dives (m)	Mean Duration Foraging Dives (min)	Mean Lunges per Foraging Dive	Dives with No Lunges	Area of Bout (km^2)	Time to Next Bout (h)	Dist to Next Bout (km)	Fraction non-foraging dives
2014_5644	F	2014	Med	4.4	26	95.1	9.5	1.9	15	3.5	8.2	16.5	0.58
# bouts = 21			Max	16.5	105	226.7	16.7	4.0	55	90.4	139.8	211.1	
			Min	1.6	5	28.6	3.0	1.0	2	0.0	0.0	0.0	
2014_5650	M	2014	Med	3.5	16	64.8	7.7	1.6	12	6.4	4.8	10.1	0.75
# bouts = 29			Max	14.5	145	160.5	17.0	3.0	93	92.3	42.0	84.9	
			Min	0.8	4	19.0	3.4	1.0	2	0.1	0.0	0.0	
2014_5655	F	2014	Med	8.4	62	102.4	5.8	2.1	24	18.6	9.1	9.1	0.39
# bouts = 25			Max	19.1	220	235.0	14.1	3.3	138	360.8	23.7	86.1	
			Min	0.5	5	29.0	2.1	1.0	3	0.0	0.0	0.0	
2014_5803	F	2014	Med	8.6	55	78.0	6.6	1.5	23	68.5	5.6	13.8	0.42
# bouts = 27			Max	16.9	196	204.8	10.8	3.4	86	1181.4	16.7	81.1	
			Min	0.4	4	39.3	1.7	1.0	2	0.1	0.0	0.0	
2015_840	U	2015	Med	9.8	42.5	147.1	10.6	3.3	9	19.7	8.1	6.5	0.21
# bouts = 20			Max	17.9	100	275.9	18.7	5.0	35	85.3	178.0	211.0	
			Min	1.0	4	10.5	4.5	1.0	2	0.0	0.0	0.0	
2015_4177	M	2015	Med	2.6	10.5	75.7	10.8	1.2	7	3.4	8.1	27.7	0.67
# bouts = 34			Max	16.6	100	343.0	17.2	6.1	43	214.9	75.5	149.4	
			Min	1.0	4	17.3	4.9	1.0	2	0.0	0.0	0.0	
2015_5650	M	2015	Med	4.5	15	60.0	12.2	1.3	7	7.6	4.4	9.9	0.47
# bouts = 49			Max	20.5	97	234.7	20.0	7.5	34	904.5	49.5	74.2	
			Min	1.1	4	25.7	7.9	1.0	2	0.2	0.0	0.0	

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

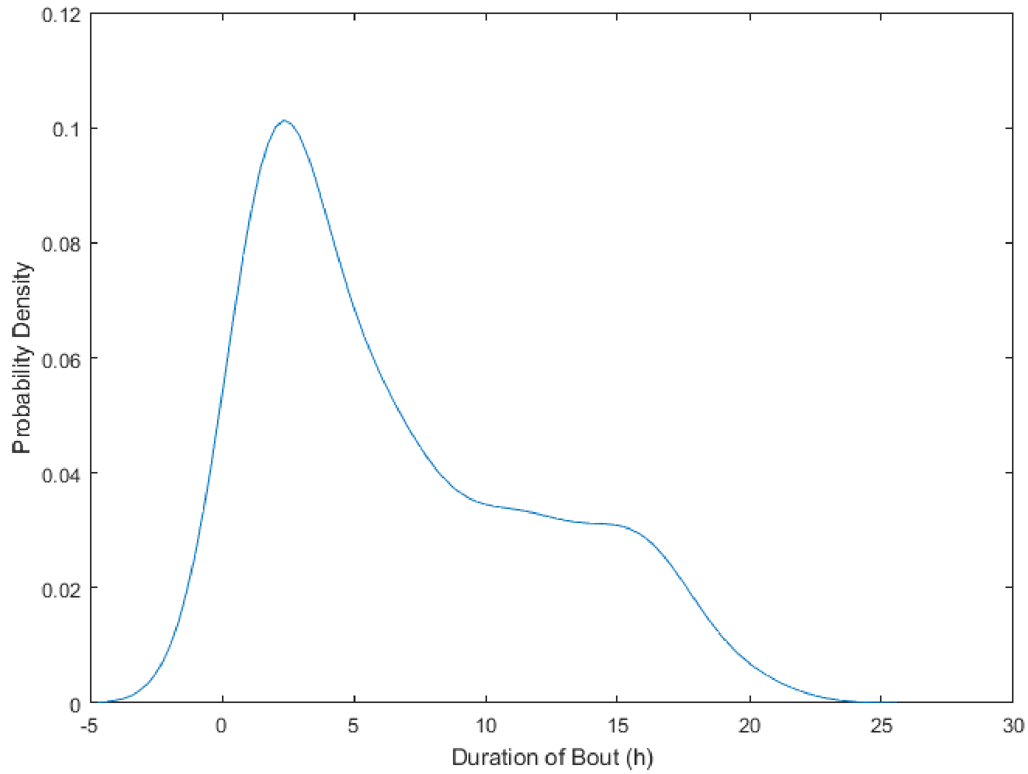

Figure 21. Kernel density plot of foraging bout duration for ADB-tagged blue whales in 2014–15.

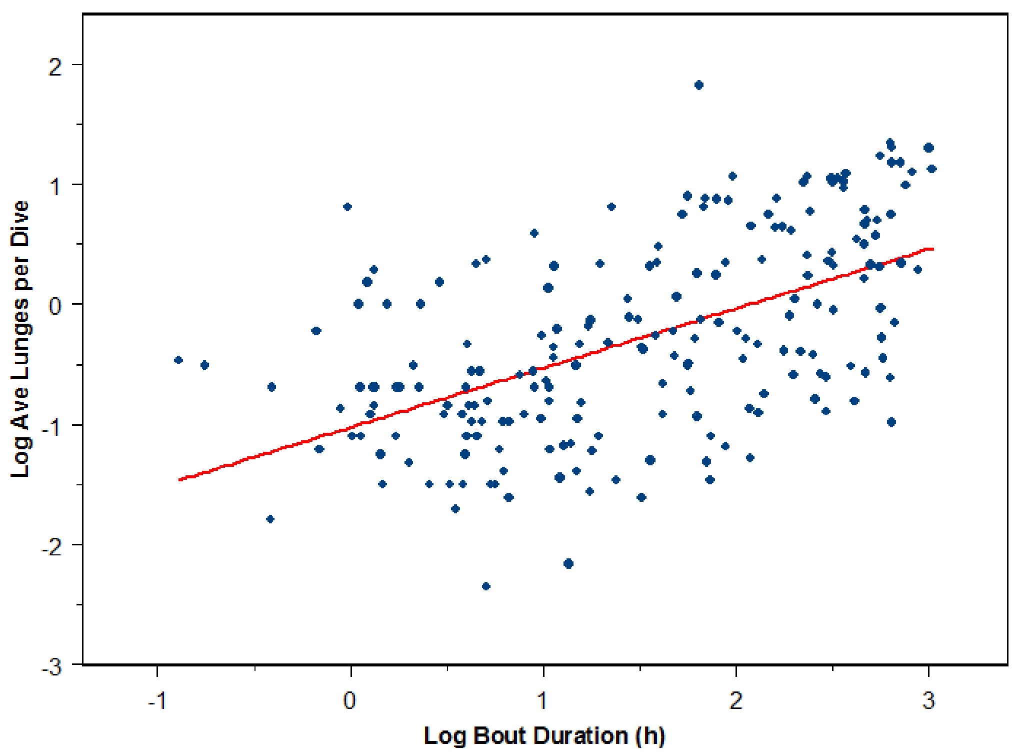

Figure 22. A plot comparing the average number of feeding lunges made per dive within a foraging bout to the duration of that bout. Red line is a linear fit through the data. Data are from blue whales tracked with ADB tags off southern California during the summer of 2014 and 2015.

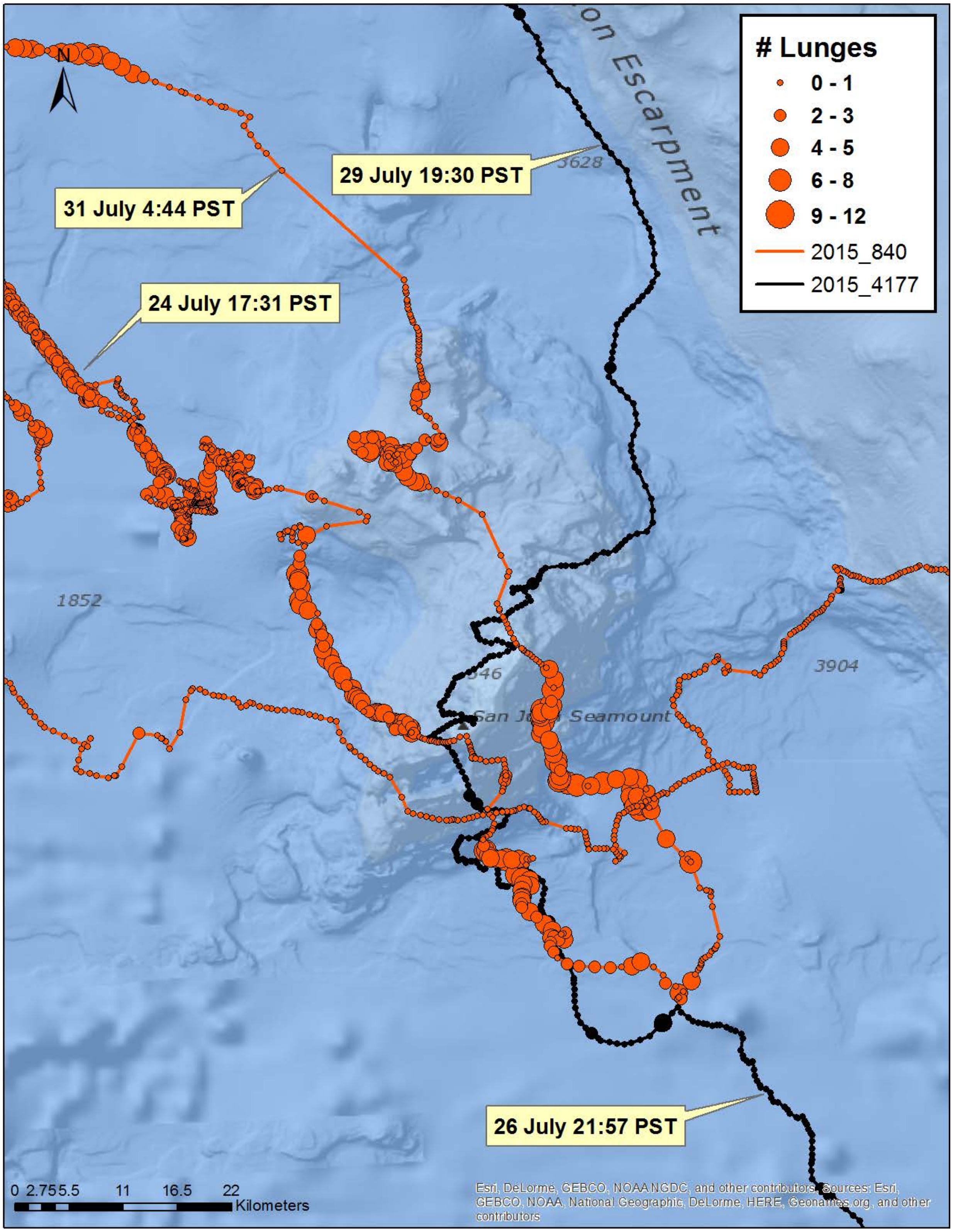

Figure 23. A map showing a portion of the tracks of two ADB-tagged blue whales off southern California in July 2015. The size of circles represents the number of foraging lunges made during a dive at that location. The image shows one whale foraging almost continuously during daylight hours while another whale passes through the same area without feeding.

Table 14. Dive summary for times when two ADB-tagged blue whales were in close proximity (< 1 km) to each other off southern California in 2014.

Tag #	Overlap Tag #	Bout #	Overlap Duration (h)	Number of Dives	Median Dive Duration (min)	Median Max Dive Depth (m)	Median # of Lunges
5650	5803	1	5.2	42	3.8	23	0
5803	5650	1	3.9	27	2.8	40	0
5650	5803	2	3.9	34	3.2	19	0
5803	5650	2	2.3	9	2.3	57	0
5650	5803	3	11.1	80	4.1	51	0
5803	5650	3	10.0	57	7.4	231	1
5650	5803	4	6.1	40	3.8	30	0
5803	5650	4	6.1	32	3.2	18.5	0
5650	5803	5	6.1	34	7.2	97.5	1
5803	5650	5	6.8	37	8.1	227	2
5650	5803	6	2.1	10	9.2	201	3
5803	5650	6	1.6	9	7.8	241	1
5650	5803	7	1.6	13	6.0	39	0
5803	5650	7	2.5	11	2.9	67	0
5650	5803	8	9.1	22	2.9	31.5	0
5803	5650	8	10.2	38	3.7	75.5	0

KEY: h = hour(s); max = maximum; min = minute(s); m = meter(s); # = number

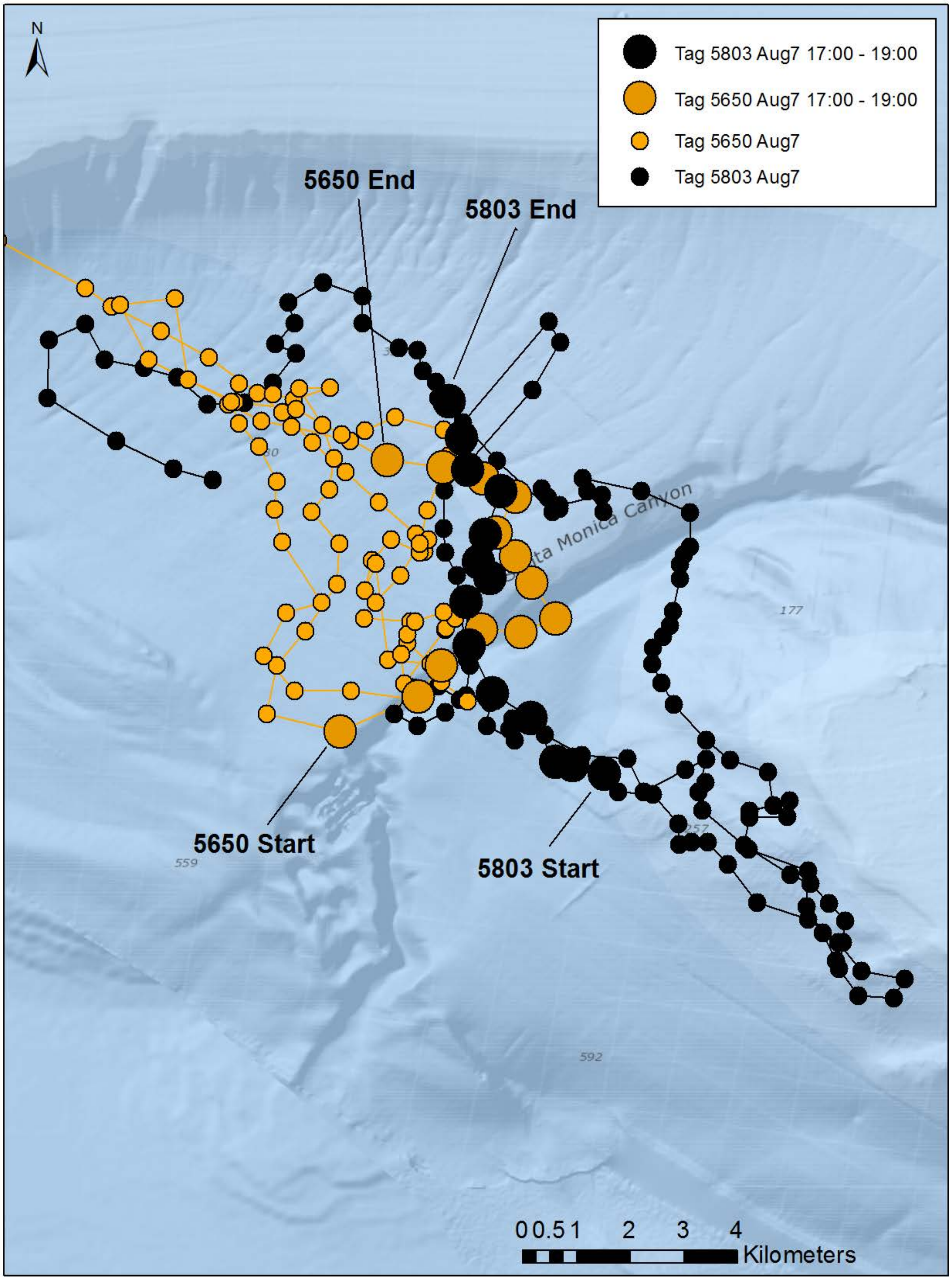

Figure 24. The tracks of two ADB-tagged blue whales on 7 August 2014. Larger circles show portions of the tracks were they were in very close proximity to one another (less than 0.5 km) at 17:00–19:00 GMT.

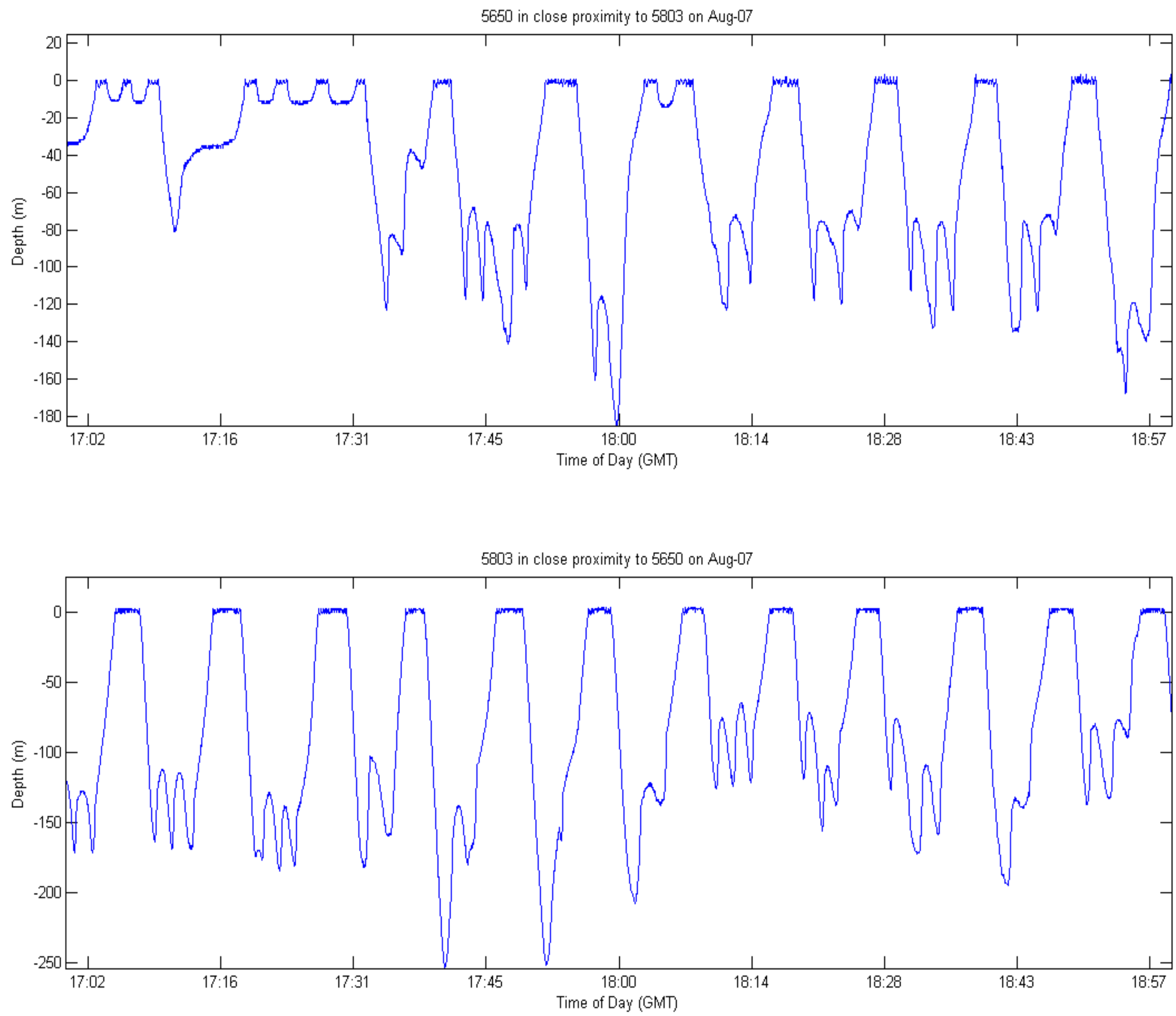

Figure 25. Dive profiles for ADB-tagged blue whales Tag #2014_5650 (top panel) and Tag #2014_5803 (bottom panel) when they were in close proximity to one another at 17:00-19:00 GMT on 7 August 2014 off southern California.

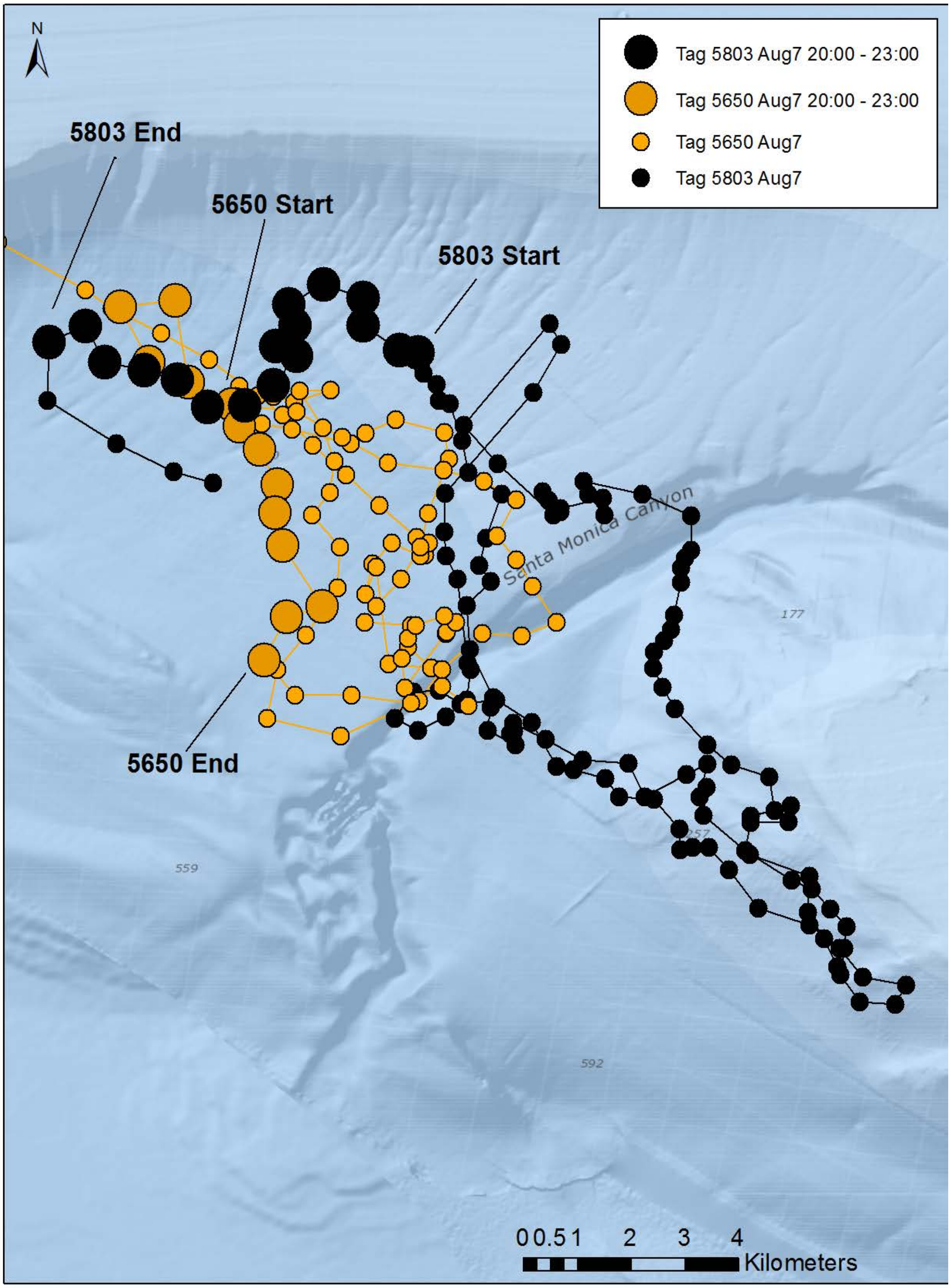

Figure 26. The tracks of two ADB-tagged blue whales on 7 August 2014. Larger circles show portions of the tracks where they were in very close proximity to one another (less than 0.5 km) at 20:00–23:00 GMT.

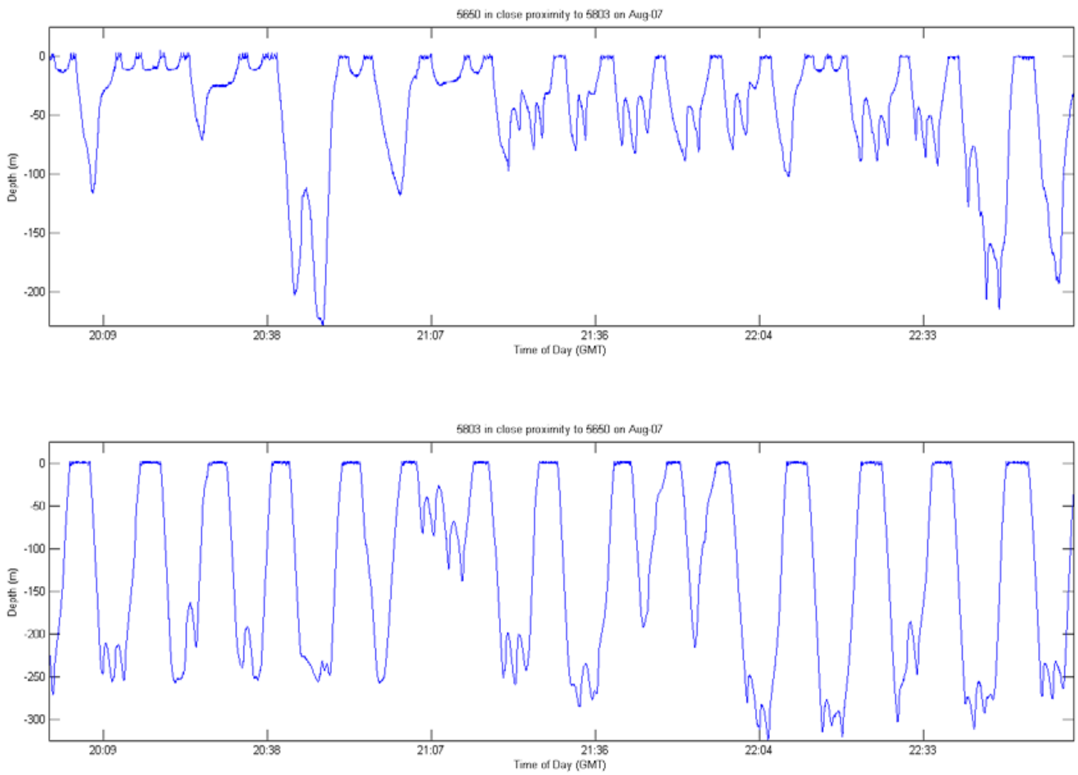

Figure 27. Dive profiles for ADB-tagged blue whales Tag #2014_5650 (top panel) and Tag # 2014_5803 (bottom panel) when they were in close proximity to one another at 20:00-23:00 GMT on 7 August 2014 off southern California.

Table 15. Behavioral responses of blue whales to satellite tagging, southern California, 2014 and 2015.

Blue whales – 2014	
# of whales	**Response to Tagging/Biopsy Darting**
16	No response
2	Quick surfacing
2	Quick dive
1	Rolled toward boat at boat approach, but no response to tag deployment
1	Fluke kick
1	Bubble blast (underwater exhalation)
1	Two quick surfacings right after tag deployment
	Responses to Biopsy Darting Alone
3	No response
1	Slight flinch
	Responses to Tagging Attempt and Miss
1	No response
Blue whales – 2015	
# of whales	**Response to Tagging/Biopsy Darting**
21	No response
1	Slight roll
	Responses to Biopsy Darting Alone
1	No response

KEY: # = number.

3.1.5 Wound Healing

Nine blue whales tagged in 2014 were photographed on days subsequent to tagging, some showing swelling, lightened skin pigmentation, or tissue extrusion at the tag sites (**Table 16**). Five blue whales tagged in 2015 were photographed 1 to 7 days after tagging with some showing moderate swelling at the tag sites (**Table 17**).

Table 16. Resightings and tag site descriptions for blue whales satellite-tagged off southern California, 2014. Size estimates are approximate.

Tag # (Type)	Days After Tagging							
	1	2	3	4	5	6	7	8
Blue Whales								
5784 (SPOT5)	swelling 20x4 cm, 1 cm high							
10834 (SPOT5)		swelling 30x15 cm, 3 cm high and tissue extrusion 1-cm diameter		swelling 30x15 cm, 3 cm high and tissue extrusion 1-cm diameter	swelling 30x15 cm, 3 cm high			
10839 (SPOT5)	no change							
10840 (SPOT5)	no change			no change				
23029 (SPOT5)	no change				no change			no change
5644+ (ADB)			no change					
5650+++ (ADB)	no change			lightened skin pigmenta-tion 15 cm diameter	lightened skin pigmenta-tion 15 cm diam.			
5655+ (ADB)	no change		no change	no change	lightened skin pigmenta-tion 10 cm diameter	normal skin pigmenta-tion	normal skin pigmenta-tion	
5803+++ (ADB)	no change					no change		

KEY: ADB = Advanced Dive Behavior; cm = centimeter(s); SPOT5 = Smart Positioning or Temperature Transmitting Tag, Version 5; # = number

+Tag is FastLoc®, Version.1; and +++Tag is FastLoc®, Version.3.

Table 17. Resightings and tag site descriptions for blue whales satellite-tagged off southern California, 2015. Size estimates are approximate.

Tag #	Tag Type	Days After Tagging		
		1	2	7
Blue Whale				
1385	SPOT5	no change		Swelling, 35 × 20 cm, 5 cm high
5678	SPOT5		Swelling. 10 ×10 cm, 2 cm high	
5700	SPOT5	no change		
23033	SPOT5	Swelling, 30 × 20 cm, 5 cm high		
840	ADB+	no change		

KEY: ADB = Advanced Dive Behavior; cm = centimeter(s); SPOT5 = Smart Positioning or Temperature Transmitting Tag, Version 5; # = number; +Tag is FastLoc®, Version1.

Five blue whales tagged in 2014 by our group were resighted during our tagging efforts in 2015; all appearing to be in good body condition (no signs of emaciation and no higher than normal external parasite load). One of these whales (Tag #2014_10834) was resighted on 8 July 2015, 319 d after the tag was deployed and 231 d after its last transmission. A whitish round protrusion was visible at the tag site that may have been a remnant of the tag covered by epibiotic growth. There was a shallow divot around the protrusion, with a slightly swollen edge (**Figure 28**). The whale with Tag #2014_10827 was resighted on 10 July 2015, with the tag still present, 301 d after the tag was deployed and 18 d after we stopped receiving locations. The tag protruded from the whale by approximately three quarters of its length (approximately 15 cm; **Figure 29**. No obvious swelling or other signs of reaction to the tag were seen. The whale with Tag #2014_5921 was also seen on 10 July 2015, 304 days after the tag was deployed and 146 days after the tag's last transmission. The tag was no longer present, and there was a shallow divot at the tag site with some loss of pigmentation (**Figure 30**). Two other tagged whales from 2014 were resighted on 18 July 2015; Tag #2014_5784 was resighted 375 days after tag deployment and 190 days after the tag's last transmission, and Tag #2014_10826 was resighted 312 days after tag deployment and 268 days after its last transmission. The former of these two whales was photographed from a long distance away and the tag site was not discernible. The latter was observed only from the side without the tag, so no photo was obtained of the tag site.

3.1.6 Photo-ID

A total of 6,134 photographs of blue whales was taken during the field efforts in 2014, of which 88 unique individuals were determined to have been encountered. Photo IDs were obtained of all 24 tagged blue whales, with both left- and right-side photos of 18 of these, four with right-side photos only, and two with left-side photos only.

A total of 7,330 photographs of blue whales was taken during the 2015 field effort, of which 212 were determined to be unique individuals. Eleven of these IDs represented resights of blue whales photographed in 2014, including the 5 tagged whales mentioned above. This provided a resight rate of 12.5 percent for all whales and 20.8 percent for tagged whales. Photo IDs were obtained of all 22 tagged blue whales, with both left- and right-side photos of seven of these, seven with right-side photos only, and eight with left-side photos only.

Figure 28. Tag site on a blue whale resighted on 8 July 2015, 319 d after deployment of a SPOT5 satellite-monitored radio tag (Tag #2014_10834) off southern California in August 2014.

Figure 29. SPOT5 satellite-monitored radio tag (Tag #2014_10827) on a blue whale resighted on 10 July 2015, 301 d after deployment off southern California in September 2014.

Figure 30. Tag site on a blue whale resighted on 10 July 2015, 304 d after deployment of a SPOT5 satellite-monitored radio tag (Tag #2014_5921) off southern California in August 2014.

3.1.7 Ecological Relationships

The SSMs generated regularized daily locations for 20 blue whale tags in 2014 and 22 tags in 2015, resulting in 1,151 and 1,586 estimated locations, respectively (**Table 18**). The geographic extent of these tracks covered approximately 47 degrees of longitude (129.8–83.2°W) and 50 degrees of latitude (0.1–50.5°N) (**Figure 31**). The majority of locations occurred in CCAL in both years (73.1 and 89.8 percent, respectively, in 2014 and 2015) and in PNEC (26.7 and 6.7 percent, respectively, in 2014 and 2015). The ALSK, NPPF, and NPTG provinces were occupied to a very small extent (0.1 percent of locations) in 2014, but not in 2015. Instead, in 2015 a few locations occurred in PQED and GUCA (2.6 and 0.8 percent, respectively) (**Table 18 and Figure 31**).

Table 18. Number of accepted SSM locations (and percentage) inside each province for each species and 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. The number of SSM tracks for each species and year is indicated (n).

