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Final Report

Baleen (Blue & Fin) Whale Tagging in Southern California in Support of Marine Mammal Monitoring Across Multiple Navy Training Areas (SOCAL, NWTRC, GOA)

Submitted to:

Naval Facilities Engineering Command Pacific
for Commander, U.S. Pacific Fleet
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A blue whale (*Balaenoptera musculus*) raises its flukes at the start of a foraging dive in Southern California, 11 September 2014. Photograph taken by Craig Hayslip under National Marine Fisheries Service Permit 14856 issued to Dr. Bruce Mate.

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Twenty-four blue whales [20 location-only tags, 4 Advanced Dive Behavior (ADB) tags] and six fin whales (3 location-only tags, 3 ADB tags) were tagged in August 2014 between Mugu Canyon, west of Malibu, and San Diego. CA .There was a great deal of individual variation in the tracks of both blue and fin whales, with blue whale locations extending from the northern tip of Vancouver Island in British Columbia to the Costa Rica Dome area off Central America, and those of fin whales extending from southern Oregon to central Baja California. Home range analysis was applied using fixed-kernel density techniques to estimate the HR and core areas of use for each tracked whale. The area of highest use for blue whales, as indicated by the largest number of overlapping core areas, was between Point Dume and Mugu Canyon off southern California, out to approximately 30 km from shore. For fin whales, areas of highest use occurred south of San Miguel Island, approximately 100 km offshore, and approximately 70 to 80 km offshore along the south-central California coast between Arroyo Grande and Big Sur.

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Executive Summary

Oregon State University's Marine Mammal Institute conducted a 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. 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 tags, 3 ADB tags) were tagged between Mugu Canyon, west of Malibu, and San Diego. One tag was still transmitting on 15 February 2015, when the data were summarized for this report. Transmissions were received from all but one tag, with tracking periods ranging from 0.7 to 156.8 days (d). Average tracking duration for location-only tags was 60.3 d for blue whales and 94.8 d for fin whales.

There was a great deal of individual variation in the tracks of both blue and fin whales, with blue whale locations extending from the northern tip of Vancouver Island in British Columbia to the Costa Rica Dome area off Central America, and those of fin whales extending from southern Oregon to central Baja California. Home range (HR) analysis was applied using fixed-kernel density techniques to estimate the HR and core areas of use for each tracked whale. The area of highest use for blue whales, as indicated by the largest number of overlapping core areas, was between Point Dume and Mugu Canyon off southern California, out to approximately 30 kilometers (km) from shore. For fin whales, areas of highest use occurred south of San Miguel Island, approximately 100 km offshore, and approximately 70 to 80 km offshore along the south-central California coast between Arroyo Grande and Big Sur.

Both blue and fin whales were tracked in the Northwest Training Range Complex (NWTRC) and the Southern California Training Range Complex (SOCAL), but neither species traveled into the Gulf of Alaska Temporary Maritime Activities Area. Only one blue whale had locations within area W237 within the NWTRC area (in August, September, and October). Blue whale presence was observed in both SOCAL and NWTRC in August, September, October, and November. Fin whale locations occurred in SOCAL in all 5 months in which they were tracked (August, September, October, November, and December), but in only 2 months in NWTRC (August and September). Eighteen blue whales spent 1 to 48 percent (37 to 414 hours [h]) of their tracking periods within the SOCAL, while four blue whales spent 3 to 45 percent (15 to 1,249 h) of their tracking periods within the NWTRC. Four fin whales spent from less than 1 to 39 percent (1 to 956 h) of their total tracking periods in SOCAL, and one fin whale spent 51 percent (811 h) of its tracking period in NWTRC. With respect to the National Oceanic and Atmospheric Administration's Biologically Important Areas (BIAs) for blue whales that overlap Navy training and testing areas, the Santa Monica Bay to Long Beach and San Diego BIAs were the most

heavily used, in terms of total number of whales with locations in the BIAs as well as percent of locations and percentage of time spent there.

ADB-tagged blue whales were tracked for a median of 19.4 d, and all four tags were recovered for data download. Each tag recorded more than 1,050 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 may have been due to tags using different versions of FastLoc® GPS software. Tagged blue whales made deeper dives during the day when most foraging activity also occurred. The whales generally foraged in small (median 1.5 square kilometers) areas, though the duration of foraging bouts ranged from less than 1 to 13.3 h. Individual variability in diving behavior was also recorded as two of the tagged whales made deeper dives than the other two whales, and in two instances, one tagged whale foraged at over twice the depth of another whale when they were within 1 km of each other.

ADB-tagged fin whales were tracked for a median of 11.1 d, and only one of the three tags was recovered for download. The shorter tracking duration compared to blue whales was due to the tags being shed by the whales more rapidly. The one recovered tag recorded more than 1,140 dives, and a total of 95 GPS locations. The two non-recovered tags transmitted dive summary information for 279 and 289 dives and 14 and 12 GPS locations, respectively, via the Argos system. Diel variability in dive depths was recorded by two of the three tags and foraging activity was recorded almost exclusively during the day by the one recovered tag. The general behavior of ADB-tagged fin whales was similar to what was recorded for blue whales; however, the fin whale tag recorded much less foraging effort during the tracking period. Tagged blue and fin whales generally used different parts of the southern California waters but the difference in the amount of recovered data between the two species makes it difficult to explain the observed differences.

An historical analysis of existing tracking data dating back to 1993 was conducted as part of our characterization of blue whale migration and foraging areas along the U.S. West Coast in relation to the Navy's training and testing areas and the National Oceanic and Atmospheric Administration's BIAs. The Marine Mammal Institute's satellite tagging and tracking program on Eastern North Pacific blue whales began in 1993 and extended through 2008. Over this 15-year period, 182 satellite tags were deployed, of which 104 transmitted for more than 7 d, representing the largest tracking data set in existence for any whale population to date. For this analysis we: (a) applied state-space models (SSMs) to regularize the tracks, improve location estimates, and classify movement behavior; (b) estimated HR using fixed-kernel density techniques to determine the areas of highest use by blue whales, and their degree of overlap with Navy areas and BIAs; (c) described blue whale distribution in the Eastern North Pacific in a biogeographic context; and (d) examined the tracking data in combination with environmental variables to characterize whale distribution in relation to habitat variability in the Eastern North Pacific.

The SSMs generated 10,664 daily locations from the set of 104 tracks. We determined the number of locations and the number of days in each year occurring inside the Navy areas and the BIAs. Overall for the Navy areas, 6.7 percent of the locations occurred within SOCAL, 2.8 percent in NWTRC, and 0.4 percent in W237. For the BIAs, 0.1 percent occurred in the San

Diego BIA, 0.3 percent in the Santa Monica Bay to Long Beach BIA, and 0.1 percent in the Tanner-Cortez BIA.

Kernel-density HR analysis for 53 tracks with 30 or more SSM-derived locations inside the U.S. Exclusive Economic Zone indicated that just two areas were most heavily used by blue whales. As many as 40 blue-whale-HRs overlapped in the area at the west end of the Santa Barbara Channel in southern California, and up to 32 HRs overlapped in the Gulf of the Farallones, off central California. Neither of these areas of highest use overlapped with the Navy areas. Up to eight HRs extended into SOCAL. Up to 16 HRs occurred along the southeastern border of the NWTRC, but only up to eight HRs included most of this area. Up to eight HRs extended into Navy area W237.

From a biogeographic perspective, the vast majority of the 10,664 daily locations from the SSMs occurred in the California Current Province (CCAL; 74.4 percent) and in the North Equatorial Countercurrent Province (PNEC; 15.9 percent). CCAL was occupied year-round, but use shifted from central and southern California in summer and fall to the southern part (along the Baja California Peninsula, Mexico) in winter and spring. PNEC was primarily occupied in winter and spring.

In terms of movement behavior, blue whales displayed area-restricted searching (ARS) behavior in both CCAL and PNEC, suggesting that blue whales forage throughout their distribution range. Within CCAL high values of ARS occurred along the coast, while in PNEC high values of ARS occurred far offshore at the southeastern terminus of the winter-spring migration near the oceanographic feature known as the “Costa Rica Dome.”

Blue whales showed distinct optima in relation to the environmental gradients examined within the two main biogeographic provinces they occupied (i.e., CCAL and PNEC). In CCAL, these optima remained generally the same across season, except for chlorophyll-*a* and depth. The chlorophyll-*a* optimum was markedly higher in summer-fall than in winter-spring. The depth optimum shifted to shallower depths in winter-spring. In terms of movement behavior, transiting was greatest during winter-spring in PNEC and in CCAL, while ARS was greatest during summer-fall in CCAL.

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Acronyms and Abbreviations

ADB	Advanced Dive Behavior
ARS	area-restricted searching
BIA	Biologically Important Area
CA	core area
CAMR	Central American Coastal Province
CCAL	California Current Province
CHL	chlorophyll-*a* concentration
cm	centimeter(s)
CRD	Costa Rica Dome
d	day(s)
g	gram(s)
GOA	Gulf of Alaska Temporary Maritime Activities Area
GPS	geographic positioning system
GUCA	Gulf of California Province
HR	home range
ID	identification
km	kilometer(s)
km/h	kilometer(s)/hour(s)
km^2	square kilometer(s)
LC	location class
LED	light-emitting diode
m	meter(s)
min	minute(s)
MMI	Marine Mammal Institute
MSA	minimum specific acceleration
Navy	U.S. Navy
NPPF	North Pacific Transition Zone Province
NWTRC	Northwest Training Range Complex
PNEC	North Equatorial Countercurrent Province
PSAE	Pacific Subarctic Gyre-East Province
PTT	Platform Transmitter Terminal
R/V	Research Vessel
s	second(s)
SD	standard deviation
SOCAL	Southern California Range Complex
SPOT	Smart Positioning or Temperature
SSH	sea surface height
SSM	state-space model
SST	sea surface temperature
U.S.	United States

1. Introduction

The United States (U.S.) Navy (Navy) conducts training and testing activities around the world to prepare Navy personnel for deployment and homeland defense by providing realistic training and testing environments. These activities have coexisted with commercial and recreational ocean activity for decades, sharing the environment with the people, plants, and animals that rely on ocean ecosystems. The Navy sets as a priority the understanding of these complex environments and takes the necessary precautions to minimize effects of military activities on these resources. In U.S. waters, the Navy is required to be in compliance with the National Environmental Policy Act and Executive Order 12114, Environmental Effects Abroad of Major Federal Actions, and it prepares Environmental Impact Statements in order to renew Federal regulatory permits and authorizations to continue military training and testing activities.

The 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), and the Southern California Training Range Complex (SOCAL) (**Figure 1-1**). 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 (Leatherwood et al. 1988, Calambokidis et al. 2009). In an effort to support the Navy in meeting regulatory requirements for monitoring under the Endangered Species Act and Marine Mammal Protection Act, a study was conducted by Oregon State University's Marine Mammal Institute (MMI) under contract to HDR, Inc. to further the understanding of this overlap. The objective of the study was to determine movement patterns, occurrence, and residence times of blue and fin whales within Navy training and testing areas along the U.S. West Coast, as compared to patterns within the rest of the Eastern North Pacific Ocean outside of Navy training and testing areas. Further, the National Oceanic and Atmospheric Administration (NOAA) recently identified nine Biologically Important Areas (BIAs) for blue whales along the West Coast of the U.S. (Calambokidis et al. 2015; NOAA Cetacean and Sound Mapping—http://cetsound.noaa.gov/important), and an additional objective of the study was to determine similar tracking metrics for blue whales within the four BIAs that overlapped the Navy areas.

To accomplish these objectives, satellite-monitored radio tags were deployed on blue and fin whales off the coast of southern California. Two types of tags were used, location-only and Advanced Dive Behavior (ADB) tags, to provide both long-range movement and distribution information and shorter-term, fine-scale dive profile information to provide data on diving and foraging habits, respectively. Spatial and temporal analysis of whale locations provided estimations of the amount of overlap and residence time within the Navy training and testing areas and the overlapping BIAs. The calculation of home ranges (HRs) and core areas (CAs) of use from the tracking data allowed for quantification of variability between individual whales and identification of areas of highest use by whales. Dive characteristic information was used to document changes in behavior over time or between individuals. An analysis of previously collected tracking data during the period of 1993 to 2008 was also conducted to provide a long-term characterization of blue whale occurrence in the Eastern North Pacific in relation to Navy training and testing areas and BIAs in relation to environmental conditions.

This report presents detailed analyses of the 2014 blue and fin whale tracking results. It includes deployment specifics and tracking information through 15 February 2015, with maps of whale tracks, HRs, and core areas of highest use (**Chapter 2**). It also includes analyses of the dive characteristics data obtained from the ADB tags (**Chapter 3**). Finally, it provides a characterization of the historical blue whale tagging data in the context of environmental conditions (**Chapter 4**).

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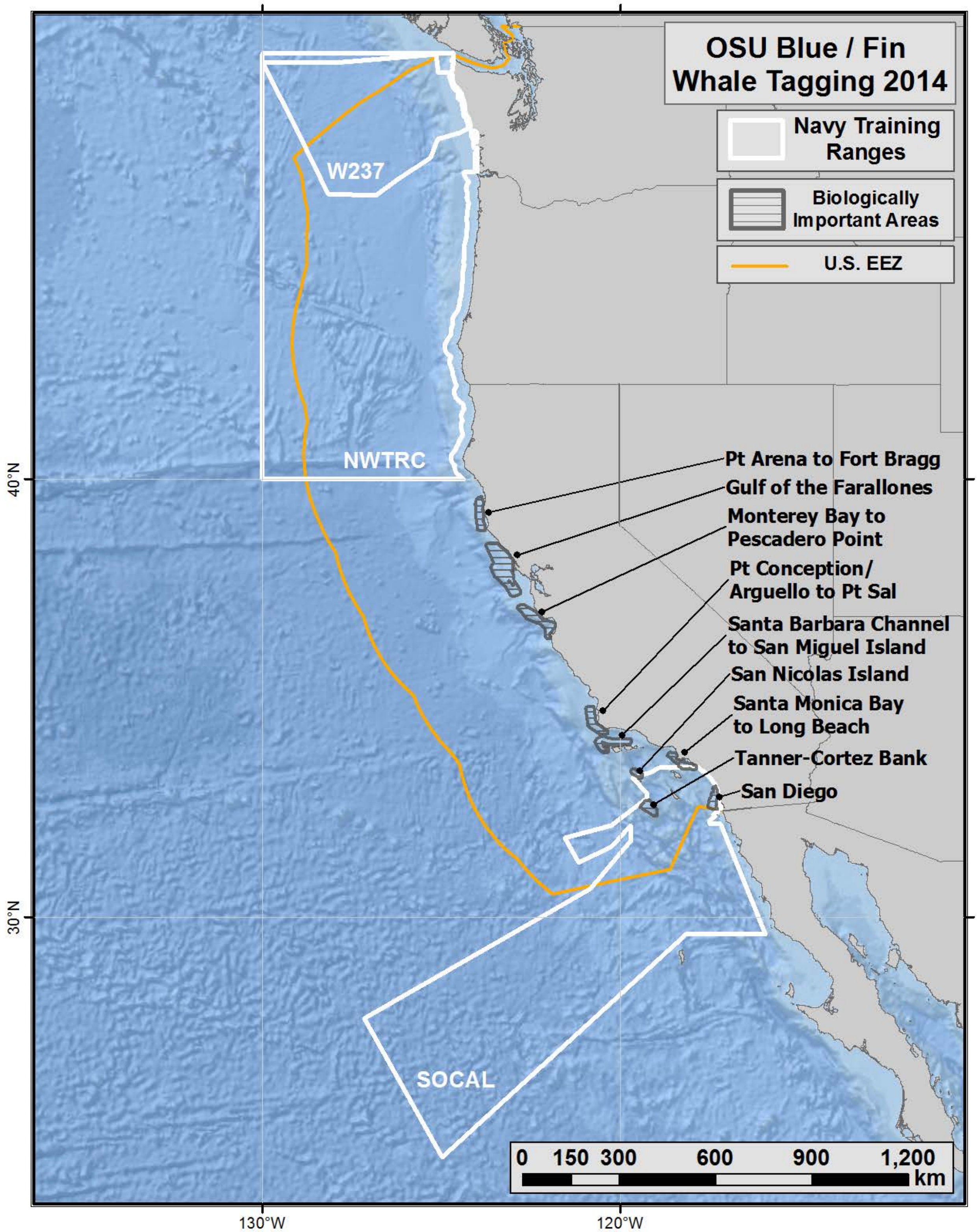

Figure 1-1. Map of the study area in the Eastern North Pacific showing the Navy training and testing areas and NOAA's nine BIAs for blue whales. Note that only four BIAs occurred in Navy training and testing areas (all in SOCAL).

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2. Field Efforts and Location Tracking

2.1 Methods

2.1.1 Field Efforts

Fieldwork took place off the coast of southern California during two 3-week cruise legs aboard the Research Vessel (R/V) *Pacific Storm*. This 26-meter (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 cruise took place 2 to 22 August 2014, departing from Santa Barbara Harbor. Leg 2 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.

All tagging efforts were conducted from a small 6.4-m rigid-hulled inflatable boat that was launched with a crane from the back deck of the R/V *Pacific Storm*. The tagging crew consisted of five individuals—tagger, biopsy darter, photographer, data recorder, and boat driver. Identification (ID) photos were taken of all tagged whales. Candidates for tagging were selected based on visual observation of body condition. No whales were tagged that appeared emaciated or extensively covered by external parasites. Wildlife Computers' Smart Positioning or Temperature (SPOT)-5 and MK10-PATF (ADB) tags were deployed using an ARTS air-powered applicator following the methods described in Mate et al. (2007). Tags were deployed from distances of 1 to 4 m with 84 to 125 pounds per square inch in the applicator's 70-cubic centimeter pressure chamber.

2.1.2 Satellite Tags

The SPOT-5 tags were made up of three parts: a main body, a penetrating tip, and an anchoring system. 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 deep 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 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 (Gentamycin 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.

In addition to providing transmissions for location calculation, the SPOT-5 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 than that, or they may stop functioning due to electronic failure while still attached to a whale. Maximum tracking duration to date for a blue whale is 505 d, but the average duration is 102.5 d (see **Chapter 4** of this report).

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 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 SPOT-5 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 tag was ejected from the housing and floated to the surface for recovery. For this study, the electro-mechanical connection between the tag and its housing was programmed to release the tag 3 weeks after tagging began on 2 August 2014. This allowed sufficient field time for tag recovery during the 6-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. 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).

2.1.3 Argos Tracking and Filtering

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 and GPS 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 and B, when derived from only one transmission, were removed from analyses because of the large errors frequently associated with these classes. 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 kilometers/hour (km/h), one of the two locations was removed, with the location resulting in a shorter overall track length being retained. GPS locations were also filtered by speed using the same 12 km/h criteria.

Minimum and maximum great-circle distances to the closest point on land were computed for each whale track. Vancouver Island was used as the land reference for whale tracks west of the island.

2.1.4 Occurrence in Navy Areas and BIAs

Numbers of Argos and GPS 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-Cortez Bank; and San Diego. Numbers of blue whale locations and corresponding percentages were also computed for these four BIAs. The other five 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 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.

2.1.5 State-Space Modeling (SSM)

A Bayesian switching state-space model (SSM) developed by Jonsen et al. (2005) was applied to the unfiltered Argos locations for each whale 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.

2.1.6 Home Range Analysis

Kernel HRs were created for each SSM track 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 (core area [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 core area were then calculated in ESRI® ArcMap v.10.0.

2.2 Results

Argos-monitored satellite radio tags were attached to 24 blue whales (20 SPOT-5, 4 ADB) and 6 fin whales (3 SPOT-5, 3 ADB) during August and September 2014. One tag was still transmitting on 15 February when the data were summarized for this report. Although not part of the analysis for this report, one blue whale tag continued to transmit on 28 May 2015 [255 d (8.5 months)]. This particular whale spent 188 d on the Costa Rica Dome, a longer period of time in this region than previously documented by MMI since Dr. Bruce Mate started tracking North Pacific blue whales in 1993. All tags were deployed off southern California, between Mugu Canyon (west of Malibu) and San Diego. Transmissions were received from all but one tag, with an average tracking duration for SPOT5 tags of 60.3 and 94.8 d for blue and fin whales, respectively (as of 15 February 2015; **Tables 2-1 and 2-10**). Total tracking periods for both species combined ranged from 0.7 to 156.8 d for SPOT-5 tags (as of 15 February 2015) and 4.9 to 19.8 d for ADB tags. Five ADB tags were recovered (4 on blue whales, 1 on a fin whale), providing information on 9,234 dives (analysis of ADB data is presented in **Chapter 3** of this report).

Eight of the 24 tagged blue whales 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 2-2**). Two of six tagged fin whales responded to the tagging/biopsy process (**Table 2-2**).

A total of 6,134 photographs of blue whales was taken during the field efforts, of which 83 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. Nine blue whales were photographed on days subsequent to tagging, some showing swelling, lightened skin pigmentation, or tissue extrusion at the tag sites (**Table 2-3**).

A total of 2,265 photos of fin whales was taken during the 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. Only one fin whale 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 2-3**).

2.2.1 Blue Whales

Twenty-four tags were deployed on blue whales between 3 August and 12 September 2014. Locations were received from 22 of these tags, providing tracking periods ranging from 0.7 to 156.8 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 884.8 km) and latitudinal movement along the coastline (from 7.4 to 50.5°N; **Figure 2-1 and Table 2-4**). 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 which spent the months of December, January, and February in the Costa Rica Dome upwelling area.

None of the tagged blue whales were tracked within the GOA. Two blue whales had locations inside both the SOCAL and the NWTRC areas (**Tables 2-5 and 2-6**, **Figures 2-2 and 2-3**). Two others had training range locations only within NWTRC, and 16 had locations only within SOCAL. Of the four blue whales with locations inside NWTRC, only one had locations inside area W237 (19 percent of its total locations; **Figure 2-4**). All locations within the Navy areas were less than 225 km from shore in SOCAL and less than 125 km in NWTRC for all but one whale. The exception was Tag #847 that had maximum distances from shore of 621 km within SOCAL and 287 km within NWTRC. Blue whale locations occurred in both SOCAL and NWTRC in 4 of the 6 months in which whales were tracked (August, September, October, and November). Locations inside area W237 of the NWTRC occurred only in August, September, and October.