Province	Blue whales 2014 (n = 20)	Blue whales 2015 (n = 22)	Fin whales 2014 (n = 5)	Fin whales 2015 (n = 10)	Hybrid whale 2015 (n = 1)	Bryde's whale 2015 (n = 1)
ALSK	1 (0.1%)	NA	NA	51 (10.3%)	NA	NA
CCAL	841 (73.1%)	1425 (89.8%)	261 (100%)	446 (89.7%)	28 (100%)	72 (100%)
GUCA	NA	13 (0.8%)	NA	NA	NA	NA
NPPF	1 (0.1%)	NA	NA	NA	NA	NA
NPTG	1 (0.1%)	NA	NA	NA	NA	NA
PNEC	307 (26.7%)	107 (6.7%)	NA	NA	NA	NA
PQED	NA	41 (2.6%)	NA	NA	NA	NA
Accepted locs.	**1151 (100%)**	**1586 (100%)**	**261 (100%)**	**497 (100%)**	**28 (100%)**	**72 (100%)**
Excluded locs.	18	101	12	56	0	13
Land locs.	14	28	29	11	1	2
Total locs.	**1183**	**1715**	**302**	**564**	**29**	**87**

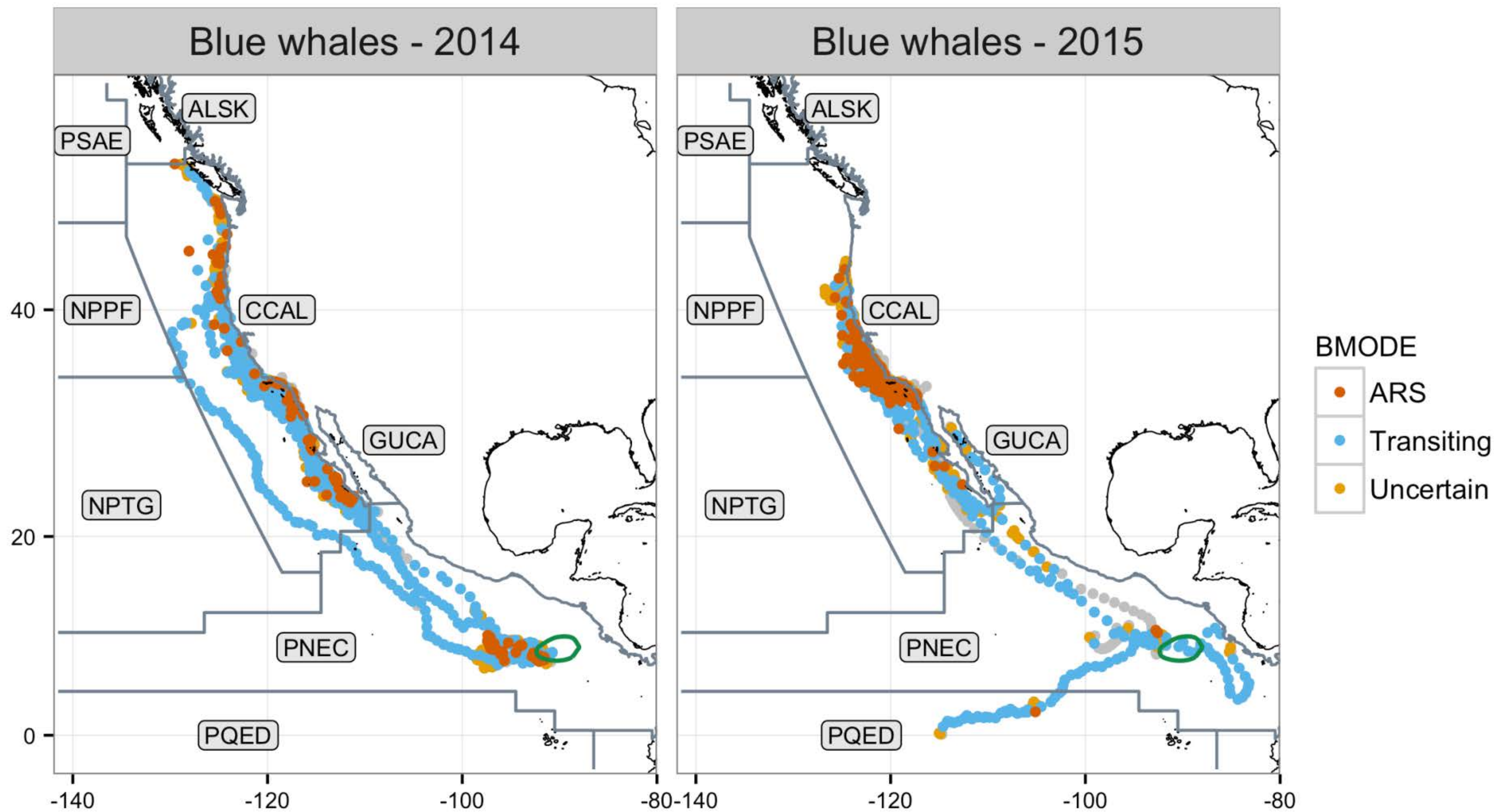

Figure 31. Accepted SSM locations for blue whales colored by behavioral mode. Locations that were excluded from the analyses are in gray. The eight biogeographic provinces identified by Longhurst (1998, 2006) in the eastern North Pacific are outlined. The green, oval-shaped contour in PNEC outlines the 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 **Figure 31**. The number and proportion of locations classified by behavioral mode is only reported for CCAL, which was the only biogeographic province consistently occupied by all species in all years (**Table 19**). For blue whales, 828 SSM locations had a behavioral classification in 2014 and 1,410 in 2015. The proportion of locations classified as ARS was lower (11.2%) in 2014 than in 2015 (18.4%), while the proportion classified as transiting was higher (46.3%) in 2014 than in 2015 (22.8%). Locations considered uncertain made up the remainder (42.5 in 2014 and 58.9% in 2015).

Details of the environmental variables obtained for the SSM locations are provided in **Table 17**. Summary statistics for these variables obtained for the SSM locations are reported for CCAL only (**Tables 20 and 21**), as this was the only biogeographic province consistently occupied by all species in all years. On average, blue whales were found in areas with weakly positive upwelling velocities both in 2014 and 2015 (WEKM = 7.2e-07 and 6.8e-07 m s^{-1}, respectively). Average SST in the areas occupied by blue whales in CCAL was warmer by almost 1.5 degree Celsius (°C) in 2014 (21.26°C) compared to 2015 (19.78°C). Average CHL concentrations were elevated and similar in both years (0.82 and 0.74 milligrams per cubic meter [mg m^{-3}], respectively). The values at each location for these environmental variables are shown in **Figures 32 through 34**.

In 2014 blue whales occurred in deeper waters that were also farther away from the shelf break and from shore (mean DEPTH = -1684.63 m, DISTSHELF = 59.15 km, DISTSHORE = 88.56 km) than in 2015 (mean DEPTH = -1482.8 m, DISTSHELF = 37.67 km, DISTSHORE = 62.06 km). Nevertheless, SLOPE (46.7 and 45.68 m km^{-1}, respectively, for 2014 and 2015) and ASPECT (208.52 and 220.88°, respectively, for 2014 and 2015) values were similar in both years (**Table 21**). The values at each location for these seafloor relief variables are shown in **Figures 35 through 38**.

3.1.8 Genetics and Species Identification

In 2014, skin biopsy samples were collected from 16 of the tagged whales, considered to be blue whales based on field observations (**Figure 39**). All samples provided DNA profiles sufficient for subsequent analyses.

In 2015, skin biopsy samples were collected from 15 of the tagged whales, considered to be blue whales based on field observations (**Figure 40**). All samples provided DNA profiles sufficient for subsequent analyses.

The mtDNA sequences of the 31 samples resolved 9 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.

3.1.8.1 SEX DETERMINATION

The 31 blue whale samples represented 13 females and 18 males (**Tables 1 and 6**).

Table 19. Number of classified SSM locations (and percentage) in CCAL for each behavioral mode for each species and year. The number of SSM tracks for each species and year is indicated (n). Because the last location of each track is not assigned a behavioral mode, a number of locations in each column are listed as "unclassified." This number can be lower than the number of tracks because of the exclusion of locations on land and those with high estimation uncertainty.

Behavioral mode	Blue whales 2014 (n = 20)	Blue whales 2015 (n = 22)	Fin whales 2014 (n = 5)	Fin whales 2015 (n = 10)	Hybrid whale 2015 (n = 1)	Bryde's whale 2015 (n = 1)
Transiting	383 (46.3%)	321 (22.8%)	50 (19.5%)	157 (35.8%)	2 (7.4%)	10 (14.1%)
Uncertain	352 (42.5%)	830 (58.9%)	158 (61.7%)	230 (52.4%)	23 (85.2%)	56 (78.9%)
ARS	93 (11.2%)	259 (18.4%)	48 (18.8%)	52 (11.8%)	2 (7.4%)	5 (7%)
Classified locs.	**828 (100%)**	**1410 (100%)**	**256 (100%)**	**439 (100%)**	**27 (100%)**	**71 (100%)**
Unclassified	16	18	5	7	1	1

Table 20. Summary statistics (mean and standard deviation) for the remotely sensed variables obtained for each SSM location in CCAL. The total number of locations and the number of locations with valid matching environmental values 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
Fin whale 2014	256	154	1.0e-06	4.6e-06	248	18.8	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
Hybrid whale 2015	27	14	4.9e-06	5.2e-06	25	18.12	0.62	27	0.69	0.46
Bryde's whale 2015	71	50	3.8e-07	3.3e-06	71	21.07	1.52	71	0.31	0.16

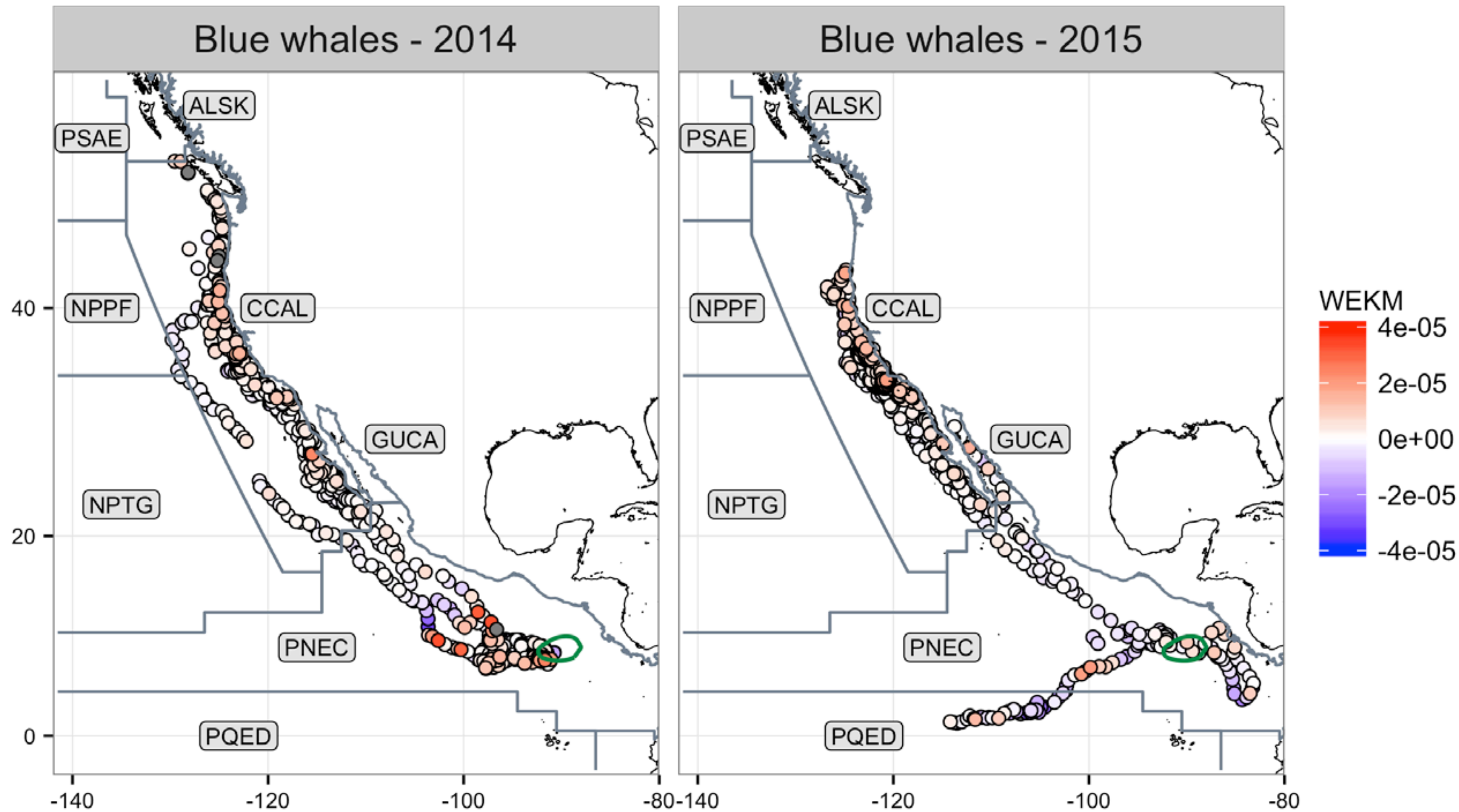

Figure 32. Map representation of vertical upwelling velocity (WEKM, m s^{-1}) values obtained from satellite remote sensing around each blue whale location. The Longhurst biogeographic provinces are indicated. The green, oval-shaped contour in PNEC outlines the position of the CRD. The left and right panels represent blue whales tagged in 2014 and 2015, respectively

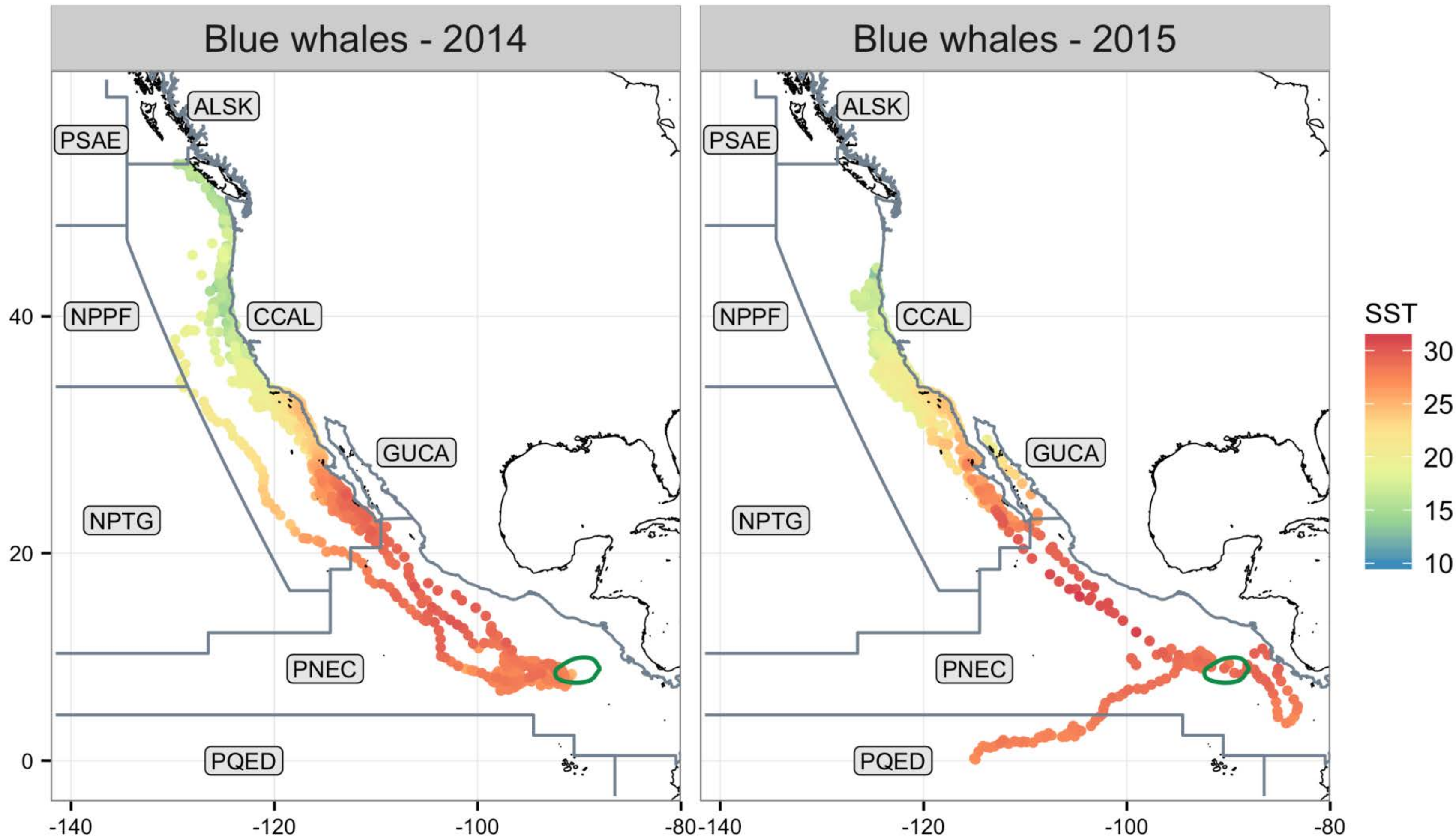

Figure 33. Map representation of sea surface temperature (SST, °C) values obtained from satellite remote sensing around each blue whale location. The Longhurst biogeographic provinces are indicated. The green, oval-shaped contour in PNEC outlines the position of the CRD. The left and right panels represent blue whales tagged in 2014 and 2015, respectively

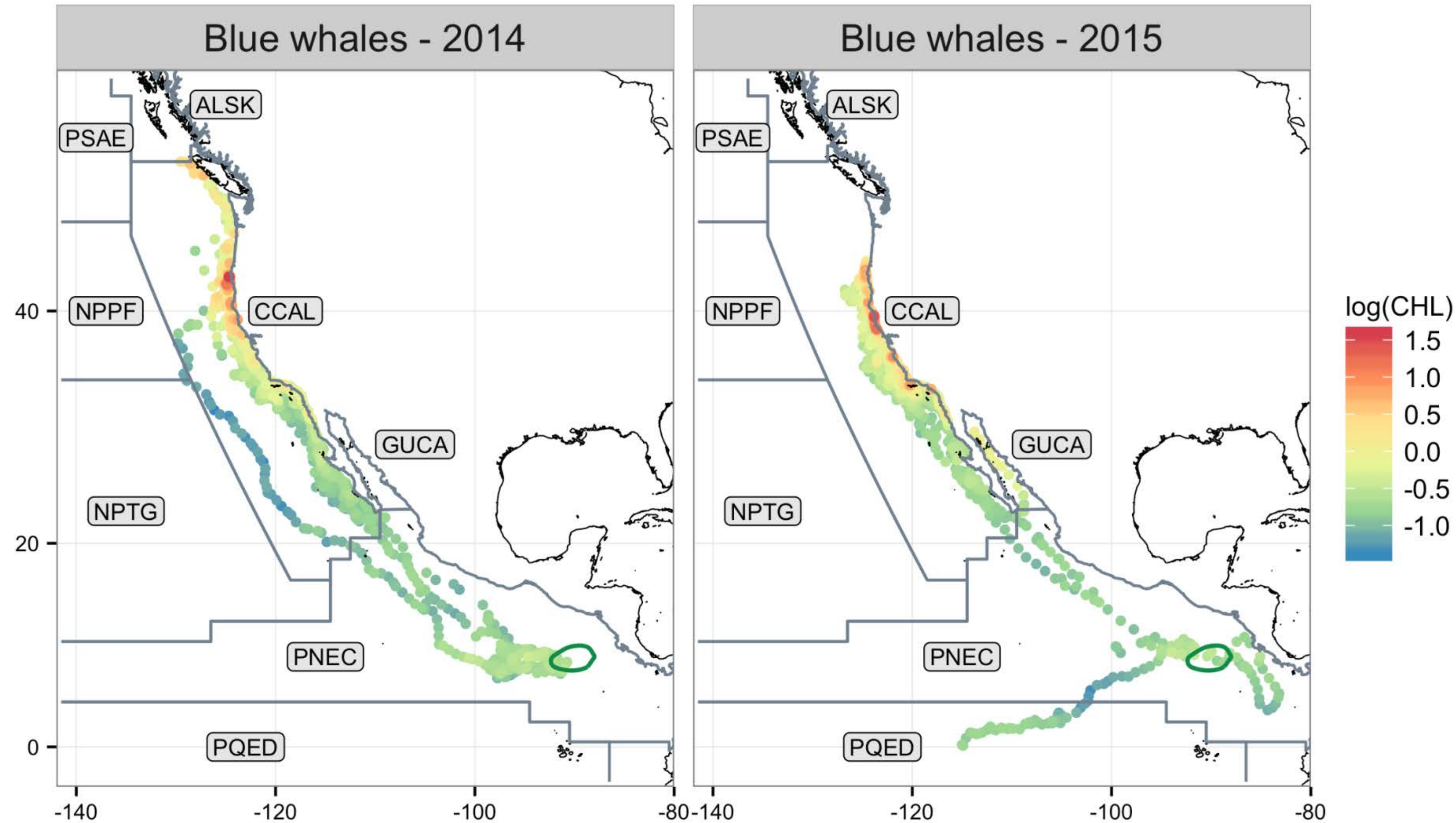

Figure 34. Map representation of chlorophyll-a concentration (CHL, mg m^{-3}, log-transformed) values obtained from satellite remote sensing around each blue whale location. The Longhurst biogeographic provinces are indicated. The green, oval-shaped contour in PNEC outlines the position of the CRD. The left and right panels represent blue whales tagged in 2014 and 2015, respectively

Table 21. Summary statistics (mean and standard deviation) for the seafloor relief variables obtained for each SSM location in CCAL. The total number of locations and the number of locations with valid matching environmental values 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 (degrees)		
		n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD
Blue whale 2014	828	819	-1684.63	1489.89	819	59.15	100.16	819	88.56	113.38	819	46.7	47.01	819	208.52	76.58
Blue whale 2015	1410	1401	-1482.8	1367.54	1401	37.67	45.37	1401	62.06	49.28	1401	45.68	43.22	1401	220.88	71.95
Fin whale 2014	256	255	-1696.44	1254.46	255	45.14	44.45	255	62.45	47.58	255	50.14	51.71	255	212.11	69.38
Fin whale 2015	439	438	-2145.73	1285.89	438	62.11	59.12	438	90.3	63.76	438	42.85	44.42	438	223.74	65.9
Hybrid whale 2015	27	26	-1286.77	1210.54	26	29.82	27.18	26	49.09	21.47	26	42.58	31.92	26	227.99	59.17
Bryde's whale 2015	71	71	-1244.51	1109.18	71	26.75	38.4	71	56.35	45.11	71	53.82	45.54	71	188.9	82.49

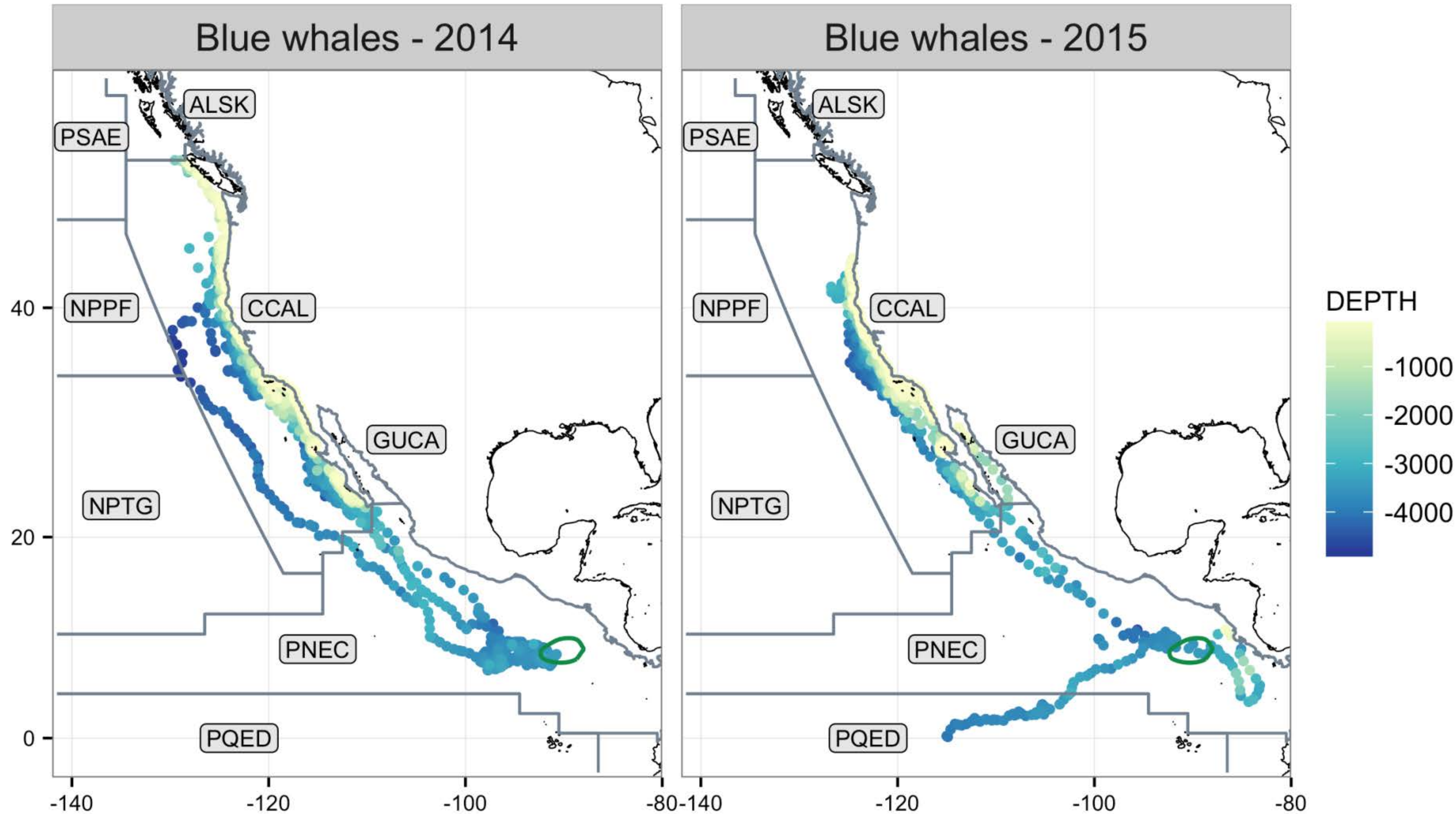

Figure 35. Map representation of seafloor depth (DEPTH, m) values obtained from ETOPO1 around each blue whale location. The Longhurst biogeographic provinces are indicated. The green, oval-shaped contour in PNEC outlines the position of the CRD. The left and right panels represent blue whales tagged in 2014 and 2015, respectively

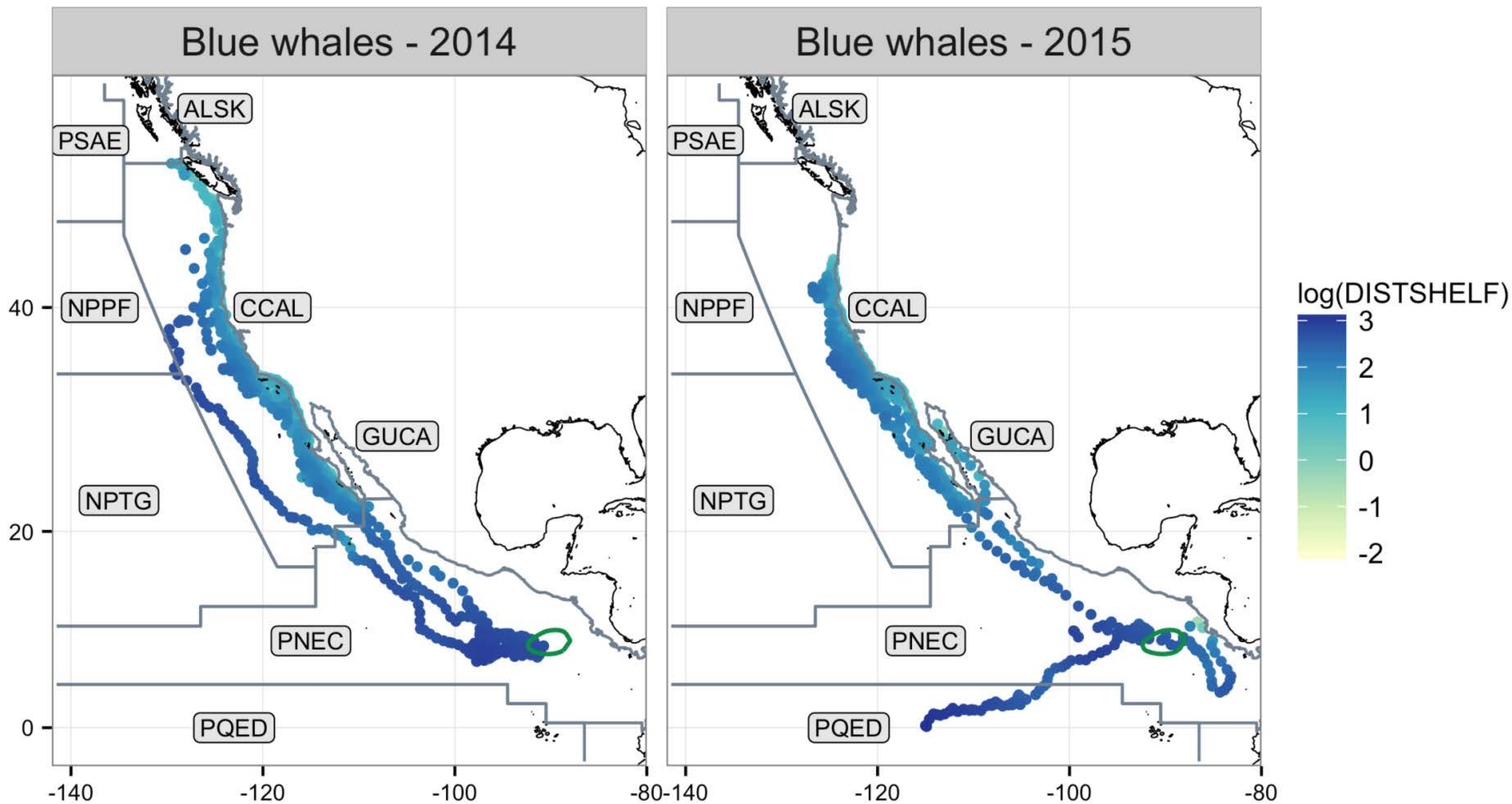

Figure 36. Map representation of distance to the 200-m isobath (DISTSHELF, km, log-transformed) values obtained from ETOPO1 around each blue whale location. The Longhurst biogeographic provinces are indicated. The green, oval-shaped contour in PNEC outlines the position of the CRD. The left and right panels represent blue whales tagged in 2014 and 2015, respectively

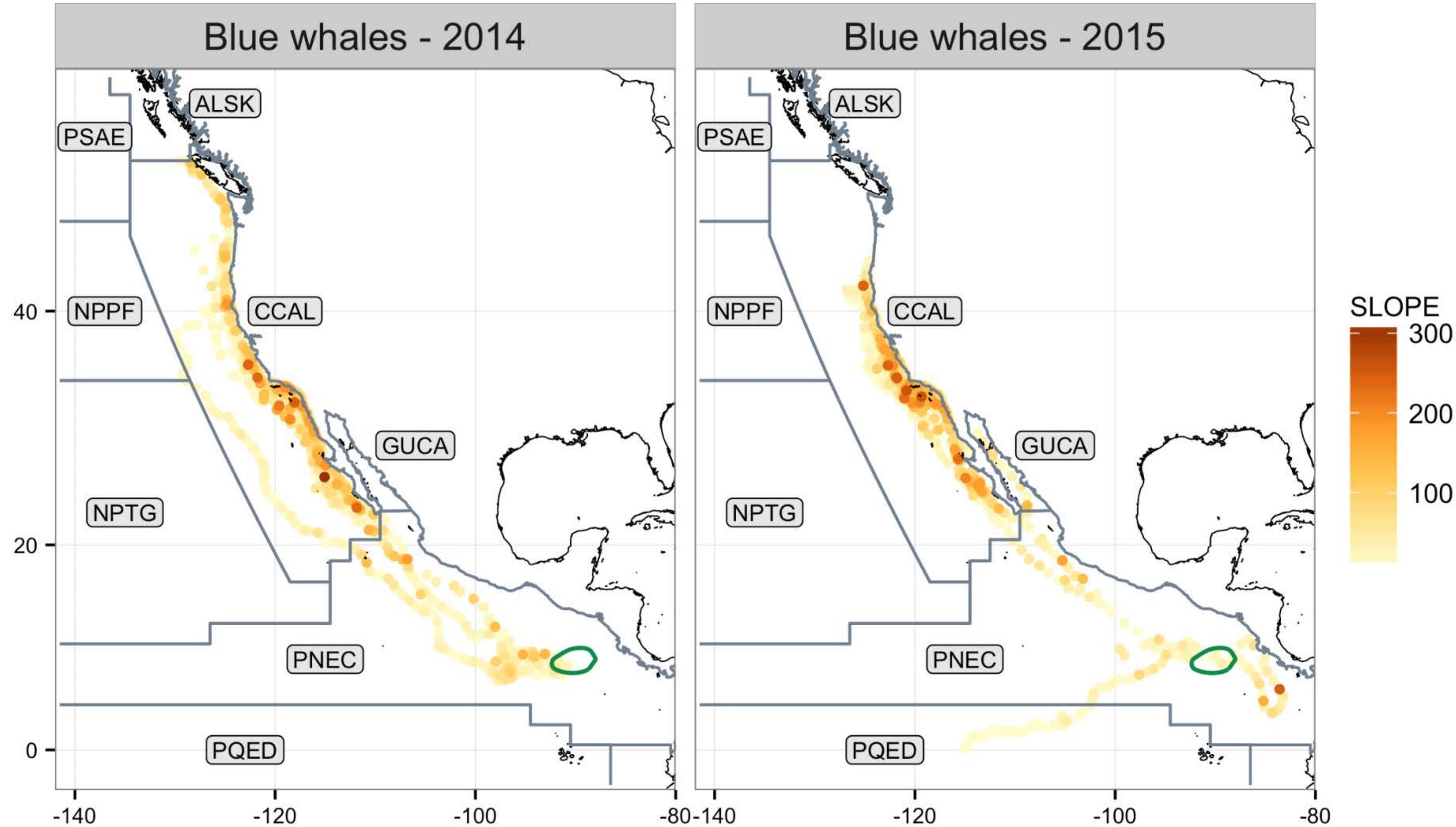

Figure 37. Map representation of seafloor slope (SLOPE, m km^{-1}) values obtained from ETOPO1 around each blue whale location. The Longhurst biogeographic provinces are indicated. The green, oval-shaped contour in PNEC outlines the position of the CRD. The left and right panels represent blue whales tagged in 2014 and 2015, respectively