For the 18 blue whales with locations in SOCAL, time spent there ranged from 1 to 48 percent of their total tracking periods (**Tables 2-5 and 2-6**), representing 37 to 414 h in this Navy area. Time spent in the NWTRC ranged from 3 to 45 percent for the four blue whales with locations there (15 to 1,249 h). One of these whales spent 20 percent of its total tracking period or 468 h within area W237. Percentages of time spent in training areas from Argos locations were similar to those from GPS locations for the same ADB tags.

The two most heavily used BIAs (of the four overlapping with SOCAL) by tagged blue whales were Santa Monica Bay to Long Beach and San Diego (**Tables 2-7 and 2-8**, **Figures 2-5 and 2-8**). Ten blue whales had locations in the Santa Monica Bay to Long Beach BIA, spending 1 to 14 percent of their track time there, and 1 to 18 percent of their locations. Fourteen blue whales had locations in the San Diego BIA (1 to 17 percent of total locations) and spent 1 to 11 percent of their total time there. The track of one blue whale (Tag #10839) crossed the San Nicolas Island BIA, for a total of 5.8 h, but no locations were received from within the BIA itself (**Figure 2-6**). Another blue whale (Tag #10827) spent 16 h in the Tanner-Cortez Bank BIA (**Figure 2-7**), representing less than 1 percent of its total track time and 1 percent of its locations. All of the blue whale locations within these four BIAs occurred in August or September, the timing of which falls within the months of primary occurrence (June-October) listed for those BIAs (Calambokidis et al. 2015).

Five blue whales provided enough locations to calculate HRs and core areas within waters of the U.S. Exclusive Economic Zone (**Table 2-9 and Figure 2-9**). HR sizes ranged from 50,179 to 176,028 square kilometers (km^2) (mean=145,301.6 km^2; standard deviation [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, Point Conception, and the Channel Islands. Core areas 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 core areas for all five blue whales, was between Point Dume and Mugu canyons and seaward to approximately 30 km from shore.

2.2.2 Fin Whales

Six tags were deployed on fin whales between 3 and 15 August 2014 (**Table 2-10**). Locations were received from all tags, providing tracking periods ranging from 4.9 to 143.7 d. Locations extended along the coastline from 30.0 to 42.3^{o} N, with distance to shore ranging from less than 1 to 231.9 km (**Table 2-11**). After spending time in the inner Southern California Bight waters, fin whale movement was predominantly directed offshore, beyond the Channel Islands (**Figure 2-10**). 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 SPOT-5 tags were spread out between San Clemente Island in southern California and the Oregon/California border. One of these latter 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.

None of the tagged fin whales were tracked within GOA. Four fin whales had locations within SOCAL and one had locations within NWTRC (**Tables 2-12 and 2-13**, **Figures 2-11 and 2-12**). There were no fin whale locations inside area W237 within the NWTRC. The maximum distance from shore for these locations was 83 km within SOCAL and 72 km within NWTRC. Fin whale locations occurred in SOCAL in all 5 months in which they were tracked (August, September, October, November, and December), but in only 2 months in NWTRC (August and September).

The four fin whales with locations in SOCAL spent from less than 1 to 39 percent of their total tracking periods in the training range (**Tables 2-12 and 2-13**), representing 1 to 965 h. One fin whale spent 811 h in the NWTRC, or 51 percent of its tracking period. GPS locations from the ADB tags provided slightly higher percentages of time spent in SOCAL than did the Argos locations from those same tags (47 and 56 percent of total track time for GPS locations versus 39 and 38 percent of total track time for Argos locations), attributable perhaps to the higher temporal resolution for GPS locations.

Three fin whale tags provided enough locations to calculate HRs and core areas within the EEZ waters of the U.S (**Table 2-14 and Figure 2-13**). 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. Core areas 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 core areas. 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.

2.3 Discussion

Blue whales were both more numerous and easier to approach than fin whales during the field efforts in southern California in August and September 2014, with the result that many more tags were applied to blue whales than fins (24 blue whales versus 6 fin whales). A comparison of tracking durations between the two species is unwarranted because of these unequal sample sizes, especially given the small sample for fin whales, and the fact that one blue whale tag was still transmitting at the time of report preparation. Nevertheless, the median tracking duration for SPOT-5 tags on fin whales (74.4 d) was 72 percent longer than for blue whales (43.3 d).

With the close proximity of tagging locations to the SOCAL area, it is not surprising that whales spent time there, with 18 blue whales and 4 fin whales having locations inside SOCAL. What is surprising is that the majority of the blue whales spent less than 25 percent of their locations or time in the SOCAL area and eight whales (six blue whales and two fin whales) had no locations in SOCAL at all. Time of year for these locations was probably a contributing factor, and it is possible that more locations/whales would occur in SOCAL if tagging took place earlier in the feeding season, or if tags lasted into the whales' southward migration from areas further north.

Only one-sixth of the tagged blue whales traveled into the NWTRC area during their tracking period. Three of these four animals moved out of NWTRC, heading southward before their tags stopped transmitting. The fourth whale's tag stopped transmitting (in early November) while it was still inside the NWTRC area. This latter whale was the only one to have locations inside area W237. The paucity of tagged blue whale presence in NWTRC may reflect differing individual preferences, short tracking periods, or both. We can be fairly confident that nine of the tagged blue whales did not travel into the NWTRC area in the fall and early winter of 2014. Eight of these whales were halfway down the Baja California coast or farther by mid-October and the ninth one had almost reached the southern tip of Baja California by mid-November. It is highly unlikely that these whales would have migrated north to NWTRC before January 2015. We cannot rule out the possibility that some or all of the remaining 11 whales may have been tracked into the NWTRC area had their tags lasted longer. Two of these whales provided no locations at all, and three were only tracked for 1 week or less. The other six were tracked for periods ranging from 18.9 to 39.8 d, giving them plenty of time to reach the NWTRC area, but as the majority of their locations were in southern California/northern Mexico waters, travel north into NWTRC was highly unlikely for these whales.

Only one fin whale was tracked in the NWTRC area, with locations there in August and September. This whale had the shortest tracking period of the three whales equipped with SPOT-5 tags (66.3 d compared to 74.4 d and 143.7 d). The other two whales with SPOT-5 tags showed no indication of heading north into NWTRC, focusing their movements off central and southern California as well as Mexico. The ADB tags on fin whales transmitted for periods of two weeks or less. As with blue whales, the low proportion of tagged fin whales in NWTRC could reflect individual preferences or short tracking periods.

While the number of whales visiting the NWTRC area was not high, three of the five whales that traveled there (two blue whales and one fin whale) spent more than 40 percent of their 2+ month tracking periods in this Navy area (811 to 1,249 h). This resulted in core areas also being identified for these whales in NWTRC and highlights the area as important feeding habitat for both blue and fin whales.

In terms of BIAs that overlapped Navy areas, Santa Monica Bay to Long Beach and San Diego were the most heavily used by tagged blue whales in 2014; however, percentage of time spent in these areas did not exceed 15 percent for any whale. The Tanner-Cortez Bank and San Nicolas Island BIAs saw very little use by tagged blue whales, despite being identified, along with the other BIAs, as areas of more consistent occurrence from year to year (Calambokidis et al. 2015). Tracking duration and/or environmental conditions in the summer/fall of 2014 may have played a role in the lack of locations in the Tanner-Cortez Bank and San Nicolas Island BIAs, or perhaps in the short-term use of the other two BIAs.

NOAA has not designated BIAs for fin whales, but BIAs for this species likely should include offshore areas as well as occasional concentrations in more coastal areas (Calambokidis et al. 2015). The core areas 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 (Calambokidis et al. 2015), specifically those off Monterey Bay, Point Buchon, and south and west of San Miguel Island. 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. All three fin whales in this study carrying the longer-term SPOT-5 tags visited more than one of the regions delineated by Falcone et al. (2011), after remaining in the area in which they were tagged for several days. One whale spent time in both northern California and the Southern California Bight regions. The other two fin whales spent time in three regions; one in the Southern California Bight, northern California, and Oregon-Washington regions, and one in the Southern California Bight, northern California, and Baja California regions. Contrary to photo-ID studies, these inter-regional movements occurred within the same year and involved movements back and forth between the regions, rather than unidirectional movement that might signify migration (at least in the conventional sense).

Additional tagging efforts in July 2015 will add valuable early-season information to the results obtained in the 2014 study. They 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, potentially identifying use of other Navy areas or additional BIAs. With such information, the Navy will be better equipped toward their efforts to minimize effects of military activities on blue and fin whales.

2.4 Literature Cited

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Table 2-1. Deployment and performance data for satellite-monitored radio tags attached to blue whales in southern California, 2014.

Argos Locations							GPS Locations				
Tag #	**Tag Type**	**Deploy Date**	**Last Transmission**	**# of Days Tracked**	**# of Locations**	**Total Distance (km)**	**Recovered**	**Last Location**	**# Days of Tracked**	**# of Locations**	**Total Distance (km)**
847	SPOT-5	3-Aug-14	26-Nov-14	115.5	315	9,205					
5641	SPOT-5	2-Aug-14	6-Nov-14	95.6	422	5,998					
5784	SPOT-5	7-Aug-14	1-Sep-14	24.8	0	0					
5826	SPOT-5	11-Sep-14	11-Sep-14	0.0	0	0					
5840	SPOT-5	5-Aug-14	12-Aug-14	7.2	15	275					
5921	SPOT-5	9-Sep-14	14-Feb-15	156.7	315	7,707					
5922	SPOT-5	12-Sep-14	3-Nov-14	52.1	126	2,296					
5923	SPOT-5	8-Aug-14	5-Sep-14	27.5	112	1,630					
10826	SPOT-5	9-Sep-14	23-Oct-14	43.3	117	2,418					
10827	SPOT-5*	12-Sep-14	15-Feb-15	156.8	385	9,152					
10829	SPOT-5	12-Sep-14	6-Oct-14	23.8	77	1,855					
10830	SPOT-5	10-Aug-14	11-Aug-14	0.7	5	60					
10833	SPOT-5	11-Sep-14	17-Nov-14	66.5	112	1,763					
10834	SPOT-5	8-Aug-14	19-Nov-14	102.8	361	6,593					
10836	SPOT-5	13-Aug-14	6-Dec-14	115.3	317	6,438					
10839	SPOT-5	11-Sep-14	6-Oct-14	24.6	41	1,912					
10840	SPOT-5	8-Aug-14	13-Aug-14	4.5	15	187					
23029	SPOT-5	5-Aug-14	26-Aug-14	21.0	58	684					
23030	SPOT-5	12-Sep-14	18-Nov-14	66.6	45	5,393					
23031	SPOT-5	5-Aug-14	14-Sep-14	39.8	71	2,744					
5644	ADB[+]	4-Aug-14	23-Aug-14	18.9	263	1,720	Yes	23-Aug-14	19.0	185	1,454
5650	ADB[+++]	4-Aug-14	23-Aug-14	19.0	268	1,424	Yes	24-Aug-14	20.0	2297	1,708
5655	ADB[+]	6-Aug-14	26-Aug-14	19.8	239	1,530	Yes	26-Aug-14	19.8	799	1,563
5803	ADB[+++]	4-Aug-14	23-Aug-14	18.3	201	1,704	Yes	23-Aug-14	18.3	2539	2,033

*Tag is still transmitting as of 15-Feb-15, [+]Tag is FastLoc® v.1, [+++]Tag is FastLoc® v.3

Table 2-2. Responses of blue and fin whales to satellite tagging, southern California, 2014.

Blue whales

# of	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
2	No response
1	Slight flinch

Fin whales

# of	Response to tagging/biopsy darting
4	No response
2	Rolled toward boat

Table 2-3. Resightings and tag site descriptions for blue and fin whales satellite-tagged off southern California, 2014. Size estimates are approximate.

Tag #	Days After Tagging							
	1	2	3	4	5	6	7	8
Blue Whales								
5784	swelling 20X4 cm, 1 cm high							
10834		swelling 30X15 cm, 3 cm high and tissue extrusion 1-cm diam.		swelling 30X15 cm, 3 cm high and tissue extrusion 1-cm diam.	swelling 30X15 cm, 3 cm high			
10839	no change							
10840	no change			no change				
23029	no change				no change			no change
5644[+]			no change					
5650[+++]	no change			lightened skin pigmentation 15 cm diam.	lightened skin pigmentation 15 cm diam.			
5655[+]	no change		no change	no change	lightened skin pigmentation 10 cm diam.	normal skin pigmentation	normal skin pigmentation	
5803[+++]	no change					no change		
Fin Whales								
10831	Swelling 35X20 cm, 4 cm high	Swelling 35X20 cm, 4 cm high	Swelling 25X15 cm, 3 cm high	Swelling 15X15 cm, 2 cm high		Swelling 15X10 cm, 1 cm high		

[+] ADB Tag is FastLoc® v.1, [+++] ADB Tag is FastLoc® v.3

Table 2-4. Great-circle distances (km) to nearest point on land for blue whales tagged off southern California, 2014. For locations west of Vancouver Island, British Columbia, Vancouver Island was used when determining nearest point to land. SD is standard deviation.

Tag #	Tag Type	# Locations	Mean (km)	SD (km)	Minimum (km)	Maximum (km)
847	SPOT-5	316	294.7	264.13	0.4	676.0
5641	SPOT-5	422	38.0	26.45	0.9	165.2
5840	SPOT-5	16	37.8	33.04	6.5	120.9
5921	SPOT-5	303	374.9	246.10	8.5	813.7
5922	SPOT-5	127	55.1	31.02	3.0	139.7
5923	SPOT-5	113	143.1	64.83	0.4	274.7
10826	SPOT-5	118	81.9	74.38	0.1	257.0
10827	SPOT-5	301	494.7	305.80	3.8	884.8
10829	SPOT-5	78	101.1	84.97	2.2	265.4
10830	SPOT-5	6	6.5	2.08	4.1	10.0
10833	SPOT-5	108	61.8	51.51	7.9	215.9
10834	SPOT-5	362	52.8	41.29	1.1	229.1
10836	SPOT-5	317	69.4	43.35	<1	203.7
10839	SPOT-5	42	89.5	68.60	0.9	231.9
10840	SPOT-5	17	12.1	9.99	0.6	43.7
23029	SPOT-5	59	8.6	7.04	0.4	32.0
23030	SPOT-5	44	163.1	169.41	4.5	651.7
23031	SPOT-5	71	69.0	50.56	1.6	188.5
5644^{+}	ADB	264	18.5	18.59	0.5	86.0
5650^{+++}	ADB	269	44.6	46.78	<1	136.5
5655^{+}	ADB	240	11.5	6.04	0.2	41.5
5803^{+++}	ADB	202	28.3	25.49	0.7	99.1

*Tag is still transmitting as of 15-Feb-15, $^{+}$Tag is FastLoc® v.1, +$^{++}$Tag is FastLoc® v.3

Table 2-5. Percentage of Argos locations and time spent inside the SOCAL and NWTRC areas for blue whales tagged off southern California, 2014.

Argos Locations												
		Total		SOCAL			NWTRC			W237		
Tag #	Tag Type	# Locations	# Days Tracked	% of Locations	% of Time Tracked	Hours	% of Locations	% of Time Tracked	Hours	% of Locations	% of Time Tracked	Hours
847	SPOT-5	315	115.5	6	5	131	26	21	573	0	0	0
5641	SPOT-5	422	95.6	0	0	0	42	40	928	19	20	468
5784	SPOT-5	0	24.8	0	0	0	0	0	0	0	0	0
5826	SPOT-5	0	0.0	0	0	0	0	0	0	0	0	0
5840	SPOT-5	15	7.2	47	48	83	0	0	0	0	0	0
5921	SPOT-5	315	156.7	2	1	37	0	0	0	0	0	0
5922	SPOT-5	126	52.1	7	5	60	0	0	0	0	0	0
5923	SPOT-5	112	27.5	14	13	83	0	0	0	0	0	0
10826	SPOT-5	117	43.3	11	8	83	0	0	0	0	0	0
10827*	SPOT-5	385	156.8	11	7	251	0	0	0	0	0	0
10829	SPOT-5	77	23.8	22	24	135	0	0	0	0	0	0
10830	SPOT-5	5	0.7	0	0	0	0	0	0	0	0	0
10833	SPOT-5	107	66.5	17	8	122	0	0	0	0	0	0
10834	SPOT-5	361	102.8	19	17	414	0	0	0	0	0	0
10836	SPOT-5	317	115.3	3	3	91	50	45	1249	0	0	0
10839	SPOT-5	41	24.6	49	40	235	0	0	0	0	0	0
10840	SPOT-5	16	4.5	0	0	0	0	0	0	0	0	0
23029	SPOT-5	58	21.0	5	11	57	0	0	0	0	0	0
23030	SPOT-5	43	66.6	21	7	115	0	0	0	0	0	0
23031	SPOT-5	70	39.8	10	10	98	0	0	0	0	0	0
5644[+]	ADB	263	18.9	39	38	174	0	0	0	0	0	0
5650[+++]	ADB+	268	19.0	39	38	175	0	0	0	0	0	0
5655[+]	ADB	239	19.8	44	45	216	0	0	0	0	0	0
5803[+++]	ADB+	201	18.3	0	0	0	1	3	15	0	0	0

*Tag is still transmitting as of 15-Feb-15, [+]Tag is FastLoc® v.1, +[++]Tag is FastLoc® v.3

Table 2-6. Percentage of GPS locations and time spent inside the SOCAL and NWTRC areas for blue whales tagged off southern California, 2014.

GPS Locations												
		Total		SOCAL			NWTRC			W237		
Tag #	Tag Type	# Locations	# Days Tracked	% of Locations	% of Time Tracked	Hours	% of Locations	% of Time Tracked	Hours	% of Locations	% of Time Tracked	Hours
5644[+]	ADB	185	19.0	28	38	175	0	0	0	0	0	0
5650[+++]	ADB+	1,697	20.0	10	37	176	0	0	0	0	0	0
5655[+]	ADB	799	19.8	44	45	212	0	0	0	0	0	0
5803[+++]	ADB+	2,539	18.3	0	0	0	2	2	8	0	0	0

[+]Tag is FastLoc® v.1, +[++]Tag is FastLoc® v.3

Table 2-7. Percentage of Argos locations and time spent inside blue whale BIAs that overlap SOCAL for blue whales tagged off southern California, 2014.

Argos Locations															
				Santa Monica			San Nicolas			Tanner-Cortez			San Diego		
Tag #	Tag Type	# Locations	# Days Tracked	% of Locations	% of Time Tracked	Hours	% of Locations	% of Time Tracked	Hours	% of Locations	% of Time Tracked	Hours	% of Locations	% of Time Tracked	Hours
847	SPOT-5	315	115.5	0	0	0	0	0	0	0	0	0	0	0	0
5641	SPOT-5	422	95.6	1	1	32	0	0	0	0	0	0	0	0	0
5784*	SPOT-5	0	24.8	0	0	0	0	0	0	0	0	0	0	0	0
5826*	SPOT-5	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0
5840	SPOT-5	15	7.2	13	8	14	0	0	0	0	0	0	0	0	0
5921	SPOT-5	315	156.7	0	0	0	0	0	0	0	0	0	2	1	25
5922	SPOT-5	126	52.1	0	0	0	0	0	0	0	0	0	6	4	53
5923	SPOT-5	112	27.5	1	1	6	0	0	0	0	0	0	1	1	7
10826	SPOT-5	117	43.3	0	0	0	0	0	0	0	0	0	3	2	25
10827	SPOT-5	385	156.8	0	0	0	0	0	0	1	<1	16	1	1	30
10829	SPOT-5	77	23.8	0	0	0	0	0	0	0	0	0	4	2	11
10830	SPOT-5	5	0.7	0	0	0	0	0	0	0	0	0	0	0	0
10833	SPOT-5	107	66.5	0	0	0	0	0	0	0	0	0	10	5	73
10834	SPOT-5	361	102.8	9	6	157	0	0	0	0	0	0	4	4	89
10836	SPOT-5	317	115.3	0	0	0	0	0	0	0	0	0	0	0	0
10839	SPOT-5	41	24.6	0	0	0	0	1	5.8	0	0	0	17	9	55
10840	SPOT-5	16	4.5	0	0	0	0	0	0	0	0	0	0	0	0
23029	SPOT-5	58	21.0	7	5	25	0	0	0	0	0	0	0	0	0
23030	SPOT-5	43	66.6	0	0	0	0	0	0	0	0	0	12	3	49
23031	SPOT-5	70	39.8	3	5	46	0	0	0	0	0	0	1	2	19
5644[+]	ADB	263	18.9	16	14	64	0	0	0	0	0	0	5	5	22
5650[+++]	ADB+	268	19.0	4	4	17	0	0	0	0	0	0	1	1	4
5655[+]	ADB	239	19.8	8	8	37	0	0	0	0	0	0	10	11	51
5803[+++]	ADB+	201	18.3	8	8	35	0	0	0	0	0	0	0	0	0

*Tag is still transmitting as of 15-Feb-15, [+]Tag is FastLoc® v.1, [+++]Tag is FastLoc® v.3

Table 2-8. Percentage of GPS locations and time spent inside blue whale BIAs that overlap SOCAL for blue whales tagged off southern California, 2014.

GPS Locations															
				Santa Monica			San Nicolas			Tanner-Cortez			San Diego		
Tag #	Tag Type	# Locations	# Days Tracked	% of Locations	% of Time Tracked	Hours	% of Locations	% of Time Tracked	Hours	% of Locations	% of Time Tracked	Hours	% of Locations	% of Time Tracked	Hours
5644+	ADB	185	19.0	18	14	65	0	0	0	0	0	0	4	5	22
5650+++	ADB+	2,297	20.0	4	4	18	0	0	0	0	0	0	1	1	3
5655+	ADB	799	19.8	5	11	52	0	0	0	0	0	0	10	11	54
5803+++	ADB+	2,539	18.3	11	11	47	0	0	0	0	0	0	0	0	0

+Tag is FastLoc® v.1, +++Tag is FastLoc® v.3

Table 2-9. Sizes of HRs and CAs of use in the U.S. EEZ for five blue whales tagged off southern California, 2014.