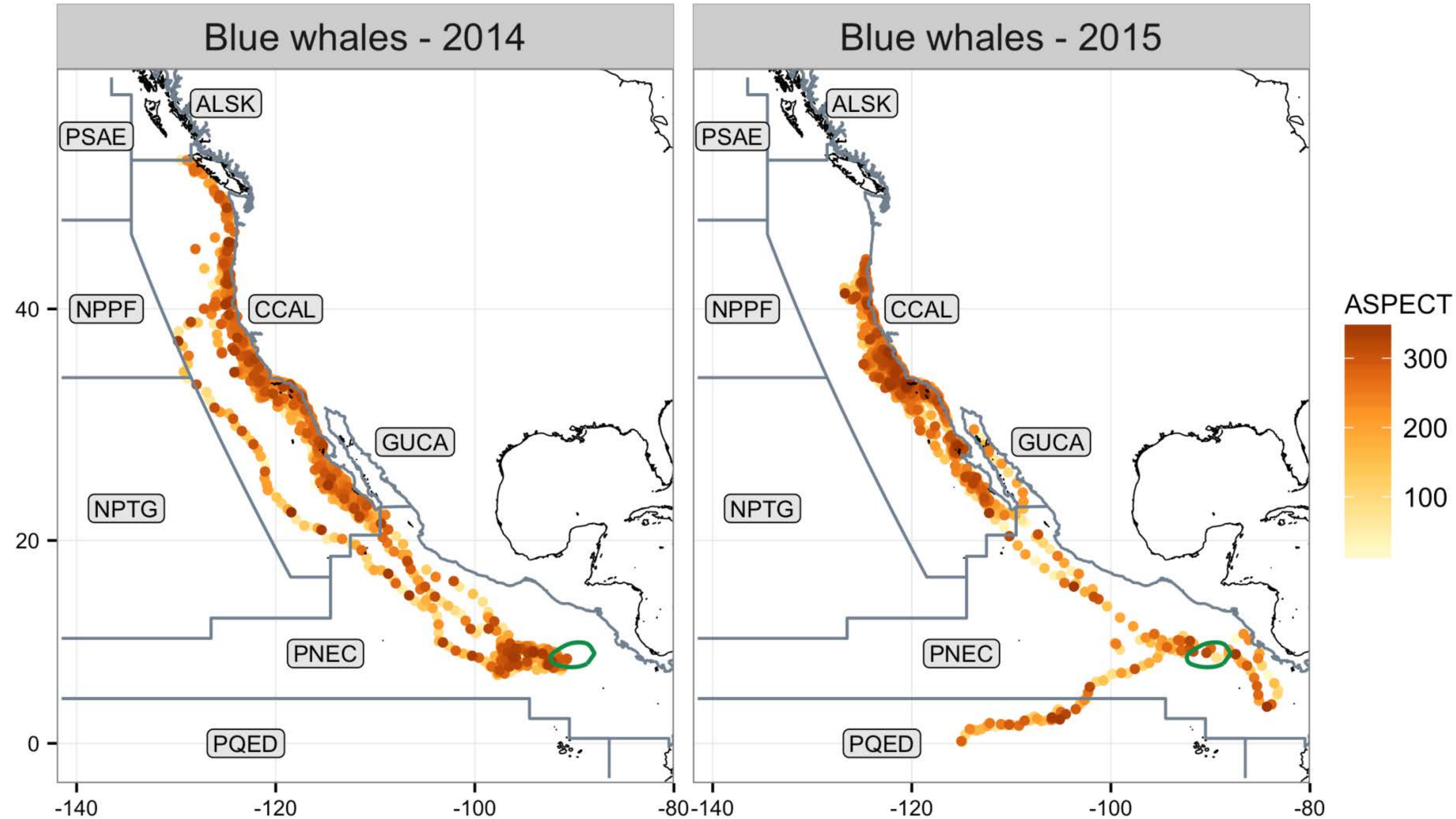

Figure 38. Map representation of seafloor slope aspect (ASPECT, degrees) values obtained from ETOPO1 around each blue whale location. The Longhurst biogeographic provinces are indicated. The green, oval-shaped contour in PNEC outlines the position of the CRD. The left and right panels represent blue whales tagged in 2014 and 2015, respectively

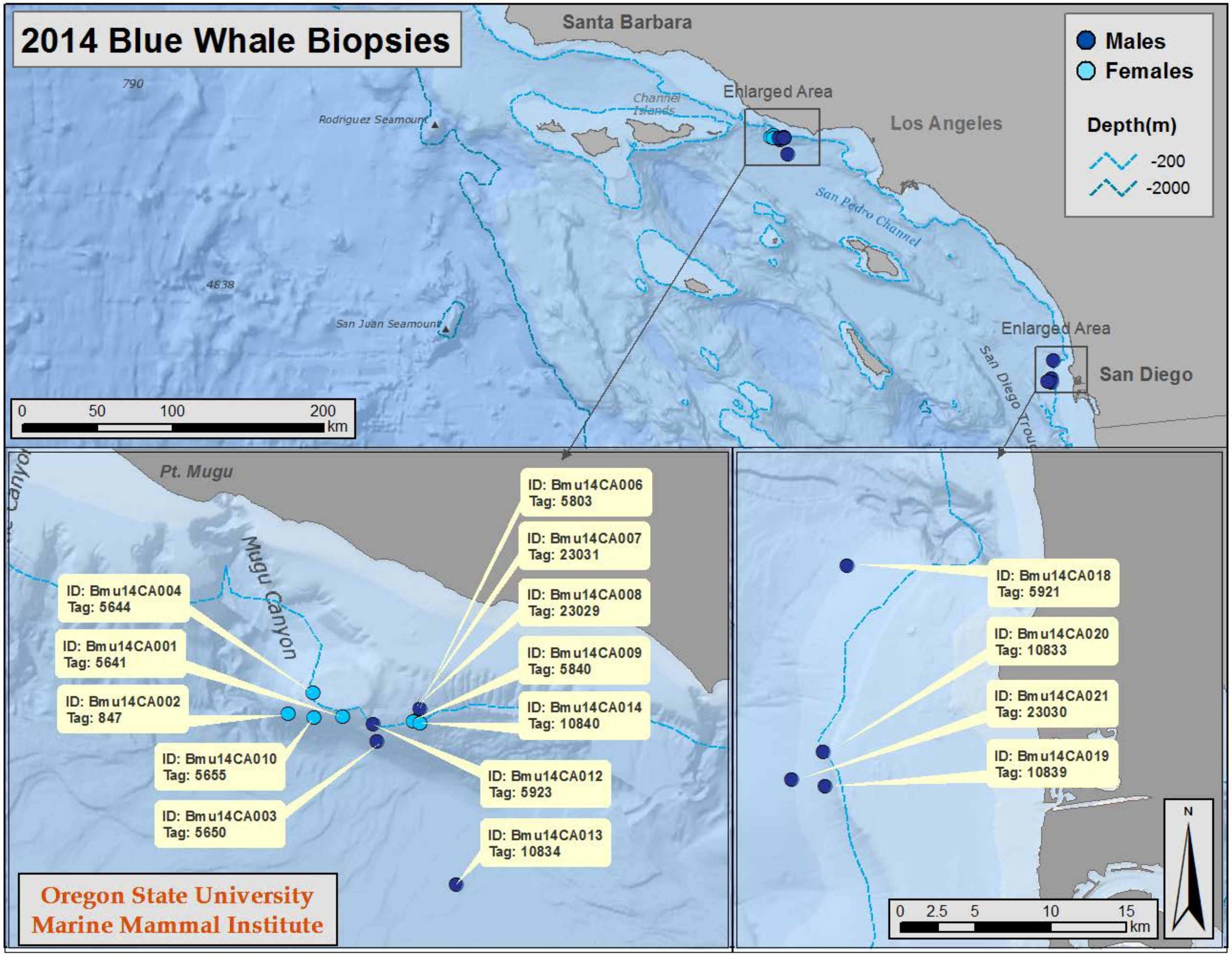

Figure 39. The location of biopsy sample collections from blue whales tagged in 2014.

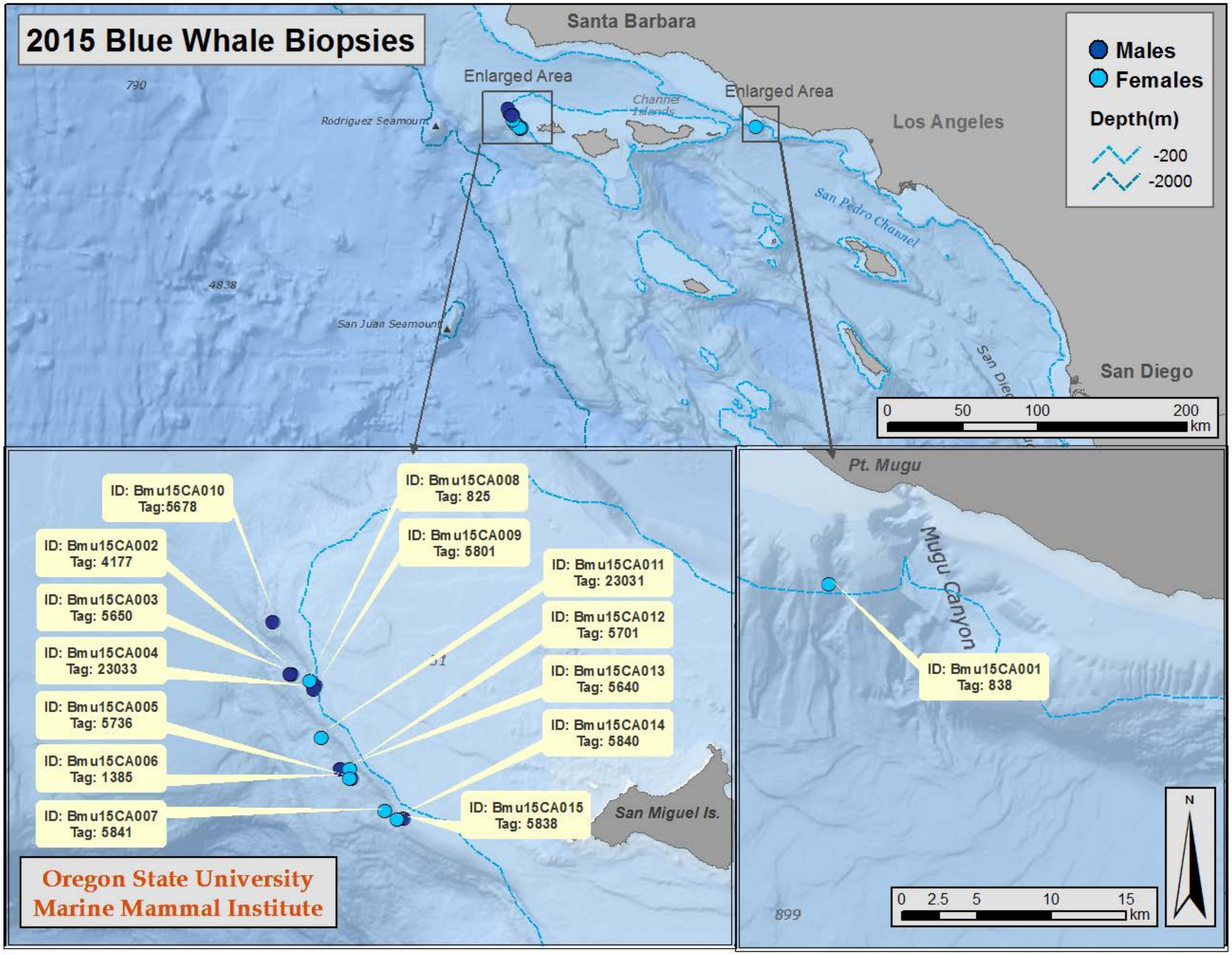

Figure 40. The location of biopsy sample collections from blue whales tagged in 2015.

3.1.8.2 INDIVIDUAL IDENTIFICATION

All 31 samples were represented by unique multi-locus genotypes and the probability of identity for the 17 loci was very low, 7.6×10^{-15} (i.e., there was a very low probability of a match by chance). Consequently, we are confident that the 31 unique multi-locus genotypes represented 31 individuals, i.e., there were no replicate samples among the blue whales tagged in 2014–15. This was consistent with sex and mtDNA haplotypes, as provided in the full DNA profile.

The DNA profiles of the 31 blue whales tagged in 2014–15 were compared to a reference database of blue whales sampled previously in the eastern North Pacific by the MMI or made available through a collaborative agreement with Cascadia Research (**Figure 41**). 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 31 blue whales tagged in 2014–15.

3.1.8.3 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 22**): the eastern South Pacific (Chile), Australia and New Zealand, and the Antarctic. The total of 327 samples represented 74 mtDNA haplotypes based on a 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 at the MMI 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 63 individuals with mtDNA haplotypes. These represented 15 haplotypes based on the consensus sequence of 410 bp.

Of the 9 haplotypes resolved in the tagged blue whales from 2014–15, 6 matched to the 15 haplotypes represented in reference database from the eastern North Pacific, resulting in a total of 18 haplotypes for this stock. Of these 18 haplotypes, 7 were also shared with one or more of the other stocks or subspecies, including two shared with the Antarctic subspecies. In total, the sample from the 2014–15 tagging and the reference databases represented 84 haplotypes, 66 of which were not shared with the eastern North Pacific.

The test of differentiation showed no significant differences in haplotype frequencies between the 13 females and 18 males ($p = 0.323$) or between the two years ($p = 0.671$) for the 2014–15 tagged whales. The combined sample of 31 tagged whales showed no significant differences with the reference dataset representing the eastern North Pacific (**Table 23**). 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 2014–15 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).

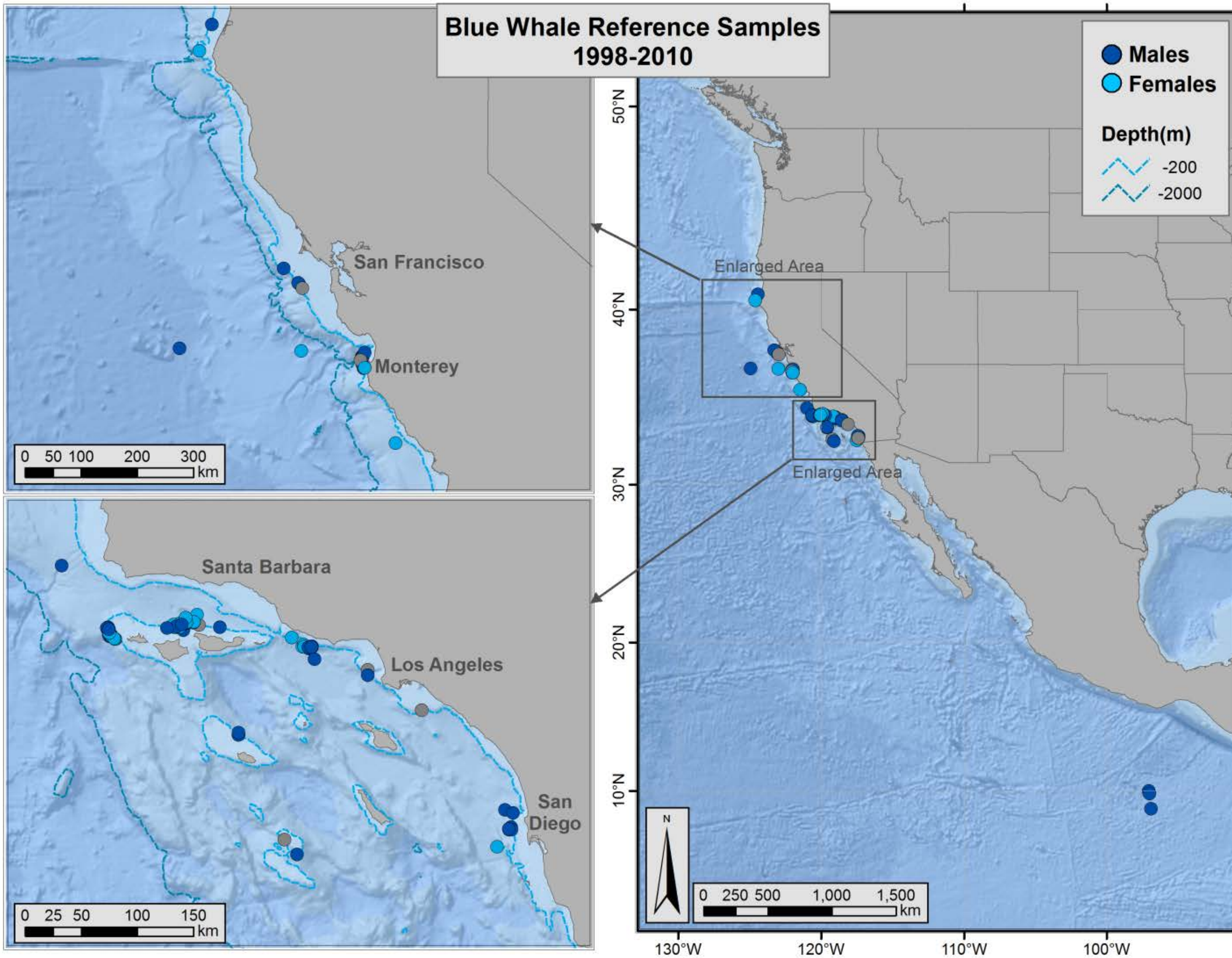

Figure 41. The sample location of blue whales used in the reference database for population structure.

Table 22. The frequency and identity of 18 mtDNA haplotypes for blue whales in the eastern North Pacific, including 9 from the 2014–15 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	2014–15 Tagged Whales
haplotype d	EU093921	4	31	1	4	
haplotype dd	EU093947			4		1
haplotype e	EU093922		5		1	2
haplotype q	EU093934			20	8	3
haplotype r	EU093935	2	1	19	25	17
haplotype t	EU093937			9	1	
BMCH01	JX035887			2	2	4
NPBW06(Bmu07CA001)	JQ717166				5	1
NPBW13(Bmu07Ca016)	JQ717173				3	
NPBW15(Bmu06Ca005)	JQ717175				3	
NPBW16(Bmu07Ca002)	JQ717176				2	
NPBW18(Bmu06CA002)	JQ717178				4	1
Hap53(Bmu07Ca004)	KP187717				1	
Bmu07Ca006					1	
Bmu08Ca002					1	
Bmu51118					2	
Bmu15CA007						1
Bmu15CA004						1
Unshared haplotypes (66)		178 (50)	14 (8)	37 (9)		
Total individuals		**184**	**51**	**92**	**63**	**31**

Table 23. Pairwise tests of differentiation (F_{ST}) 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.

Strata 1	n 1	Strata 2	n 2	F_{ST}	p value
Antarctic	184	SoCal tagging	31	**0.150**	< 0.001
Australia/New Zealand	51	SoCal tagging	31	**0.340**	< 0.001
Eastern South Pacific	92	SoCal tagging	31	**0.091**	<0.001
Eastern North Pacific	63	SoCal tagging	31	0.010	0.170

3.2 Fin Whales

3.2.1 2014 Location Tracking

Six tags were deployed on fin whales (3 SPOT5, 3 ADB) between 3 and 15 August 2014 (**Table 24**). Locations were received from all tags, providing tracking periods ranging from 4.9 to 143.7 d. Average tracking duration was 90.8 d (SD = 46.9 d, median = 74.3 d) for SPOT5 tags and 10.8 d (SD = 5.1 d, median = 13.3 d) for ADB tags. Locations extended along the coastline from 30.0 to 42.5ºN, with distance to shore ranging from less than 1 to 243 km (median distance = 46 km; **Table 25, Figure 42**;). After spending time in the inner Southern California Bight waters, fin whale movement was predominantly directed offshore, beyond the Channel Islands. Three whales then traveled north beyond Point Conception. The three ADB tags all stopped transmitting by 25 August, according to their pre-determined deployment period. By mid-September the three whales equipped with SPOT5 tags were spread out between San Clemente Island in southern California and the Oregon/California border. One of these whales spent the remainder of its tracking period between the outer Channel Islands and Monterey Bay before its tag stopped transmitting at the end of October. Another whale traveled extensively throughout the southern and central California coast before heading south into Mexican waters by the beginning of November. This whale then moved back and forth between southern California and the central Baja California coast before its tag stopped transmitting on 24 December, 143.7 d after tagging.

All six of the tagged fin whales were tracked within the PT MUGU range, spending 5 to 59 percent of their total tracking periods there, or <1 to 49 d (**Table 26 and Figure 43**). Four of these whales also spent from 2 to 47 percent of their total tracking periods within SOCAL, representing <1 to 45 d in that area (**Figure 44**). Only one fin whale had locations within NWTRC, spending 36 d or 54 percent of its tracking period there (**Figure 45**). There were no fin whale locations inside area W237 (**Figure 46**). None of the tagged fin whales were tracked within the GOA range. The maximum distance from shore for Navy training range locations was 223 km within PT MUGU, 137 km within SOCAL, and 84 km within NWTRC. Fin whale locations occurred in SOCAL in all 5 months in which they were tracked (August, September, October, November, and December) and in PT MUGU during 4 of those months (August, September, October, and November). Fin whale locations occurred in the NWTRC in only 2 months, however (August and September).

Three fin whale tags provided enough locations to calculate HRs and CAs within the EEZ waters of the U.S. (**Table 27, Figures 47 and 48**). HR sizes ranged from 50,319 to 80,130 km^2 (mean = 64,515.5 km^2, SD = 14,956.08 km^2) and extended from the California/Mexico border to Cape Blanco in southern Oregon. Areas of overlapping HRs for all three fin whales occurred off the northwest corner of Santa Catalina Island in the Santa Monica Basin and south of San Miguel Island. CAs ranged from 10,376 to 12,571 km^2 (mean = 11,580.0 km^2, SD = 1,113.04 km^2). Only two of the three fin whales had overlapping CAs, all off California. This overlap occurred at three localities: one south of San Miguel Island, approximately 100 km offshore, one approximately 80 km offshore of Arroyo Grande near the Santa Lucia Bank, and the third approximately 70 km off Big Sur.

Table 24. Deployment and performance data for satellite-monitored radio tags deployed on fin whales in southern California, 2014. In the Sex column, F = female, M = male, and U = unknown sex, because no biopsy sample was collected. See Section 3.2.2 for location filtering method. Tag #5838 was eventually recovered in May 2016, but the data are not presented here.

Tag #	Sex	Tag Type	Deployment Date	Most Recent Location	# Days Tracked	# Filtered Locations	# GPS/Argos Locations	Total Distance (km)
5648	U	SPOT5	3-Aug-14	24-Dec-14	143.7	299	0 / 299	7,549
10821	M	SPOT5	15-Aug-14	29-Oct-14	74.3	272	0 / 272	4,723
10831	M	SPOT5	4-Aug-14	28-Sep-14	54.3	137	0 / 137	2,844
Mean		**SPOT5**			**90.8**	**236**		**5,039**
Median		**SPOT5**			**74.3**	**272**		**4,723**
5685⁺	M	ADB	6-Aug-14	21-Aug-14	14.2	148	93 / 55	1,257
5790⁺*	F	ADB	11-Aug-14	25-Aug-14	13.3	153	14 / 139	2,200
5838⁺*	F	ADB	11-Aug-14	16-Aug-14	4.9	87	11 / 76	510
Mean		**ADB**			**10.8**	**129**		**1,322**
Median		**ADB**			**13.3**	**148**		**1,257**

KEY: ADB = Advanced Dive Behavior; km = kilometer(s); GPS = geographic positioning system; SPOT5 = Smart Positioning or Temperature Transmitting Tag, Version 5; # = number; ⁺ Tag is FastLoc®, Version1; *Tags were not recovered so values are from data transmitted through Argos.

Table 25. Great-circle distances to nearest point on land for fin whales tagged off southern California, 2014. The number of locations includes filtered locations (see Section 3.2.2 for filtering method) plus deployment location.

Tag #	Tag Type	# Locations	Median (km)	Mean (km)	SD (km)	Minimum (km)	Maximum (km)	Deploy Location Distance (km)
5648	SPOT5	301	41.0	53.8	39.66	0.0	192.7	9.5
10821	SPOT5	274	94.5	103.5	49.14	26.6	243.1	26.6
10831	SPOT5	139	50.5	50.7	32.49	2.0	241.3	10.9
5685⁺	ADB	149	92.6	103.0	54.30	8.3	222.8	8.3
5790⁺	ADB	154	22.2	25.5	19.74	3.0	116.7	7.3
5838⁺	ADB	88	25.9	26.6	14.05	5.1	67.6	8.9
Mean				**60.5**		**7.5**	**180.7**	**11.9**
Median			**45.8**			**4.1**	**207.8**	**9.2**

KEY: ADB = Advanced Dive Behavior; km = kilometer(s); SD = standard deviation; SPOT5 = Smart Positioning or Temperature Transmitting Tag, Version 5; # = number; ⁺Tag is FastLoc®, Version.1

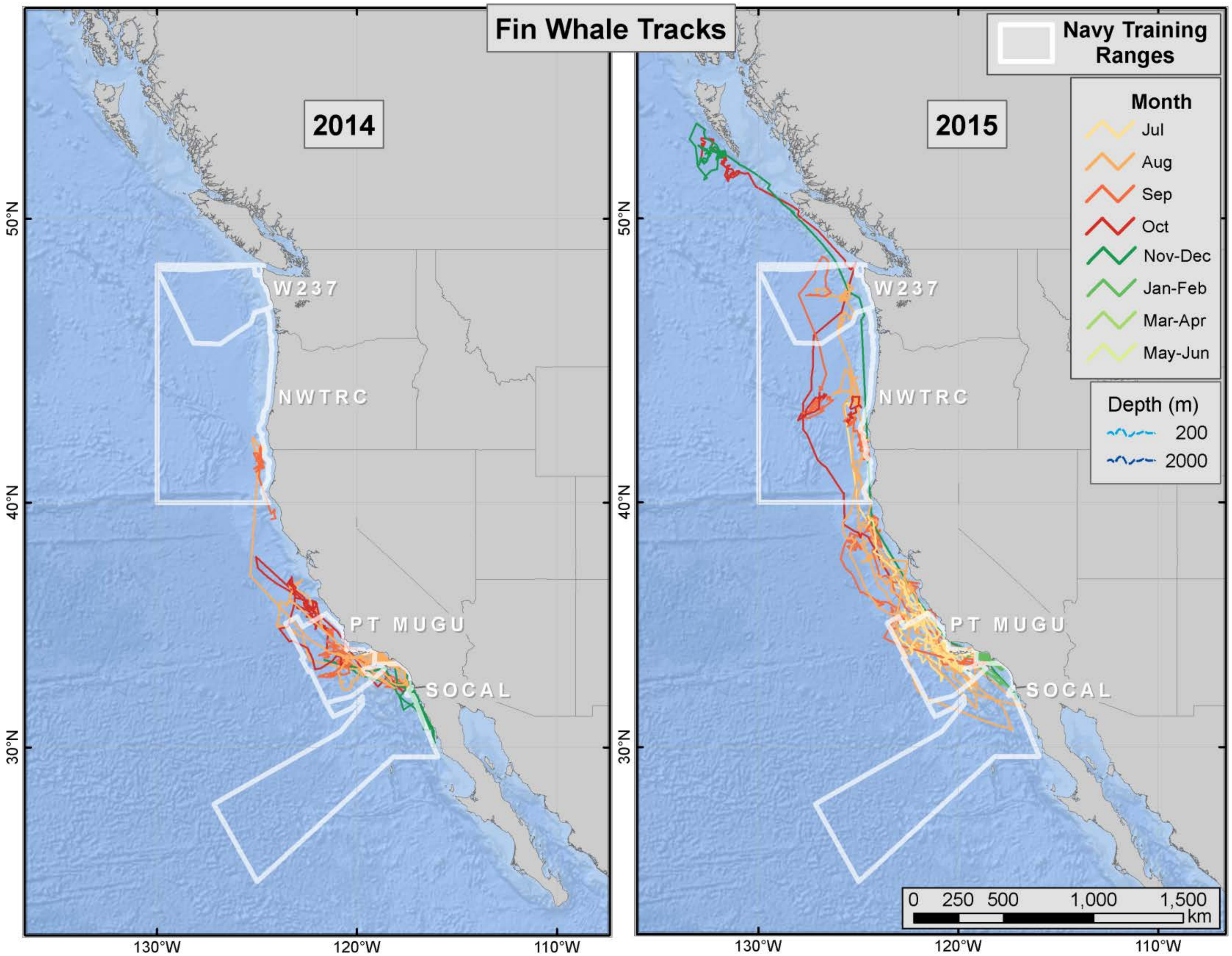

Figure 42. Satellite-monitored radio tracks for fin whales tagged off southern California in August 2014 (left panel; 3 SPOT5 tags, 3 ADB tags), and July, 2015 (right panel; 9 SPOT5 tags, 2 ADB tags).

Table 26. Percentage of filtered locations (Locs) and time spent inside the SOCAL, PT MUGU, NWTRC, and W237 areas for fin whales tagged off southern California, 2014. See Section 3.2.2 for location filtering method.

		Filtered Locations														
Tag #	Tag Type	Total		SOCAL			PT MUGU			NWRTC			W237			
		# Locs	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	
5648	SPOT5	299	143.7	36	31	45.1	32	34	49.3							
10821	SPOT5	272	74.4				59	59	44.2							
10831	SPOT5	137	66.3				7	5	3.1	73	54	35.7				
5685+	ADB	148	11.8	47	47	5.5	55	51	6.0							
5790+	ADB	153	13.3	52	47	6.3	16	28	3.7							
5838+	ADB	87	4.9	2	2	0.1	10	10	0.5							

KEY: ADB = Advanced Dive Behavior; SPOT5 = Smart Positioning or Temperature Transmitting Tag, Version 5; # = number
+Tag is FastLoc®, Version.1

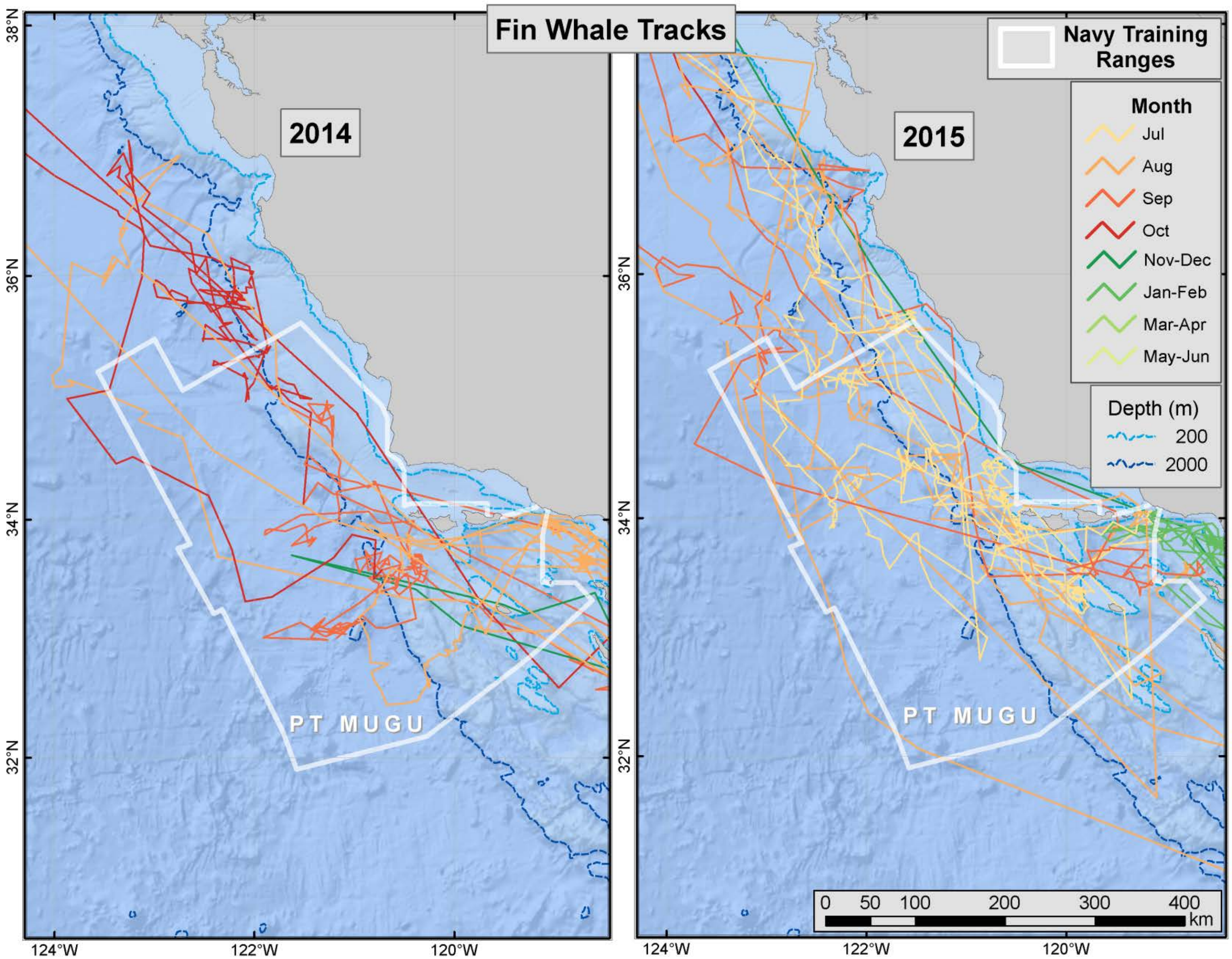

Figure 43. Satellite-monitored radio tracks in PT MUGU for fin whales tagged off southern California in August and September 2014 (left panel; 3 SPOT5 tags, 3 ADB tags) and July 2015 (right panel; 9 SPOT5 tags, including the blue/fin hybrid whale, 2 ADB tags).

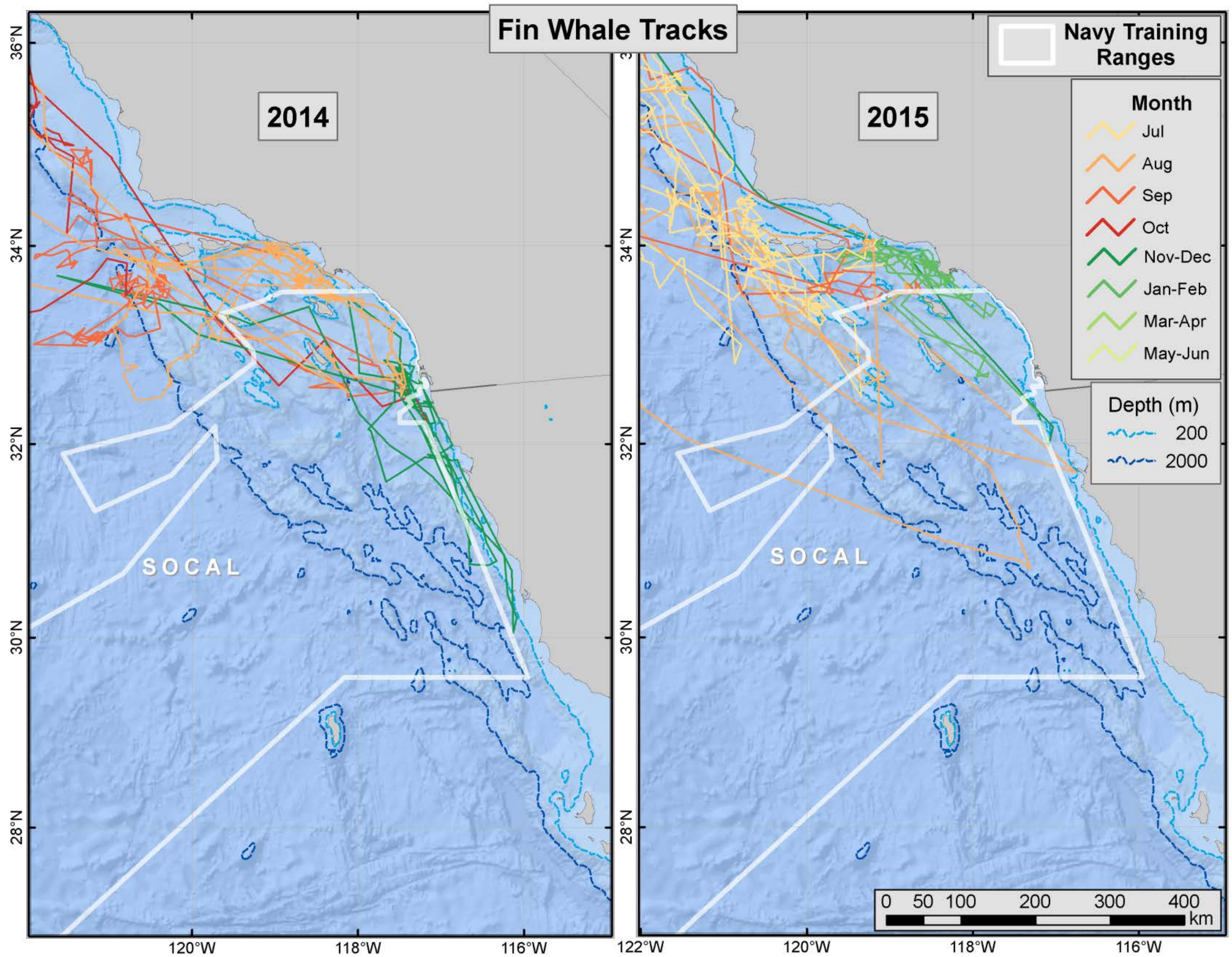

Figure 44. Satellite-monitored radio tracks in SOCAL for fin whales tagged off southern California in August and September 2014 (left panel; 1 SPOT5 tag, 3 ADB tags) and July 2015 (right panel; 4 SPOT5 tags).

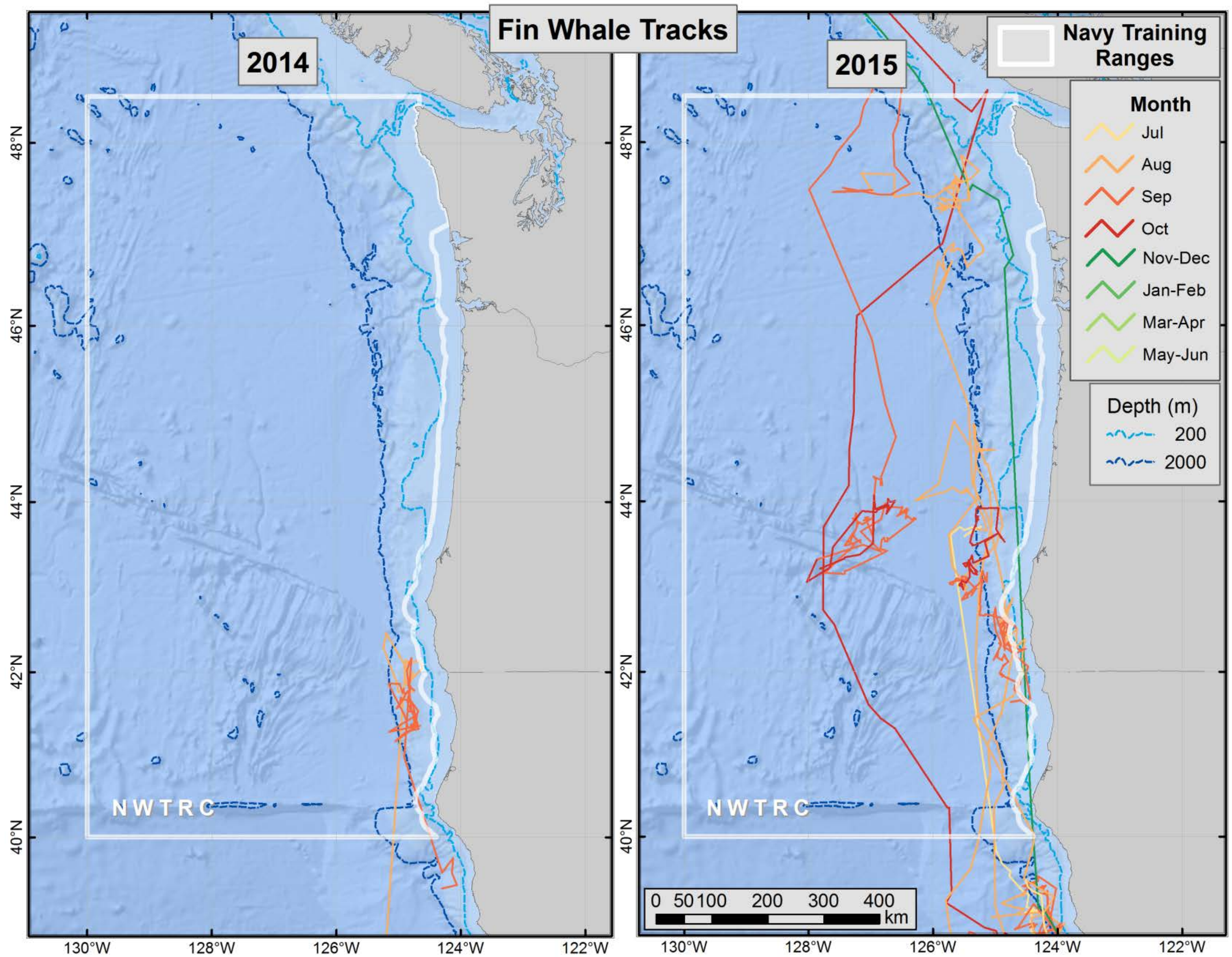

Figure 45. Satellite-monitored radio tracks in NWTRC for fin whales tagged off southern California in August and September 2014 (left panel; 1 SPOT5 tag) and July 2015 (right panel; 4 SPOT5 tags).

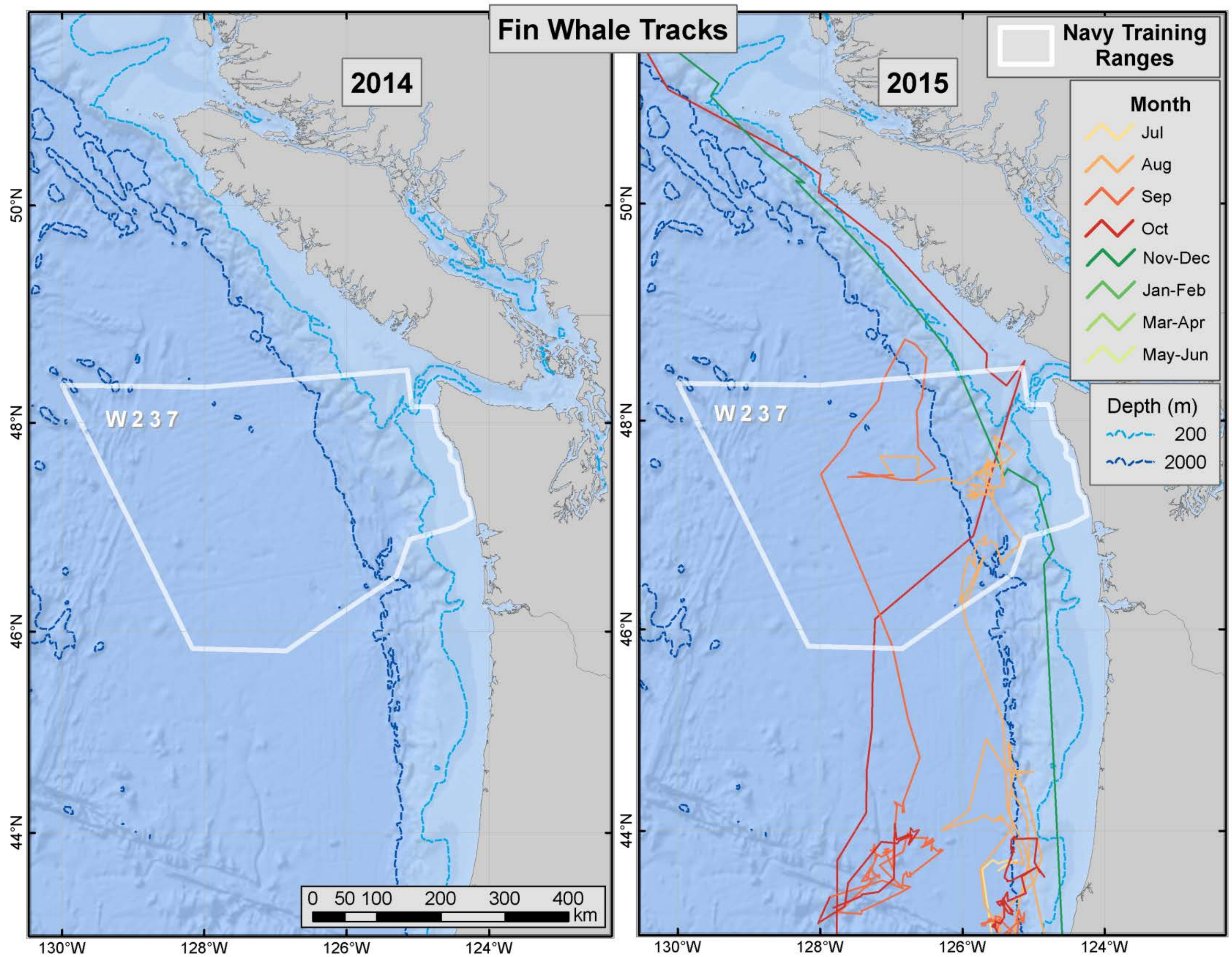

Figure 46. Satellite-monitored radio tracks in area W237 for fin whales tagged off southern California in August and September 2014 (left panel; 0 tags) and July 2015 (right panel; 2 SPOT5 tags).

Table 27. Sizes of HRs and CAs of use in the U.S. EEZ calculated from SSM locations for three fin whales tagged off southern California, 2014.

Fin Whales				
Tag #	**# SSM Locations**	**Sex**	**HR Size (km^2)**	**CA Size (km^2)**
5648	103	U	63,097	10,376
10821	75	M	50,319	12,571
10831	54	M	80,130	11,793
Mean			**64,515.5**	**11,580.0**

Key: km^2 = square kilometer(s).

Note: The U.S. EEZ is located from the shoreline to 370.4 km (200 nautical miles) from shore.

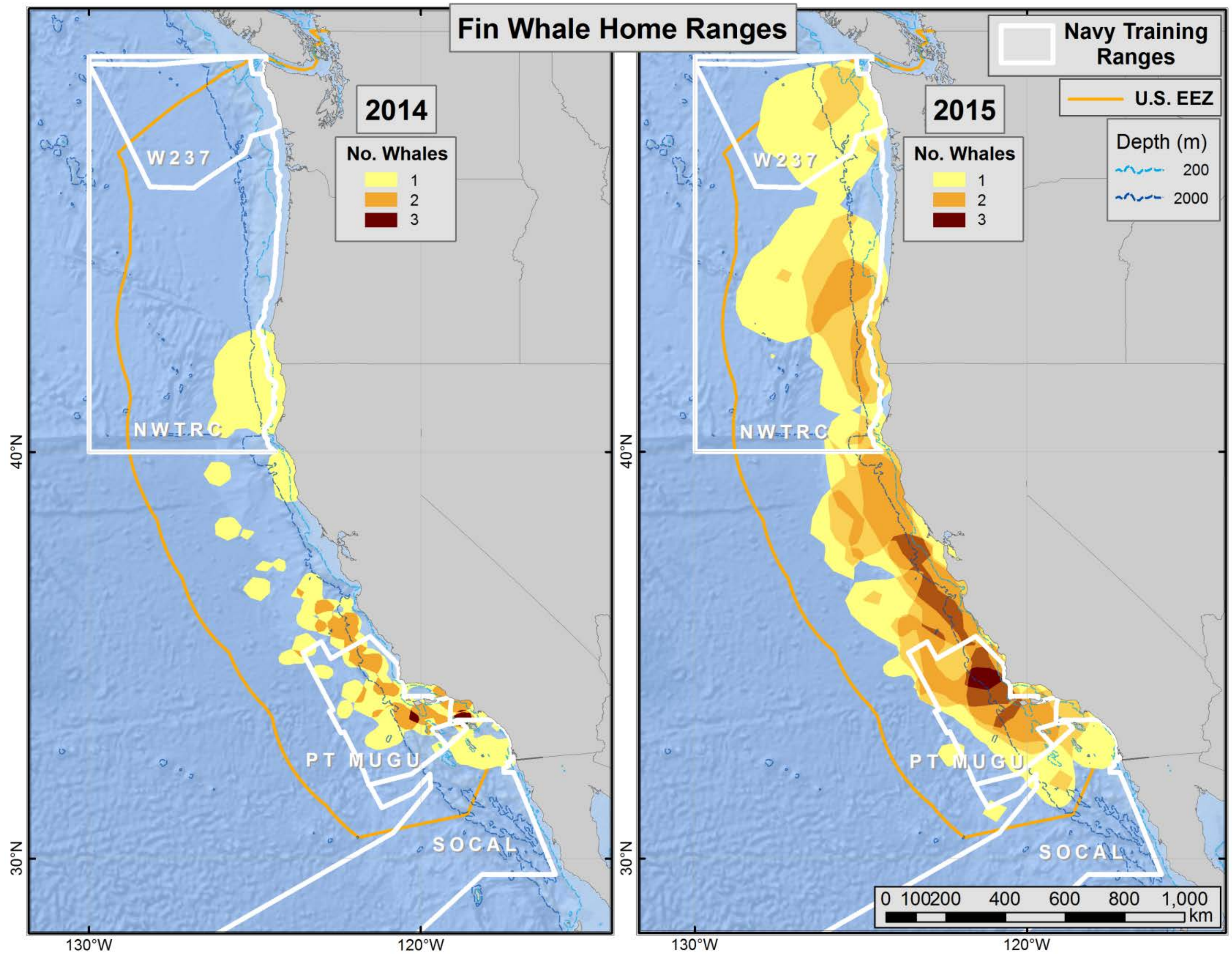

Figure 47. HRs in the U.S. EEZ for fin whales tagged off southern California in 2014 (left panel; 3 whales), and in 2015 (right panel; 5 whales). Shading represents the number of individual whales with overlapping HRs.

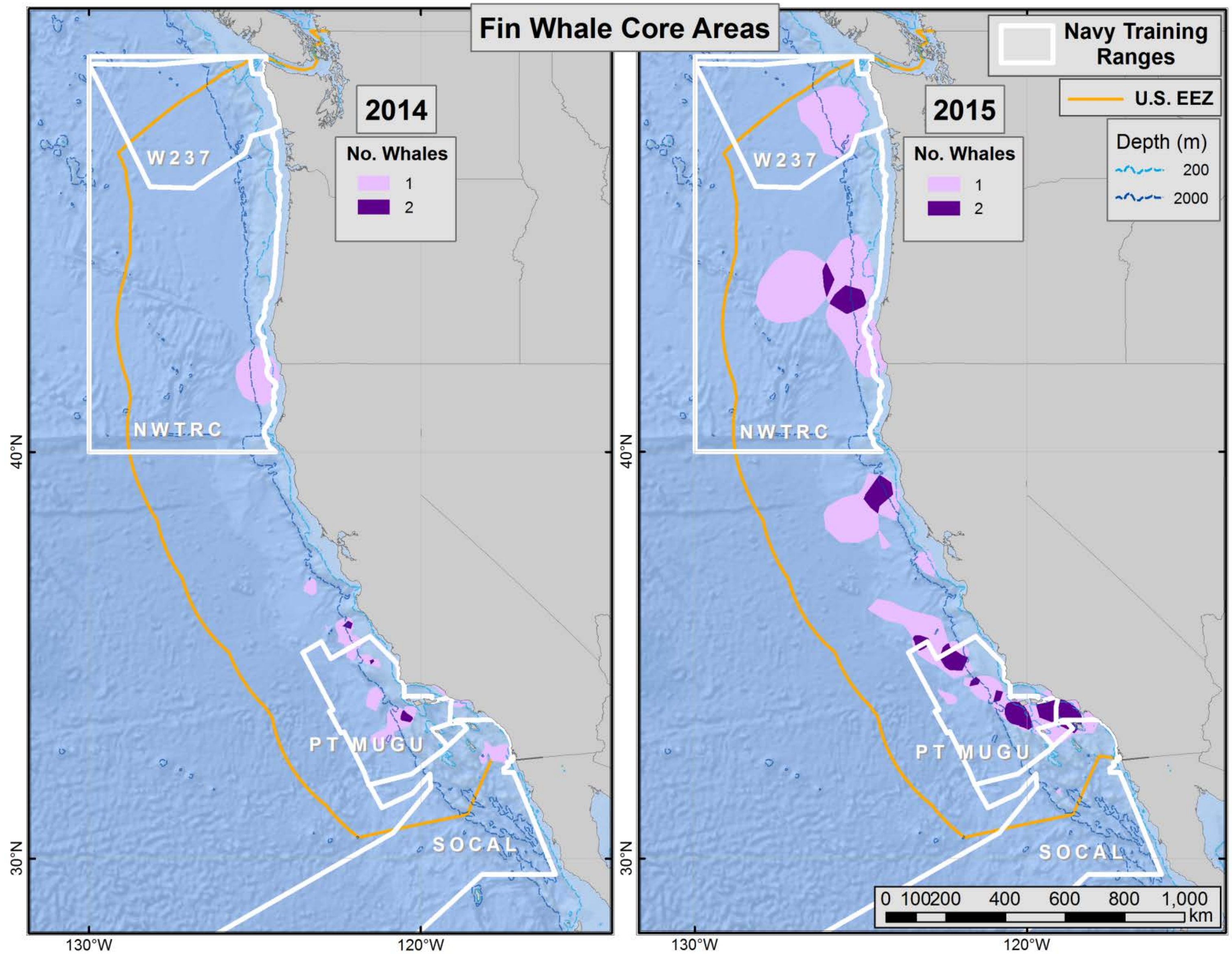

Figure 48. CAs of use in the U.S. EEZ for fin whales tagged off southern California in 2014 (left panel; 3 whales), and in 2015 (right panel; 5 whales). Shading represents the number of individual whales with overlapping HRs.

3.2.2 2015 Location Tracking

Eleven tags were deployed on fin whales (9 SPOT5, 2 ADB) and one SPOT5 tag was deployed on a blue/fin whale hybrid (that was identified in the field as a fin whale) between 8 and 28 July 2015 (**Figures 42 and 49**). All tags were deployed off southern California, between Mugu Canyon (west of Malibu, California) and the west coast of San Miguel Island. One fin whale tag was still transmitting at the time of report preparation on 29 February 2016. The tracking data for the blue/fin whale hybrid are included in the fin whale section for this report. Transmissions were received from all 12 tags; however, one fin whale tag provided no locations. Tracking periods ranged from 6.2 to 220.2 d (as of 29 February 2016), with average fin whale tracking durations of 73.1 d (SD = 66.3 d, median = 66.3 d) for SPOT5 tags and 15.7 d (SD = 0.4 d, median = 15.7 d) for ADB tags (**Table 28**). The blue/fin hybrid was tracked for 28.1 d. Distances to shore ranged from <1 to 324 km (median = 70 km; **Table 29**). Median distances to shore for the blue/fin hybrid and Bryde's whale locations were 40.8 km and 68.2 km, respectively.

By the end of July, one fin whale had traveled as far north as Coos Bay in southern Oregon (**Figure 42)**. The other eight whales were spread out between the Southern California Bight and Monterey Bay, California, with locations ranging from near the shore out to 300 km. During August, two of the whales had ventured south into Mexican waters, but by the end of the month they were back in southern California waters. The other four whales still being tracked at that time ranged from San Nicolas Island, California, to the Olympic Peninsula in Washington. Toward the end of September, the four fin whales still being tracked were all located off northern California or southern Oregon—one off Point Reyes, California; one off Cape Mendocino, California; and two off Cape Blanco, Oregon. By the middle of November, one fin whale tag was still transmitting and the whale was located off the island of Haida Gwaii (Queen Charlotte Islands) in British Columbia, where it remained until the end of November. The whale then traveled south along the west coast during the month of December, reaching Ensenada, Mexico, on December 29. After this the whale headed north into the Southern California Bight, where it spent the next 2 months, predominantly in nearshore waters off Palos Verdes. This whale's tag (Tag #2015_5742) was still transmitting at the time of report preparation on 29 February 2016, 221 d after tagging.

PT MUGU was the most heavily used training range for fin whales, with all 10 tracked fin whales and the blue/fin hybrid having locations in the area (**Table 30 and Figure 43**). Locations in PT MUGU occurred in 5 of the 8 months in which these whales were tracked (July, August, September, December, and January). Four fin whales had locations in SOCAL, with these occurring during six months (July, August, September, December, January, and February; **Table 30 and Figure 44**). Four fin whales also had locations in the NWTRC, with two of these also having locations in W237 (**Figures 45 and 46**). Locations in the NWTRC occurred during July, August, September, October, and December; locations in W237 occurred in August, September, October, and December. None of the tagged fin whales were tracked within the GOA training area. The maximum distance from shore for locations in training areas was 281 km within PT MUGU, 208 km within SOCAL, 282 km within NWTRC, and 279 km within W237.

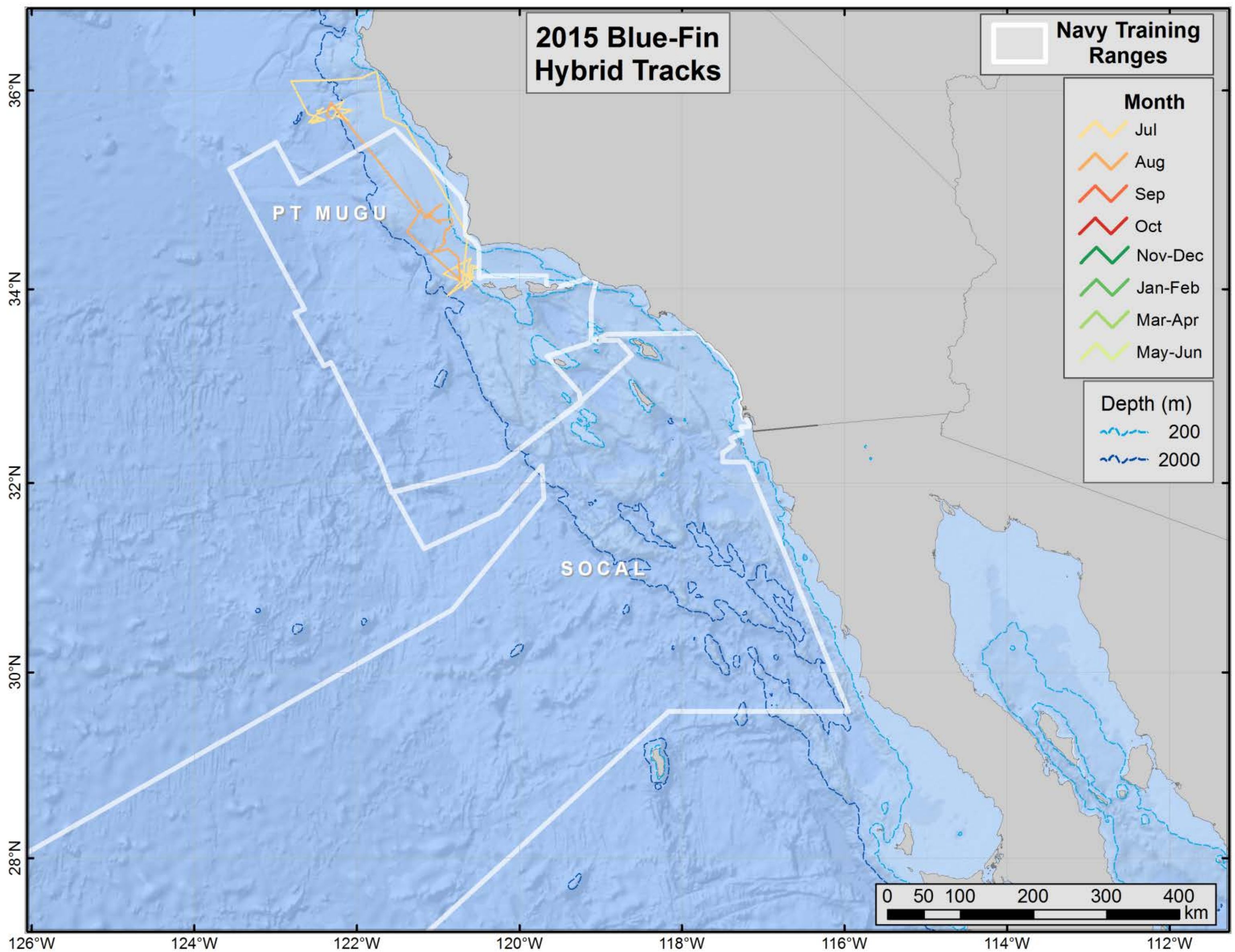

Figure 49. Satellite-monitored radio track for a blue/fin hybrid whale tagged off southern California in July 2015 (SPOT5 tag).

Table 28. Deployment and performance data for satellite-monitored radio tags deployed on fin whales, a blue/fin hybrid, and a Bryde's whale in southern California, 2015.In the Sex column, F = female, M = male, and U = unknown sex, because no biopsy sample was collected. See Section 3.2.2 for location filtering method.

Tag #	Sex	Tag Type	Deployment Date	Most Recent Location	# Days Tracked	# Filtered Locations	# GPS/Argos Locations	Total Distance (km)
832	F	SPOT5	22-Jul-15	20-Aug-15	28.7	23	0 / 23	1,509
839	M	SPOT5	8-Jul-15	24-Sep-15	78.0	269	0 / 269	6,797
5742*	M	SPOT5	23-Jul-15	29-Feb-16	220.2	645	0 / 645	13,475
5743	U	SPOT5	9-Jul-15	6-Aug-15	28.2	53	0 / 53	1,321
5790	F	SPOT5	28-Jul-15		0.0	0	0 / 0	0
5800	F	SPOT5	17-Jul-15	7-Oct-15	81.8	290	0 / 290	5,234
5923	M	SPOT5	28-Jul-15	21-Sep-15	54.6	92	0 / 92	3,349
10838	U	SPOT5	17-Jul-15	12-Oct-15	86.9	378	0 / 378	5,161
23032	F	SPOT5	28-Jul-15	3-Aug-15	6.2	29	0 / 29	565
Mean		**SPOT5**			**73.1**	**222**		**4,676**
Median		**SPOT5**			**66.3**	**180**		**4,255**
5644+	U	ADB	10-Jul-15	26-Jul-15	15.4	186	175 / 11	1,570
5654+	U	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**
Blue/Fin Hybrid								
10831	M	SPOT5	16-Jul-15	13-Aug-15	28.1	95	0 / 95	1,445
Bryde's whale								
833	F	SPOT5	23-Aug-15	18-Oct-15	86.7	94	0 / 94	134,331

KEY: ADB = Advanced Dive Behavior; km = kilometer(s); GPS = geographic positioning system; SPOT5 = Smart Positioning or Temperature Transmitting Tag, Version 5; # = number; *Tag was still transmitting as of 29 February 2016; + Tag is FastLoc®, Version1.

Table 29. Great-circle distances to nearest point on land for fin whales, a blue/fin hybrid, and a Bryde's whale tagged off southern California, 2015. For locations west of Vancouver Island, British Columbia, Vancouver Island was used when determining nearest point to land. The number of locations includes filtered locations (see Section 3.2.2 for filtering method) plus deployment location.

Tag #	Tag Type	# Locations	Median (km)	Mean (km)	SD (km)	Minimum (km)	Maximum (km)	Deploy Location Distance (km)
832	SPOT5	22	102.0	99.8	38.61	8.3	164.6	8.3
839	SPOT5	272	111.8	118.6	51.11	34.6	281.2	39.9
5742*	SPOT5	646	64.3	99.6	86.04	0.2	324.3	3.7
5743	SPOT5	54	107.5	97.5	41.92	19.4	184.9	40.9
5800	SPOT5	290	132.6	143.5	71.70	8.2	282.4	38.5
5923	SPOT5	97	73.7	86.9	54.59	3.2	249.8	7.0
10838	SPOT5	379	66.2	71.8	42.97	2.8	230.5	35.5
23032	SPOT5	30	20.3	28.6	20.25	7.0	74.0	8.4
5644+	ADB	187	57.5	72.6	56.78	6.5	195.4	41.9
5654+	ADB	1763	65.1	70.5	31.72	21.1	136.2	38.0
Mean				**88.9**		**11.1**	**212.3**	**26.2**
Median			**70.0**			**7.6**	**213.0**	**37.0**
Blue/Fin Hybrid								
10831	SPOT5	96	40.8	44.2	20.21	1.0	92.6	43.6
Bryde's								
833	SPOT5	95	68.2	78.3	55.76	5.0	267.9	10.0

KEY: ADB = Advanced Dive Behavior; km = kilometer(s); SD = standard deviation; SPOT5 = Smart Positioning or Temperature Transmitting Tag, Version 5; # = number; *Tag is still transmitting as of 29 February 2016; +Tag is FastLoc®, Version.1

Table 30. Percentage of filtered locations (Locs) and time spent inside the SOCAL, PT MUGU, NWTRC and W237 areas for fin whales, a blue/fin hybrid, and a Bryde's whale tagged off southern California, 2015. See Section 3.2.2 for location filtering method.

		Filtered Locations														
Tag #	Tag Type	Total		SOCAL			PT MUGU			NWRTC			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							
839	SPOT5	269	78.0	3	5	3.6	20	16	12.8	24	31	23.9				
5742*	SPOT5	645	220.7	4	7	15.1	10	10	23.1	4	6	14.1	1	2	5.1	
5743	SPOT5	53	28.2				75	79	22.3							
5790	SPOT5	0	9.2													
5800	SPOT5	290	81.8				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							
10838	SPOT5	378	86.9				21	21	18.4	51	49	42.3				
23032	SPOT5	29	6.2				90	88	5.4							
5644+	ADB	186	15.4				58	48	7.3							
5654+	ADB	1,762	16.0				76	69	11.0							
Blue/Fin Hybrid																
10831	SPOT5	95	28.0				66	65	18.3							
Bryde's																
833	SPOT5	94	89.8	18	24	21.9	68	67	60.3							

KEY: ADB = Advanced Dive Behavior; SPOT5 = Smart Positioning or Temperature Transmitting Tag, Version 5; # = number
*Tag is still transmitting as of 29 February 2016; +Tag is FastLoc®, Version.1.

The 11 fin whales and the blue/fin whale hybrid spent from 11 to 88 percent of their total tracking periods in the PT MUGU area, representing 5 to 36 days (**Table 30**). The four fin whales with locations in SOCAL spent from 5 to 26 percent of their total tracking periods in that training range, representing 4 to 15 days. Four fin whales spent from 14 to 57 days in the NWTRC, or 6 to 70 percent of their total tracking periods. The two fin whales with locations in area W237 spent 5 and 22 days, respectively, in that area, representing 2 and 27 percent of their total tracking periods.

Five fin whale tags provided enough locations to calculate HRs and CAs within the EEZ waters of the United States (**Table 31, Figures 47 and 48**). HR sizes ranged from 110,335 to 265,809 km^2 (mean = 183,527.1 km^2, SD = 69,525.69 km^2) and extended from the California/Mexico border to the northern tip of the Olympic Peninsula in Washington. The densest area of overlapping HRs (for all five fin whales) occurred west of Point Conception, California, out to approximately 115 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 22,148 to 58,285 km^2 (mean = 36,284.3 km^2, SD = 16,251.20 km^2). The highest number of whales for which CAs overlapped was two. These areas of highest use for fin whales were scattered from the Southern California Bight (out to approximately 85 km southwest of Palos Verdes) up to Coos Bay, in southern Oregon (out to approximately 170 km offshore).

Table 31. 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.

Fin Whales				
Tag #	**# SSM Locations**	**Sex**	**HR Size (km^2)**	**CA Size (km^2)**
839	77	M	248445	58285
5742	159	M	157814	22148
5800	79	F	265809	48974
5923	52	M	110335	26363
10838	87	U	135232	25651
Mean			**183527.1**	**36284.3**

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

The sizes of fin whale HRs and CAs were significantly lower in 2014 than 2015, with a mean HR of 64,515.5 km^2 in 2014 and 183,527.1 km^2 in 2015 (GLM, $p = 0.03$; Levene's test for equality of variances, $p = 0.16$; Kolmogorov-Smirnov test for normality, $p = 0.99$), and mean CAs of 11,580.0 km^2 in 2014 compared to 36,284.3 km^2 in 2015 (GLM, $p = 0.04$; Levene's test for equality of variances, $p = 0.24$; Kolmogorov-Smirnov test for normality, $p = 0.63$). There was no relationship between the number of SSM locations used in the analysis and the size of either HRs or CAs (linear regression, $p > 0.8$).

3.2.3 ADB Tracking

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 9.1 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/MMI. By the time the data were downloaded by the manufacturer, there was too little time to include the data in this report before the deadline.

In 2014, the whales carrying the two longest-lasting ADB tags used different portions of southern California waters (**Figure 50**). 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 51**). In all, three of the five tagged whales left southern California waters during the tracking period.

The two recovered tags recorded 1,188 and 1,695 dives (**Table 32**), and 95 and 1,591 FastLoc® GPS locations, respectively, 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 three non-recovered tags transmitted dive summary information for a median of 289 dives and 12 GPS locations via Argos (**Table 32**).

A diel pattern in maximum dive depths was recorded by the tags, with deeper dives occurring during the daytime than at night (**Figure 52**). 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 foraging activity occurred near the southeastern side of San Clemente Island and southwest of San Nicolas Island (**Figure 50**), with the majority of foraging in the 2015 track occurring in an area extending from the tagging area down almost to San Nicolas Island (**Figure 51**). The median durations of foraging bouts recorded by the two recovered data archives were approximately equal for both whales, although Tag #2015_5654 made generally deeper dives during bouts and more feeding dives per bout (**Table 33**). Most foraging bouts were either 2 to 5 h in duration, or very long (> 15 h duration, **Figure 53**) and the average number of feeding lunges per dive increased with increasing duration of a foraging bout ($p < 0.001$, $R^2 = 0.45$, linear regression, **Figure 54**).

Table 32. Deployment summary for ADB tags attached to fin whales in southern California during summer 2014–15.

Species	Tag #	Sex	Recovered?	Duration (min)	# of Dives	# GPS locations	Dives/ day	GPS Locs/ day	Total Distance (km)
2014									
Fin whale	5685	M	Yes	14.2	1188	95	84	6	1,037.10
Fin whale	5790	F	No*	13.3	279	14	N/A	N/A	426.2
Fin whale	5838	F	No*+	4.9	289	12	N/A	N/A	132.8
	Median			**9.1**					
2015									
Fin whale	5644	U	No*	15.4	406	12	N/A	N/A	1,517
Fin whale	5654	U	Yes	16.0	1695	1,591	106	99	1,370
	Median			**15.7**					

KEY: *Data were transmitted through Service Argos, Inc., + Tag was recently recovered from a beach but data have not yet been analyzed.