Blue Whales			
Tag #	# SSM Locations	Home Range Size (km^2)	Core Area Size (km^2)
847	56	171,044	25,423
5641	77	176,028	37,065
10834	76	50,179	13,854
10836	90	190,022	41,199
23031	36	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.

Table 2-10. Deployment and performance data for satellite-monitored radio tags attached to fin whales in southern California, 2014.

Argos Locations							GPS Locations				
Tag #	Tag Type	Deploy Date	Last Transmission	# of Days Tracked	# of Locations	Total Distance (km)	Recovered	Last Location	# of Days Tracked	# of Locations	Total Distance (km)
5648	SPOT-5	3-Aug-14	24-Dec-14	143.7	164	6,230					
10821	SPOT-5	15-Aug-14	29-Oct-14	74.4	199	4,294					
10831	SPOT-5	4-Aug-14	10-Oct-14	66.3	94	2,327					
5685+	ADB	6-Aug-14	21-Aug-14	14.2	71	1,072	Yes	18-Aug-14	11.9	95	1,037
5790+*	ADB	11-Aug-14	25-Aug-14	13.3	88	1,357	No	23-Aug-14	11.8	14	426
5838+*	ADB	11-Aug-14	16-Aug-14	4.9	60	441	No	16-Aug-14	4.1	12	133

+ Tag is FastLoc® v.1

*Tags were not recovered so values are from data transmitted through Argos

Table 2-11. Great-circle distances (km) to nearest point on land for fin whales tagged off southern California, 2014. SD is standard deviation.

Tag #	Tag Type	# Locations	Mean (km)	SD (km)	Minimum (km)	Maximum (km)
5648	SPOT-5	165	51.8	38.85	<1	192.7
10821	SPOT-5	200	104.2	47.65	25.7	231.9
10831	SPOT-5	95	47.6	23.37	2.0	158.9
5685+	ADB	72	109.2	41.93	8.3	186.5
5790+	ADB	89	33.0	29.83	4.4	116.7
5838+	ADB	61	23.7	12.29	5.2	60.4

+ Tag is FastLoc® v.1

Table 2-12. Percentage of Argos locations and time spent inside the SOCAL and NWTRC areas for fin whales tagged off southern California, 2014.

Argos Locations												
		Total		SOCAL			NWTRC			W237		
Tag #	Tag Type	# Locations	# Days Tracked	% of Locations	% of Time Tracked	Hours	% of Locations	% of Time Tracked	Hours	% of Locations	% of Time Tracked	Hours
5648	SPOT-5	164	143.7	35	28	965	0	0	0	0	0	0
10821	SPOT-5	199	74.4	0	0	0	0	0	0	0	0	0
10831	SPOT-5	94	66.3	0	0	0	73	51	811	0	0	0
5685+	ADB	71	14.2	31	39	134	0	0	0	0	0	0
5790+	ADB	88	13.3	41	38	120	0	0	0	0	0	0
5838+	ADB	60	4.9	2	<1	1	0	0	0	0	0	0

+Tag is FastLoc® v.1

Table 2-13. Percentage of GPS locations and time spent inside the SOCAL and NWTRC areas for fin whales tagged off southern California, 2014.

GPS Locations												
		Total		SOCAL			NWTRC			W237		
Tag #	Tag Type	# Locations	# Days Tracked	% of Locations	% of Time Tracked	Hours	% of Locations	% of Time Tracked	Hours	% of Locations	% of Time Tracked	Hours
5685+	ADB	95	11.9	40	47	133	0	0	0	0	0	0
5790+	ADB	14	11.8	64	56	160	0	0	0	0	0	0
5838+	ADB	12	4.1	0	0	0	0	0	0	0	0	0

+Tag is FastLoc® v.1

Table 2-14. Sizes of HRs and CAs of use in the U.S. EEZ for three fin whales tagged off southern California, 2014.

Fin Whales			
Tag #	# SSM Locations	Home Range Size (km^2)	Core Area Size (km^2)
5648	103	63,097	10,376
10821	75	50,319	12,571
10831	54	80,130	11,793
Mean		64,515.5	11,580.0

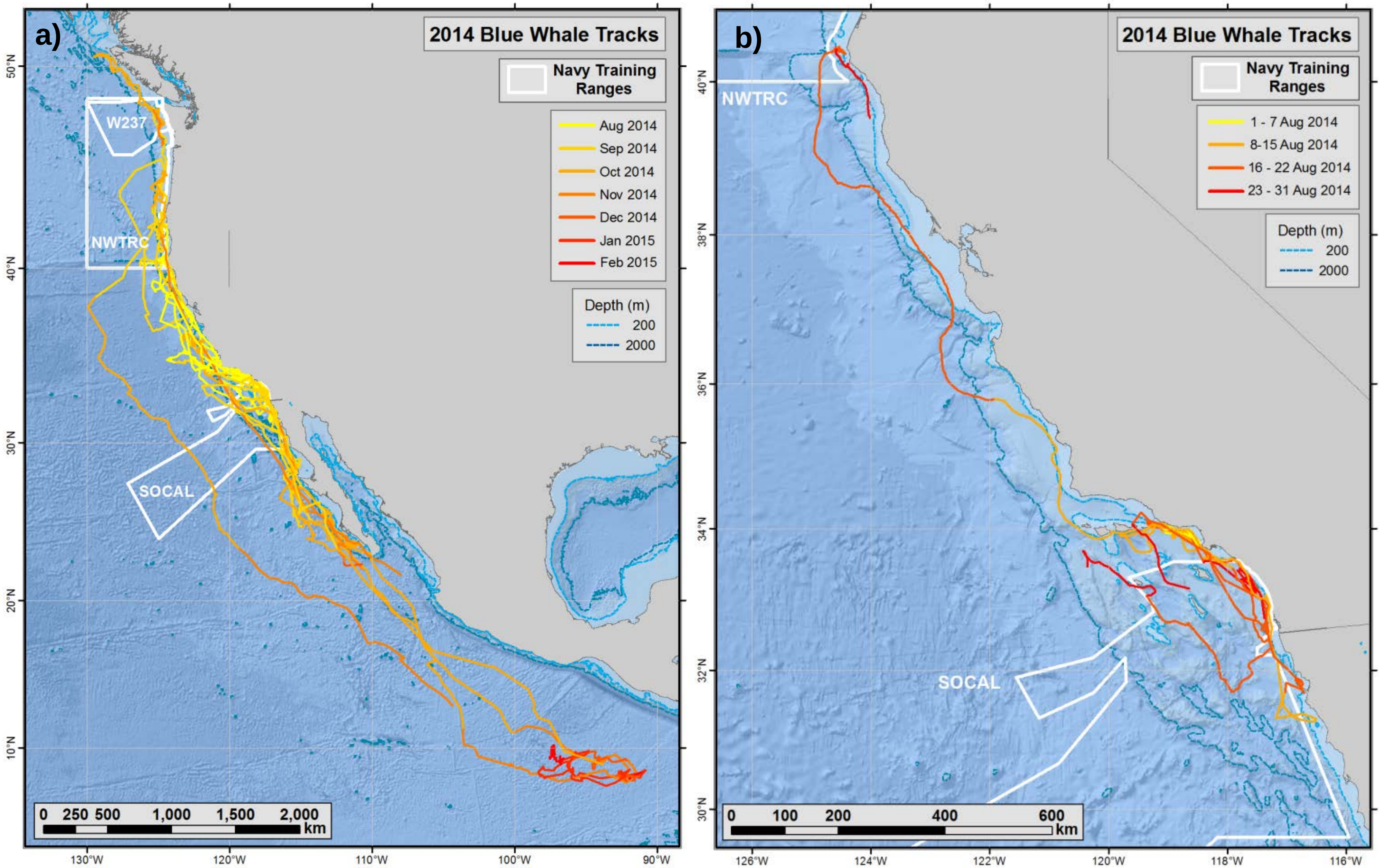

Figure 2-1. Satellite-monitored radio tracks for blue whales tagged off southern California, 2014: a) Argos locations from SPOT-5 (*n*=18) and ADB (*n*=4) tags. b) GPS locations from ADB tags (*n*=4).

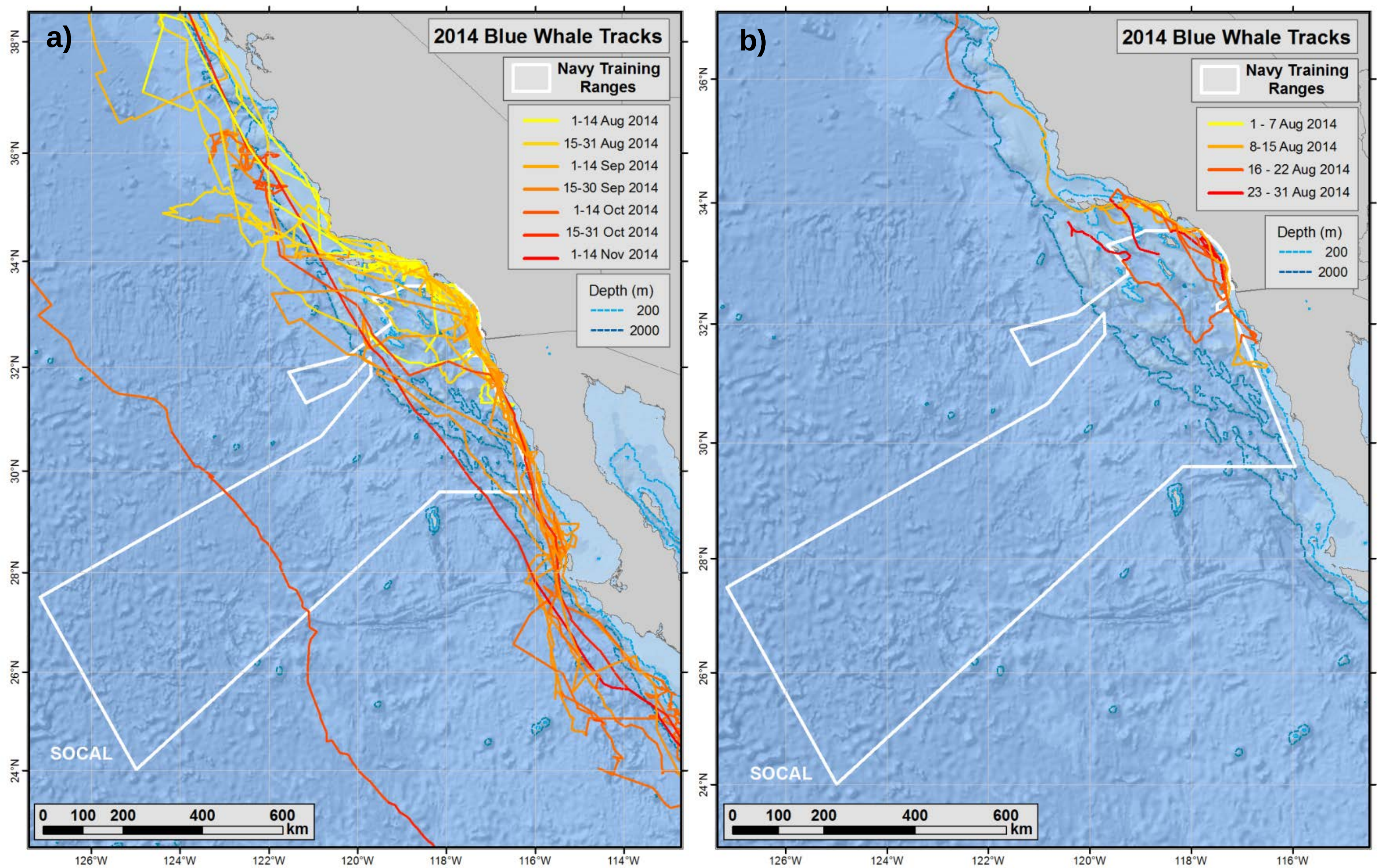

Figure 2-2. Satellite-monitored radio tracks in SOCAL for blue whales tagged off southern California, 2014: a) Argos locations from SPOT-5 (*n*=15) and ADB (*n*=3) tags. b) GPS locations from ADB tags (*n*=3).

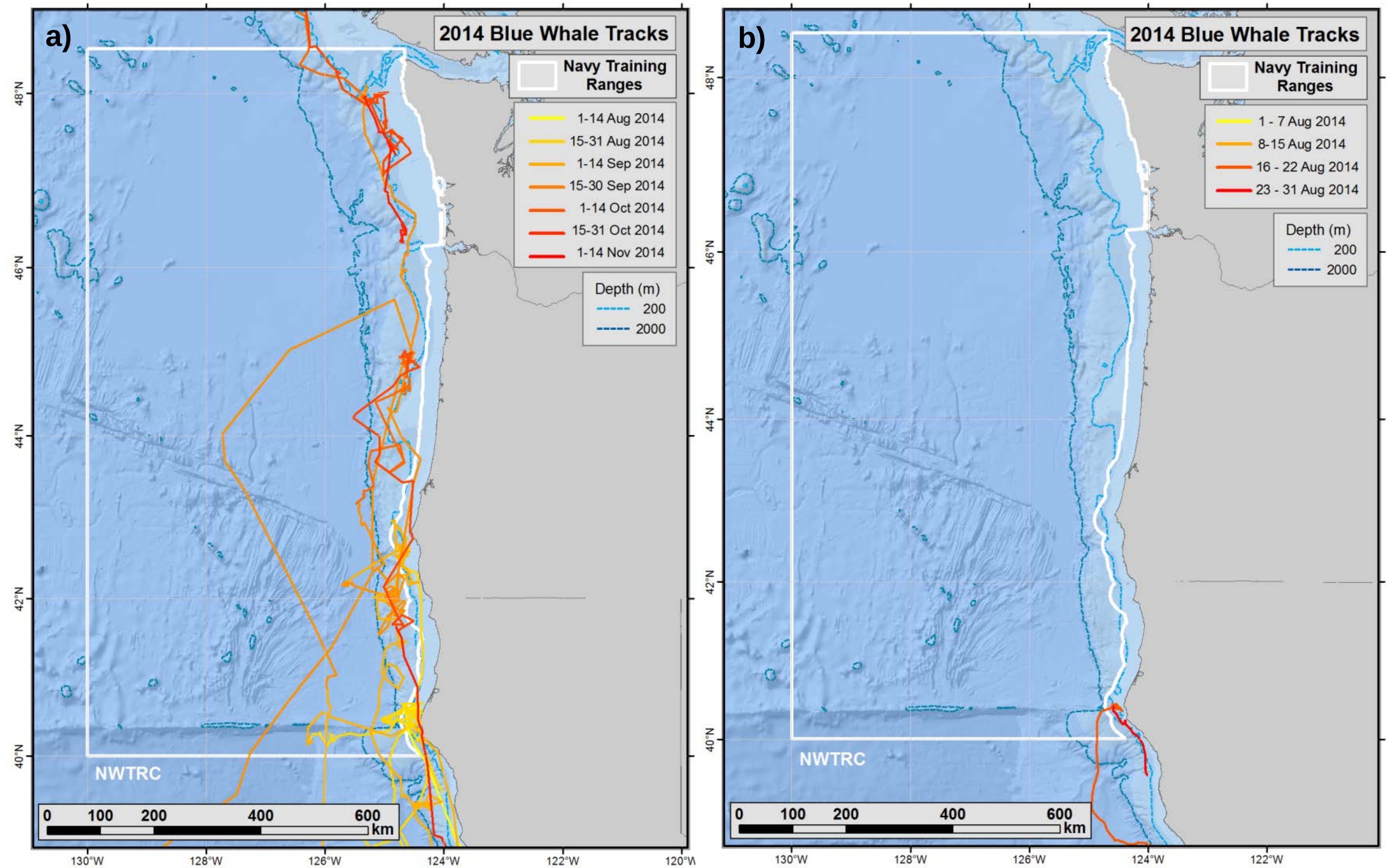

Figure 2-3. Satellite-monitored radio tracks in NWTRC for blue whales tagged off southern California, 2014: a) Argos locations from SPOT-5 (*n*=3) and ADB (*n*=1) tags. b) GPS locations from ADB tags (*n*=1).

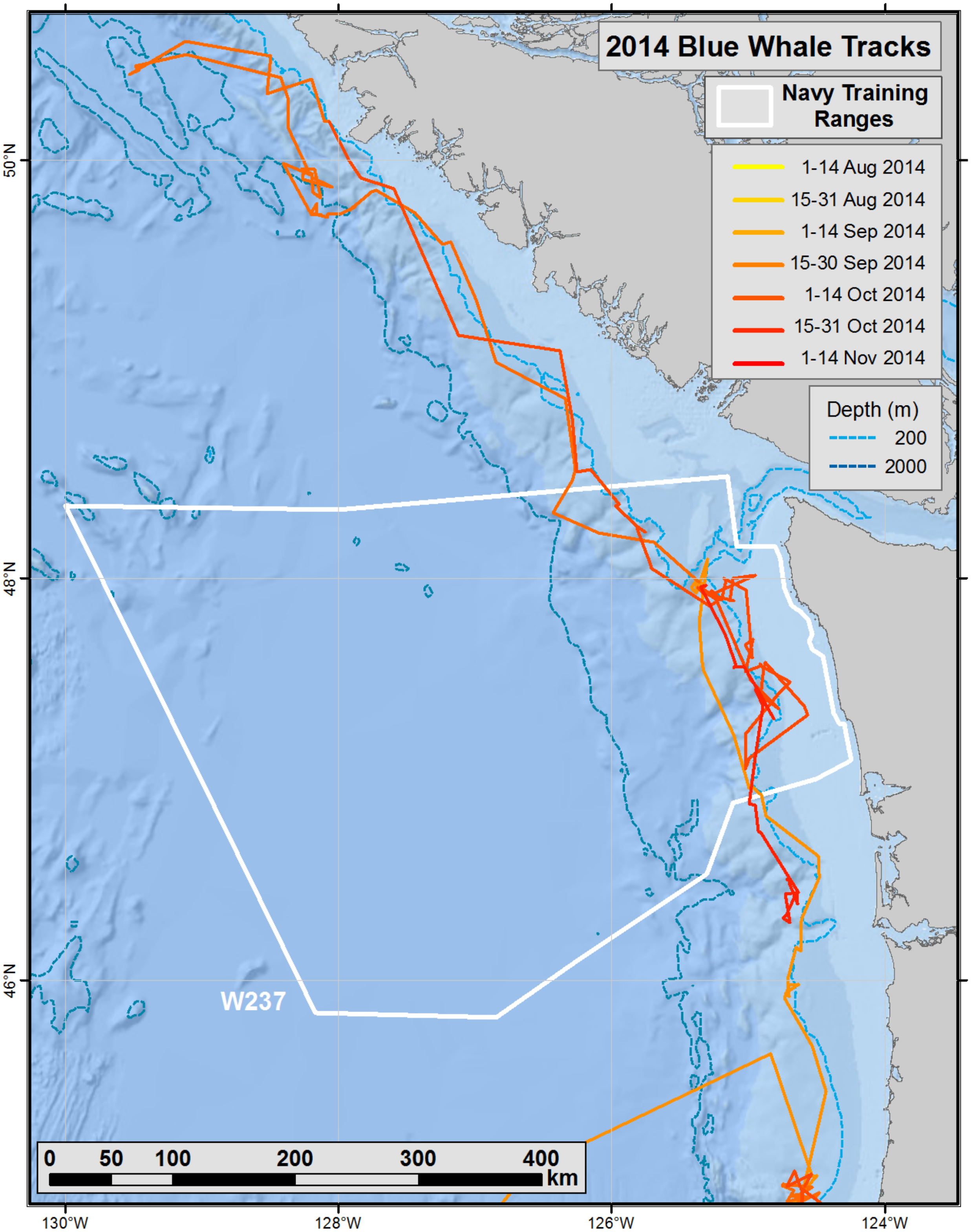

Figure 2-4. Satellite-monitored radio tracks for blue whales tagged off southern California, 2014, showing tracks of one whale inside area W237 of NWTRC.