Table 33. Summary of dives occurring during foraging bouts made by seven ADB-tagged fin whales tagged off southern California in August 2014 and July 2015. Foraging bouts are sequences of dives with no more than 75 min between dives with foraging lunges.

Tag #	Sex	Year		Bout Duration (h)	# Dives	Mean Max Dive Depth Foraging Dives (m)	Mean Duration Foraging Dives (min)	Mean Lunges per Foraging Dive	Dives With No Lunges	Area of Bout (km^2)	Time to Next Bout (h)	Dist to Next Bout (km)	Fraction non-foraging Dives
2014_5685	M	2014	Median	5.1	26.5	84.3	9.2	2.1	15	6.6	481.8	23.0	0.55
# Bouts = 12			Max	16.6	94	177.5	13.0	4.5	41	296.6	3191.6	113.3	
			Min	1.2	7	56.5	7.1	1.0	4	0.0	0.0	0.0	
2015_5654	U	2015	Median	4.5	35	127.5	9.2	2.2	7	16.5	528.3	10.1	0.20
# Bouts = 15			Max	18.6	116	291.1	11.8	4.6	91	642.1	2663.9	107.3	
			Min	0.6	5	13.5	2.6	1.0	3	0.1	0.0	0.0	

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

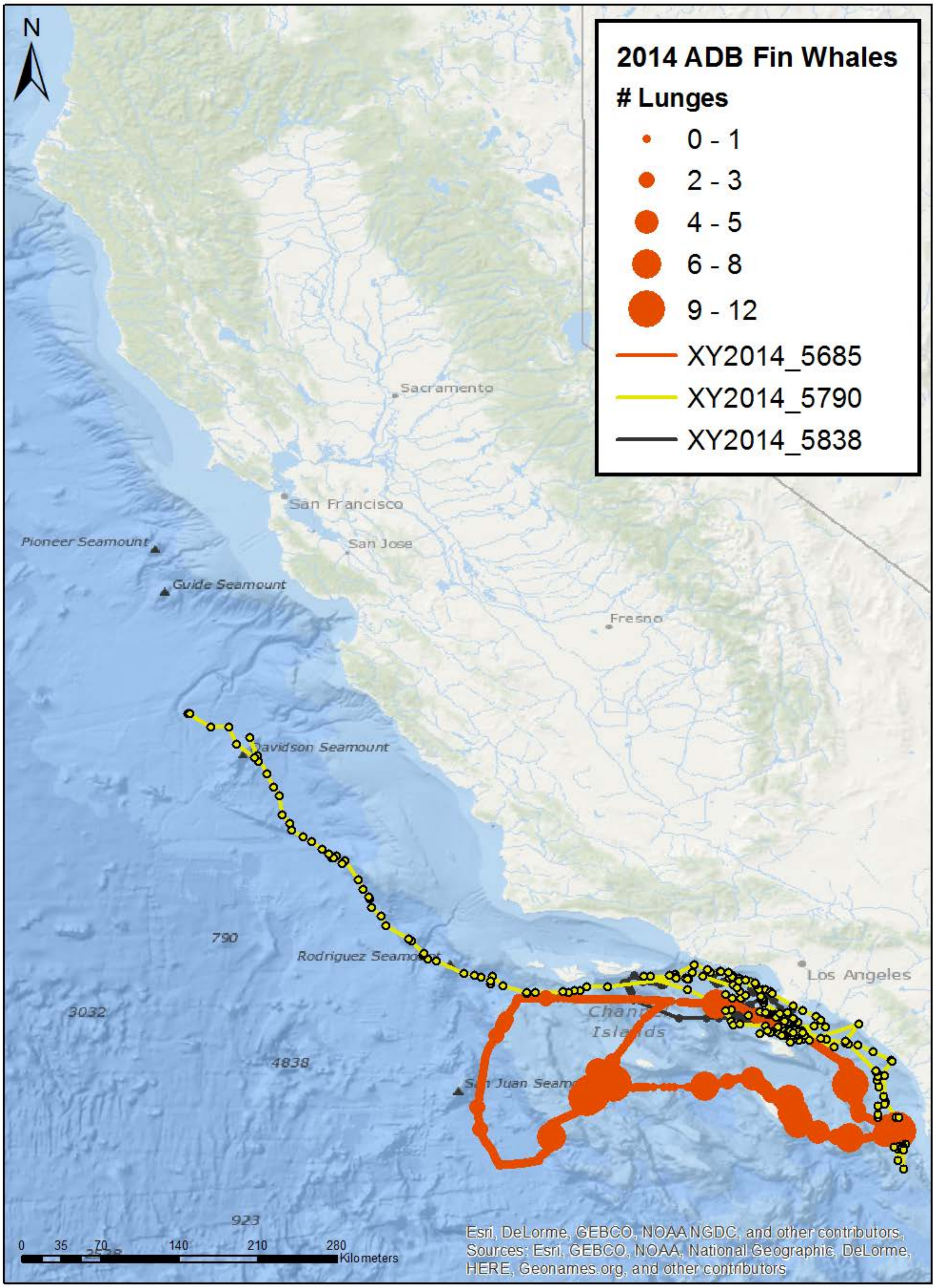

Figure 50. Tracks of three ADB-tagged fin whales off southern California in August 2014. Size of the circles represents the number of feeding lunges that occurred during a dive at that location. Tags #2014_5790 and 2014_5838 were not recovered. Therefore, no foraging data are available, and only locations are shown.

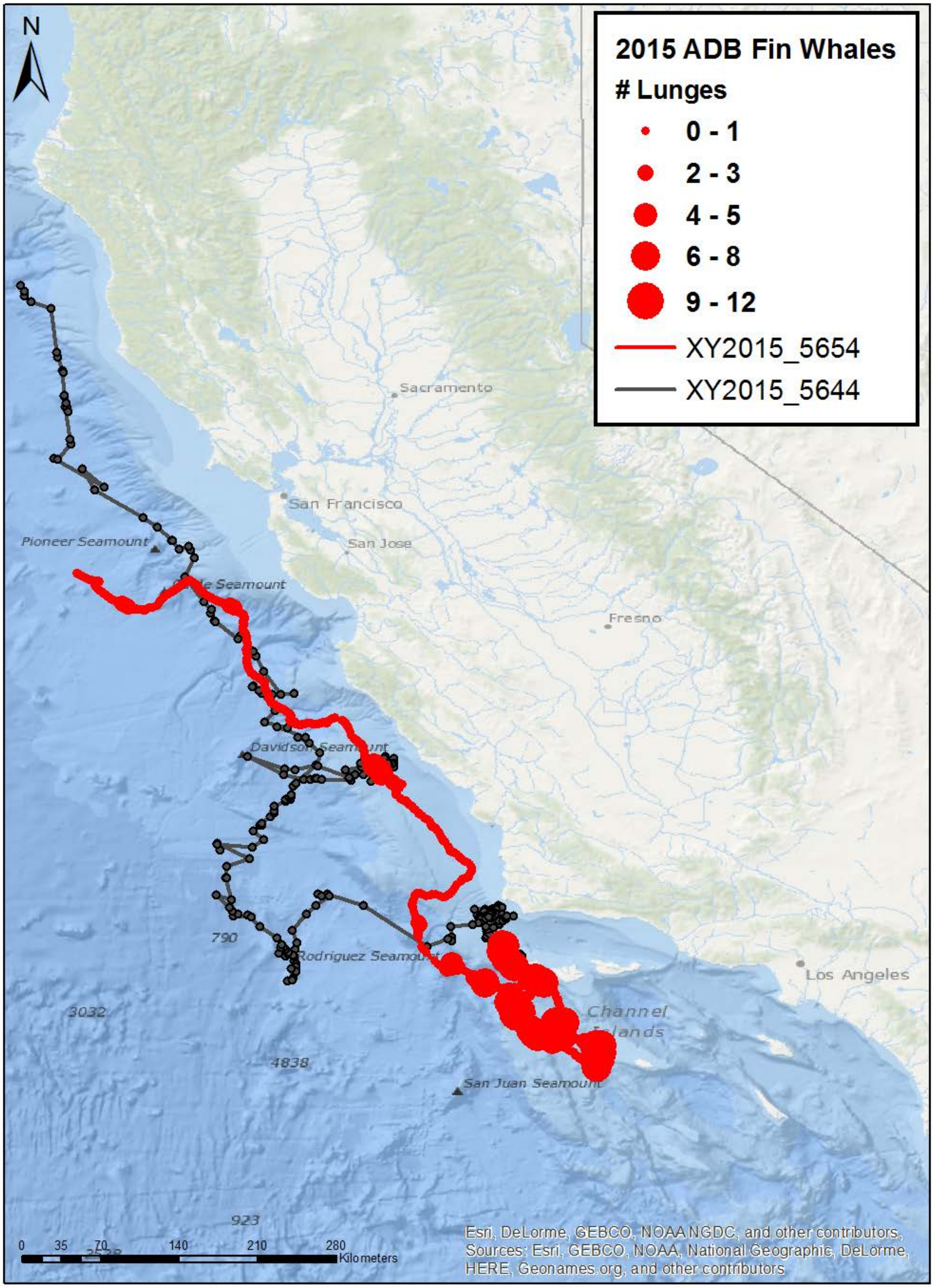

Figure 51. Tracks of two ADB-tagged fin whales off southern California in August 2014. Size of the circles represents the number of feeding lunges that occurred during a dive at that location. Tag #2015_5644 was not recovered. No foraging data are available, and only locations are shown.

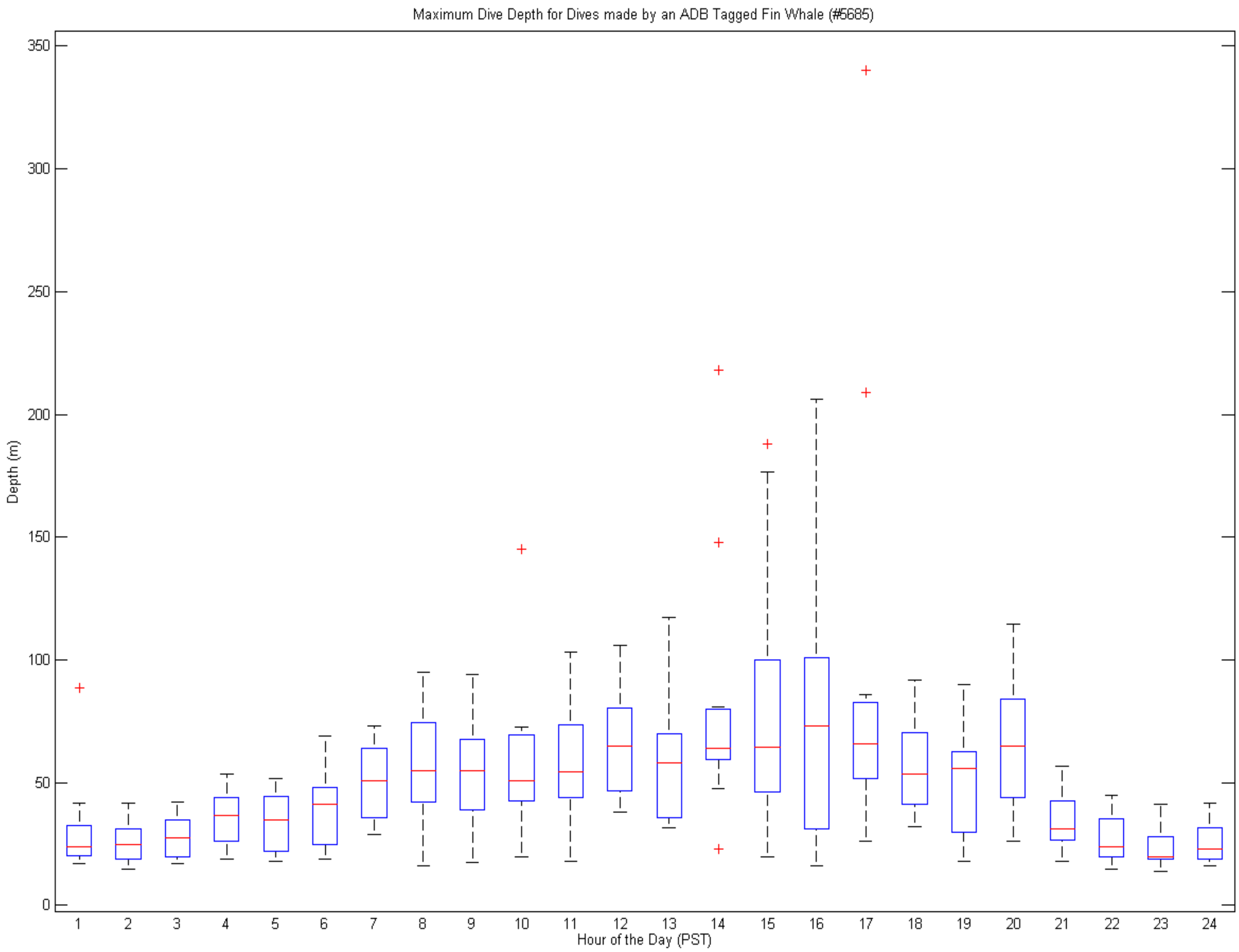

Figure 52. The distribution of maximum dive depths for dives made by ADB-tagged fin whale Tag #2015_5685 tagged off southern California during each hour of the day.

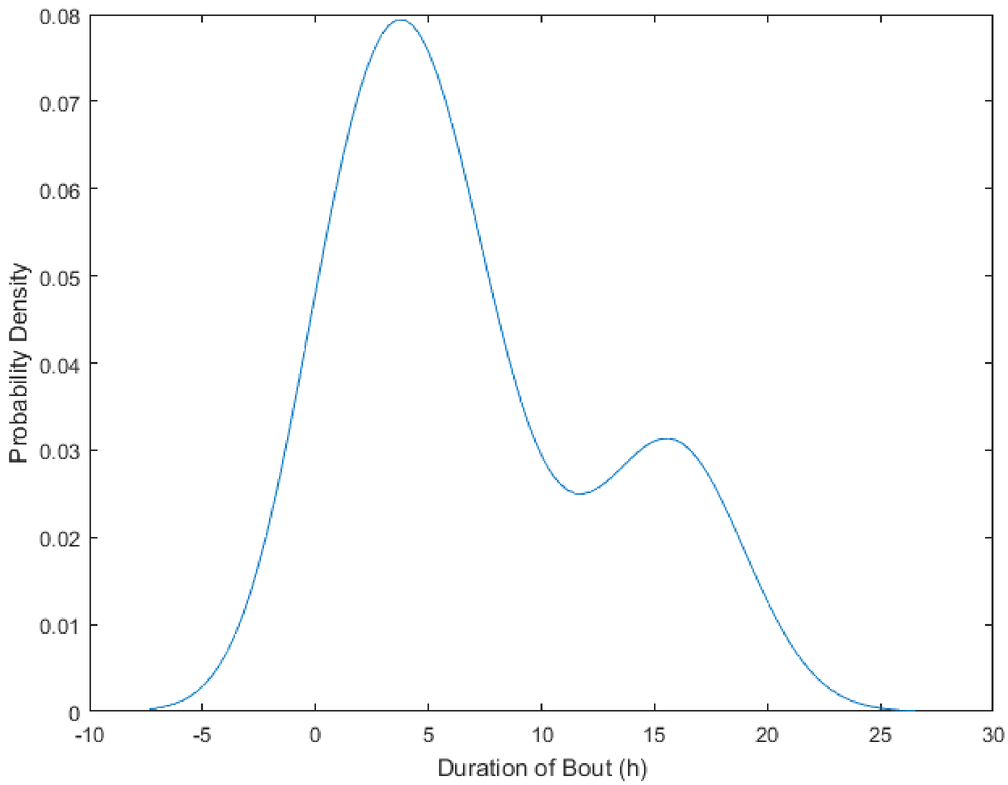

Figure 53. Kernel density plot of foraging bout duration for ADB-tagged fin whales in 2014–15.

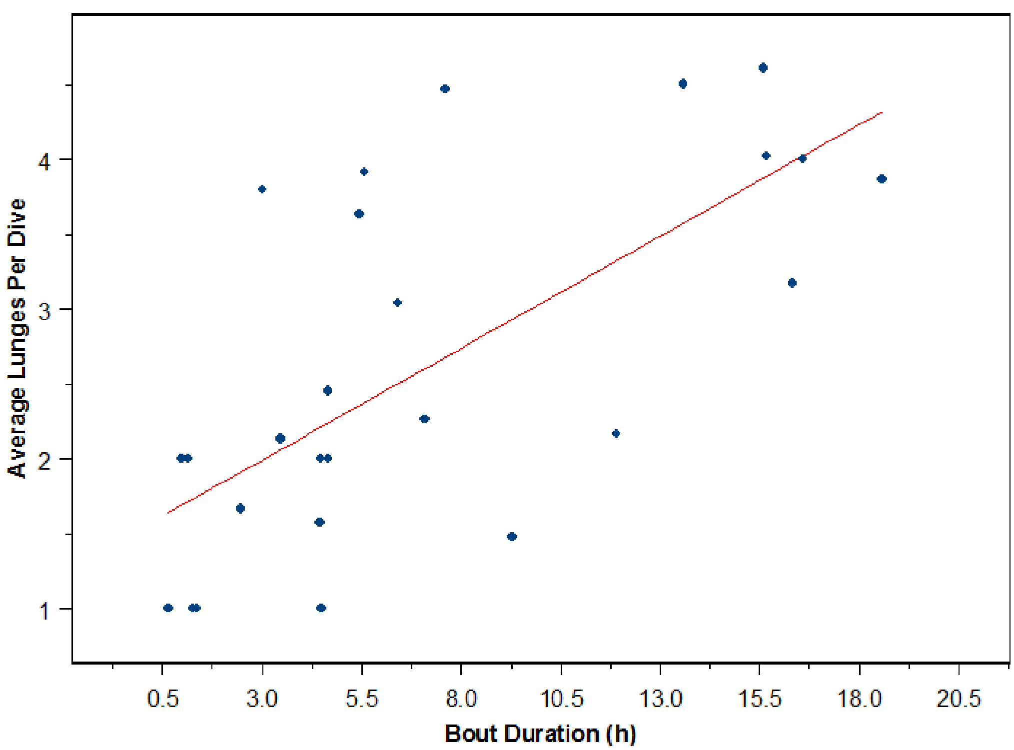

Figure 54. A plot comparing the average number of feeding lunges made per dive within a foraging bout to the duration of that bout. Red line is a linear fit through the data. Data are from fin whales tracked with ADB tags off southern California during the summer of 2014 and 2015.

3.2.4 Behavioral Responses to Tagging

Two of six tagged fin whales in 2014 and three of 11 tagged fin whales in 2015 responded to the tagging/biopsy process (**Table 34**). The short-term startle responses consisted of rolling on the side or small fluke kicks. The blue/fin hybrid whale did not respond to the tagging process.

Table 34. Behavioral responses of fin whales and a blue/fin hybrid whale to satellite tagging, southern California, 2014 and 2015.

Fin whales – 2014	
Number of whales	**Response to Tagging/Biopsy Darting**
4	No response
2	Rolled toward boat
Fin whales – 2015	
Number of whales	**Response to Tagging/Biopsy Darting**
8	No response
2	Small fluke kick
1	Slow roll
	Responses to Biopsy Darting Alone
1	No response
Blue/Fin Hybrid – 2015	
Number of whales	**Response to Tagging/Biopsy Darting**
1	No response

3.2.5 Wound Healing

Only one fin whale tagged in 2014 was seen again after tagging, showing moderate swelling at the tag site one day after tagging. This swelling was reduced 4 d after tagging and only slightly visible 6 d after tagging (**Table 35**).

Table 35. Resightings and tag site descriptions for fin whales and the blue/fin hybrid satellite-tagged off southern California, 2015. Wound size estimates are approximate.

Tag #	**Tag Type**	**Days After Tagging**				
		1	**2**	**3**	**4**	**6**
Fin Whale – 2014						
10831	SPOT5	Swelling, 35 × 20 cm, 4 cm high	Swelling, 35 × 20 cm, 4 cm high	Swelling, 25 × 15 cm, 3 cm high	Swelling, 15 × 15 cm, 2 cm high	Swelling, 15 × 10 cm, 1 cm high
Fin Whale – 2015						
5742	SPOT5	Swelling, 10 × 10 cm, 3 cm high				
5800	SPOT5	no change				
5743	SPOT5		Swelling, 10 × 10 cm, 2 cm high			
Blue/Fin Hybrid – 2015						
10831	SPOT5				tag site not seen	

KEY: cm = centimeter(s); SPOT5 = Smart Positioning or Temperature Transmitting Tag, Version 5; # = number.

Three fin whales tagged in 2015 where seen 1 to 2 d after tagging with two having slight swelling (**Table 35**). The blue/fin whale hybrid was resighted 4 d after tagging, but the tag site was not visible at this sighting. No fin whales tagged in 2014 were resighted in 2015.

3.2.6 Photo-ID

A total of 2,265 photos of fin whales was taken during the 2014 cruise, of which 37 unique individuals were determined to have been encountered. Photo-IDs were obtained of all six tagged fin whales, with both left- and right-side photographs of five of these and one with a right-side photo only.

A total of 2,929 photos of fin whales was taken during the 2015 cruise resulting in IDs for 34 unique individuals. No fin whales photographically identified from 2014 were resighted in 2015. Photo-IDs were obtained of 10 of the 11 tagged fin whales, with both left- and right-side photographs of seven of these, one with a left-side photo only, and two with right-side photos only. Photos were obtained for the 11th tagged whale, but they were of too poor quality to be usable for ID purposes.

A total of 70 photos was taken of the tagged blue/fin whale hybrid. ID photos were taken of both its left (**Figure 55**) and right side.

Figure 55. Identification photo of the left side of a tagged blue/fin hybrid whale (Tag #2015-10831), showing dark coloration and tall dorsal fin with low forward margin angle, characteristic of a fin whale. The irregular shape of the dorsal fin may be the result of an injury. The whale had a U-shaped rostrum (not shown in this figure) characteristic of a blue whale. There was no white lower right lip characteristic of a fin whale.

3.2.7 Ecological Relationships

The SSMs generated regularized daily locations for 5 fin whale tags in 2014 and 10 tags in 2015, resulting in 261 and 497 estimated locations, respectively (**Table 18**). The geographic extent of these tracks covered approximately 17 degrees of longitude (133.1–116.1°W) and 22 degrees of latitude (30.1–52.6°N) (**Figure 56**). The vast majority of locations occurred in CCAL in both years (100 and 89.7 percent, respectively) and in 2015 the ALSK province was also occupied (10.3 percent of locations) (**Table 18 and Figure 56**).

The behavioral classification for each location for all tracks is shown in **Figure 56**. The number of locations classified by behavioral mode for fin whales in CCAL was 256 in 2014 and 439 in 2015 (**Table 19**). The proportion of locations classified as ARS was higher (18.8 percent) in 2014 than in 2015 (11.8 percent), while the proportion classified as transiting was lower (19.5 percent) in 2014 than in 2015 (52.4 percent). Locations considered uncertain made up the remainder (61.7 percent in 2014 and 58.9 percent in 2015).

Details of the environmental variables obtained for the SSM locations are provided in **Table 17**. Summary statistics for these variables in CCAL are provided in **Tables 20 and 21**. On average, fin whales were found in areas with stronger positive upwelling velocities (WEKM = 1.0e-06 m s^{-1}) in 2014 and weaker upwelling velocities by an order of magnitude in 2015 (6.1e-07 m s^{-1}). Average SST in the areas occupied by fin whales was warmer by approximately 1°C in 2014 (18.8°C) compared to 2015 (17.6°C). Average CHL concentrations in these areas were intermediate and similar in both years (0.56 and 0.64 mg m^{-3}, respectively). The values at each location for these environmental variables are shown in **Figures 57 through 59**.

In 2014 fin whales occurred in shallower waters that were also closer to the shelf break and to the shore (mean DEPTH = -1696.44 m, DISTSHELF = 45.14 km, DISTSHORE = 62.45 km) than in 2015 (mean DEPTH = -2145.73 m, DISTSHELF = 62.11 km, DISTSHORE = 90.3 km). Nevertheless, SLOPE (50.14 and 42.85 m km^{-1}, respectively for 2014 and 2015) and ASPECT (212.11 and 223.74°, respectively for 2014 and 2015) values appeared to be similar in both years (**Table 21**). The values at each location for these seafloor relief variables are shown in **Figures 60 through 63**.

The SSMs generated 28 regularized daily locations for the blue/fin hybrid whale tagged in 2015 (**Table 18**). The geographic extent of this track covered about 2 degrees of longitude (122.7–120.6°W) and 2 degrees of latitude (34.1–36.2°N) (**Figure 64**). All locations (100 percent) occurred within CCAL. Of these, 27 locations received a behavioral classification, with 7.4 percent being considered as ARS, 7.4 percent as transiting, and 85.2 percent as uncertain (**Table 19 and Figure 64**).

In comparison to the fin whales tracked in 2015, the blue/fin hybrid whale occupied areas within CCAL that on average had stronger upwelling velocities (WEKM = 4.9e-06 m s^{-1}), slightly warmer SSTs (18.12°C), and similar CHL levels (0.69 mg m^{-3}) (**Table 20**). The 26 SSM locations for which seafloor relief variables were obtained indicated that, compared to the fin whales tracked in 2015, the blue/fin hybrid whale occurred in waters that were shallower and markedly closer to the shelf break and to shore (mean DEPTH = -1286.77 m, DISTSHELF = 29.82 km, DISTSHORE = 49.09 km). In addition, they had a similar SLOPE (42.58 m km^{-1}) and a slightly higher ASPECT (227.99°) (**Table 21**). The values at each location for these variables are shown in **Figures 65 through 71**.

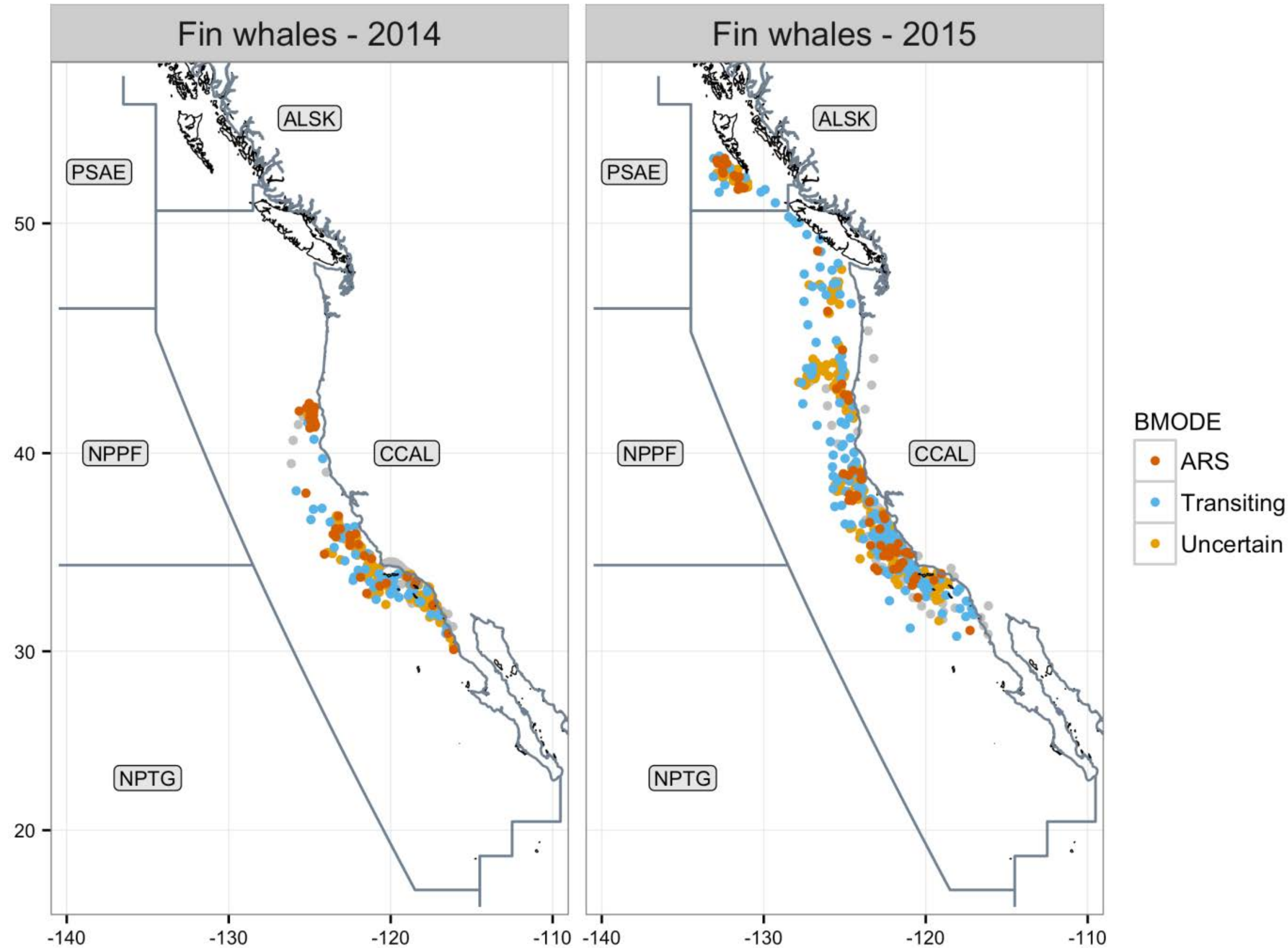

Figure 56. Accepted SSM locations for fin whales colored by behavioral mode. Locations excluded from the analyses are in gray. Five of the Longhurst biogeographic provinces in the region occupied by tagged fin whales are outlined. The left and right panels represent fin whales tagged in 2014 and 2015, respectively.

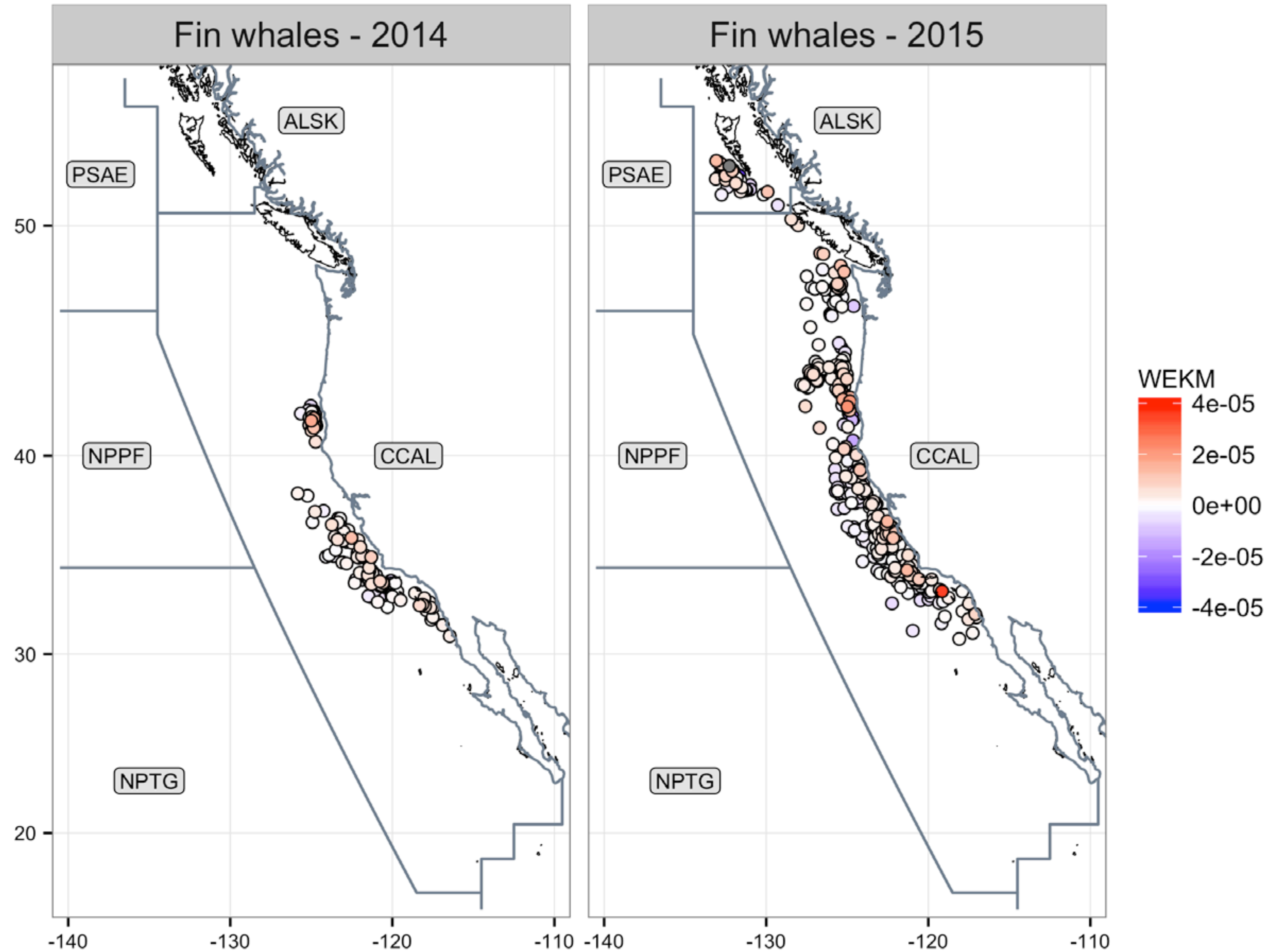

Figure 57. Map representation of vertical upwelling velocity (WEKM, m s^{-1}) values obtained from satellite remote sensing around each fin whale location. The Longhurst biogeographic provinces are indicated.