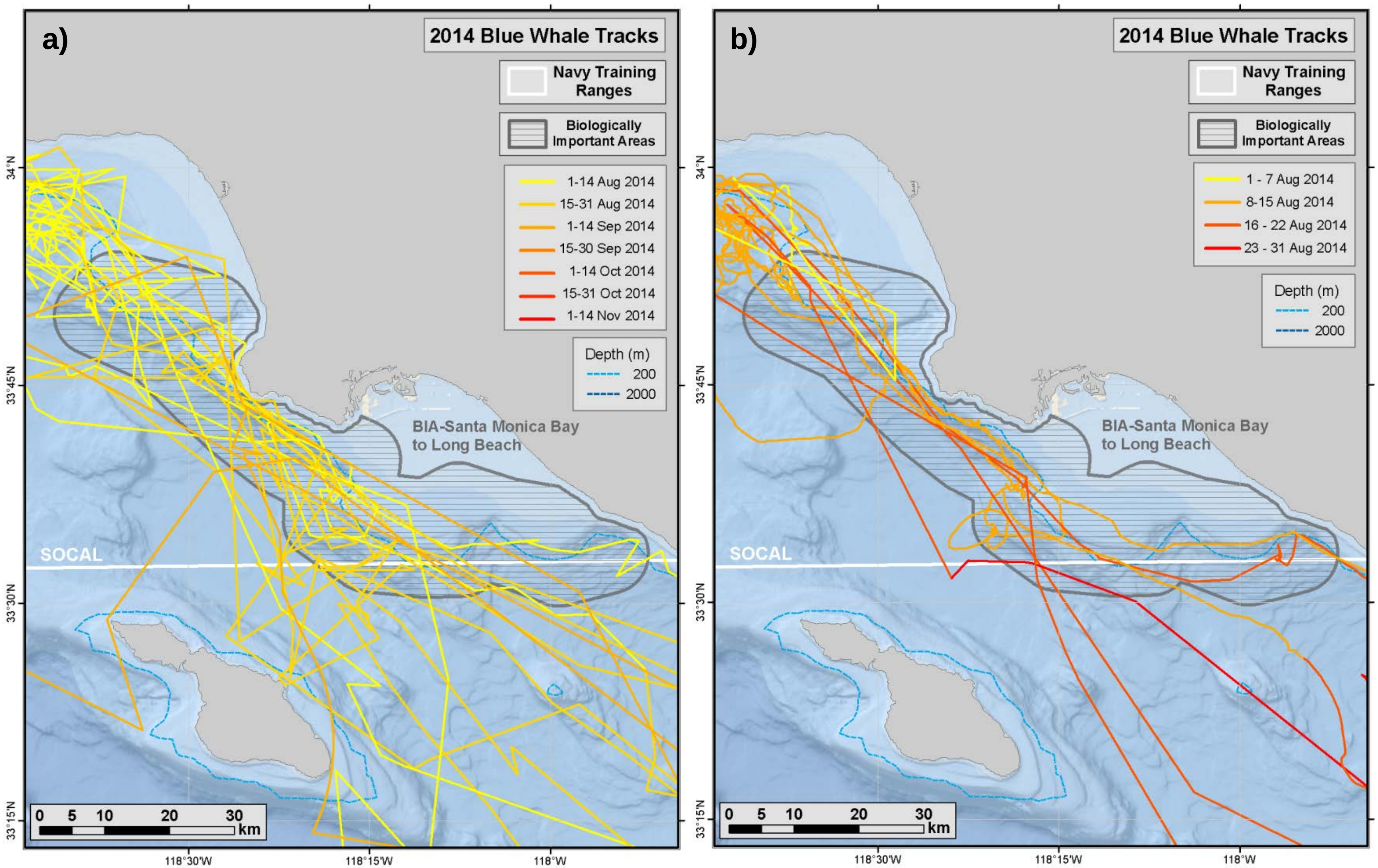

Figure 2-5. Satellite-monitored radio tracks in the Santa Monica Bay to Long Beach BIA for blue whales tagged off southern California, 2014. a) Argos locations from SPOT-5 (*n*=6) and ADB (*n*=4) tags. b) GPS locations from ADB tags (*n*=4).

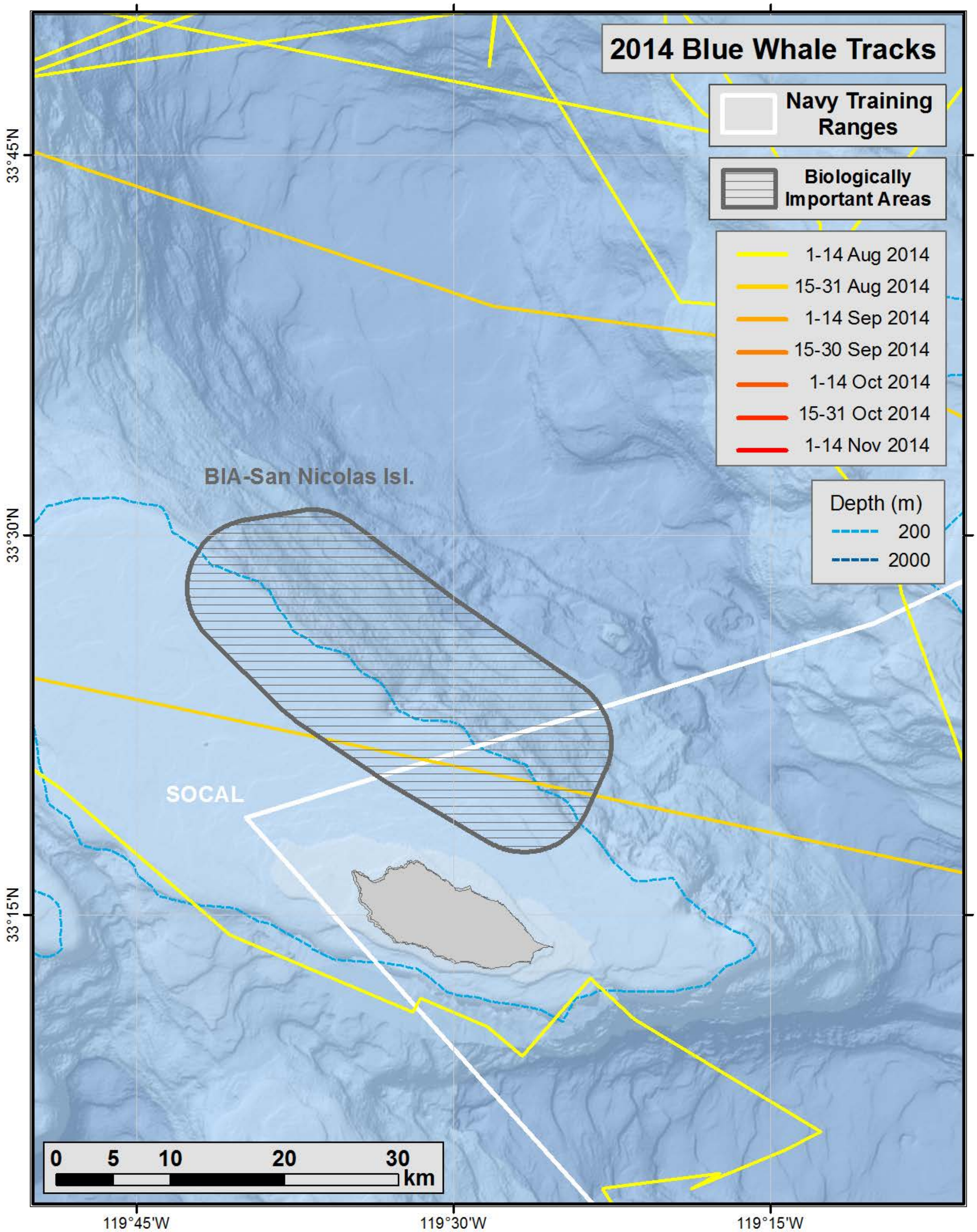

Figure 2-6. Satellite-monitored radio tracks from Argos locations of blue whales tagged off southern California, 2014, showing the track of one blue whale in the San Nicolas Island BIA.

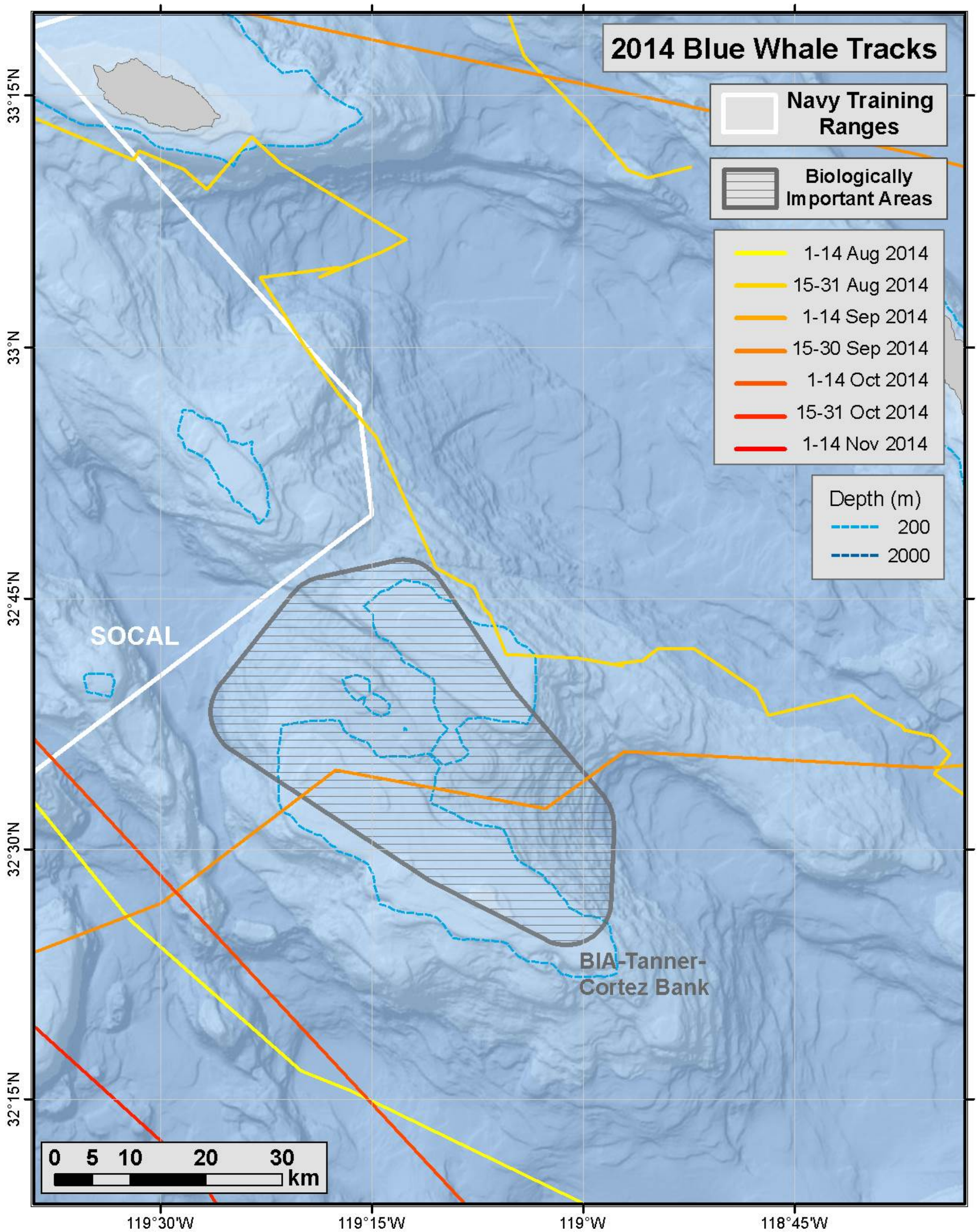

Figure 2-7. Satellite-monitored radio tracks from Argos locations of blue whales tagged off southern California, 2014, showing the track of one blue whale in the Tanner-Cortez Bank BIA.

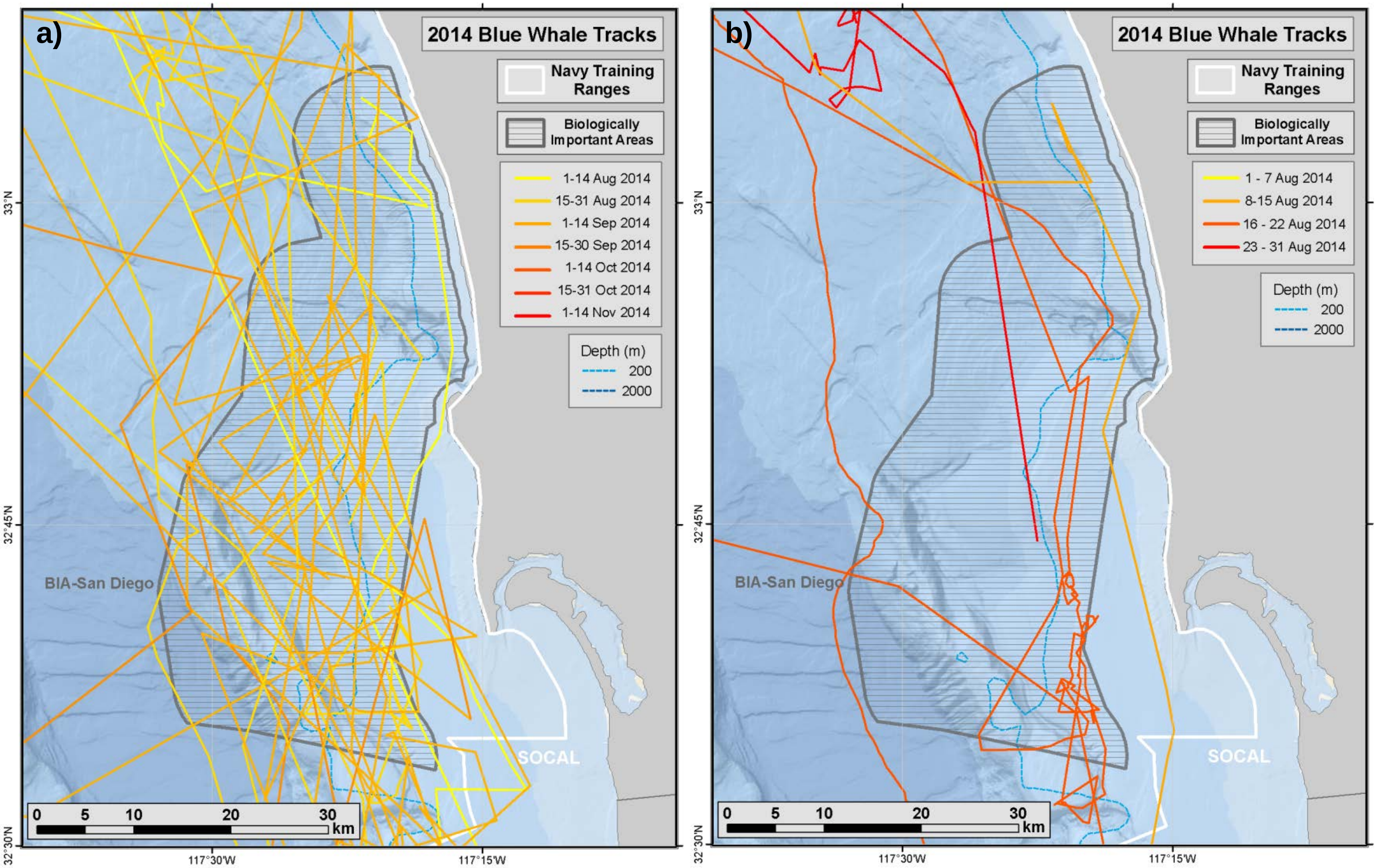

Figure 2-8. Satellite-monitored radio tracks in the San Diego BIA for blue whales tagged off southern California, 2014: a) Argos locations from SPOT-5 (*n*=11) and ADB (*n*=3) tags, b) GPS locations from ADB tags (*n*=3).

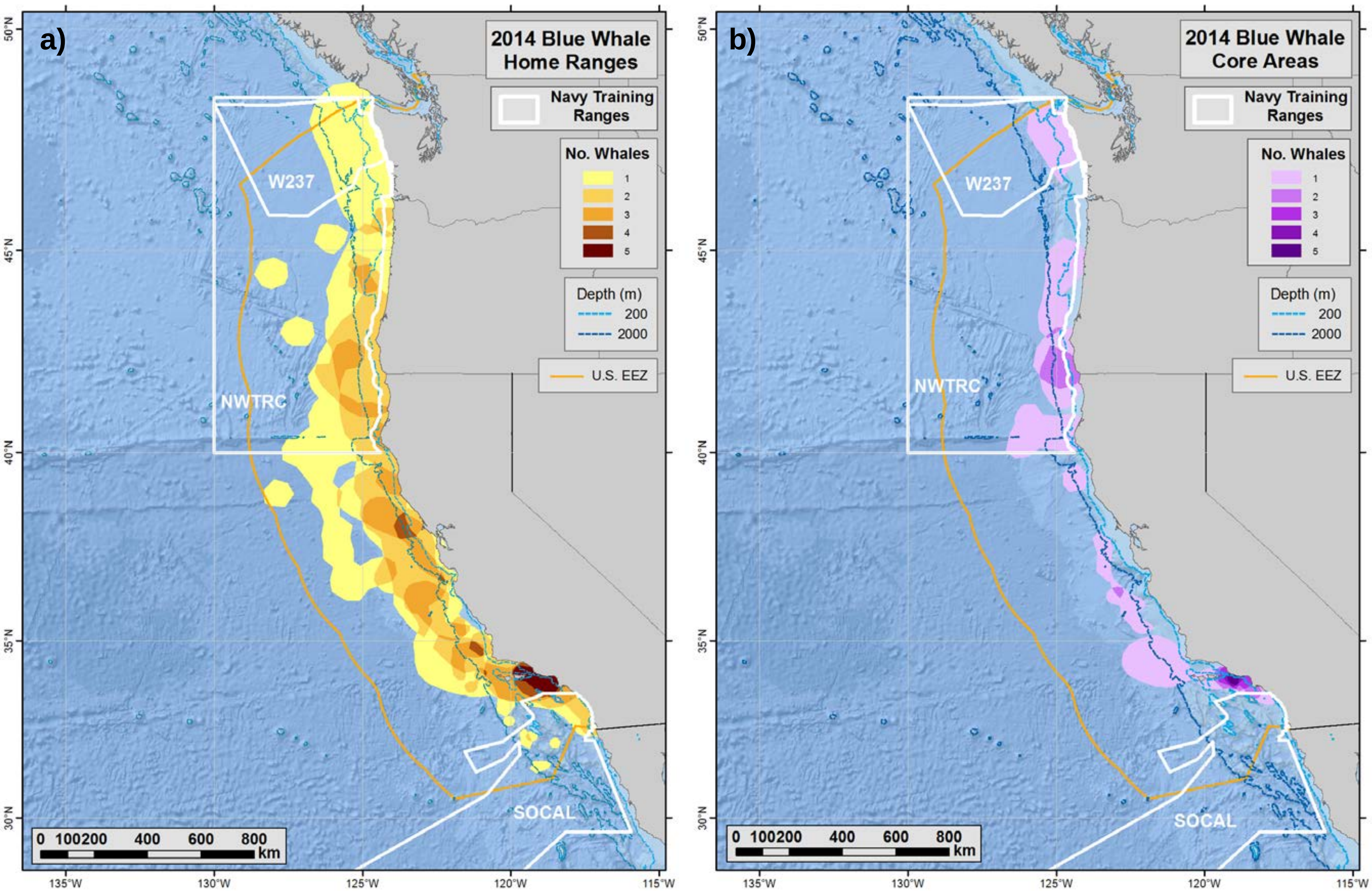

Figure 2-9. Home ranges (a) and core areas of use (b) in the U.S. EEZ for 5 blue whales tagged off southern California, 2014. Shading represents the number of individual whales with overlapping home ranges and core areas.

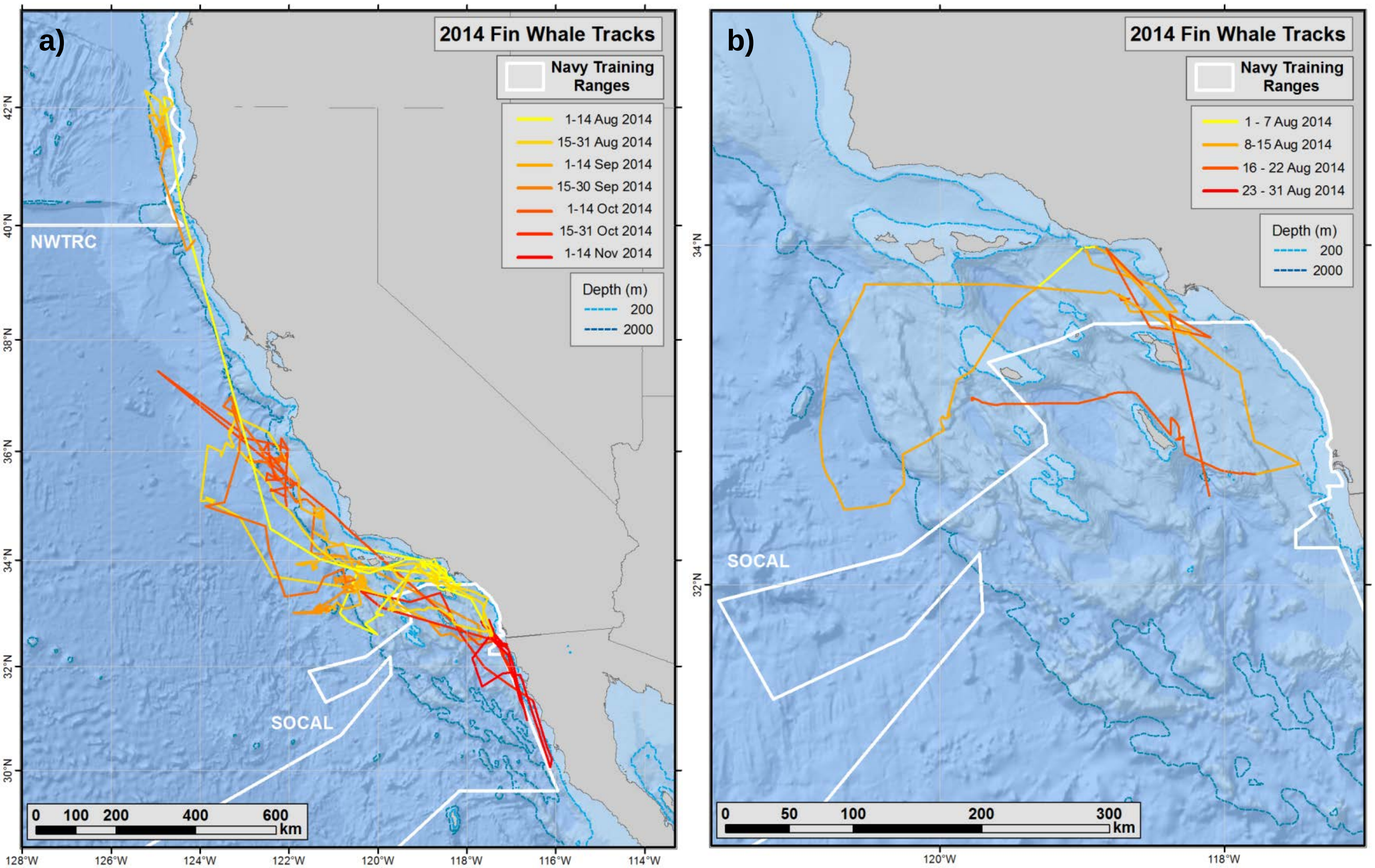

Figure 2-10. Satellite-monitored radio tracks for fin whales tagged off southern California, 2014. a) Argos locations from SPOT-5 (*n*=3) and ADB (*n*=3) tags. b) GPS locations from ADB tags (*n*=3). Two ADB tags were not recovered, so only GPS locations transmitted through Argos are depicted here for those tags (14 locations for Tag #5790, 12 locations for Tag #5838).

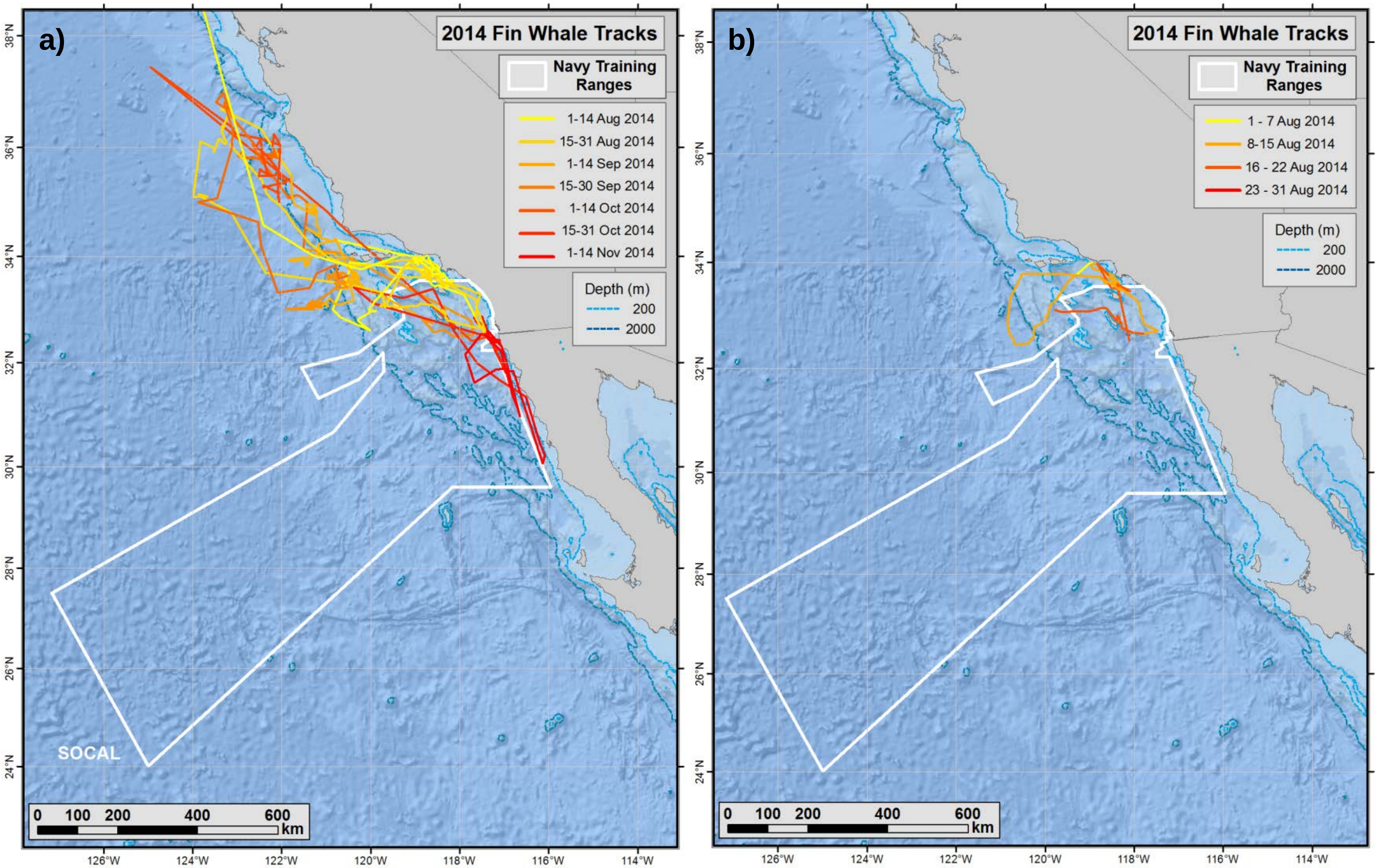

Figure 2-11. Satellite-monitored radio tracks in SOCAL for fin whales tagged off southern California, 2014. a) Argos locations from SPOT-5 (*n*=1) and ADB (*n*=3) tags. b) GPS locations from ADB tags (*n*=2). One ADB tag with locations in SOCAL was not recovered, so only GPS locations transmitted through Argos are depicted here for this tag (9 locations for Tag #5790).

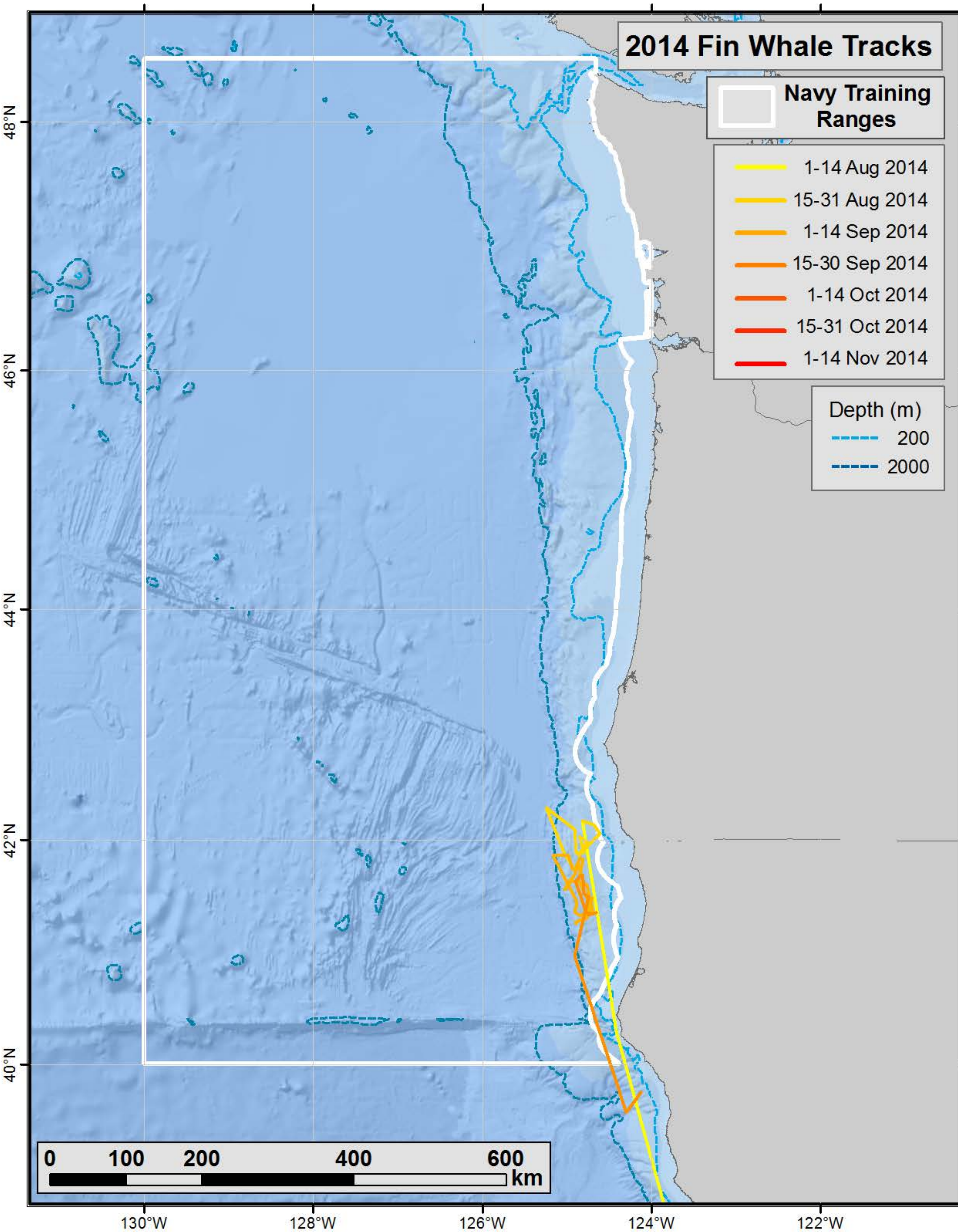

Figure 2-12. Satellite-monitored radio track in NWTRC for a fin whale tagged with a SPOT-5 Argos transmitter off southern California, 2014

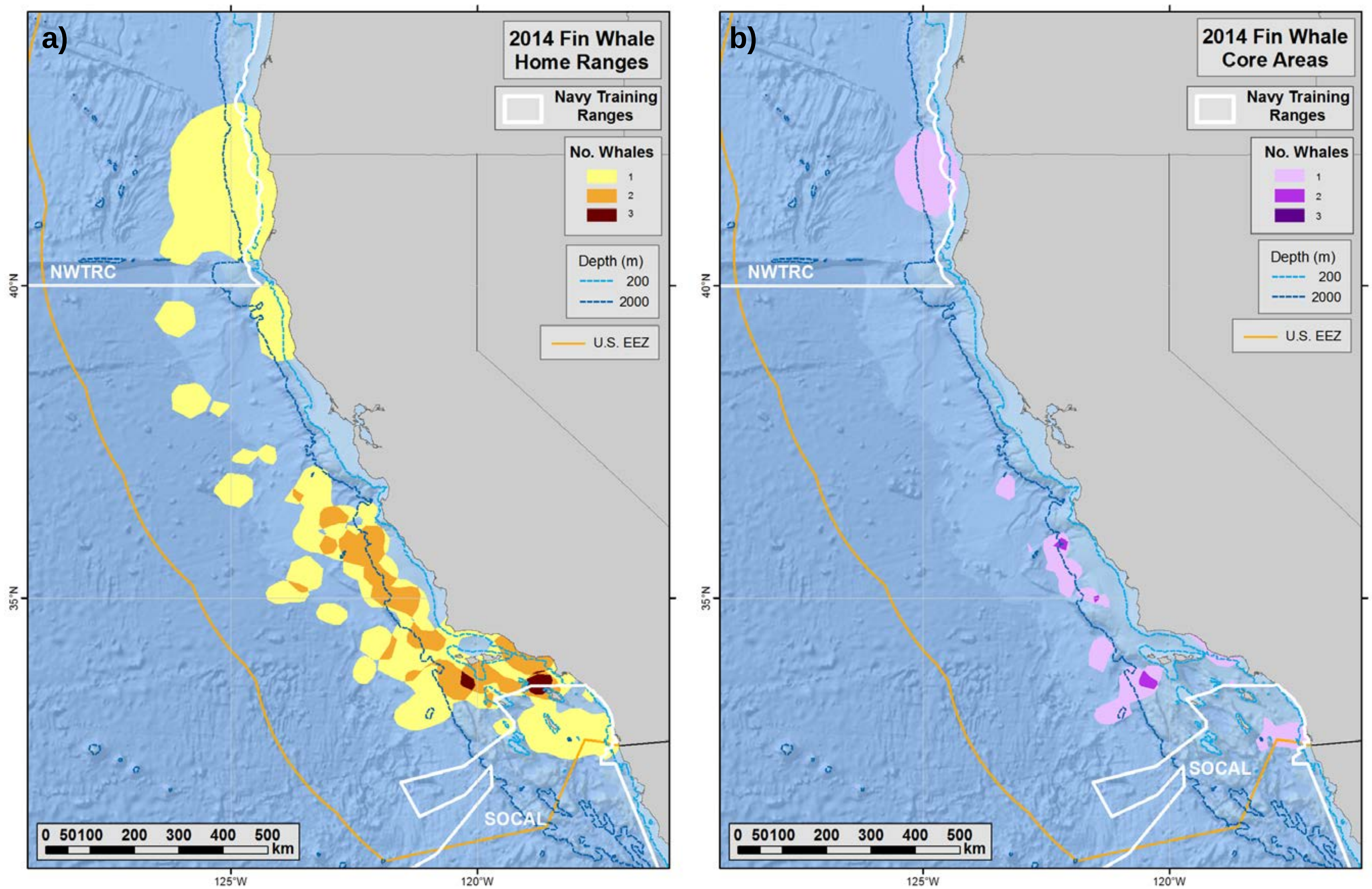

Figure 2-13. HRs (a) and CAs of use (b) in the U.S. EEZ for three fin whales tagged off southern California, 2014. Shading represents the number of individual whales with overlapping home ranges and core areas.

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3. Blue/Fin Whale ADB Tag Analysis

3.1 Methods

3.1.1 ADB Data 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 and 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 (**Figure 3-1**) as the whale typically accelerates, then decelerates rapidly and rolls as it opens the mouth to engulf prey (Goldbogen et al. 2006, Simon et al. 2012). Dives longer than 2 min in duration and 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.

Sequences of dives with no more than three consecutive non-foraging dives (dives with no lunges) 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. Sequences of tracks where two whales were in close proximity to each other were isolated by identifying locations on one track where another whale recorded a location within 1 km and no more than 30 min from the time of the location. Dive summary statistics were calculated for each section of track in close proximity to another whale for comparison between individuals.

3.2 Blue Whale Results

Four blue whales were tagged with ADB tags and tracked for a median of 19.4 d (**Table 3-1**). 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 after the tag triggered a programmed premature release after detecting it had been on the bottom for more than 24 h. Three of the four ADB-tagged blue whales remained in southern California waters after departing the tagging area, but one whale traveled up to Cape Mendocino, California, before the tag was shed.

The four recovered ADB tags each recorded more than 1,050 dives longer than 2 min in duration and greater than 10 m in depth, with a median of 107 dives/day (**Table 3-1**). The number of FastLoc® GPS locations recorded by the tags varied widely, with two tags using newer FastLoc® v. 3 technology recording 2,297 and 2,539 locations, respectively (approximately 120 locations/day, **Table 3-1**) compared to the FastLoc® v.1 tags which recorded a median of 25 locations/day. Feeding lunges were detected in the data record for all whales as spikes in Jerk and MSA calculated from the accelerometer data (**Figure 3-2**) 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).

While the overall dive behavior of tagged whales was generally similar, there were differences between individuals, both in areas occupied and behavior (**Figures 3-3 through 3-38**). ADB-tagged blue whales generally made deeper dives during the daytime than at night (**Figures 3-7 through 3-14**); however, there was high variability within and between individuals and daytime surface feeding was recorded on multiple occasions. Dives recorded by Tag #s 5803 and 5655 were frequently almost double the depth of those made by Tag #s 5644 and 5650 and overall daytime dive depths were highly variable for all whales. Dive durations were more consistent throughout the day for two of the whales (Tag #s 5650 and 5803) but the other two (#s 5644 and 5655) also recorded a diel trend with longer dives occurring during the day (**Figures 3-19 through 3-26**). Most foraging activity (as measured by lunge-feeding events) occurred near the tagging location (west of Santa Monica Bay), with occasional clusters of foraging activity recorded after departure from the tagging area, but these were typically of limited duration (**Figures 3-27 through 3-29**) with the exception of Tag #5803 which travelled up to Cape Mendocino where there was extensive foraging activity (**Figure 3-30**). Foraging activity generally took place during the daylight hours, though nighttime lunges were recorded on some occasions for multiple whales (**Figures 3-31 through 3-38**). For additional visualizations of ADB-tagged blue whale data, see **Figures 3-60 through 3-75** in this chapter's appendix.

Overall, a median of 42 percent of dives longer than 2 min in duration and greater than 10 m in depth were foraging dives, though Tag #5650 recorded foraging dives with less than half the frequency of the next lowest tag (16 percent, **Table 3-1**). Tagged blue whales generally foraged in relatively small areas with a median foraging bout size of 1.5 km^2 (**Table 3-2**, **Appendix Tables 3-5 through 3-8**). The median distance travelled between consecutive foraging bouts was more variable across the whales, ranging from 2.8 to 19.3 km, though instances where the following foraging bout overlapped with the preceding one were recorded for all whales. The whale with the largest distance between foraging bouts (Tag #5644) also recorded the fewest GPS locations, so it is possible that the sparse (compared to the other whales) locations may have artificially inflated the distance between foraging bouts. The median duration of a foraging bout lasted 2.2 to 4.1 h and included 8 to 14.5 dives per bout, though both values ranged widely both within and across whales with some bouts lasting as long as 13.3 h and including 125 dives. Average dive depths during foraging bouts followed a similar trend to what was observed for all dives where Tag #s 5644 and 5650 generally made shallower dives during foraging bouts than Tag #s 5655 and 5803. Interestingly, there was not as much variability in average dive duration within foraging bouts between individuals and the whale carrying Tag #5644 averaged longer dives per bout than the two whales that dove deeper (Tag #s 5655 and 5803).

The extremely high numbers of GPS locations recorded by Tag #s 5650 and 5803 allowed for comparisons of diving behavior between 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 3-39 and 3-40**). GPS locations for the other two whales were sparse enough that portions of the tracks within close proximity were interpolated locations and could therefore not be verified as actually being within the required distance criteria. Tag #s 5650 and 5803 were in close proximity nine times across a 9-day period. Those periods of overlap included both foraging and non-foraging behavior (**Table 3-3**). Dive depths and durations were approximately equal during overlap periods with no foraging lunges, though the whale carrying Tag #5803 generally made deeper dives than Tag #5650. However, on two occasions during overlap periods with foraging recorded, the whale carrying Tag #5803 dove over twice as deeply as Tag #5650, and in one instance, was foraging when the whale with Tag #5650 was not. There appears to be additional variability within close proximity events as demonstrated by overlap bout number 6 (**Table 3-3)**. During the first 2 h of the overlap period, the whales appear to have been behaving similarly after coming closer than 0.5 km from each other (**Figures 3-39 and 3-40**), with both whales making foraging dives to a similar depth. An hour later the whale carrying Tag #5803 was feeding deeper in the water column than the whale carrying Tag #5650 (**Figure 3-41 and 3-42**).

3.3 Blue Whale Discussion

These 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 four tagged whales departed the tagging area none (but Tag #5803, which travelled north to Cape Mendocino) stayed in one area for any period of time. Their behavior would best be described as searching with occasional short bouts of foraging. This suggests that prey was 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. Two of the whales (Tag #s 5644 and 5655) moved south near San Diego after leaving the tagging area and exhibited relatively consistent, moderate levels of foraging activity. A third whale (Tag #5650) passed through the area without stopping on a loop through most of the southern California waters, suggesting that it was either 1) not able to find the prey being consumed by Tag #s 5644 and 5655, 2) the prey was so ephemeral it has 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.

The general dive behaviors recorded by the ADB tags, showing 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 3-27 through 3-30**). This kind of information will be 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 amount 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 3-2**). 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 (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. The long-term behavior data collected by the ADB tags can help address that question by looking at the intensity of the foraging effort leading up to and following the nighttime feeding effort.

The spatial distribution of foraging bouts was highly variable within and between individuals, though the results suggest that blue whales typically forage in areas smaller than 1.5 km^2. It is likely that some of the larger foraging clusters were the result of an insufficient number of locations to define the true extent of the area being used for foraging. Foraging bouts were more numerous and overlapped more frequently earlier in the tracks 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. Further work is needed to determine if prey is uniformly concentrated on the scale observed during the foraging bouts, or if it is composed of smaller patches within those areas.

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 dives. 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, but the idea is further reinforced by the differing dive depths recorded between the two whales foraging in close proximity (**Table 3-3**). That would suggest they were exploiting different parts of the same prey patch and therefore, possibly different concentrations of prey. 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), while others expend more effort and forage deeper where prey is more dense. This idea could be supported by Tag #5640 passing through the area where Tag #s 5644 and 5655 had been foraging without stopping. Further effort is needed to resolve these questions.

3.4 Fin Whale Results

Three fin whales were tagged with ADB tags and tracked for a median of 11.1 d (**Table 3-4**). All three tags were shed prior to their scheduled release date and sank to the bottom. Two tags released from their housings while on the bottom as programmed and floated to the surface for recovery. One was recovered and the other was lost when its batteries were exhausted during bad weather that prevented a recovery effort. The last tag never released from its housing for unknown reasons and was lost. The whales carrying the two longest-lasting ADB tags used different portions of the southern California waters. One whale (Tag #5685) travelled in a long loop encircling most of the southern California waters and rarely stopping for any length of time. The other whale (Tag #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 #5838) generally stayed in an area southwest of the tagging area between Catalina Island and Dana Point.

The one recovered tag recorded 1,140 dives longer than 2 min in duration and more than 10 m in depth (72 dives/day, **Table 3-4**). A total of 95 FastLoc® GPS locations was also recorded (6 GPS locations/day) and feeding lunges were detected in the data record. The two non-recovered tags transmitted dive summary information for 279 and 289 dives and 14 and 12 GPS locations, respectively, via Argos (**Table 3-4**).

A high degree of variability was seen in areas traveled as well as in dive behavior, both within and between individual fin whales (**Figures 3-42 through 3-55**). A diel pattern in maximum dive depths was recorded by two of the three tags, with deeper dives occurring during the daytime than at night (**Figures 3-45 through 3-47**). Dive durations were highly variable for all three whales (**Figures 3-51 through 3-53**), but none showed a diel trend to match the maximum dive depths. Foraging activity (as measured by lunge-feeding events) was relatively limited for the whale carrying the one recovered tag and took place exclusively during daylight/twilight hours (**Figures 3-55**). Most foraging activity occurred near the south-eastern side of San Clemente Island and southwest of San Nicolas Island, with occasional, very limited clusters of foraging activity recorded in other parts of the track (**Figure 3-54**). Dive summaries for foraging bouts were not calculated for the one recovered tag due to the limited number of foraging dives and the relatively limited number of GPS locations, which would lead to an overestimation of bout size. For additional visualizations of ADB-tagged fin whale data, see **Figures 3-76 through 3-78** in this chapter's appendix.