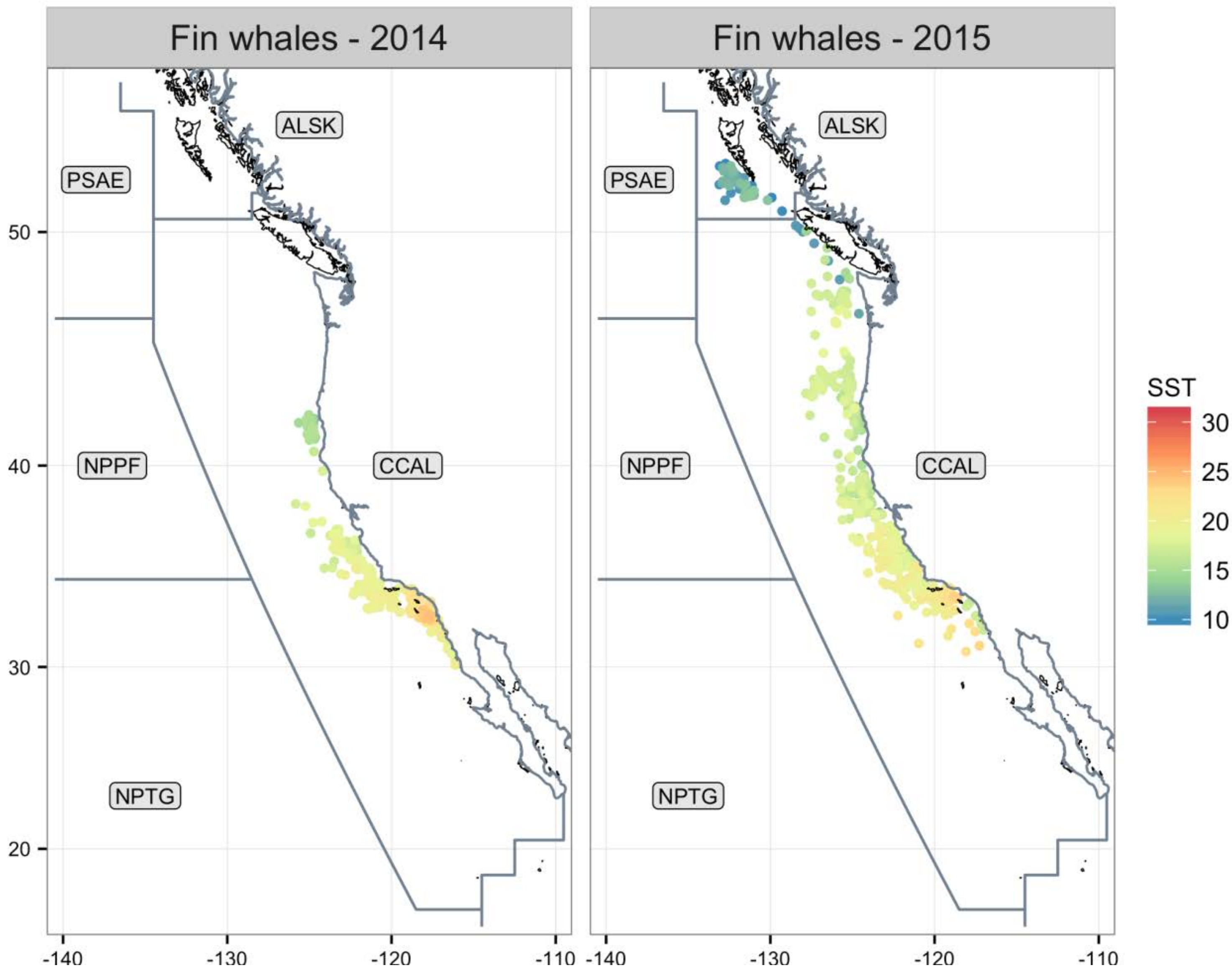

Figure 58. Map representation of sea surface temperature (SST, °C) values obtained from satellite remote sensing around each fin whale location. The Longhurst biogeographic provinces are indicated. The left and right panels represent fin whales tagged in 2014 and 2015, respectively.

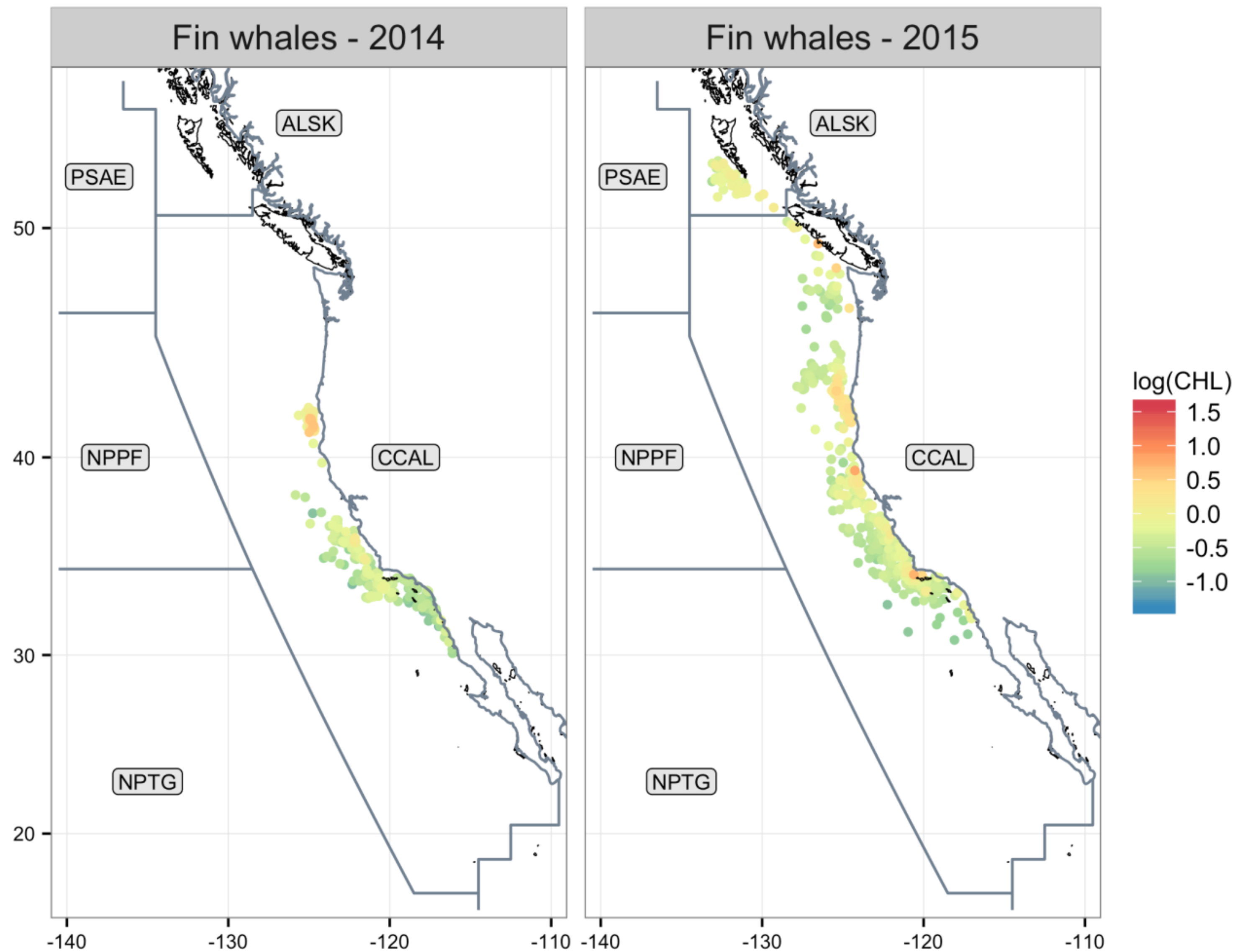

Figure 59. Map representation of chlorophyll-*a* concentration (CHL, mg m^{-3}, log-transformed) values obtained from satellite remote sensing around each fin whale location. The Longhurst biogeographic provinces are indicated. The left and right panels represent fin whales tagged in 2014 and 2015, respectively.

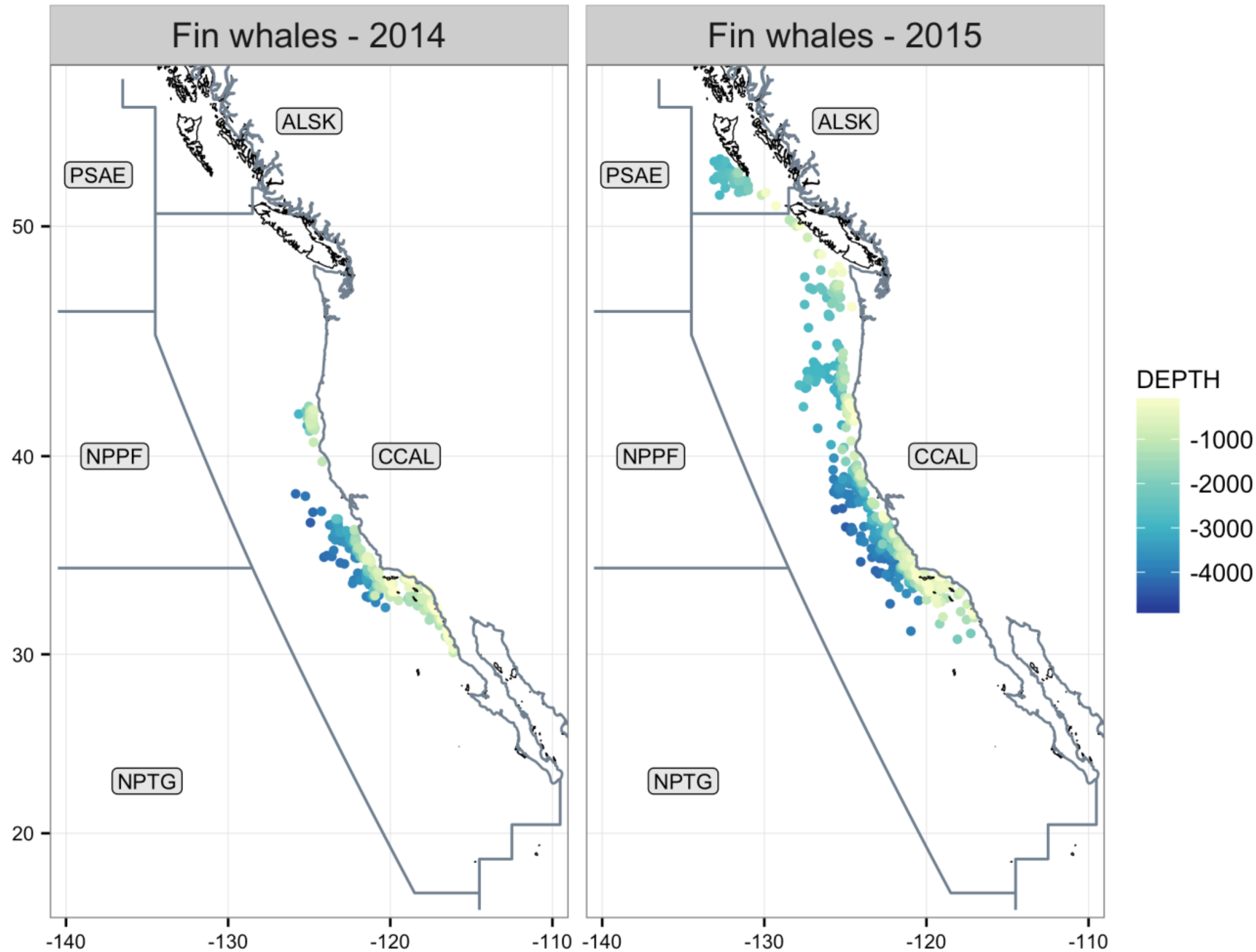

Figure 60. Map representation of seafloor depth (DEPTH, m) values obtained from ETOPO1 around each fin whale location. The Longhurst biogeographic provinces are indicated. **The left and right panels represent fin whales tagged in 2014 and 2015, respectively.**

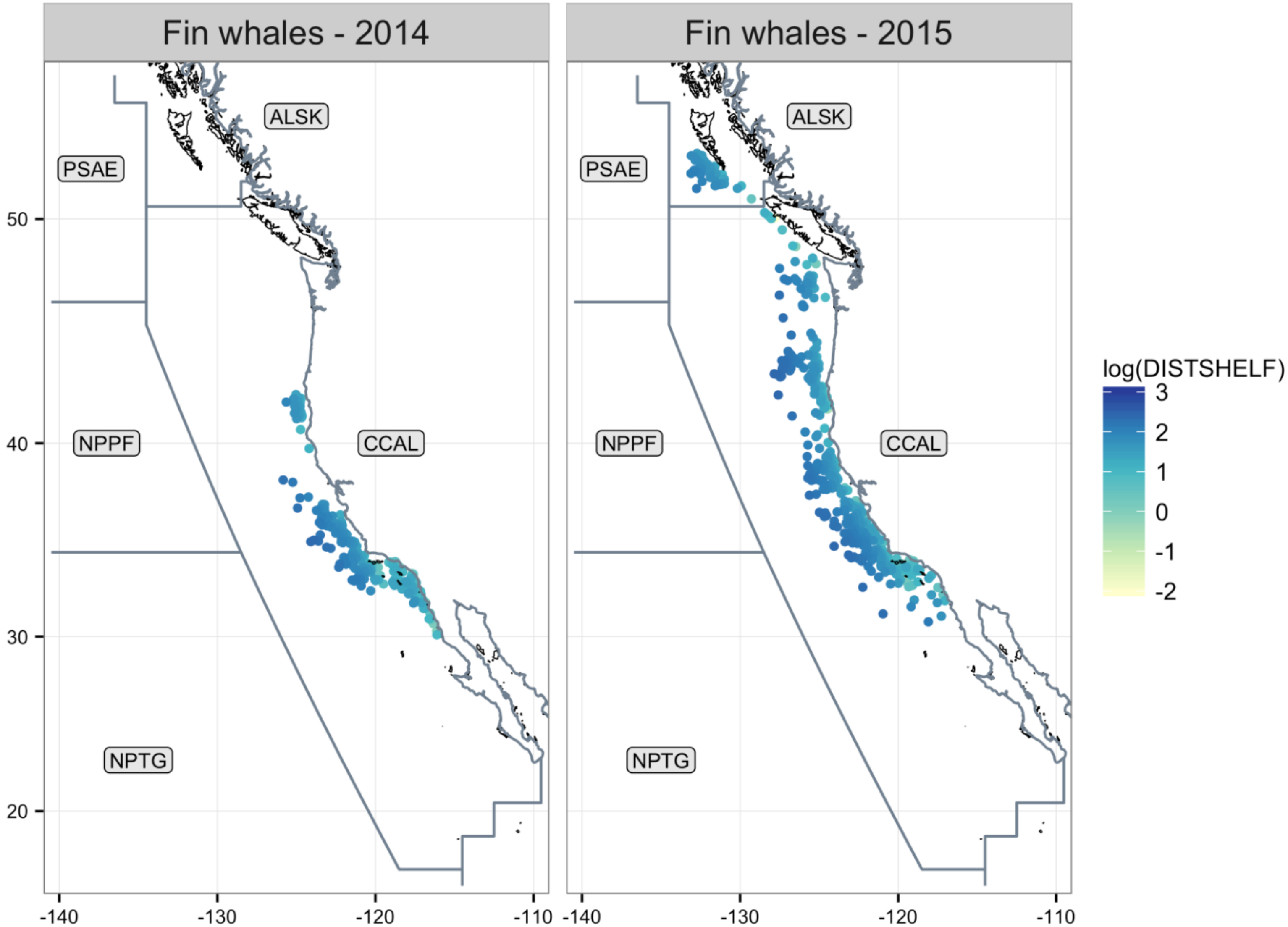

Figure 61. Map representation of distance to the 200-m isobath (DISTSHELF, km, log-transformed) values obtained from ETOPO1 around each fin whale location. The Longhurst biogeographic provinces are indicated. The left and right panels represent fin whales tagged in 2014 and 2015, respectively.

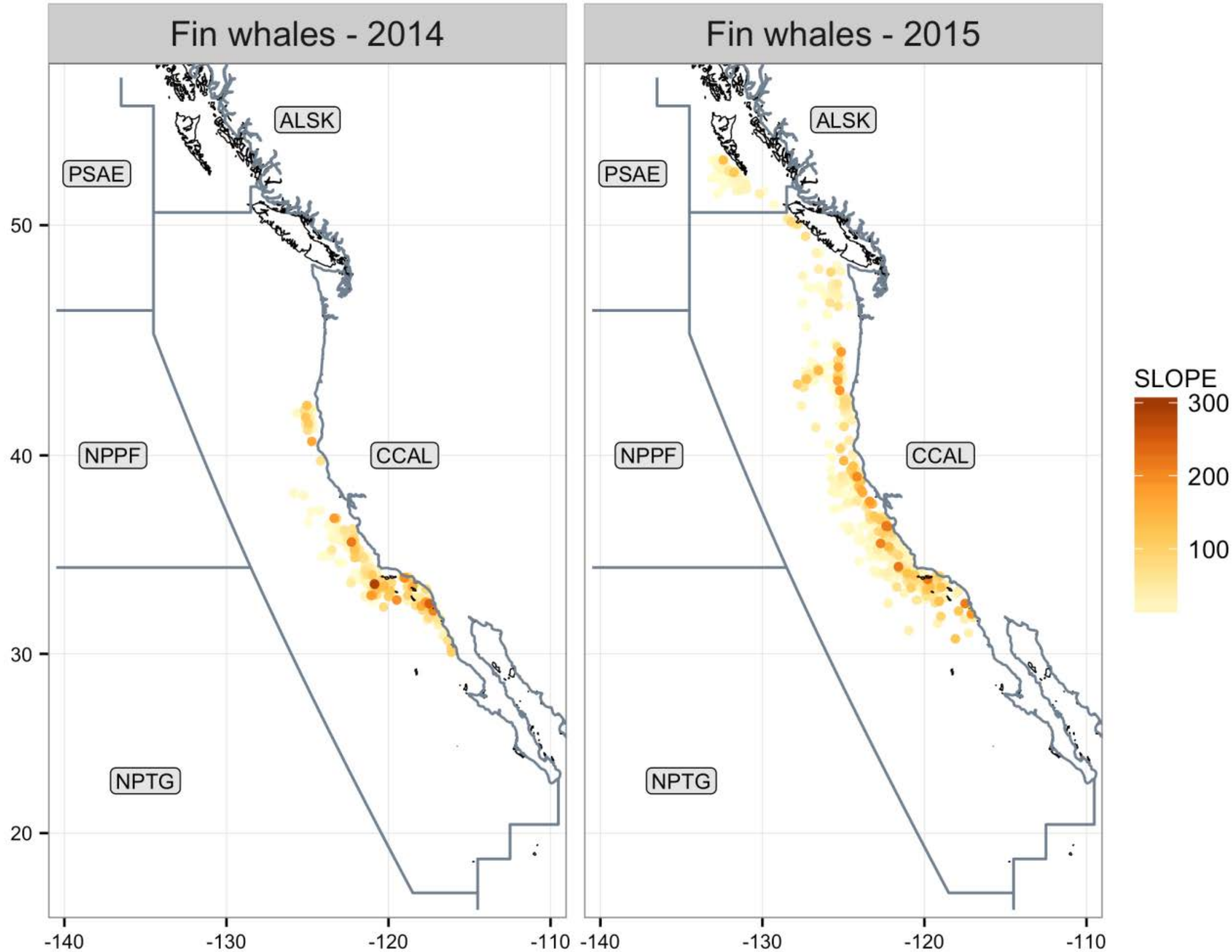

Figure 62. Map representation of seafloor slope (SLOPE, m km^{-1}) values obtained from ETOPO1 around each fin whale location. The Longhurst biogeographic provinces are indicated. The left and right panels represent fin whales tagged in 2014 and 2015, respectively.

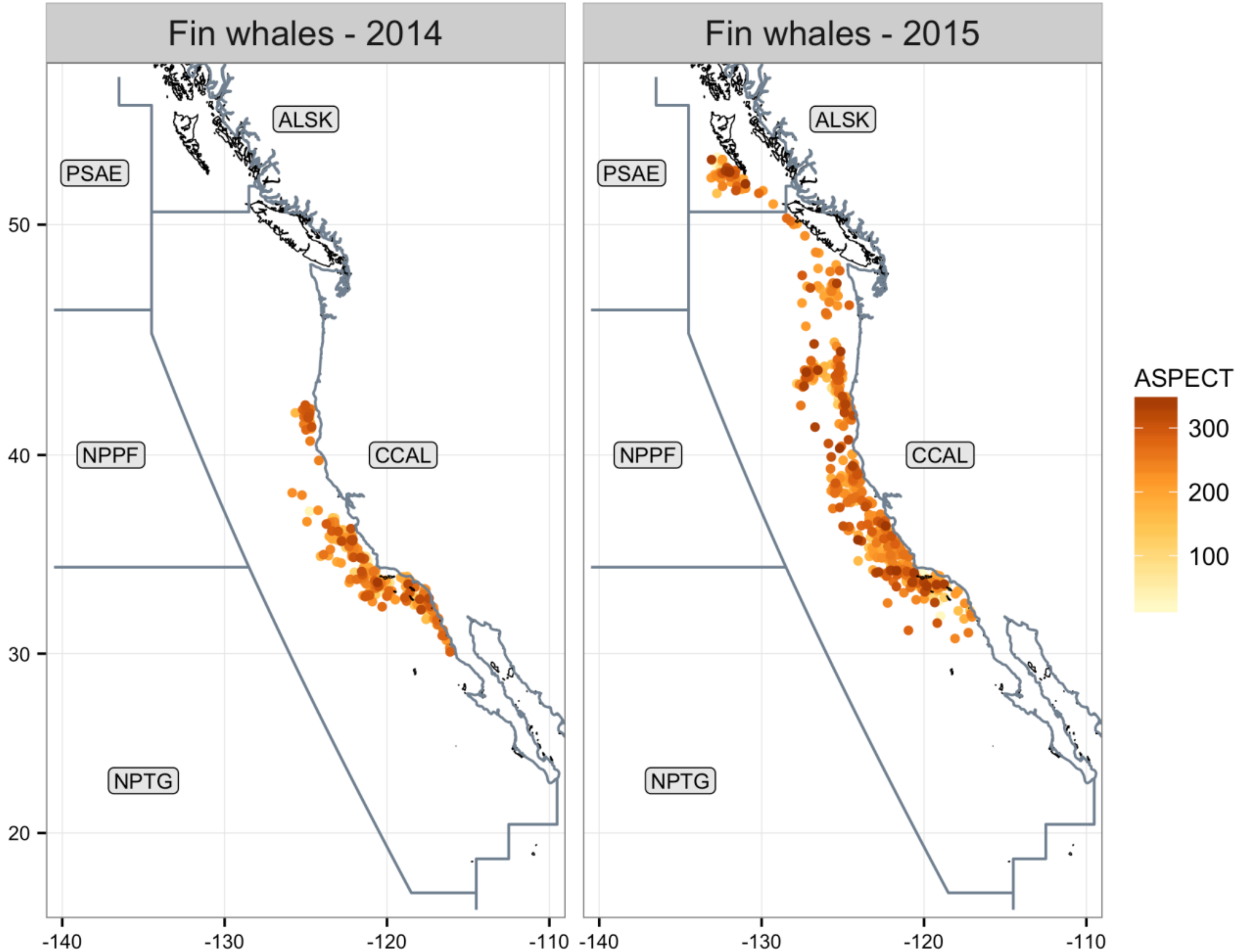

Figure 63. Map representation of seafloor slope aspect (ASPECT, degrees) values obtained from ETOPO1 around each fin whale location. The Longhurst biogeographic provinces are indicated. The left and right panels represent fin whales tagged in 2014 and 2015, respectively.

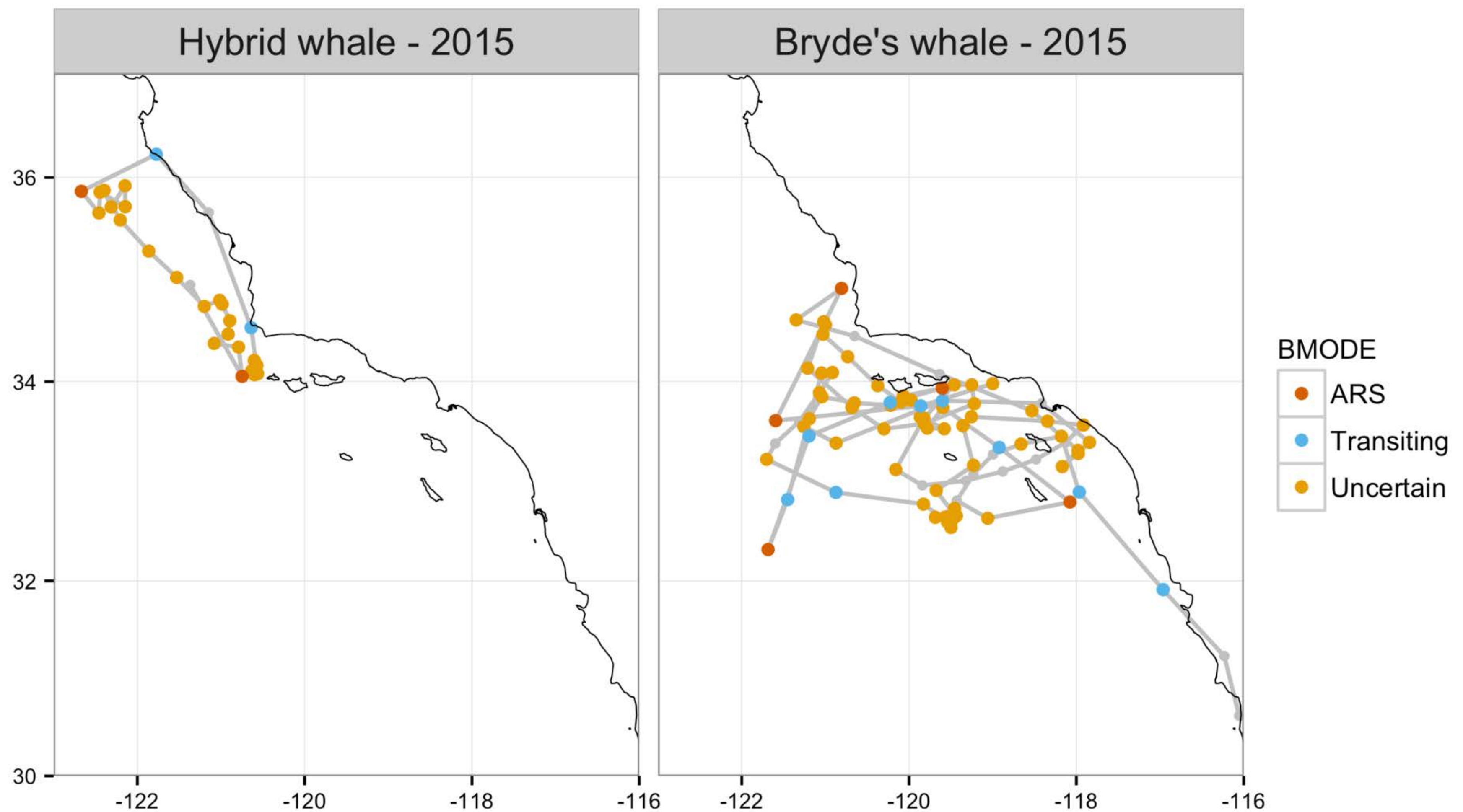

Figure 64. Accepted SSM locations colored by behavioral mode for the blue/fin hybrid whale (left panel) and for the Bryde's whale (right panel). Locations that were excluded from the analyses are in gray.

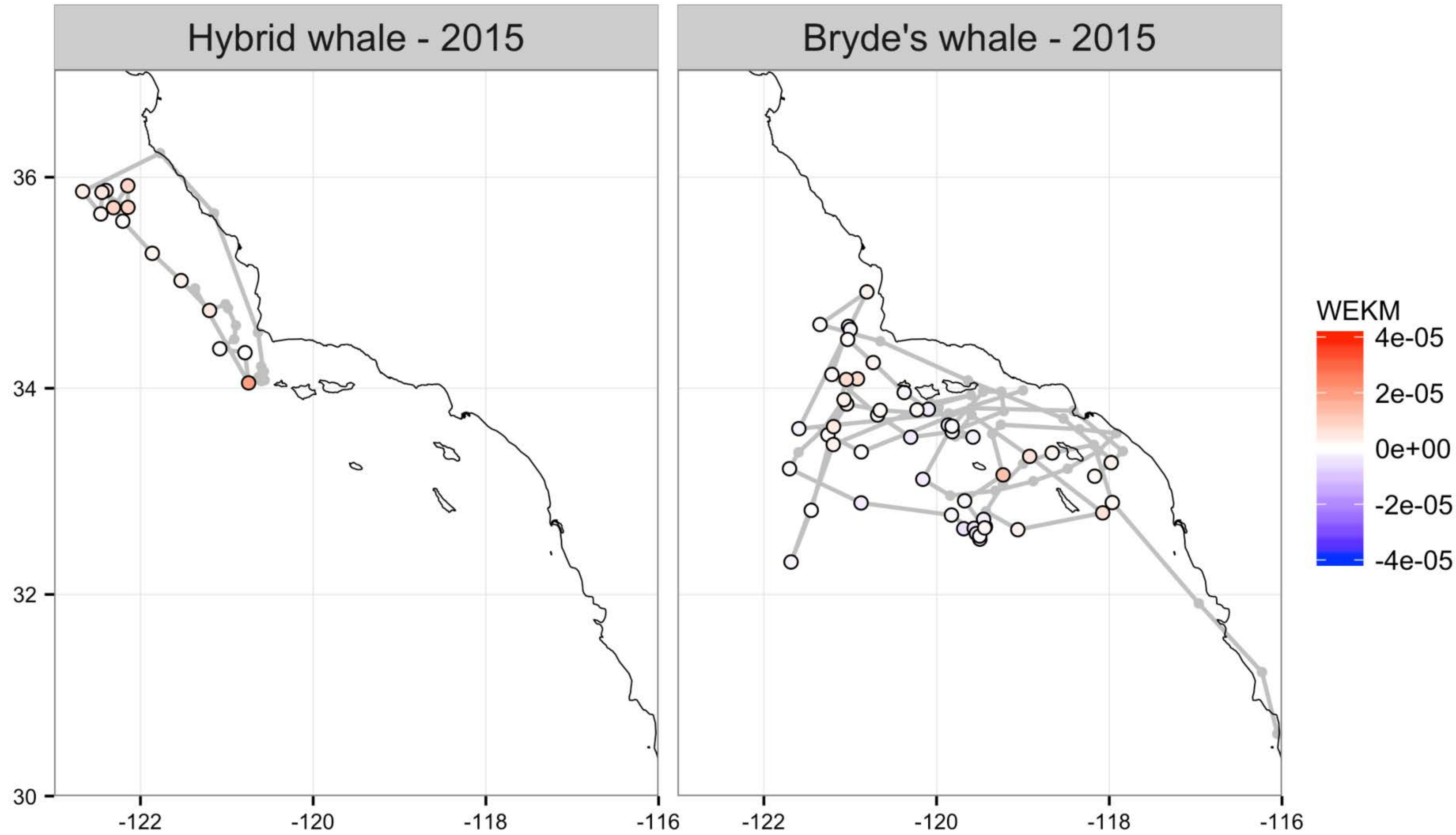

Figure 65. Map representation of vertical upwelling velocity (WEKM, m s^{-1}) values obtained from satellite remote sensing around the blue/fin hybrid whale (left panel) and the Bryde's whale (right panel) locations.

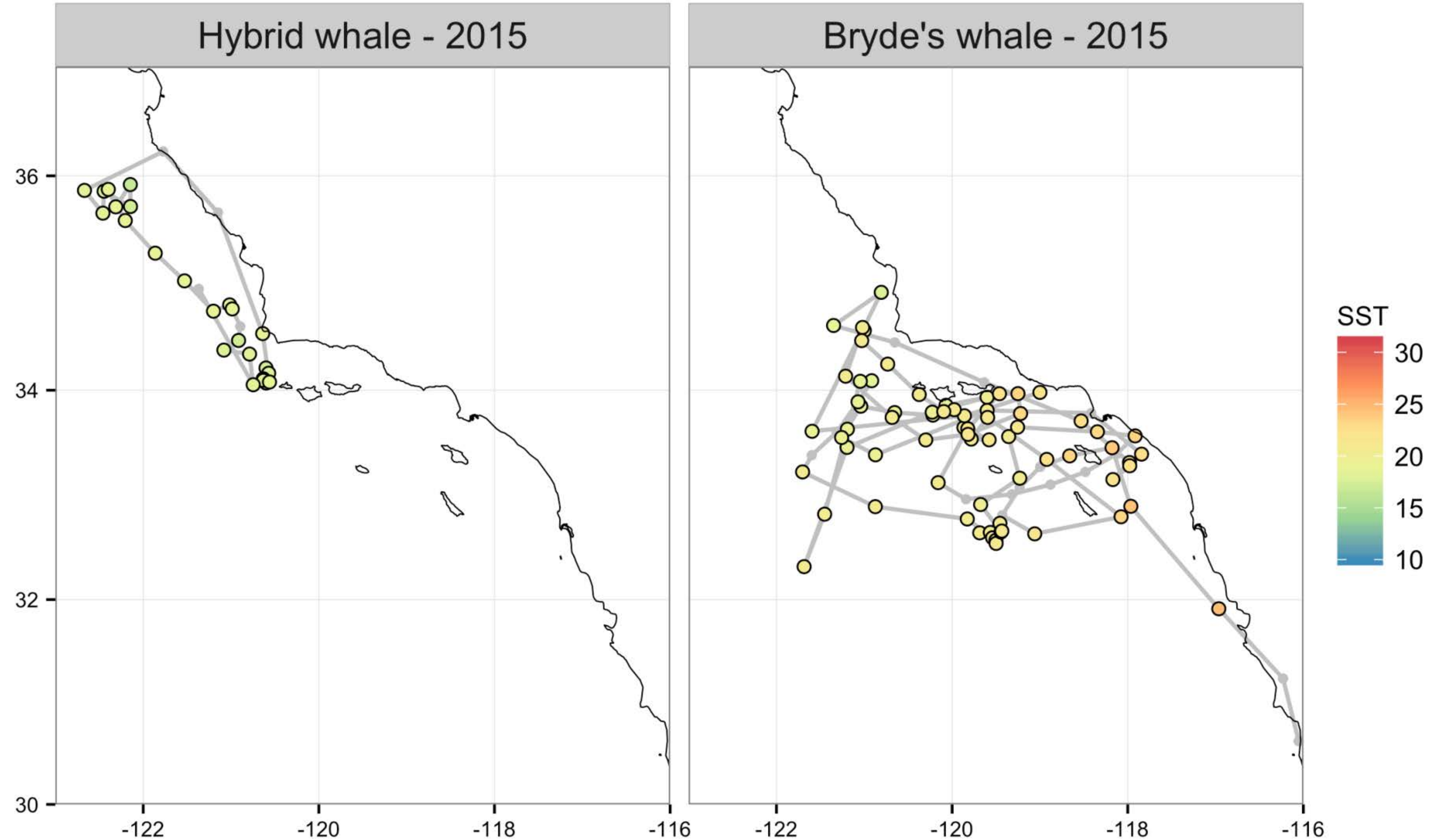

Figure 66. Map representation of sea surface temperature (SST, °C) values obtained from satellite remote sensing around the blue/fin hybrid whale (left panel) and the Bryde's whale (right panel) locations.