3.5 Fin Whale Discussion

These 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) by the recovered tag 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 two unrecovered tags when one tag (Tag #5790) functioned over twice as long as the other (Tag #5838). Further work is needed to determine if this was a technological or behavioral issue.

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), the data from the one recovered tag showed remarkably little foraging effort. Fin whales in the North Pacific prefer to forage on euphausiids; however, they will also feed on anchovies and other small schooling fish (Clapham et al. 1997). If the whale's foraging behavior is different when it is foraging on non-euphausiid species, it is possible that the current analysis was not able to detect all foraging effort by the whale. The majority of the recorded foraging effort occurred during portions of the track with clustered locations, so it is likely that the track would display a cluster of locations during a foraging bout even if the foraging behavior was not detectable with the current analysis. Therefore, any foraging effort that was not identified by this analysis was likely of short duration.

Data on foraging effort were not available for the other two tagged fin whales, but the cluster of locations northwest of Catalina Island in the track of Tag #5838, and the recorded diel variability of the dive depths it made, are characteristic of a rorqual foraging on diel vertically migrating prey (Calambokidis et al. 2007, Doniol-Valcroze et al. 2011). During the time the whale carrying Tag #5838 was apparently foraging northwest of Catalina Island, the whale carrying Tag #5685 passed through the same area without stopping. This suggests that either 1) it was not able to find the prey being consumed by the whale carrying Tag #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. Rorquals are thought to forage as often as possible during the feeding season, so this may indicate the tracking period coincided with a time when the whale could be more selective it its choices of prey patches to exploit, perhaps due to successful foraging prior to tagging.

It is unclear if the lack of a diel pattern in the dive depths of the whale carrying Tag #5790 was a result of a more limited sample size compared to the track length, or a genuine difference of behavior between it and the other two tagged whales. There appears to be clusters of locations in the whale's track near where the whale carrying Tag #5838 appeared to forage, as well as near the southeastern side of Santa Cruz Island, but it is difficult to be certain with the more intermittent dive record and lower accuracy of the Argos locations

3.6 Conclusions/Blue-Fin Comparison

Both blue and fin whales were tagged with ADB tags allowing for a comparison of dive behavior between species, though only one of the three ADB tags attached to fin whales was recovered. 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. However, the fin whale made dramatically fewer lunges during the tracking period compared to the blue whales. The relatively fewer FastLoc® v.1 GPS locations recorded by the fin whale tag makes movement comparisons with tagged blue whales more difficult, but contrary to the tagged blue whales, the fin whale left the tagging area almost immediately after tagging, travelling offshore before eventually circling back to pass near the vicinity of the tagging area again. The fin whale also did not occupy any area for an extended period of time; however, it spent the most time foraging near the southeastern side of San Clemente Island. Further comparisons are difficult due to the recovery of only one fin whale tag, and the low number of foraging dives recorded by that tag. The dramatic difference between the amount of recorded blue and fin whale foraging behavior suggests there may be inter-species differences in foraging behavior; however, the blue whale carrying Tag #5650 also recorded very little foraging activity after departing the tagging location, and conducted a long circuit of the southern California waters similar to the fin whale, so it is possible that the tracking period happened to coincide with an exploratory period, or a period of insufficient prey abundance for the tagged fin whale. Additional ADB deployments are necessary to better understand the variability in fin whale behavior. Analysis of the archived ADB data is ongoing, due to the highly detailed nature of the data collected and the large numbers of dives recorded. This combination provides a highly detailed look at blue and fin whale movements and diving behavior over an unprecedented time period which should offer additional insights into blue and fin whale behavior as we have the opportunity to work with the data more.

3.7 Literature Cited

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Table 3-1. Deployment summary for ADB tags attached to blue whales in southern California during August 2014.

Species	Tag #	Duration (min)	# Dives	# GPS Locations	Dives/Day	GPS Locs/Day	Total Distance (km)	Fraction Foraging Dives
Blue	5644+	19	1068	185	56.2	9.7	1,454.00	0.44
Blue	5650+++	20	2,276	2,297	113.9	115	1,708.20	0.16
Blue	5655+	19.8	2,918	799	147.3	40.3	1,563.40	0.55
Blue	5803+++	18.3	1,832	2,539	100.3	139.1	2,032.90	0.39
	Median	19.4	2,054.0	1,548.0	107.1	77.7	1,635.8	0.42

+Tag is FastLoc v.1, +++Tag is FastLoc v.3

Table 3-2. Summary of dives occurring during foraging bouts made by ADB-tagged blue whales tagged off southern California in August 2014. Foraging bouts are sequences of dives with no more than three dives in a row with no recorded foraging lunges

Tag #		Bout Duration (h)	*n* Dives	Ave Max Dive Depth (m)	Ave Dive Duration (min)	Ave # Lunges	Dives No Lunges	Area Of Bout (km^2)	Time To Next Bout (h)	Dist To Next Bout (km)
5644	median	2.2	11.0	99.4	8.0	1.7	4.0	1.7	10.6	19.3
n=25	max	12.3	68.0	169.8	17.3	4.9	14.0	111.6	68.3	145.5
	min	0.9	5.0	33.2	3.5	0.4	0.0	0.0	0.0	0.0
5650	median	1.6	10.0	88.2	6.3	1.4	3.0	1.4	2.2	3.2
n=27	max	10.2	52.0	244.2	11.0	3.8	13.0	54.9	179.6	150.4
	min	0.5	4.0	27.7	3.2	0.5	0.0	0.0	0.0	0.0
5655	median	2.5	14.5	148.4	7.5	1.7	2.5	0.7	5.3	7.6
n=40	max	13.3	125.0	247.3	10.7	3.6	38.0	94.7	25.0	96.4
	min	0.4	4.0	31.5	2.7	0.4	0.0	0.0	0.0	0.0
5803	median	1.6	8.5	131.6	7.3	1.3	3.0	1.8	2.2	7.7
n=38	max	11.3	62.0	251.1	13.2	2.8	14.0	80.9	46.8	243.2
	min	0.5	4.0	26.3	2.8	0.4	0.0	0.0	0.0	0.0

Table 3-3. 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	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

Table 3-4. Deployment summary for ADB tags attached to fin whales in southern California during August 2014.

Species	Tag #	Duration (min)	# of Dives	# GPS locations	Dives/ day	GPS Locs/day	Total Distance (km)
Fin	5685	14.2	1140	95	72	6	1,037.10
Fin	5790*	13.3	279	14	N/A	N/A	426.2
Fin	5838*	4.9	289	12	N/A	N/A	132.8

*Tags were not recovered so values are from data transmitted through Argos

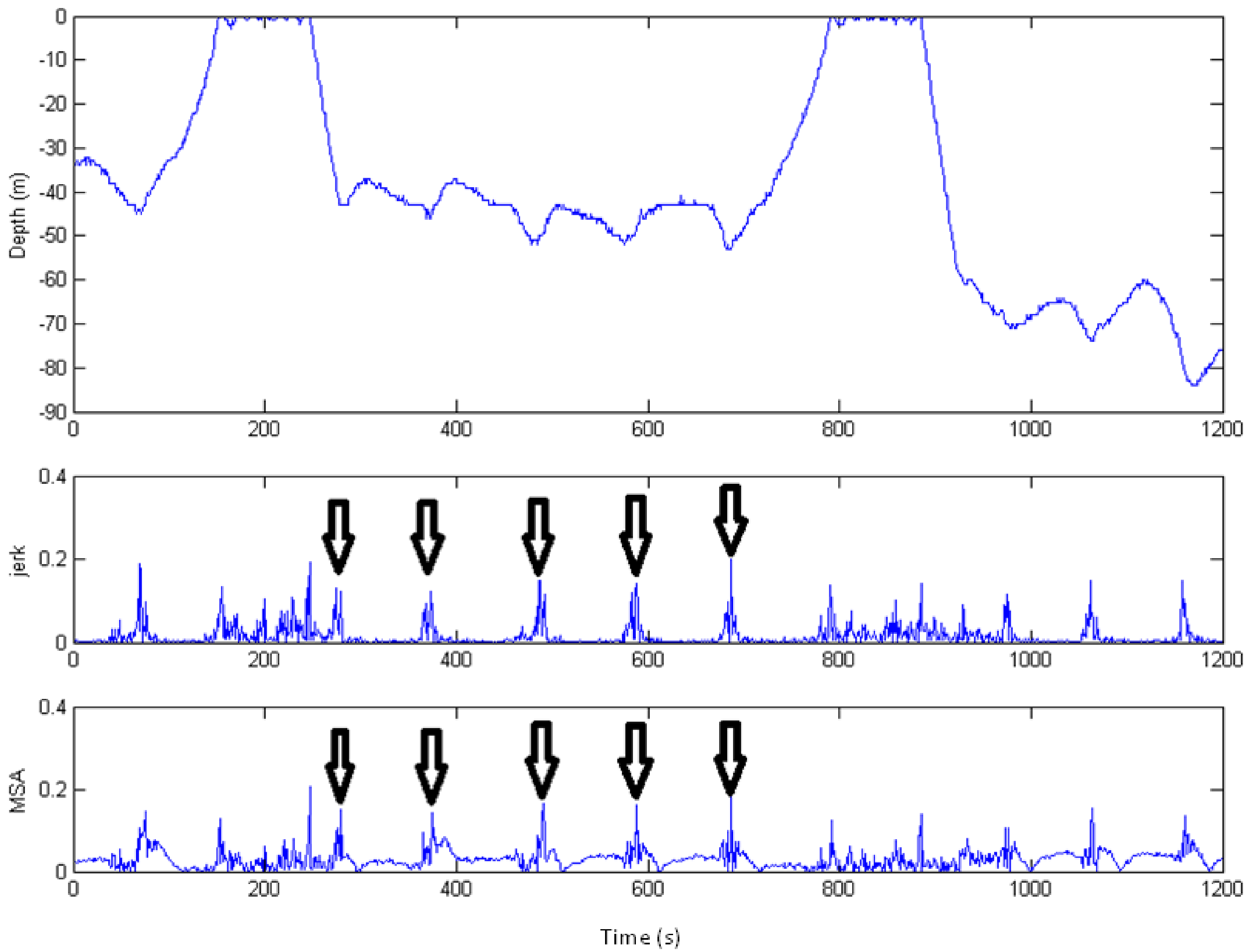

Figure 3-1. The depth profile (top panel) and corresponding Jerk (middle panel) and MSA values (bottom panel), calculated from accelerometer data for a dive (between approximately 250 and 800 s) made by an ADB-tagged blue whale off southern California. Peaks in Jerk and MSA highlighted by arrows identify lunge-feeding events during this dive.

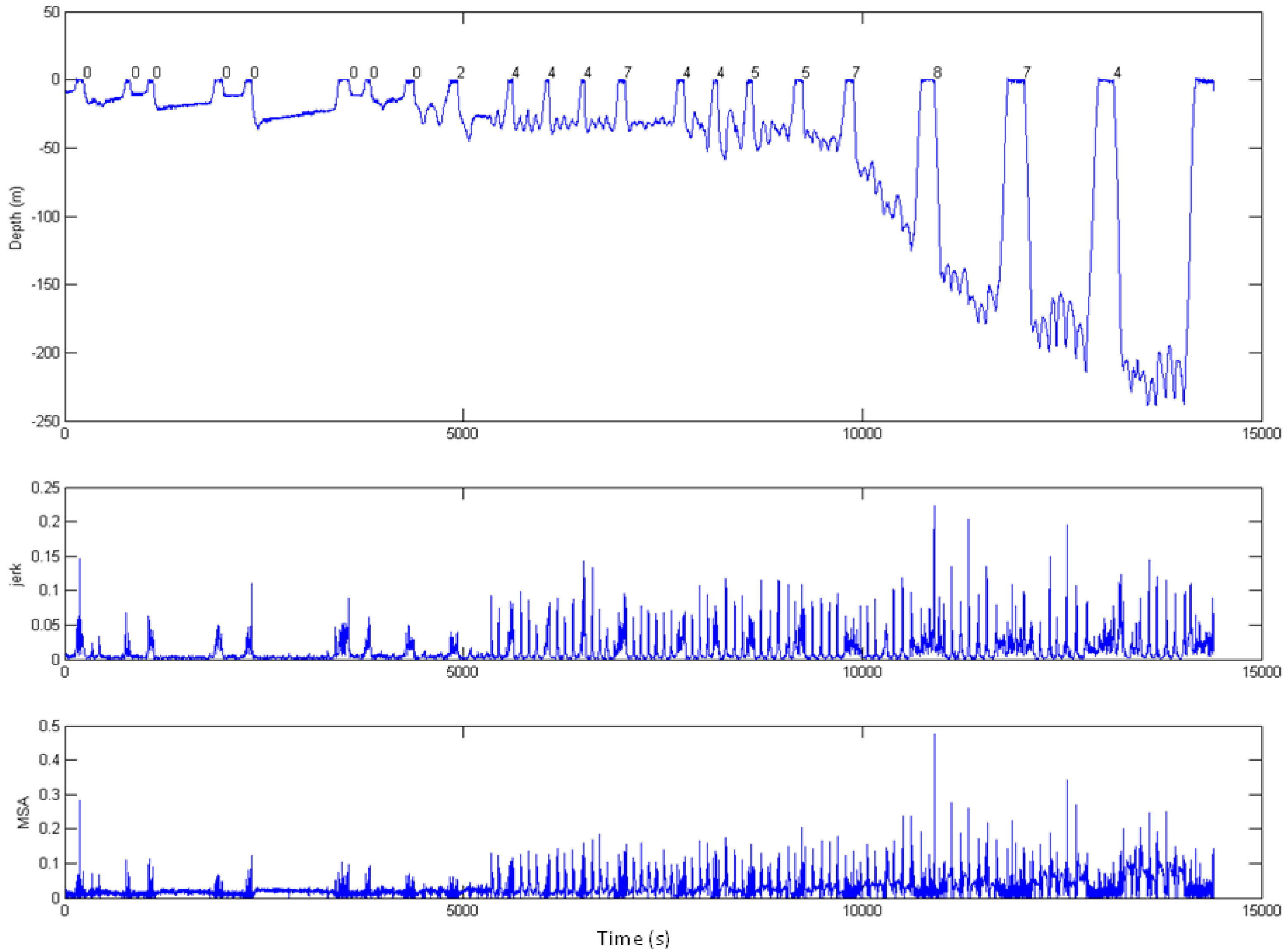

Figure 3-2. An example dive profile (top panel) of an ADB-tagged blue whale off southern California in August 2014. The numbers represent the number of lunges detected during each dive by peaks in the Jerk (middle panel) and MSA (bottom panel) calculated from accelerometer data.

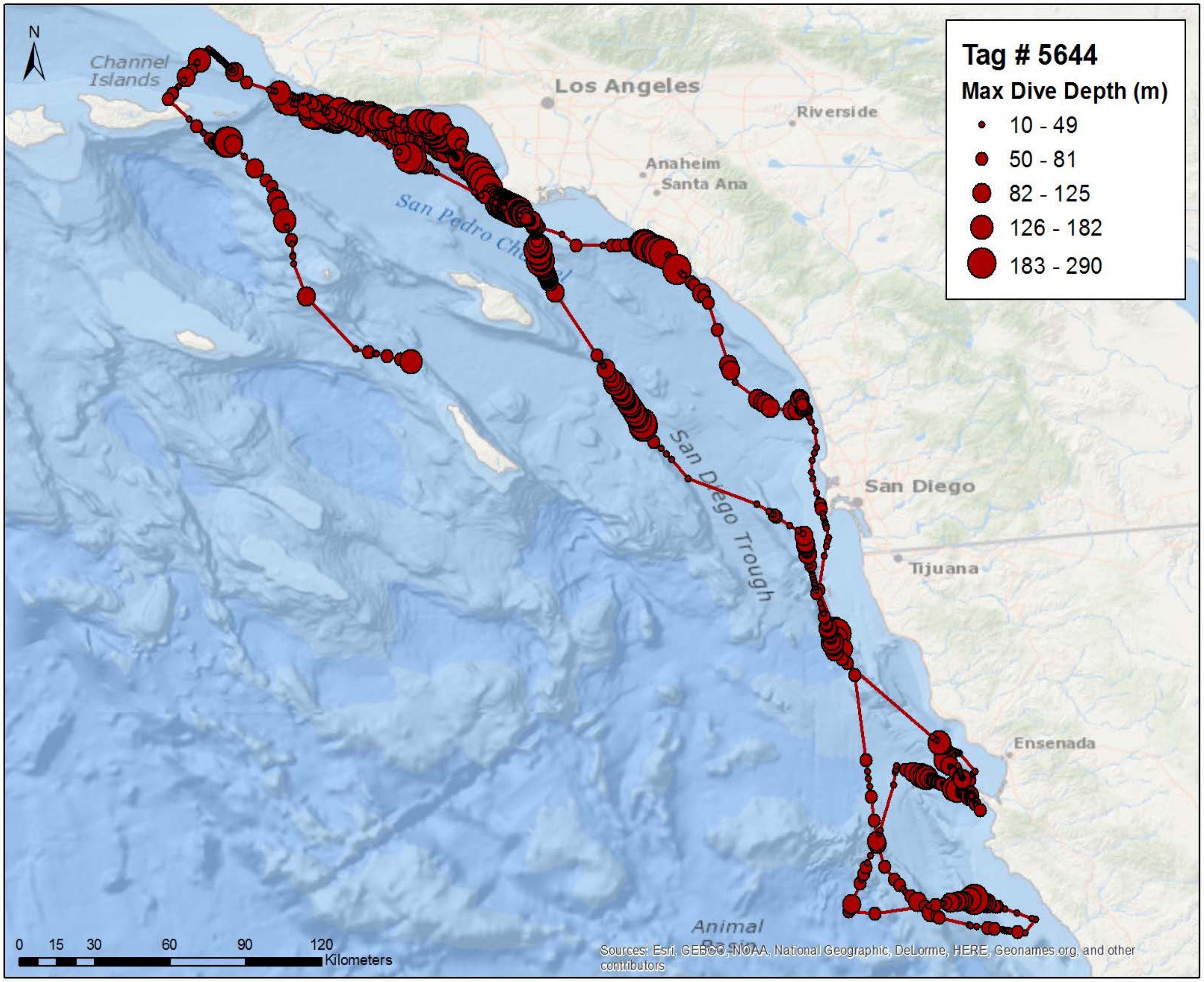

Figure 3-3. Track during 4 to 23 August 2014 of ADB-tagged blue whale #5644 tagged off southern California. Circle size represents the maximum dive depth of a dive made at that location (*n* dives=1,068).

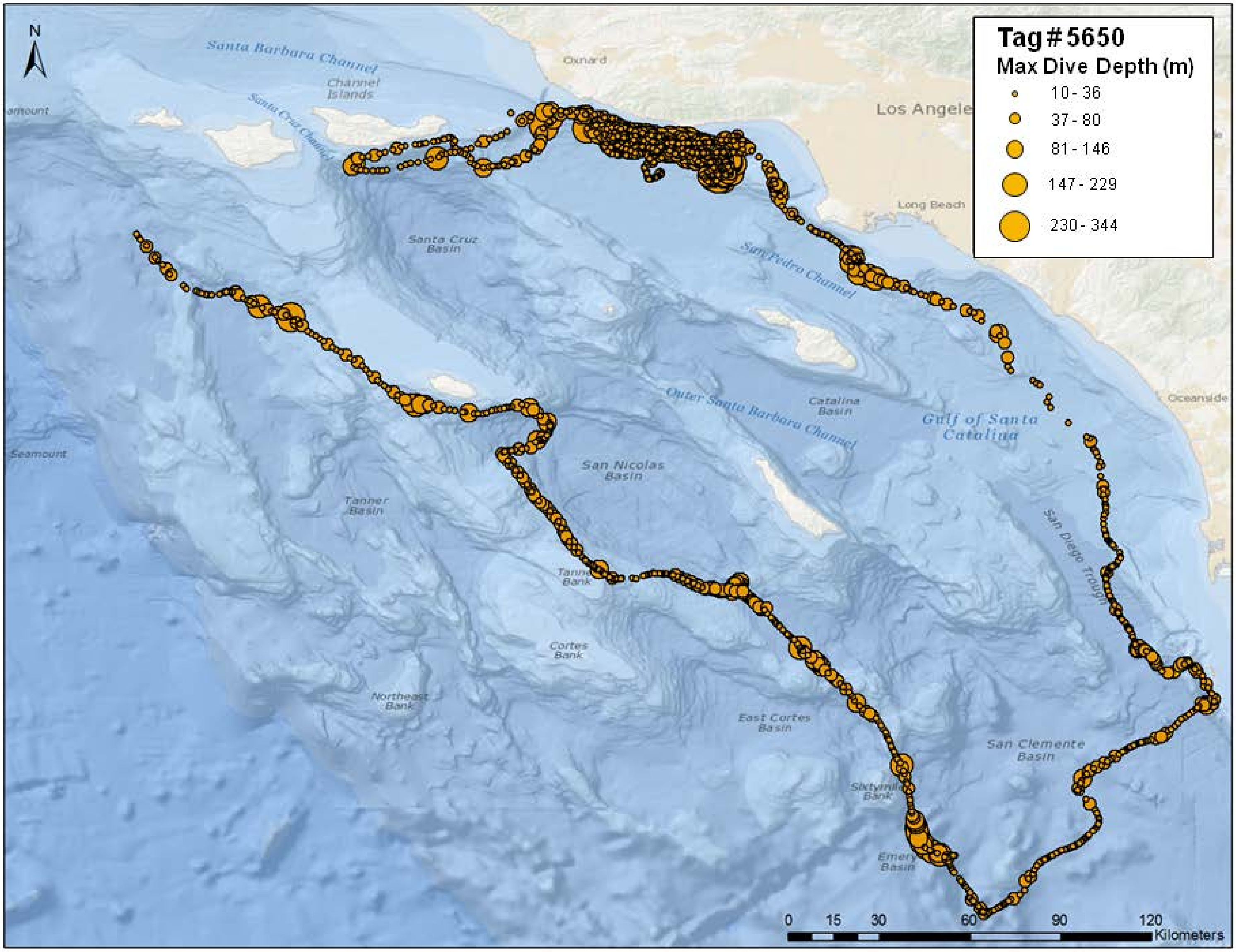

Figure 3-4. Track during 4 to 23 August 2014 of ADB-tagged blue whale #5650 tagged off southern California. Circle size represents the maximum dive depth of a dive made at that location (*n* dives=2,276).

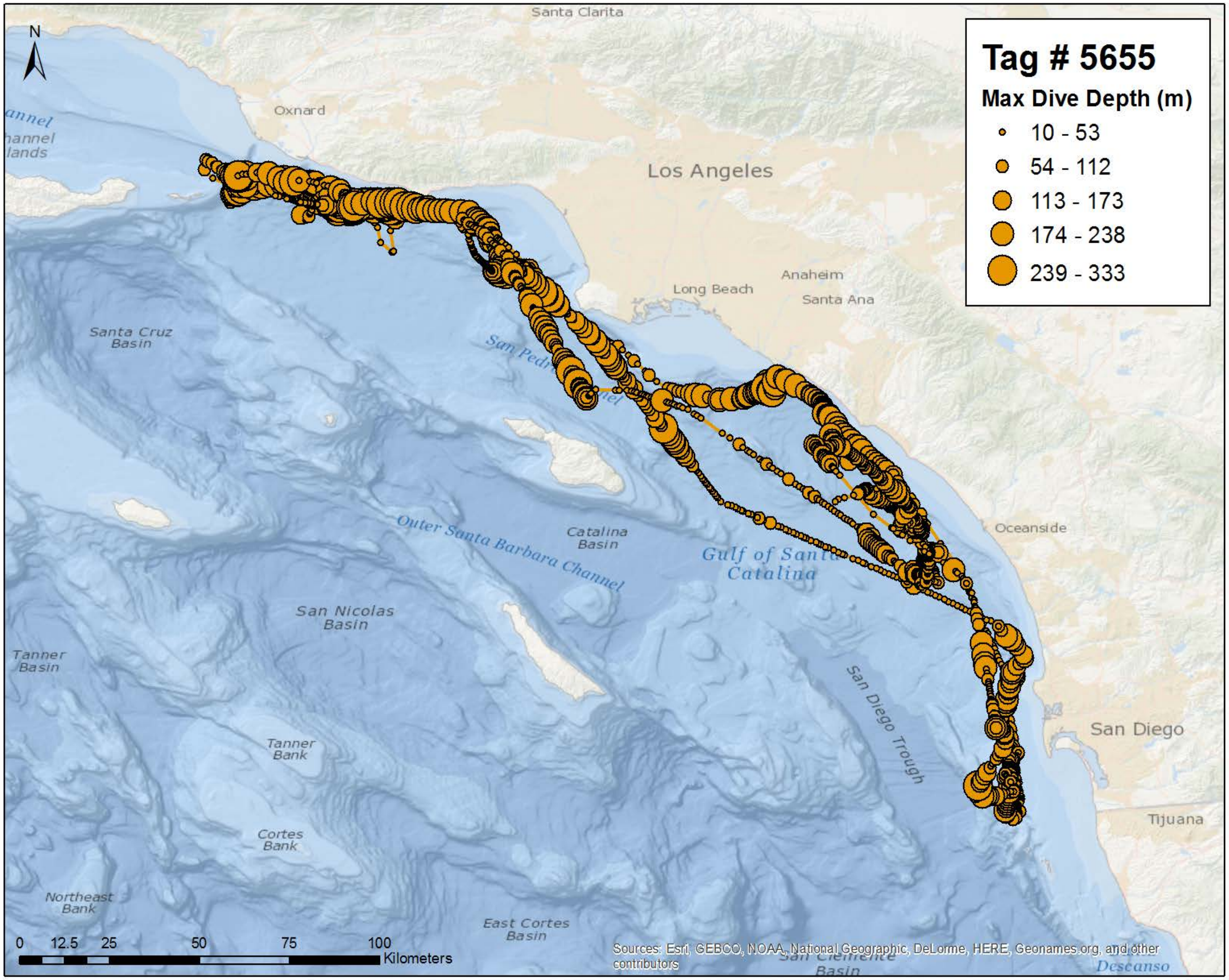

Figure 3-5. Track during 6 to 26 August 2014 of ADB-tagged blue whale #5655 tagged off southern California. Circle size represents the maximum dive depth of a dive made at that location (*n* dives=2,918).

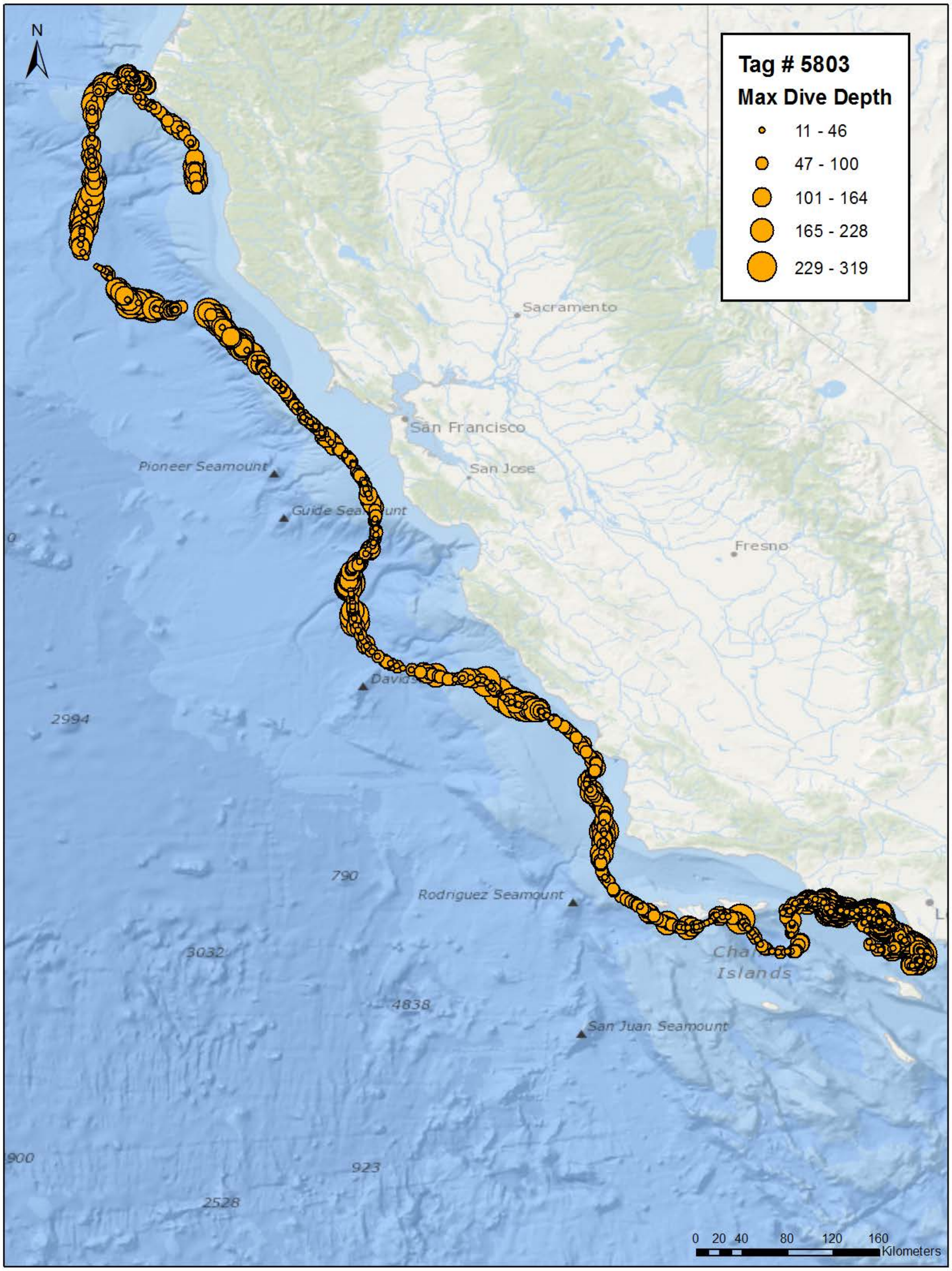

Figure 3-6. Track during 4 to 23 August 2014 of ADB-tagged blue whale #5803 tagged off southern California. Circle size represents the duration of a dive made at that location (*n* dives=1,832).

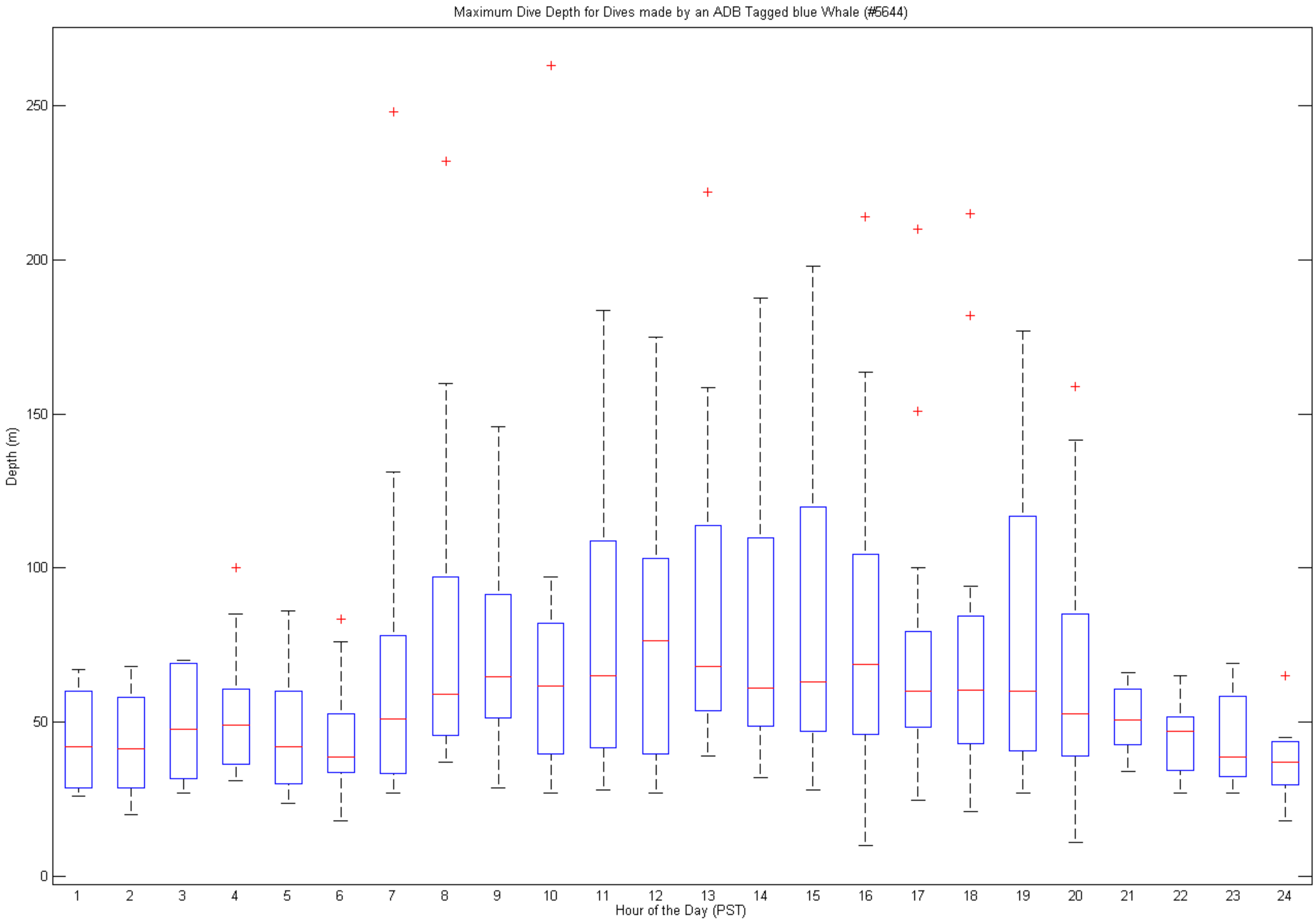

Figure 3-7. The distribution of maximum dive depths for dives made by ADB-tagged blue whale #5644 tagged off southern California during each hour of the day.

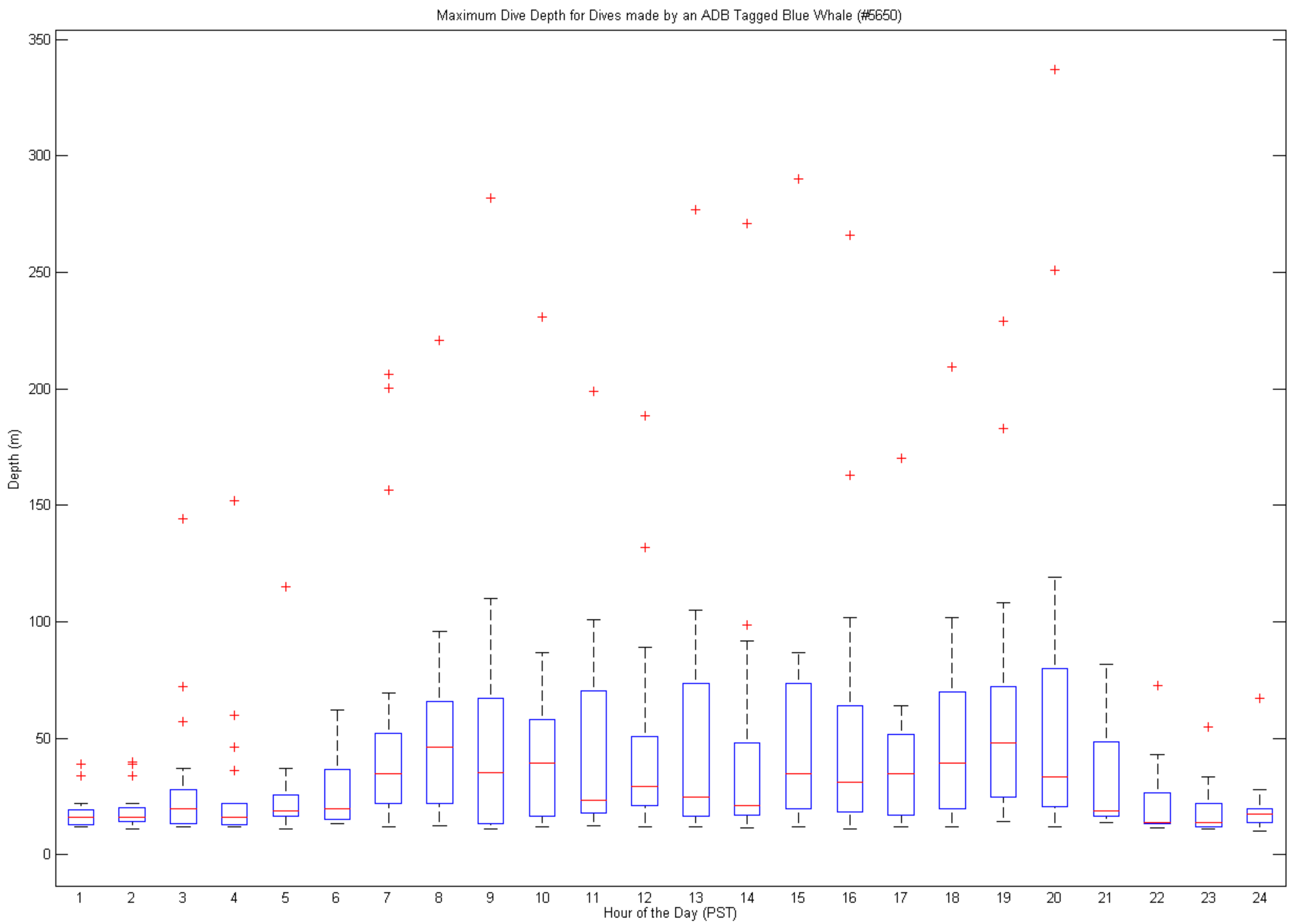

Figure 3-8. The distribution of maximum dive depths for dives made by ADB-tagged blue whale #5650 tagged off southern California during each hour of the day.

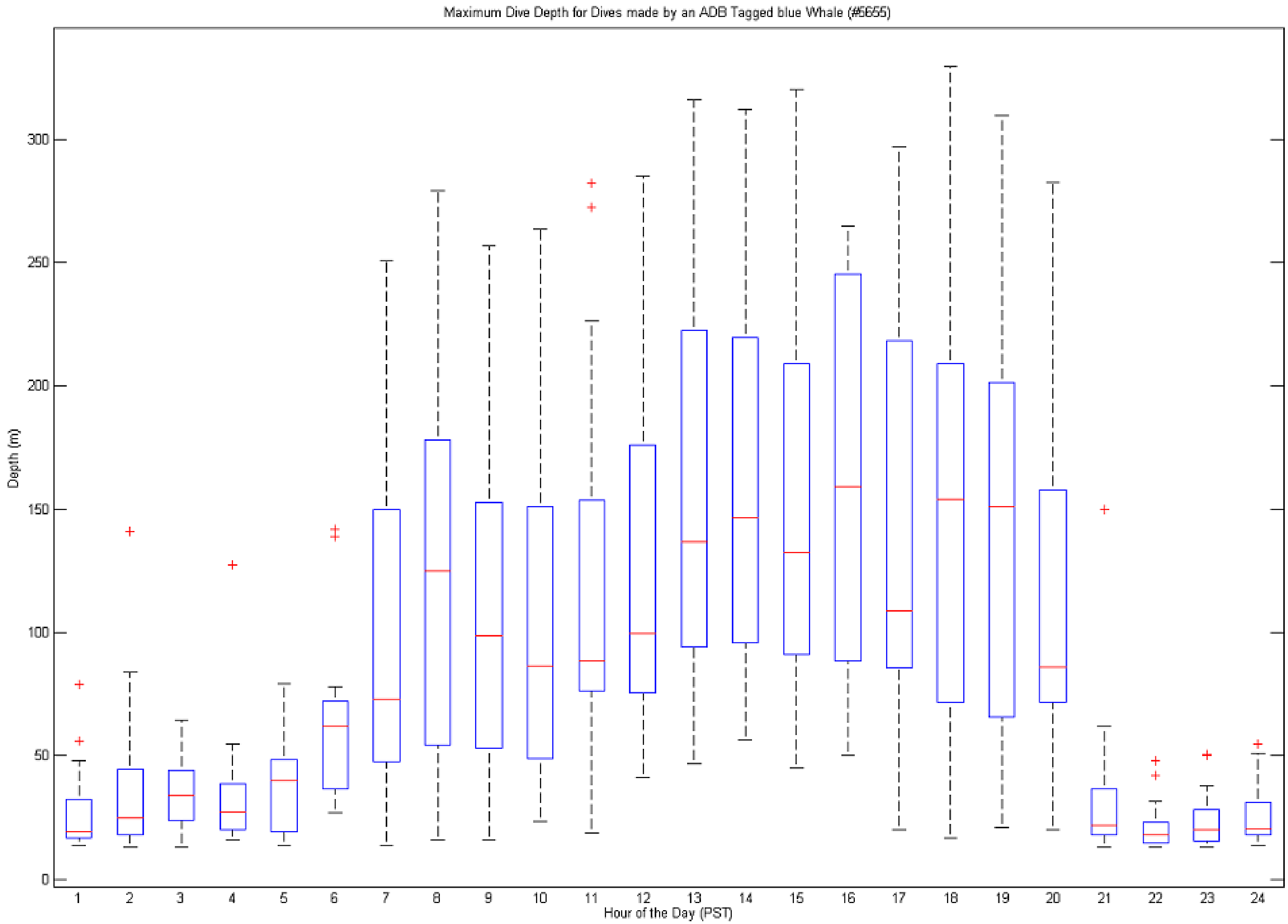

Figure 3-9. The distribution of maximum dive depths for dives made by ADB-tagged blue whale #5655 tagged off southern California during each hour of the day.