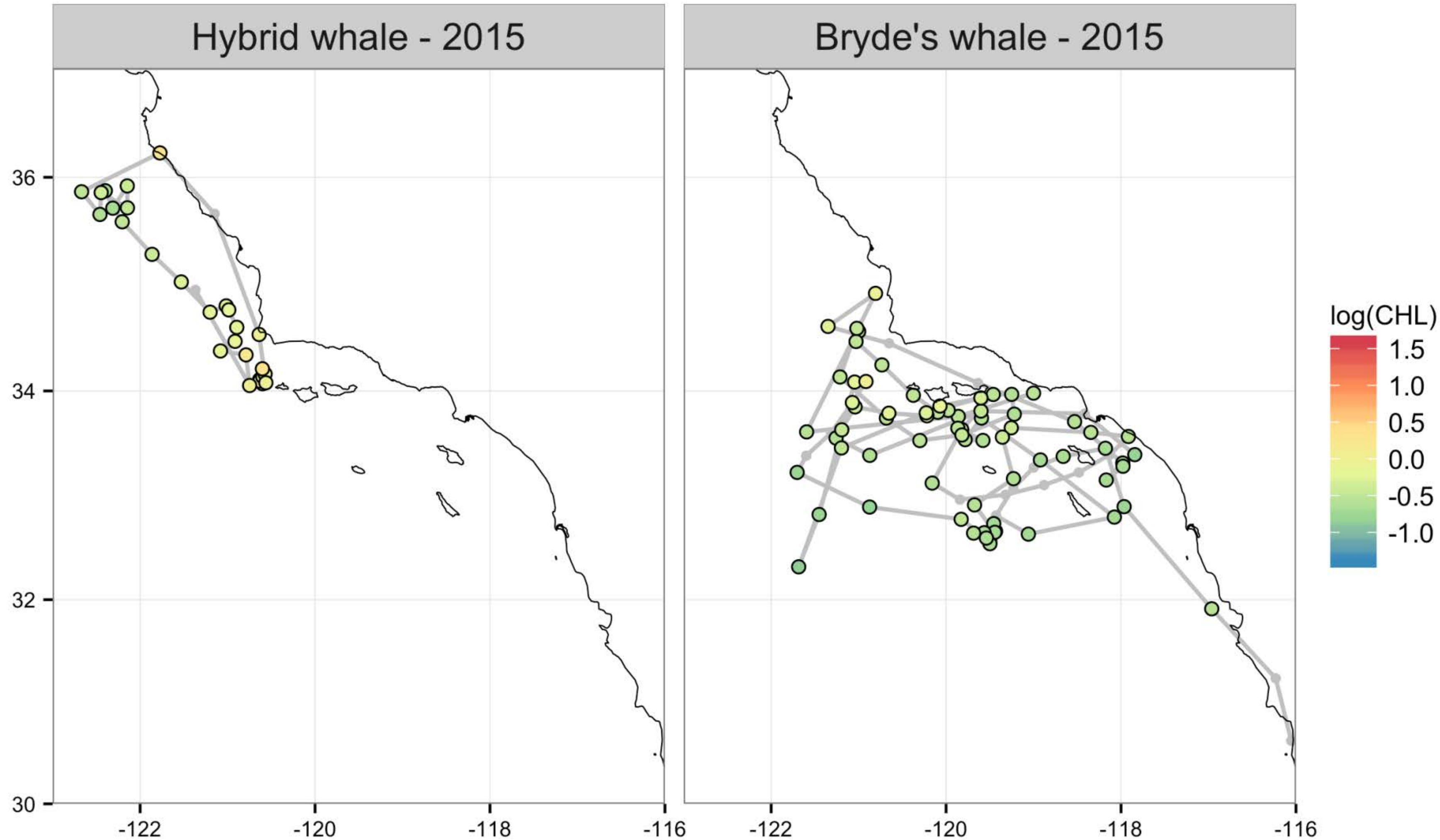

Figure 67. Map representation of chlorophyll-*a* concentration (CHL, mg m^{-3}, log-transformed) values obtained from satellite remote sensing around the blue/fin hybrid whale (left panel) and the Bryde's whale (right panel) locations.

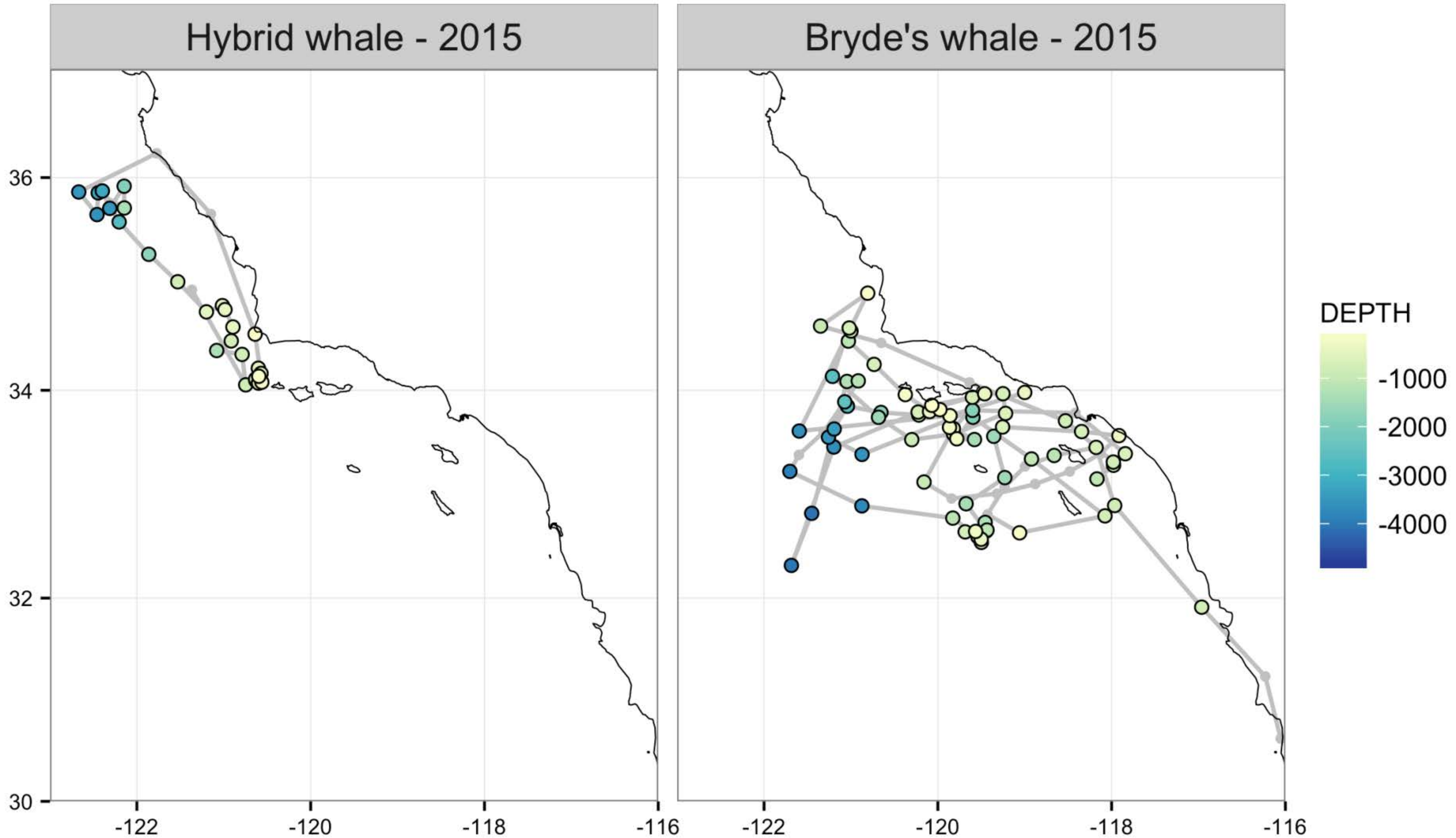

Figure 68. Map representation of seafloor depth (DEPTH, m) values obtained from ETOPO1 around the blue/fin hybrid whale (left panel) and the Bryde's whale (right panel) locations.

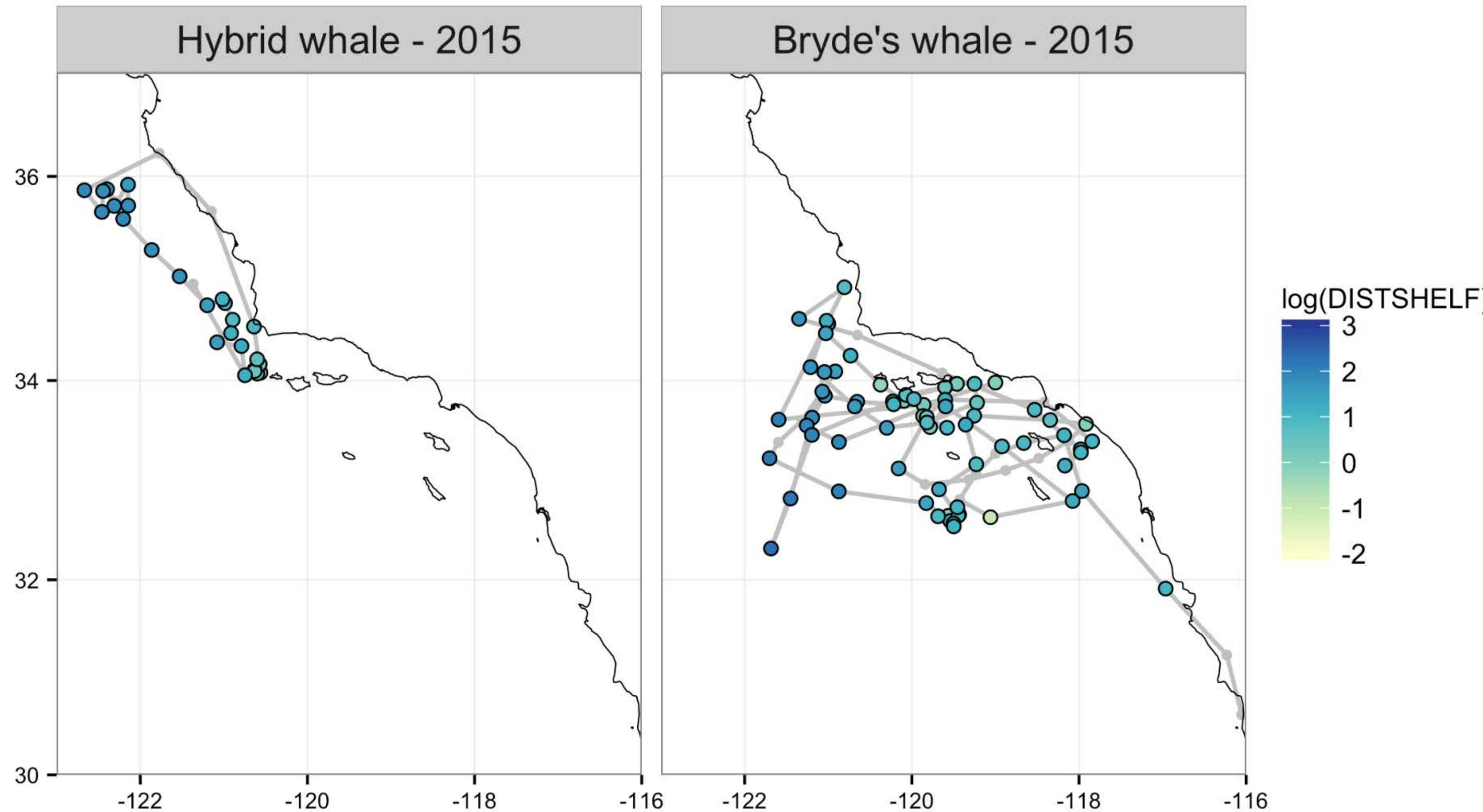

Figure 69. Map representation of distance to the 200-m isobath (DISTSHELF, km, log-transformed) values obtained from ETOPO1 around the blue/fin hybrid whale (left panel) and the Bryde's whale (right panel) locations.

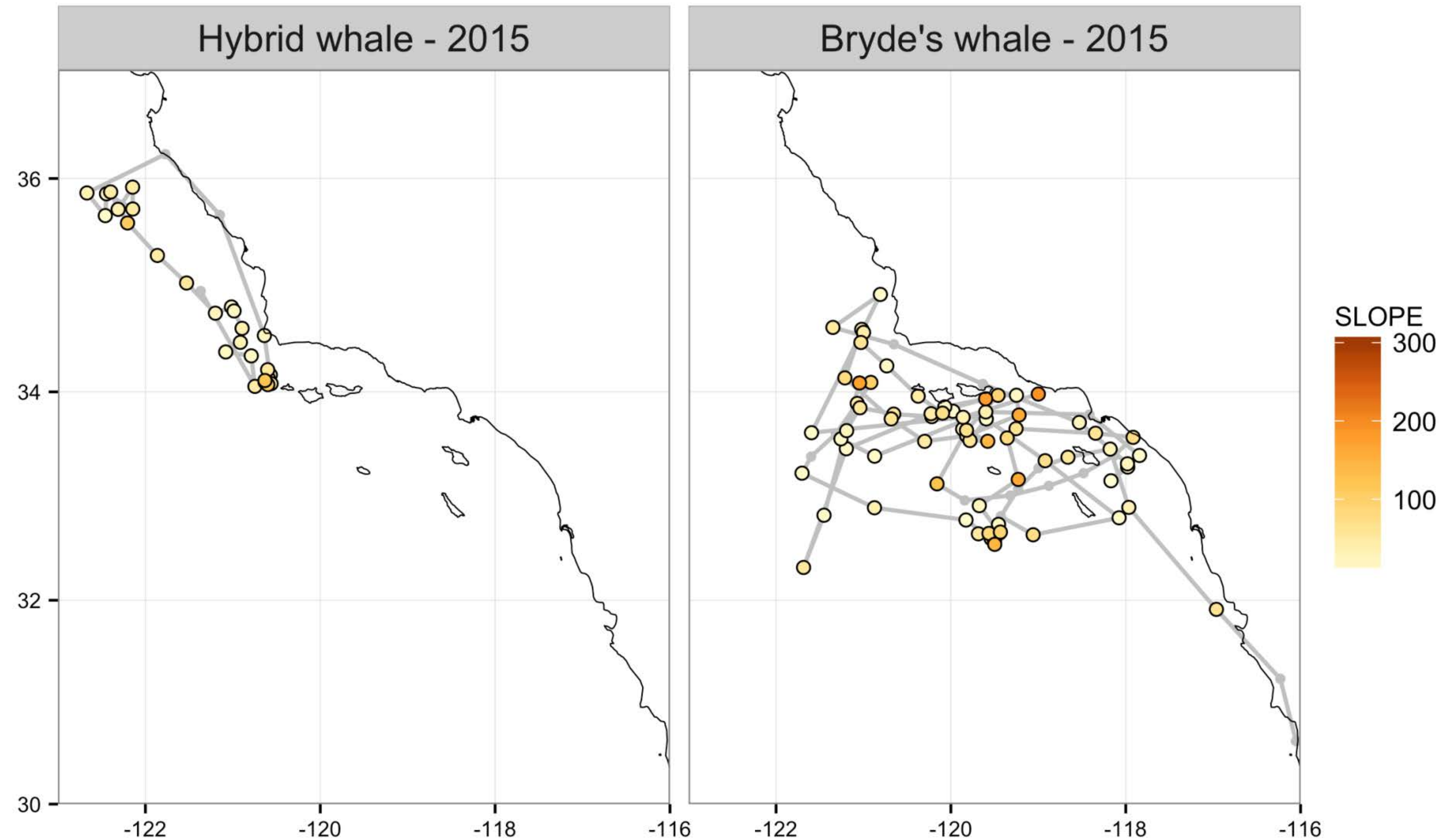

Figure 70. Map representation of seafloor slope (SLOPE, m km^{-1}) values obtained from ETOPO1 around the blue/fin hybrid whale (left panel) and the Bryde's whale (right panel) locations.

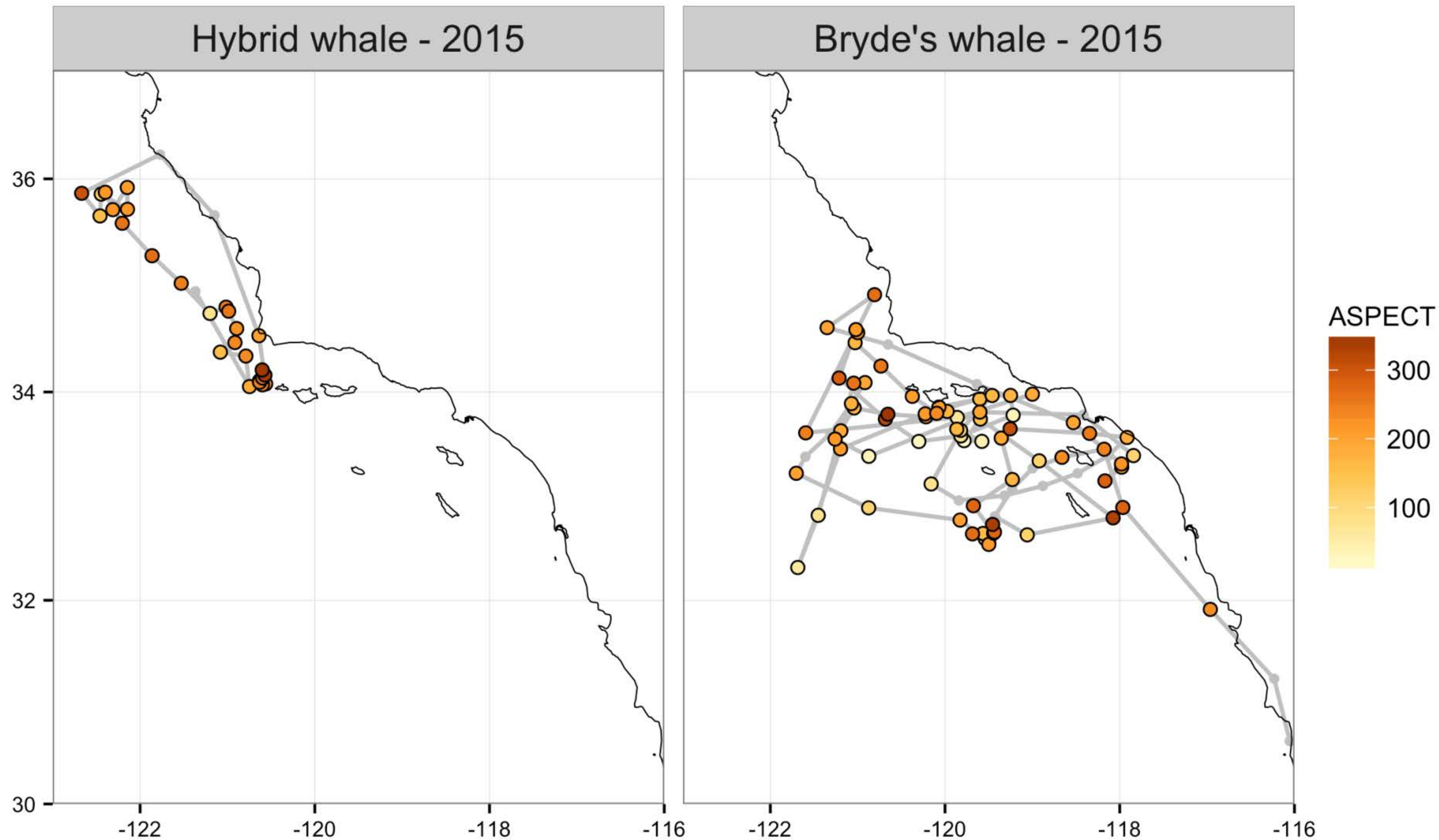

Figure 71. Map representation of seafloor slope aspect (ASPECT, degrees) values obtained from ETOPO1 around the blue/fin hybrid whale (left panel) and the Bryde's whale (right panel) locations.

3.2.8 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 (**Figure 72**). 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 (**Figure 73**). 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 (**Figure 74**; 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.

3.2.8.1 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 12 fin whales, 6 were male and 6 were female.

3.2.8.2 INDIVIDUAL IDENTIFICATION

All 12 tagged fin whales were represented by unique multi-locus genotypes and the probability of identity for the 17 loci was very low, 3.7×10^{-18} (i.e., there was a very low probability of a match by chance). Consequently, we are confident that the 12 unique multi-locus genotypes represented 12 individuals, i.e., there were no replicate samples among the fin whales tagged in 2014–15. 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 12 fin whales tagged in 2014–15.

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.

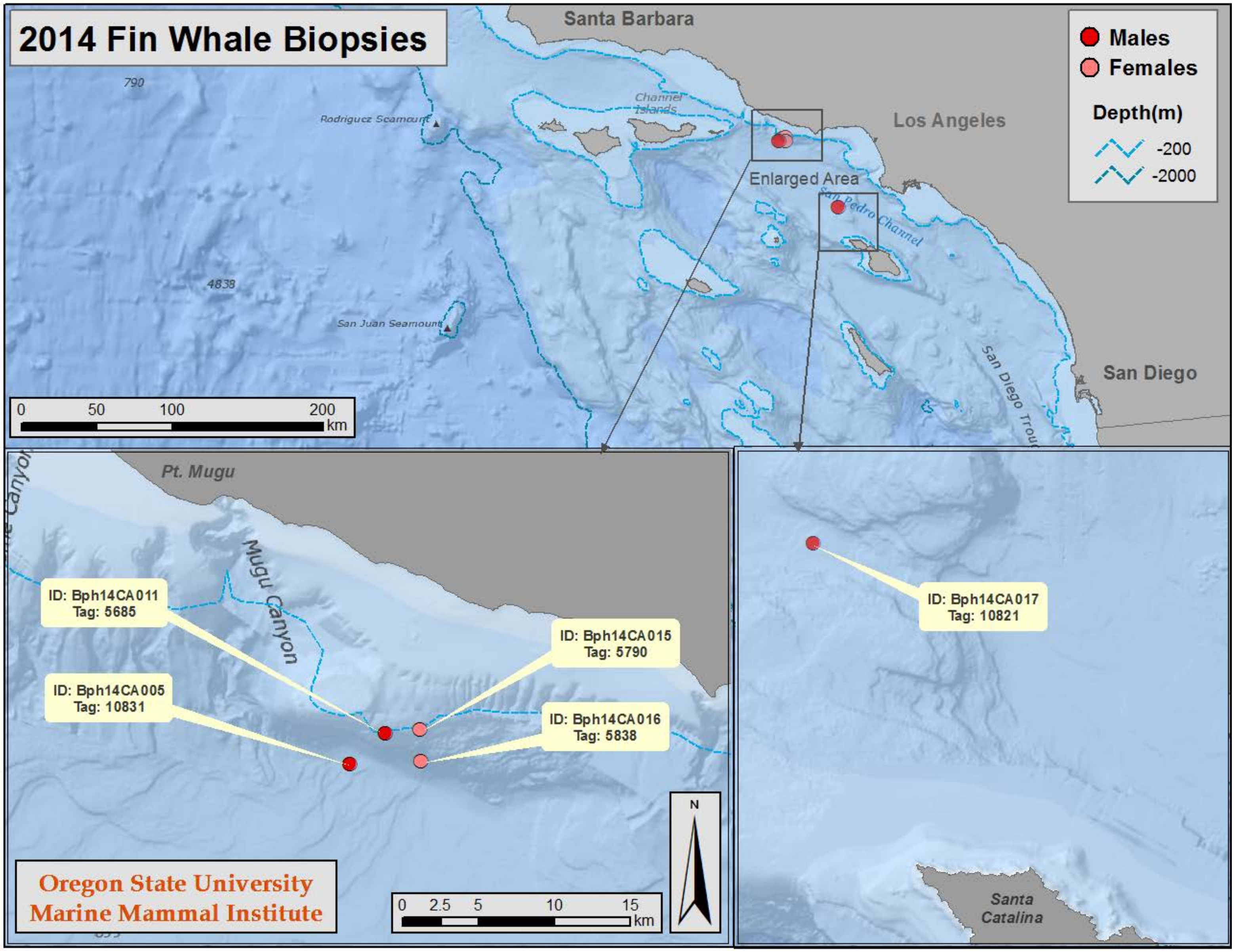

Figure 72. The location of biopsy sample collections from fin whales tagged in 2014.

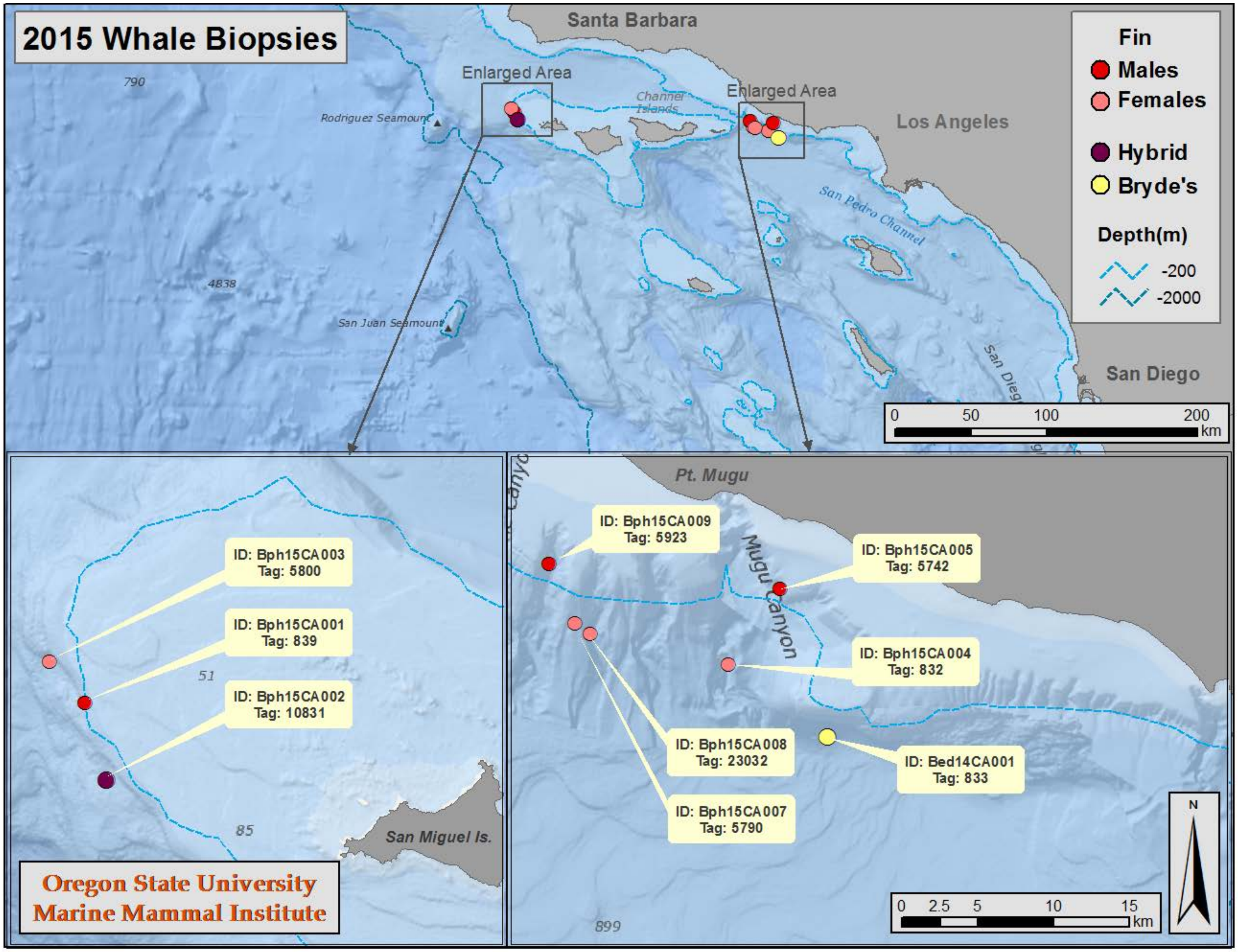

Figure 73. The location of biopsy sample collections from fin whales, a blue/fin hybrid, and a Bryde's whale tagged in 2015.

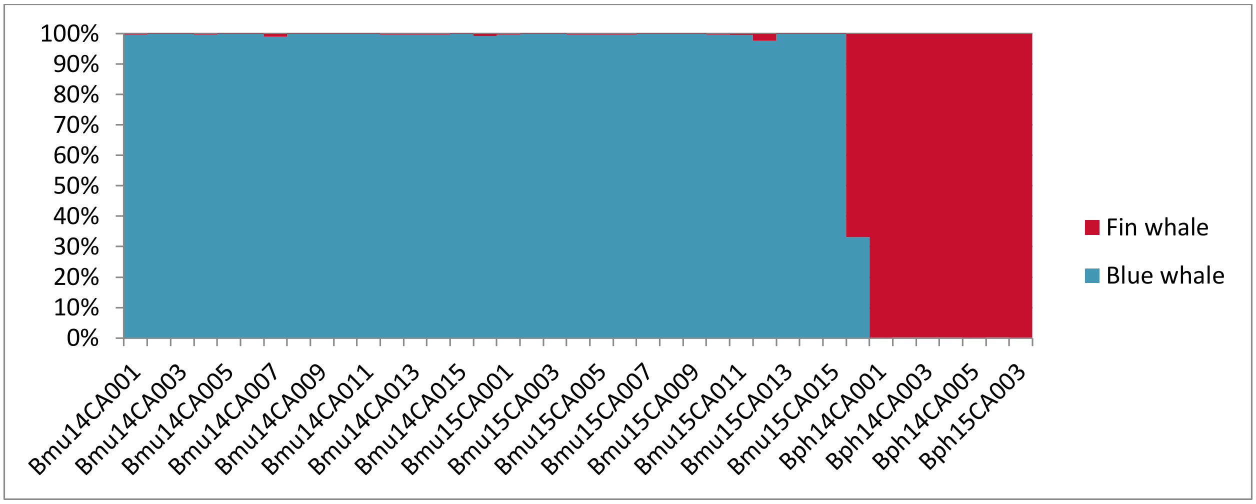

Figure 74. A plot of the species ancestry of the blue/fin hybrid based on the Bayesian clustering program Structure. Each vertical bar represents the assigned ancestry of an individual whale based on microsatellite genotypes. The reference samples show pure ancestry of either blue whale (color blue) or fin whale (color red) with the hybrid showing ancestry of both species.

3.2.8.3 STOCK IDENTIFICATION

In collaboration with the Southwest Fisheries Science Center, we compared the mtDNA haplotype frequencies of the 12 tagged fin whales to a reference dataset of 397 samples as described by Archer et al. (2013). The 397 samples represented 52 mtDNA haplotypes based on variation in the first 412 bp of the control region. For this consensus sequence, the 12 tagging samples represented 6 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 tagged fin whales to those of seven *a priori* population strata (**Figure 75**). Despite the small sample sizes for some comparisons, the haplotype frequencies of the tagged fin whales 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 36**). Further analyses indicated no heterogeneity in the haplotype frequencies for the tagged whales in the two sampling years ($p = 0.1448$) and no differences by sex ($p = 0.999$).

Table 36. Pairwise tests of differentiation (F_{ST}) for mtDNA haplotype frequencies from the tagged fin whales and seven population strata in the North Pacific (Archer et al. 2012).

Stratum 1	n 1	Stratum 2	n 2	F_{ST}	p
Southern California Bight	143	SoCal tagging	12	0.013	0.213
Gulf of California	33	SoCal tagging	12	**0.354**	**0.001**
California/Oregon/Washington	57	SoCal tagging	12	**0.056**	**0.005**
Central Pacific	14	SoCal tagging	12	0.044	0.078
Gulf of Alaska	124	SoCal tagging	12	**0.062**	**0.002**
Hawaii	4	SoCal tagging	12	0.083	0.145
Bering Sea	22	SoCal tagging	12	**0.071**	**0.002**

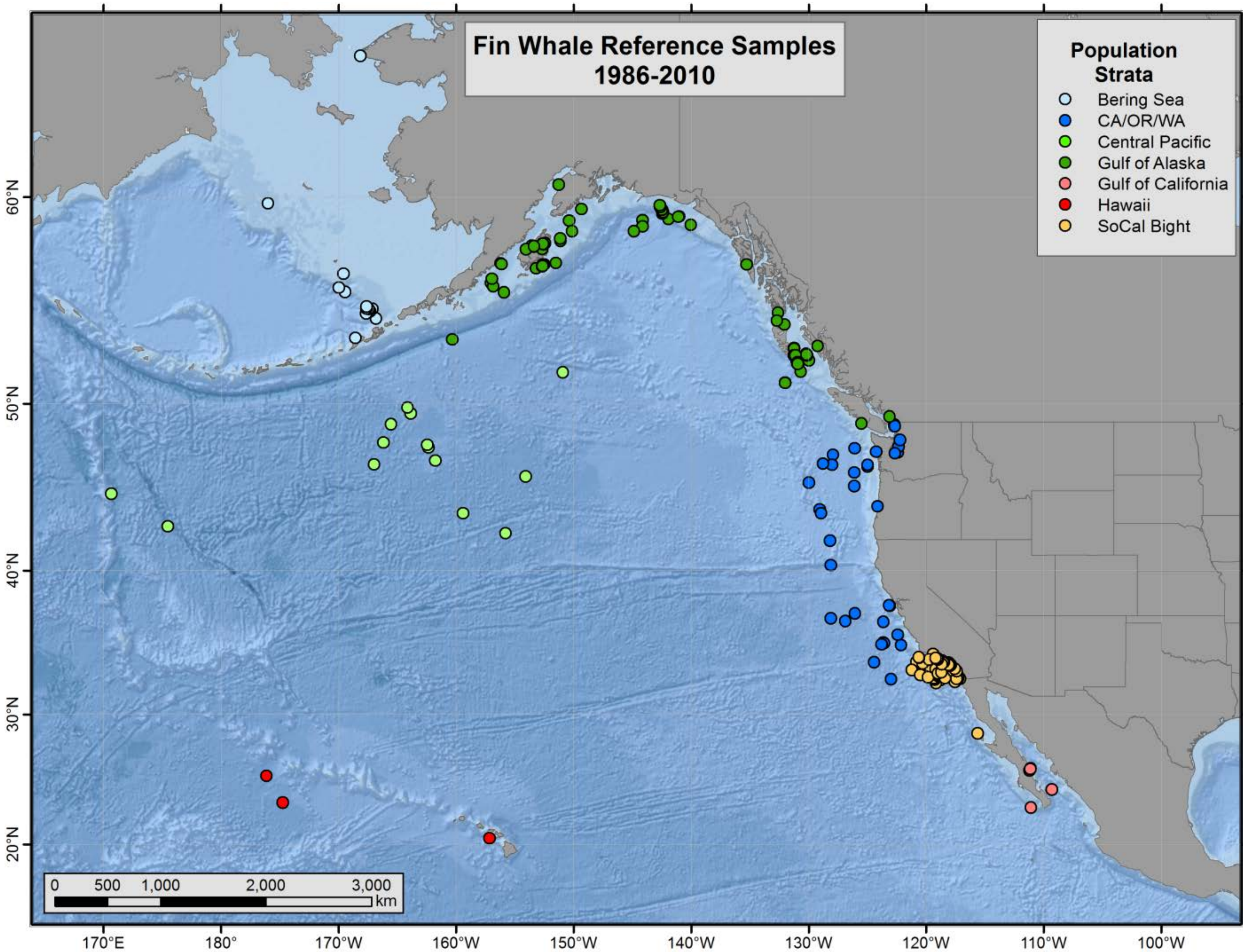

Figure 75. The seven population strata of the reference dataset (n = 397) used in the test of differentiation for the mtDNA haplotypes of the tagged fin whales (n = 12). Note that these seven *a priori* strata are under review as part of a larger study of fin whale population structure in the North Pacific (courtesy of F.I. Archer, Southwest Fisheries Science Center, La Jolla).

3.3 Bryde's Whale

A SPOT5 tag was deployed on a Bryde's whale (*Balaenoptera brydei/edeni*) mother accompanied by a calf (which were identified in the field as fin whales) on 23 July 2015, in southern California, just south of the Mugu Canyon. The tagged Bryde's whale traveled extensively throughout the Southern California Bight during its 86.7-d tracking period (**Figure 76**). Most of this animal's movements were in waters over the continental slope, ranging from Point Conception to San Clemente Island, with occasional forays out over deeper ocean basin waters (maximum distance to shore of 268 km). By mid-October, the whale had crossed into Mexican waters, heading south, and reaching Vizcaino Bay by 21 October, when its tag stopped transmitting.

The Bryde's whale spent 67 percent of its total tracking period (60 d) in PT MUGU and 24 percent of its total tracking period (22 d) in SOCAL, with none in the other training ranges (**Figure 76**). This animal was located in PT MUGU in July, August, September, and October, but was located in the SOCAL area predominantly in October.

The Bryde's whale's HR extended from the California/Mexico border to just north of Pt. Conception, California, out to approximately 200 km offshore, and covering an area measuring 64,814 km^2 (**Figure 77**). The Bryde's whale's CA occurred throughout much of the HR, measuring 24,225 km^2, and extending out to approximately 190 km offshore (**Figure 77**).

3.3.1 Photo-ID

A total of 303 photos of Bryde's whales was taken during the 2015 cruise, with eight whales being identified as unique individuals, including four mother/calf pairs. A right-side ID photo was obtained of the tagged Bryde's whale (**Figure 78**).

3.3.2 Ecological Relationships

The SSMs generated 87 regularized daily locations for the Bryde's whale tagged in 2015 (**Table 18**). The geographic extent of this track covered approximately 6 degrees of longitude (121.7–115.7°W) and 6 degrees of latitude (29.1–34.9°N) (**Figure 64**). All locations (100 percent) occurred within CCAL. Of these, 72 locations had acceptable estimation uncertainty and 71 received a behavioral classification, with 7.0 percent being considered as ARS, 14.1 percent as transiting, and 78.9 percent as uncertain (**Table 19 and Figure 64**).

Details of the environmental variables obtained for the SSM locations are provided in **Table 17**. Summary statistics for these variables in CCAL are provided in **Tables 20 and 21**. On average, the Bryde's whale tracked in 2015 occupied areas that had similar upwelling velocities to those occupied by the fin whales tracked in 2015 (WEKM = 3.8e-07 m s^{-1}), but that had warmer SST (21.07°C) and much lower CHL levels (0.31 mg m^{-3}). In addition, it occurred in shallower waters that were markedly closer to the shelf break and to shore (average DEPTH = -1244.51 m, DISTSHELF = 26.75 km, DISTSHORE = 56.35 km). The seafloor in these areas also had a higher SLOPE (53.82 m km^{-1}) and a lower ASPECT (188.9°) than for the fin whales tracked in 2015 (**Table 21**). The values at each location for these variables are shown in **Figures 65 through 71**.

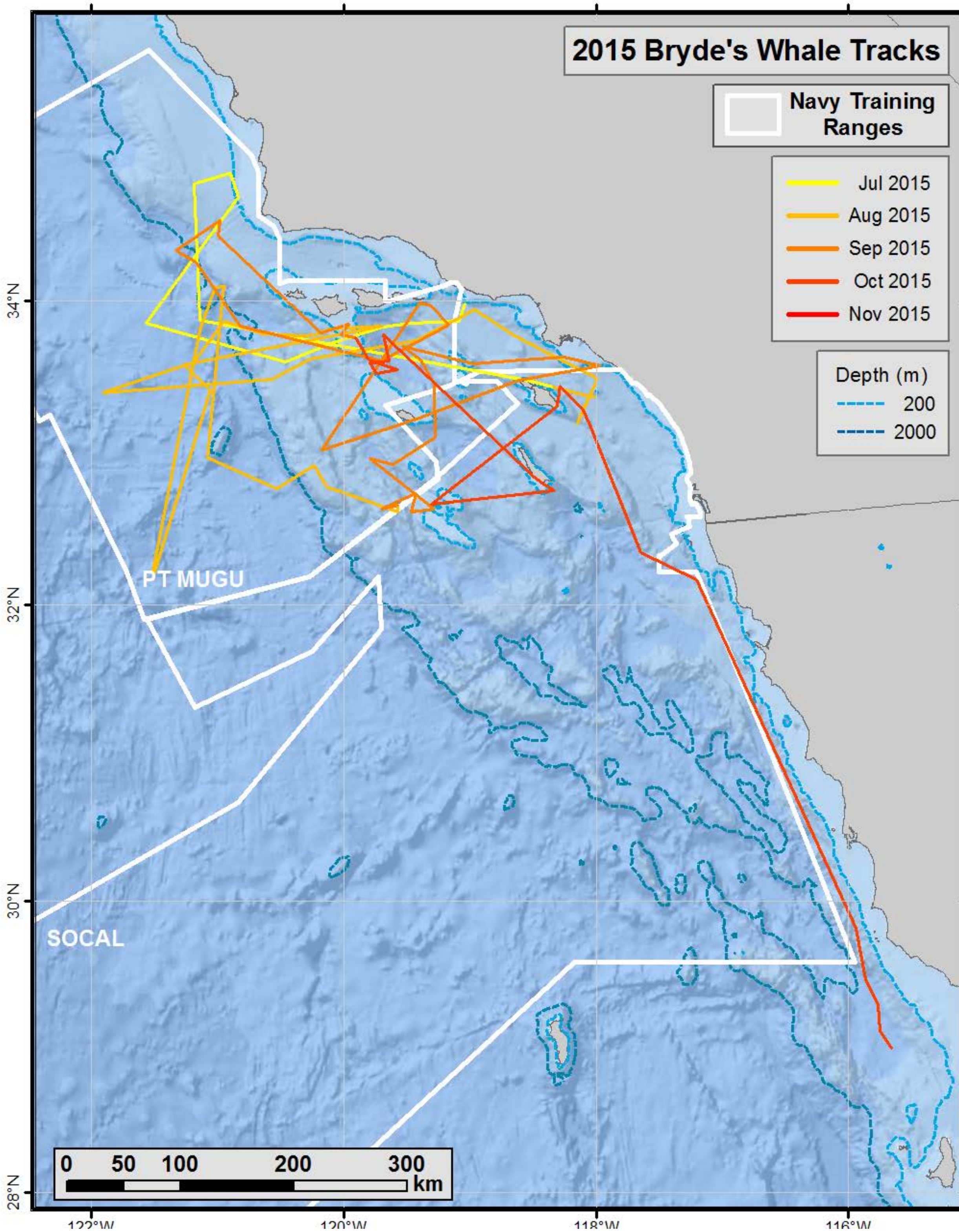

Figure 76. Satellite-monitored radio tracks for a Bryde's whale tagged with a SPOT5 Argos transmitter off southern California, 2015.

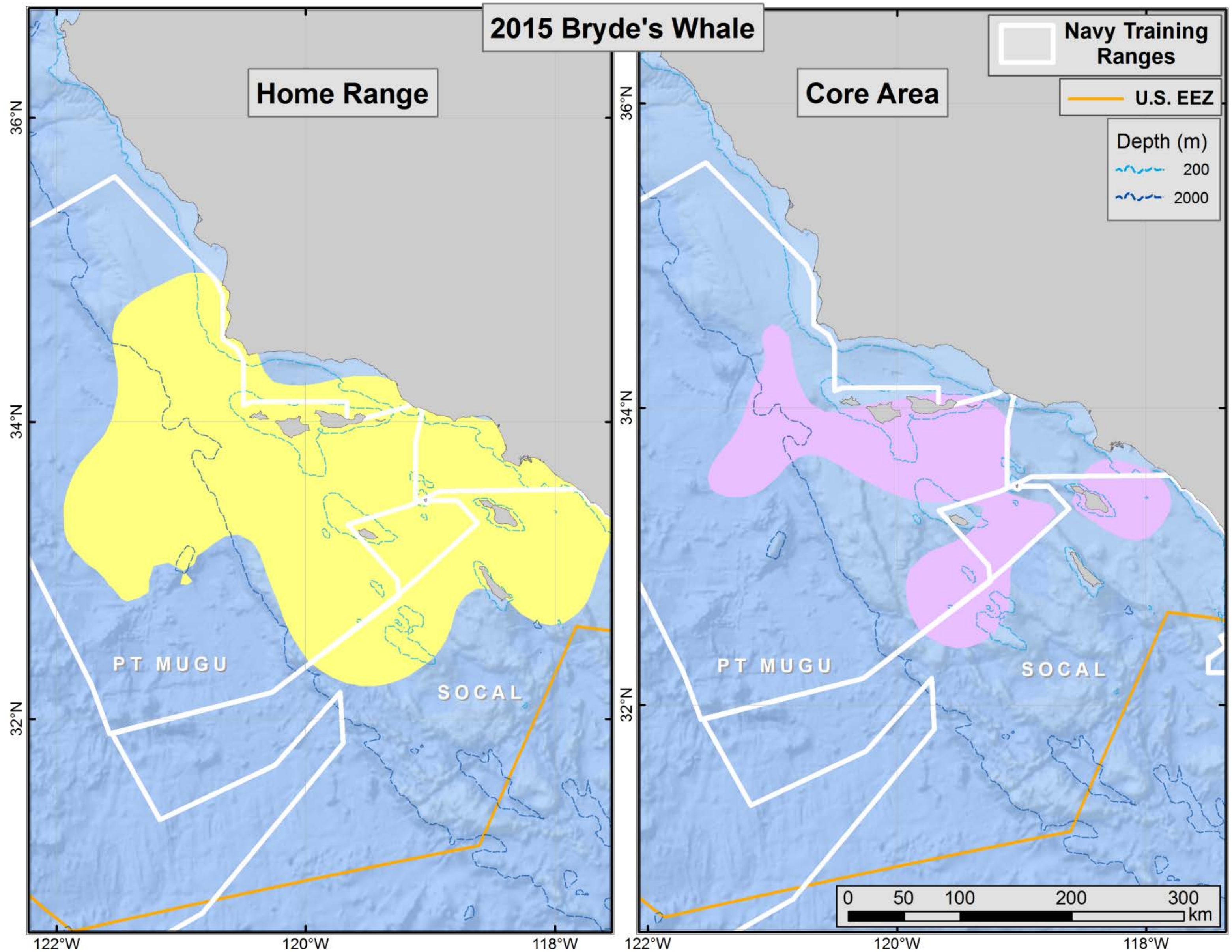

Figure 77. HR (left panel) and CA (right panel) of use in the U.S. EEZ for a Bryde's whale tagged off southern California in July 2015.

Figure 78. Identification photo of the right side of a tagged Bryde's whale (right; Tag #2015-00833) with calf, showing the dark gray coloration and tall, pointed, falcate dorsal fin characteristic of this species. The SPOT5 tag on the mother whale is visible toward the right edge of the frame.

4. Discussion

This report details the results of 2 years of tracking data for blue and fin whales tagged in southern California waters, as well as some of the first tracking results for a blue/fin whale hybrid and a Bryde's whale. 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 blue and fin 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.

During field efforts in both 2014 and 2015, blue whales were more numerous and easier to approach than fin whales, with the result that many more tags were applied to blue whales than fins (46 blue whales versus 17 fin whales). Median tracking duration was longer for fin whales (74.3 d) than blue whales (39.8 d) in 2014, but with such uneven sample sizes between the two species, this difference is not very meaningful. In 2015, median tracking durations were similar for both species (64.5 d for blue whales, 66.3 d for fin whales).

4.1 Blue Whales

4.1.1 Location Tracking

The blue whales tracked in this study ranged over a very large geographic area (50 degrees of latitude by 47 degrees of longitude), and, in the case of one whale, reached the equator for the first time in the history of blue whale tracking by the MMI since 1993. Substantial differences in distribution were seen in the 2 years of the study, with whales ranging further north in the 2014 summer/fall feeding season, and whales tagged in 2015 ranging further east and south during the winter. Despite these differences, the majority of the blue whale locations were within the distribution of blue whales described in previous studies (Calambokidis et al. 2009, Bailey et al. 2010, Irvine et al. 2014, Calambokidis et al. 2015).

Blue whales were tracked in four of the five Navy training ranges considered in this study, with the exception of the GOA area. Seasonality in the ranges was similar between the 2 years with locations occurring in the areas from August through November; however, distribution in the ranges differed from year to year. SOCAL was the most heavily used training range in 2014, in terms of number of tagged whales occurring there, whereas PT MUGU was the most heavily used area in 2015. In terms of residency and location of CAs, PT MUGU was the most extensively used range in both years; however, within the range, areas of highest use (overlapping CAs for multiple whales) were further west in 2015 than in 2014. The earlier (July) tagging and different tagging location in 2015 may account for some of these differences, with PT MUGU representing preferred habitat earlier in the feeding season. However, there were still many blue whale locations in PT MUGU after July in 2015, so the inter-annual differences noted here are more likely a reflection of differences in foraging success (related to prey distribution and availability) between the 2 years.

Use of the NWTRC by blue whales was not high in either year (17 and 9 percent of tagged whales in 2014 and 2015, respectively), and only one blue whale was located in area W237 (in 2014). Despite this low use, blue whale CAs were located in these ranges and residency was relatively long, highlighting the importance of this area as a likely northern feeding habitat for some blue whales. While short tracking periods may partially explain the low number of whales using the NWTRC and area W237, it seems more likely a reflection of individual variation, as in both years tracking periods were long enough (the minimum number of days for a tagged blue whale to reach the NWTRC was 9) to have enabled blue whales to travel from their tagging location to the NWTRC.

Not surprisingly, inter-annual differences were also striking for blue whale occurrence in NMFS-designated BIAs. Of the six BIAs that overlapped the Navy training ranges considered in this report, San Diego and Santa Monica Bay to Long Beach were the two most heavily used in 2014 (in terms of number of blue whales), whereas Santa Barbara Channel and San Miguel and Pt. Conception/Arguello were the two most heavily used in 2015. These differences at the scale of the Southern California Bight, with blue whales primarily occupying the north-central and southeastern portion in 2014 and the northwestern portion in 2015 can be explained by the collapse of upwelling at Pt. Conception and the western end of the Santa Barbara Channel (the most important foraging area for this population; Irvine et al. 2014) in 2014, and its return in 2015 (Leising et al. 2015, Jacox et al. 2016). These results indicate that inter-annual variability in oceanographic conditions needs to be considered when determining the importance of BIAs for blue whales.

Despite a large number of blue whales having locations in the four aforementioned BIAs over the 2-year tagging period, whales generally spent very little time in any of them (**Tables 5 and 10**), likely reflecting the patchiness and short-lived nature of prey aggregations. The exception to this low residency was the Santa Barbara Channel and San Miguel BIA, in which blue whales tagged in 2015 spent a much longer period of time (maximum of 50,d [mean of 11 d], compared to a maximum of 10 d [mean of 1.3 d] in all other BIAs, including the Santa Barbara Channel and San Miguel BIA in 2014). The pattern of occupation within the Santa Barbara Channel and San Miguel BIA in 2015 indicated that only a portion was consistently used. For this area only the western portion was heavily used by many whales, while the eastern portion was transited by only a few whales (**Figure 10**). Similar non-uniform spatial usage was seen in the Pt. Conception/Arguello BIA, in which only the offshore portion over the shelf break and slope was consistently used by many whales, while the inshore portion was transited by only a few whales (**Figure 11**). The San Nicolas and Tanner/Cortes Bank BIAs saw very low use by blue whales in both years (**Figures 12 and 13**), despite the fact that whales were tracked throughout the entire Southern California Bight, suggesting these two BIAs are of secondary importance. These results are not surprising considering the short residence time by blue whales in any given BIA, and the fact that these two small BIAs are found over localized bathymetric features in offshore waters, where large and persistent prey aggregations may not develop on a regular basis.

In regard to the temporal pattern of occupation, blue whales were found in the BIAs from July through October, the timing of which falls within the months of primary occurrence (June–October) listed for those areas (Calambokidis et al. 2015). These BIAs were designated as areas of most consistent blue whale occurrence from year to year by Calambokidis et al. (2015);

however the inter-annual variation we have shown here (especially with low occurrence in some over a 2-year period) stresses the need for multi-year data sets in order to define such areas.

Individual blue whale HRs and CAs in the EEZ waters of the western United States were significantly larger in 2014 than in 2015, and as a group, covered the entire western U.S. coastline in 2014, despite representing only five whales. The collective HRs and CAs for 17 whales in 2015 were spread out along the coast of California and into southern Oregon, but not farther north. Areas of highest use (where CAs overlapped for multiple whales) identified for blue whales tagged between 1998 and 2008 (Irvine et al. 2014) match well with those shown here for 2015, but not 2014. Individual blue whale CAs have been identified previously throughout most of the inshore waters of the southern California Bight (Irvine et al. 2014), but none have overlapped to the extent of those shown here for 2014. As with the other differences in distribution noted here between years, differences in HRs and CAs may reflect the different timing and location of tagging between the years, or perhaps differences in oceanographic conditions from year to year, leading to different foraging opportunities.

It is worth noting here that five blue whales tagged in 2014 in the inshore waters of the Southern California Bight (two near Mugu Canyon and three near San Diego) were resighted off the west end of San Miguel Island in the large concentration of whales encountered there in July 2015. Therefore, while differences in tagging locations may be suggested as an explanation for the differences in movements between the 2 tagging years, perhaps implying an inshore versus offshore subset of the population, this would not be the case for all tagged whales. It seems more likely that blue whales in southern California have a wide range of habitat to explore and seek out those which are most productive.

The resightings in 2015 of five of the tagged blue whales from 2014 represents a higher resight rate for tagged whales than for untagged whales (20.8 percent for tagged whales, compared to 12.5 percent for untagged whales). This may reflect a selection bias on our part, as a whale that has a tag on it, or appears to have a tag scar, may be preferentially approached for follow-up documentation of wound healing. It may also reflect a behavioral tendency of those particular tagged whales that makes them easier to approach.

4.1.2 ADB Tracking

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 FastLoc® versions of the software running the tags, but even the tags that recorded the fewest locations provided significantly more, 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 scarce in southern California waters, and the tagging location may have occurred within the only significant concentration of prey in that area during the study period. ADB-tagged whales in 2015 used areas substantially farther offshore than whales tagged in 2014 with the exception of 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 loop 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, or 3) the existing prey concentrations were not sufficient for the whale to expend the effort of foraging. 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 loop 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, 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’ circuit of southern California waters and relatively limited foraging effort.

The general dive behaviors recorded by the ADB tags, showing that the whales tended to dive deeper and forage 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, even when they are in close proximity to each other, suggests that foraging behavior in blue whales is more complex at the scales sampled by these tags than previously documented. The GPS-quality locations and high-resolution behavior data of the ADB tags allowed for the detection of relatively brief foraging bouts during what would otherwise have been considered a transit segment of the track (**Figures 16 and 17**). This kind of information is helpful to detect relatively small areas of presumed localized prey abundance, and to better understand how broader-scale tools like the location-only tags would best be used to identify important habitat.

While there was a clear diel pattern observed in the data, a non-negligible proportion of foraging 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 forage 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 foraging was occurring and what kind of behavior led up to the nightime foraging events. A number of the nightime foraging 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

(**Figure 18**). 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 forage at night, after the prey has migrated up the water column.

Foraging bouts were generally of intermediate duration, although there was substantial variability between individuals. Overall, most foraging bouts were approximately 2 h long, and bout duration was correlated to the number of lunges per dive that occurred within a foraging 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 the whales quickly left lower-density prey patches and stayed longer, and foraged more intensely, in higher-density patches. However, while the sample size is very small, female blue whales generally foraged for longer periods of time than male whales. This may be an indication that female blue whales have greater energetic requirements than males, although it also likely an indirect expression of the loops 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 than other potential rivals. 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 foraging bouts was highly variable within and between individuals, though the results suggest that blue whales typically forage in areas 7.6 km^2 in size. It is likely that some of the larger foraging bout areas were the result of an insufficient number of locations to define the true extent of the area being used for foraging. Longer-duration foraging bouts were also relatively linear at times, which would inflate the calculated area. Foraging bouts were generally more numerous and overlapped more frequently earlier in the tracks, especially in 2014, suggesting the whales were foraging 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 foraging bouts was surprising as whales would be expected to turn in order to forage within a patch, thereby creating a cluster of locations over the prey patch. Some of the foraging bouts extended across >20 km, which far exceeds the spatial scale of krill patches off central California (1.8 to 7.4 km) described using overlap with krill-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 vs. whales exploiting prey in different areas, but the idea is further reinforced by the differing dive depths recorded between the two whales foraging in close proximity (**Table 13**). That would suggest they were exploiting different parts of the same prey patch and, therefore, possibly different concentrations of prey. 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), or different age classes, while others expend more effort and forage deeper where prey is more dense. Further effort is needed to resolve these questions.

4.1.3 Ecological Relationships

The 44 SSM blue whale tracks analyzed here covered the largest geographic extent of all species tagged in this study (47 degrees of longitude by 50 degrees of latitude), with a presence in seven of the eight biogeographic provinces of the eastern North Pacific considered here. No tagged whales of any species were tracked to PSAE in the 2 years of this study, although one blue whale was tracked there 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. These large-scale shifts within the range are likely in response to the warm anomalies that occurred off the west coast of North America in 2013–2014 (Bond et al. 2014, Leising et al. 2015) and to the El Niño event that developed in 2015–2016 (Jacox et al. 2016, Levine and McPhaden 2016).

A similar explanation can be invoked to explain the increased use of CCAL and the decreased use of PNEC in 2015 relative to 2014. This is supported by a concomitant increase in ARS behavior in CCAL, suggesting that blue whales had better foraging success in summer 2015 (**Figure 31**). Indeed, the areas used by blue whales in 2015 had cooler SST and moderately high CHL, and were found shallower and closer to the shelf break and to shore than in 2014 (**Tables 20 and 21**). A higher foraging success in summer 2015 in CCAL would have been supported by strong upwelling pulses at several coastal locations in spring–summer 2015 that were responsible for maintaining an overall moderate productivity of this ecosystem during otherwise unfavorable conditions that prevailed off the west coast of North America since 2013 (Bond et al. 2014, Leising et al. 2015). In contrast, by late 2015 and early 2016 conditions in PNEC were highly disturbed because El Niño was in full swing (Jacox et al. 2016, Levine and McPhaden 2016), and the whales that were tracked there displayed almost no ARS behavior in their prime wintertime foraging destination (**Figure 31**).

4.1.4 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 31 tagged whales have been reconciled with those available from archived samples with MMI 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 2014–15 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.

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

There is a large and growing collection of telemetry results (Irvine et al. 2014) and photo-identification records (Calambokidis et al. 2009) of blue whales in the eastern North Pacific but relatively little published information on the fine-scale genetic structure of blue whales in the North Pacific (see Costa-Urrutia et al. 2013). An integration of these datasets 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).

4.2 Fin Whales

4.2.1 Location Tracking

Fin whale locations had a much wider distribution in 2015 than in 2014, both in latitudinal movement (further north in 2015) and in distance to shore (further from shore in 2015). Differences in overall tracking results between the 2 study years may reflect inter-annual differences in oceanographic conditions, but the much more likely contributor is the fact that twice as many fin whales were tagged in 2015 than in 2014, resulting in the more extensive distribution of locations seen in 2015.

As with blue whales, fin whales were tracked in four of the five Navy training ranges considered in this study, with the exception being the GOA area. PT MUGU was the most heavily used Navy training range by tagged fin whales in both years of the study, with 100 percent of tracked whales having locations there each year, in summer months (July, August, and September). Overlapping HRs and CAs occurred in PT MUGU in both years, but the spatial extent of these areas was much greater in 2015 than in 2014. The SOCAL training range was more heavily used by fin whales in 2014 than in 2015 in terms of number of whales, but the number of months in which whales were seen there was similar between years. Fin whale HRs covered a more extensive area within the northeastern corner of SOCAL in 2015 than in 2014, but there were no overlapping CAs in SOCAL in either year. Fin whales were located in the NWTRC in both years of the study, but in fewer numbers and in fewer months in 2014 than in 2015. This is most likely due to shorter tracking durations and fewer whales tagged in 2014. HRs and CAs were located in NWTRC in both years, but coverage was much more extensive in 2015, likely due to the larger number of whales there in 2015. Two fin whales were tracked in area W237 in 2015, with locations occurring there in August, September, October, and December. As with blue whales, residency in these northern ranges was relatively long and suggests that these areas provide important feeding habitat for some fin whales.

NMFS has not designated BIAs for fin whales, but BIAs for this species should likely include offshore areas in central and southern California as well as occasional concentrations in more coastal areas (Calambokidis et al. 2015). The CAs identified for fin whales by the HR analysis in this study coincide well with some of the predicted high-density areas for fin whales from habitat-based density models as well as sightings from coastal vessel-based surveys (Calambokidis et al. 2015), specifically those west of the Gulf of the Farallones, off Monterey Bay, near Point Buchon, south and west of San Miguel Island, and off the Palos Verdes Peninsula. The current study identified additional areas of high use for fin whales, specifically those off Point Arena, California and Coos Bay, Oregon.

Fin whale locations were in accordance with other satellite-tagging studies, showing greatest densities over continental shelf or slope waters (Calambokidis et al. 2015), but do not fully support the idea of regional subpopulations with little movement between regions. Nine of the 12 fin whales tracked with the longer-term SPOT5 tags (over both years of this study) visited more than one of the regions delineated by Falcone et al. (2011), and the majority of these whales spent time in three or more regions. Contrary to photo-ID studies, these inter-regional movements occurred within the same year and in many cases involved movements back and forth between the regions, rather than unidirectional movement that might signify migration (at least in the conventional sense).

Individual fin whale HRs and CAs in the EEZ waters of the United States were significantly smaller in 2014 than in 2015, and as a group (three whales), were much more sparsely located along the southern California and northern California/southern Oregon coastline. The collective HRs and CAs for five whales in 2015 covered the entire U.S. west coast. In both years, CAs overlapped for a maximum of two whales at a time, but the number of these areas of high use and their sizes were quite different from one year to the next. Differences in sample sizes may account for some of these inter-annual differences (three whales in 2014, five whales in 2015), but different oceanographic conditions and their effect on prey availability likely played a role as well.

4.2.2 ADB Tracking

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 (compared to the blue whales or the other recovered fin whale ADB tag) 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. It is also unclear why similar numbers of dives and locations were received through Argos for the unrecovered tags in 2014 when one tag (Tag #2014_5790) functioned over twice as long as the other (#2014_5838). Examination of the recently recovered archive for Tag #2014_5838 will hopefully provide answers to this question.

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 foraging effort recorded between the two recovered tags, with Tag #2014_5685 recording remarkably little foraging effort during a clockwise loop through southern California waters. Data on foraging effort were not available for the other three tagged fin whales, but the clusters of locations and the recorded diel variability of the dive depths reported through Service Argos are characteristic of a rorqual foraging on diel vertically migrating prey (Fiedler et al. 1998, Calambokidis et al. 2007, Doniol Valcroze et al. 2011). Tag #2014_5685 passed through one of these areas of presumed foraging recorded by Tag #2014_5838 area without stopping. This suggests that either 1) it was not able to find the prey being consumed by tagged whale #2014_5838, 2) the prey was so ephemeral it had already been depleted by the time the whale passed through, or 3) the existing prey concentrations were not sufficient for the whale to expend the effort of foraging. It is especially surprising that the whale passed through this area without stopping as so little foraging 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.

Three of the five ADB-tagged fin whales left southern California waters after tagging and travelled north. The portions of those tracks in southern California are indicative of the whales searching for prey as there are numerous clusters of locations and the movements cover 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 foraging. This appears to suggest that fin whales use southern California waters only briefly, and that their preferred destination during the summer is farther to the north. It is unknown if the lack of foraging 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 were willing to exploit prey when encountered while travelling north.

Foraging 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 foraging bouts were most numerous, though the whales also made very long-duration foraging 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.

4.2.2.1 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 = 2 vs. 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. Foraging bout duration was also correlated to the number of feeding lunges per dive for both species, suggesting they employed similar feeding strategies during the tracking periods. The northward movement of three of five ADB-tagged fin whales, and the directed nature of the movements, may indicate that fin whales preferentially occupy areas north of southern and possibly central California during the summer. This is in comparison to ADB-tagged blue whales, which also had three tagged whales leave southern California waters but substantially more foraging occurred during those movements and one travelled in a very meandering manner, suggesting exploration for food. The most interesting result was the apparent difference in behavior between male and female whales of both species. With one exception, male whales made large clockwise loops across southern California waters while engaging in a limited amount of foraging. Female whales produced more clustered tracks and substantially more foraging. It appears that there may be an additional factor besides the pursuit of prey driving male behavior in both species, 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 three whales traveled in the same direction 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.

4.2.3 Ecological Relationships

Although the geographic extent covered by the 15 fin whale tracks in this study was the second largest of the species tagged (17 degrees of longitude by 22 degrees of latitude) (**Figure 56**), it was much smaller than that of the blue whales. Also, while blue whales migrate in late fall and winter from CCAL to lower-latitude provinces (PNEC, GUCA, PQED), fin whales move northward and remain in CCAL or visit ALSK. There was evidence for large-scale shifts within this range between the 2 years of the study, but in contrast to blue whales, fin whales ranged farther west and north in 2015 than in 2014 (133°W and 52.6°N in 2015 versus 125.8°W and 42.3°N in 2014) (**Figure 56**).

In fact, fin and blue whales appear to be ecological counterparts in many respects. Fin whale ARS behavior was higher in 2014 than in 2015, while transiting increased in 2015—the opposite of blue whales. This was reflected in the size of HRs (and CAs), with fin whales having smaller HRs in 2014 and larger ones in 2015—again, the opposite of blue whales (see **Sections 4.1.2 and 4.2.2**). Comparison of environmental conditions in CCAL, the only biogeographic province consistently occupied by the two species in both years, indicate that the areas used by fin whales had cooler SST, somewhat lower CHL, and were found farther away from the shelf break and the shoreline than blue whales (**Tables 20 and 21**). The inter-annual pattern was also opposite, with fin whales occurring in deeper water and farther away from the shelf break and the shoreline in 2015 than in 2014. Their apparent higher foraging success in 2014 may have been related to them successfully exploiting a region of enhanced open-ocean upwelling driven by strong wind-stress curl off central California (WEKM was on f an order of magnitude higher in 2014; **Table 20 and Figure 57**). These environmental relationships suggest that while in CCAL (outside of southern California, where they 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. Thus, despite partial spatial and environmental overlap, fin and blue whales appear to have distinct ecological optima. Further, their opposite responses to the climate anomalies of 2014 and 2015 suggest that they may exploit a different resource in much of their range.

The short tracking period (28 d) and the small geographic extent (2 degrees of longitude by 2 degrees of latitude) covered by the blue/fin hybrid whale tagged in 2015 prevent us from making broad comparisons with the blue and fin whale results (**Figure 64**). Further, the SSM failed to assign most locations to a behavioral mode (85 percent were considered uncertain), so all we can say is that this animal spent small proportions of its time in activities consistent with foraging behavior (high ARS values) or with transiting. Generally, however, during the tracking period this animal remained within 50 km from shore, in an area characterized by strongly positive upwelling, cool SST, and relatively high CHL levels (**Figure 64**).

4.2.4 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 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 (SNPs)s 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, it is notable that the haplotype frequencies of the tagged whales 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.

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

Fin whales are a much less abundant species in the southern California areas where we conducted the tagging. They are also a more difficult species to approach for tagging, which explains the smaller sample size attained during this study. However, the tracking data presented here have provided a wealth of information about this poorly known species. The long tracks from some of these animals combined with the environmental data indicate that the species appears to have a distinct ecology, even though it shares a substantial part of its range with the blue whale.

There would be considerable benefit to further integration of information from the available reference 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 (F.I. Archer, pers comm).

4.3 Bryde's Whale

4.3.1 Location Tracking

The tracking data from the tagged Bryde's whale (mother with calf) represents the first of its kind for this species in the eastern North Pacific. Very little is known about the distribution of Bryde's whales off the U.S. west coast, and only a handful of confirmed sightings have been made in California waters during extensive ship and aerial surveys (NOAA 2007, Smultea et al. 2012). Bryde's whales off California are likely part of the larger eastern tropical Pacific population, which also includes whales in the Gulf of California (NOAA 2007).

The Bryde's whale in this study was tracked for 86.7 days and covered a minimum distance of 4,587 km. The majority of its time (from late July to mid-October) was spent in the PT MUGU training range with some back and forth movement between there and the northeastern part of the SOCAL range. In mid-October the whale headed south into Mexican waters, beginning what appeared to be a typical baleen whale fall migration into tropical waters.

4.3.2 Ecological Relationships

As with the blue/fin hybrid whale, the single track obtained for the Bryde's whale tagged in 2015 prevents us from making broad comparisons with the blue and fin whale results. However, this whale was tracked for a longer period (87 d), during which it covered a larger geographic extent (6 degrees of longitude by 6 degrees of latitude) (**Figure 64**). A large proportion (79 percent) of locations were classified as uncertain by the SSM, although it appeared that this animal spent a higher proportion of its time (14 percent) transiting and a small proportion (7 percent) in activities consistent with foraging (high ARS values).

During the tracking period, this animal was generally found within 56 km from shore in significantly warmer waters (21°C) and with lower CHL levels (0.31 mg m^{-3}) than any of the other species tracked in 2015. Relative to these species, the Bryde's whale occurred in shallower depths (-1245 m), over slopes that were steeper (54 m km^{-1}) and that faced more southward (189°) (**Tables 20 and 21; Figures 66 through 71**).

This evidence indicates Bryde's whale exploit a different habitat from the other species in this study. Indeed, they are known to be primarily piscivorous, while blue and fin whales primarily target euphausiids (Tershy 1992, Tershy et al. 1993, Fiedler et al. 1998). Bryde's whales are considered a tropical species. However, acoustic data suggest that their presence in California has been increasing since 2003 (Kerosky et al. 2011), and they are also being sighted there more commonly (Smultea et al. 2012), which is consistent with a range expansion possibly related to changes in prey distribution or abundance. Indeed, the photo-ID results (**Section 4.3.1**) indicated that at least eight different individuals (including four mother/calf pairs) of this species were seen during our 2015 field effort alone. Such an influx was likely related to the effects of El Niño in southern California waters; by this time pelagic red crabs (*Pleuroncodes planipes*), whose occurrence north of the U.S./Mexico border is indicative of El Niño, were washing up ashore *en masse* at San Miguel Island (R. DeLong, pers. comm.).

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

This is only the third time a Bryde's whale has been satellite-tracked worldwide. Two Bryde's whales were previously tagged in the offshore waters of the western North Pacific, with tracking durations lasting 13 and 20 d, respectively (Murase et al. 2015). The 87-d track from the animal in this study revealed its pattern of habitat use and habitat preferences while in southern California waters. In particular, environmental variables like CHL and seafloor relief (SLOPE and ASPECT) were useful in distinguishing these preferences from those of blue and fin whales. Although the species is rare in southern California, additional future tagging would provide a more robust data set to assess the species ecology at the northernmost part of its range, and the relationship of these animals to those occurring further south (in Mexican waters) and west (in the central North Pacific).

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