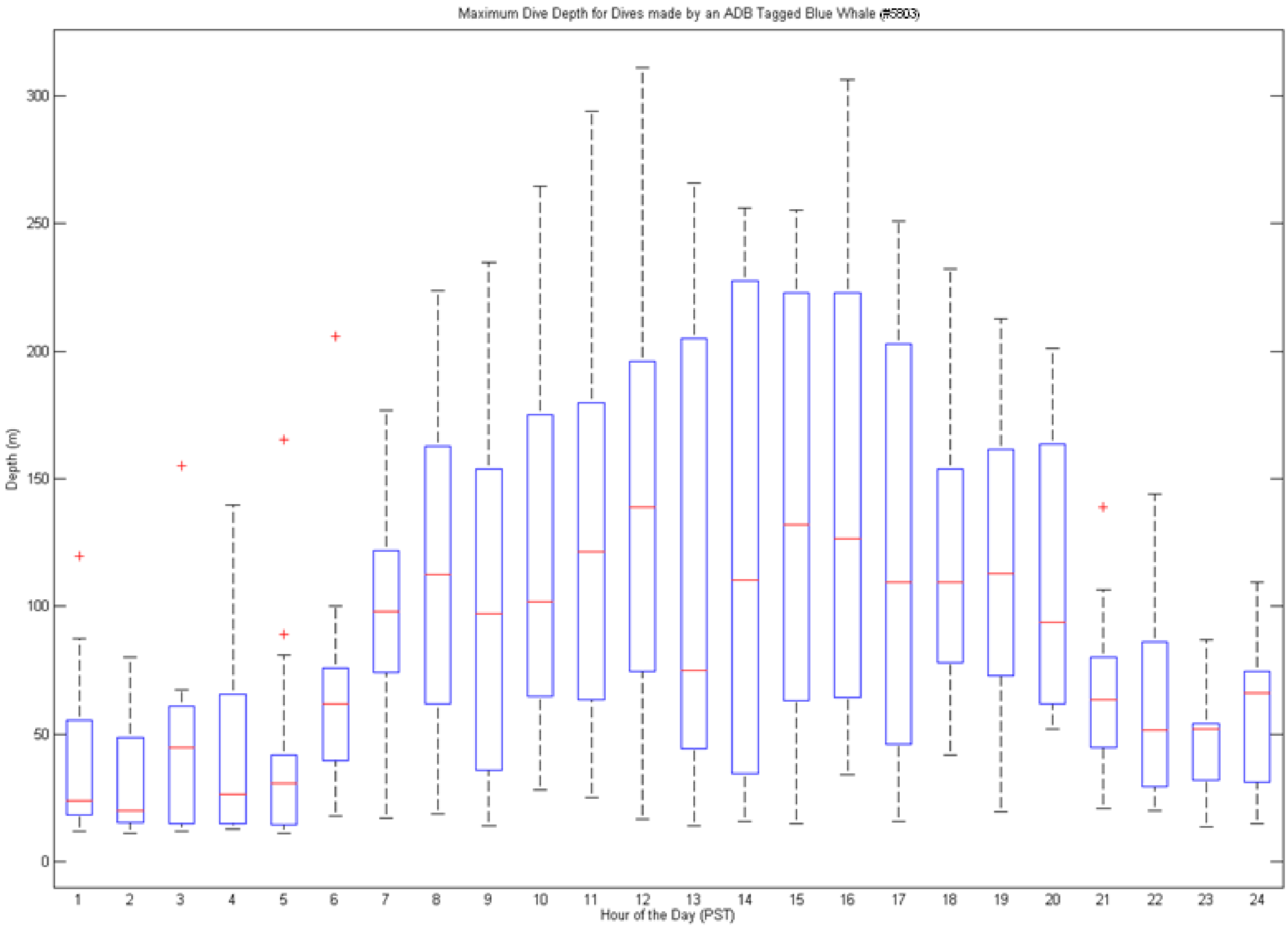

Figure 3-10. The distribution of maximum dive depths for dives made by ADB-tagged blue whale #5803 tagged off southern California during each hour of the day.

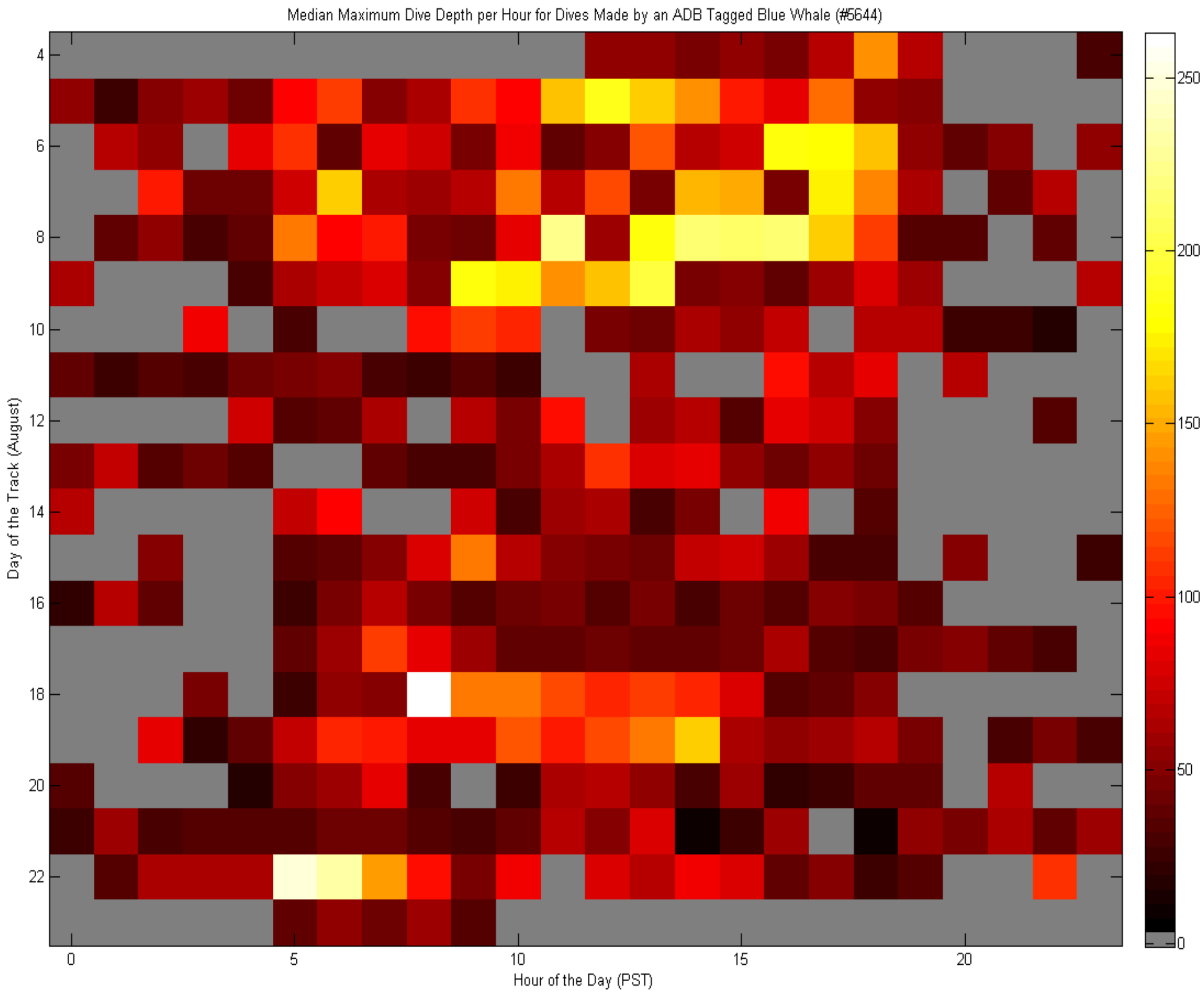

Figure 3-11. Median hourly maximum dive depths (m) for dives longer than 2 min in duration and greater than 10 m in depth made by ADB-tagged blue whale #5644 tracked off southern California (*n*=1,068). Gray color represents hours with no dives meeting the criteria.

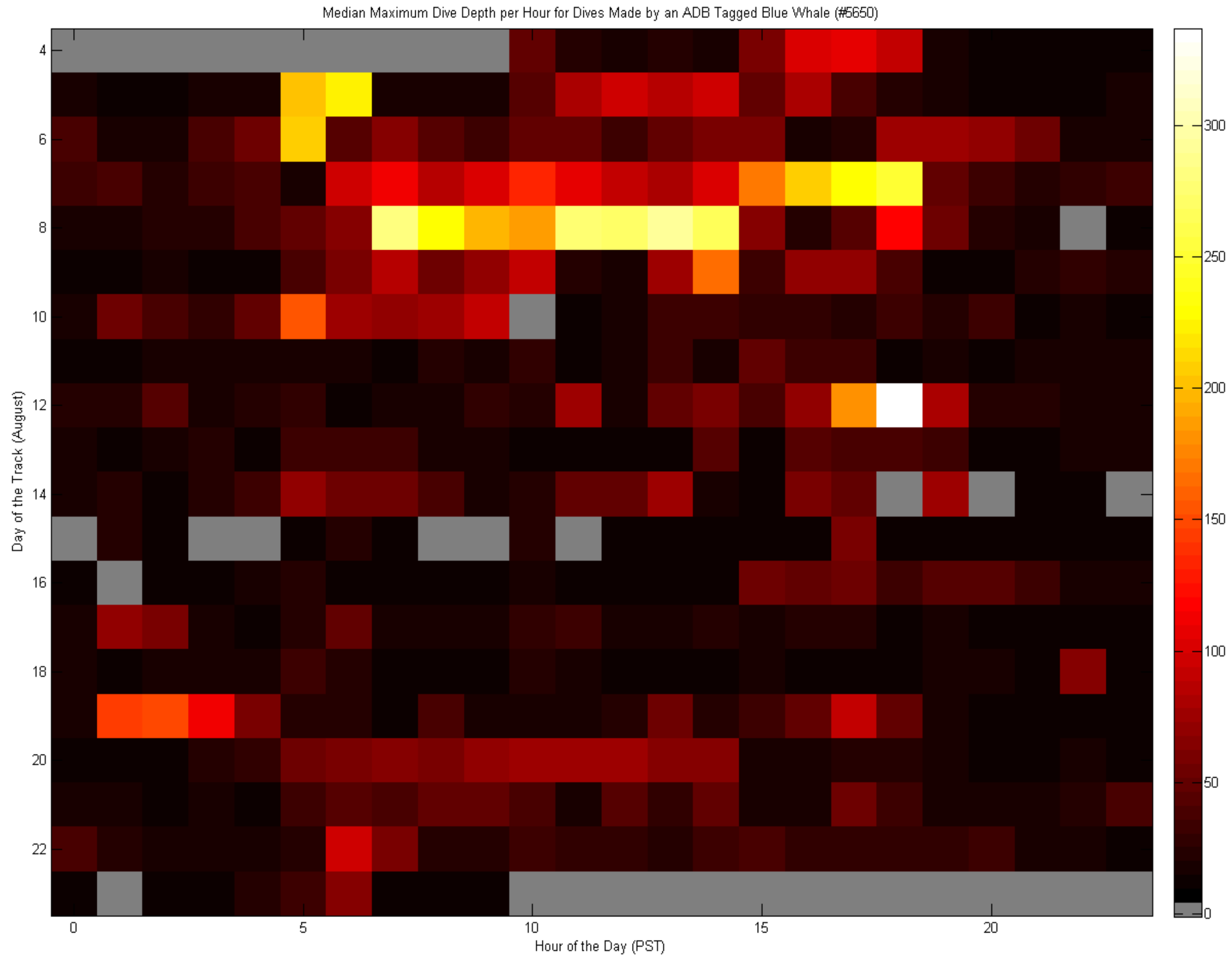

Figure 3-12. Median hourly maximum dive depths (m) for dives longer than 2 min in duration and greater than 10 m in depth made by ADB-tagged blue whale #5650 tracked off southern California (*n*=2,276). Gray color represents hours with no dives meeting the criteria.

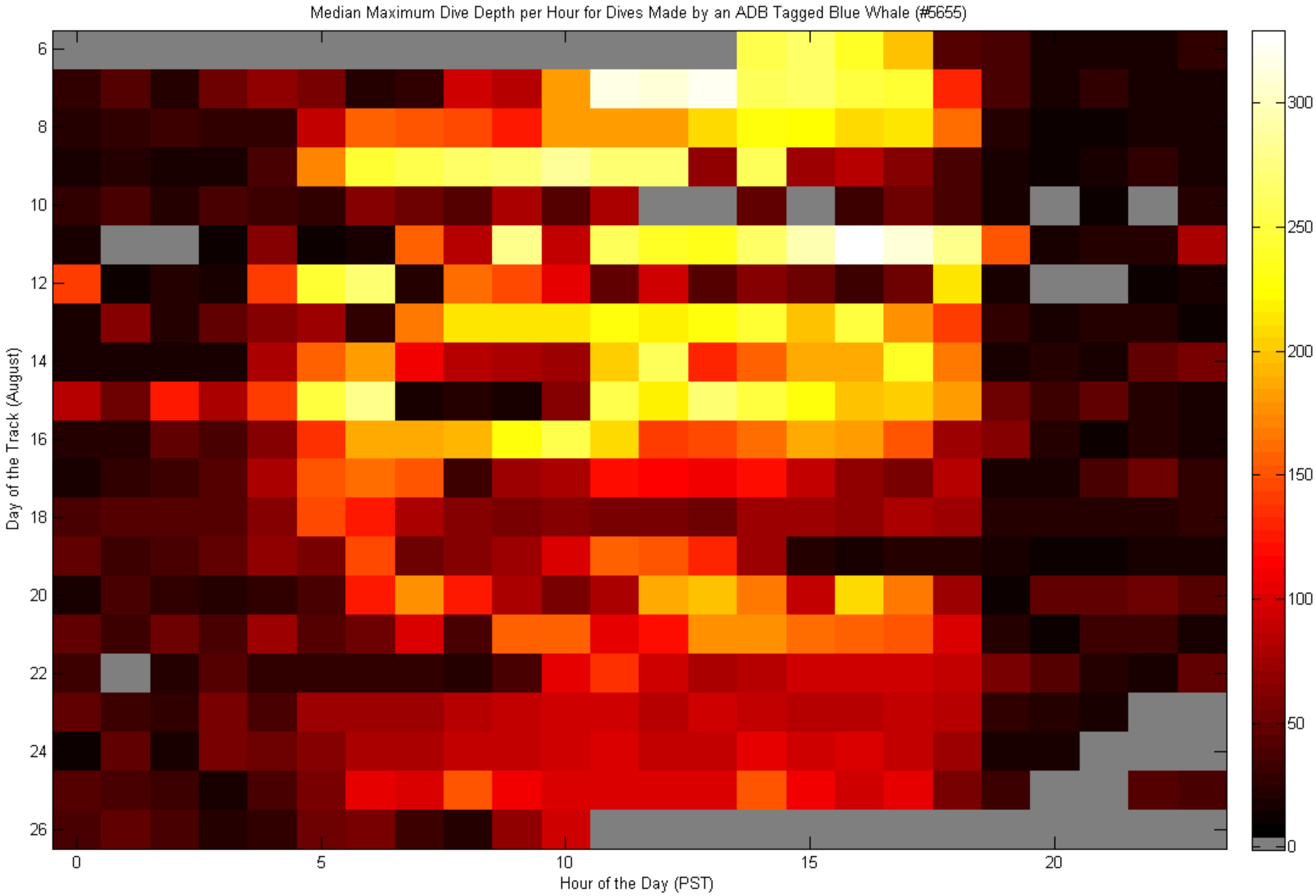

Figure 3-13. Median hourly maximum dive depths (m) for dives longer than 2 min in duration and greater than 10 m in depth made by ADB-tagged blue whale #5655 tracked off southern California (*n*=2,918). Gray color represents hours with no dives meeting the criteria.

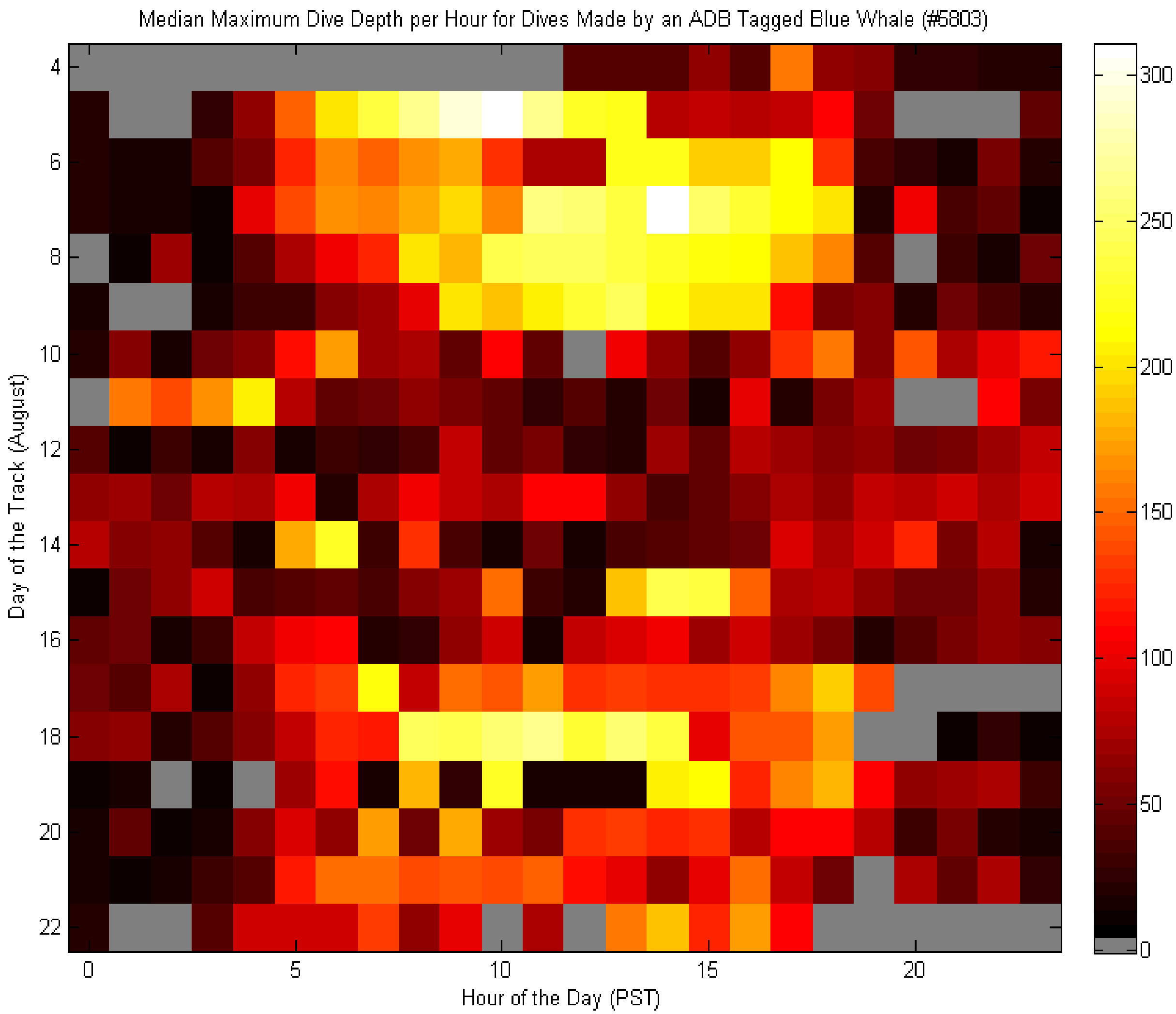

Figure 3-14. Median hourly maximum dive depths (m) for dives longer than 2 min in duration and greater than 10 m in depth made by ADB-tagged blue whale #5803 tracked off southern California (*n*=1,832). Gray color represents hours with no dives meeting the criteria.

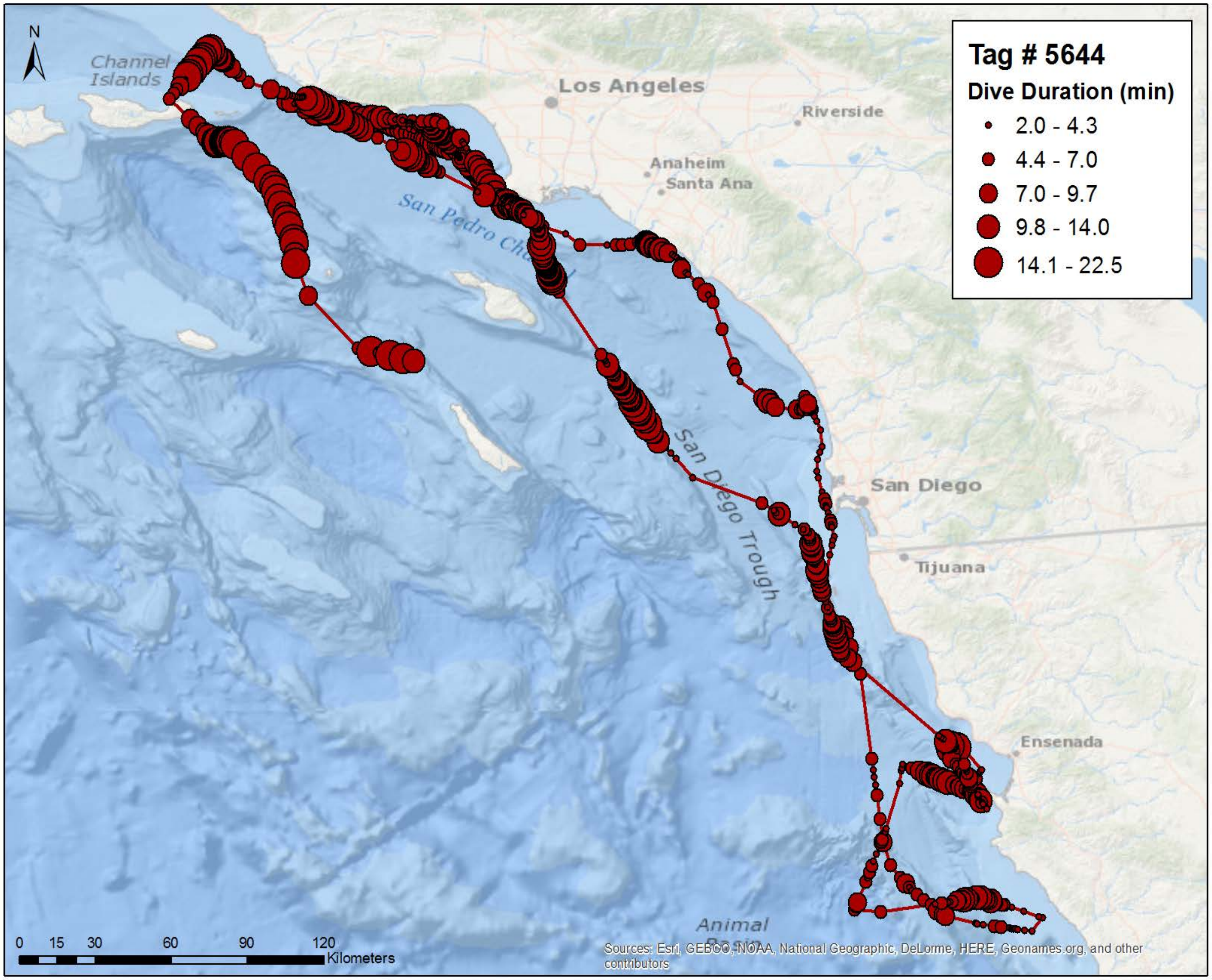

Figure 3-15. Track during 4 to 23 August 2014 of ADB-tagged blue whale #5644 tagged off southern California. Circle size represents the duration of a dive made at that location (*n* dives=1,068).

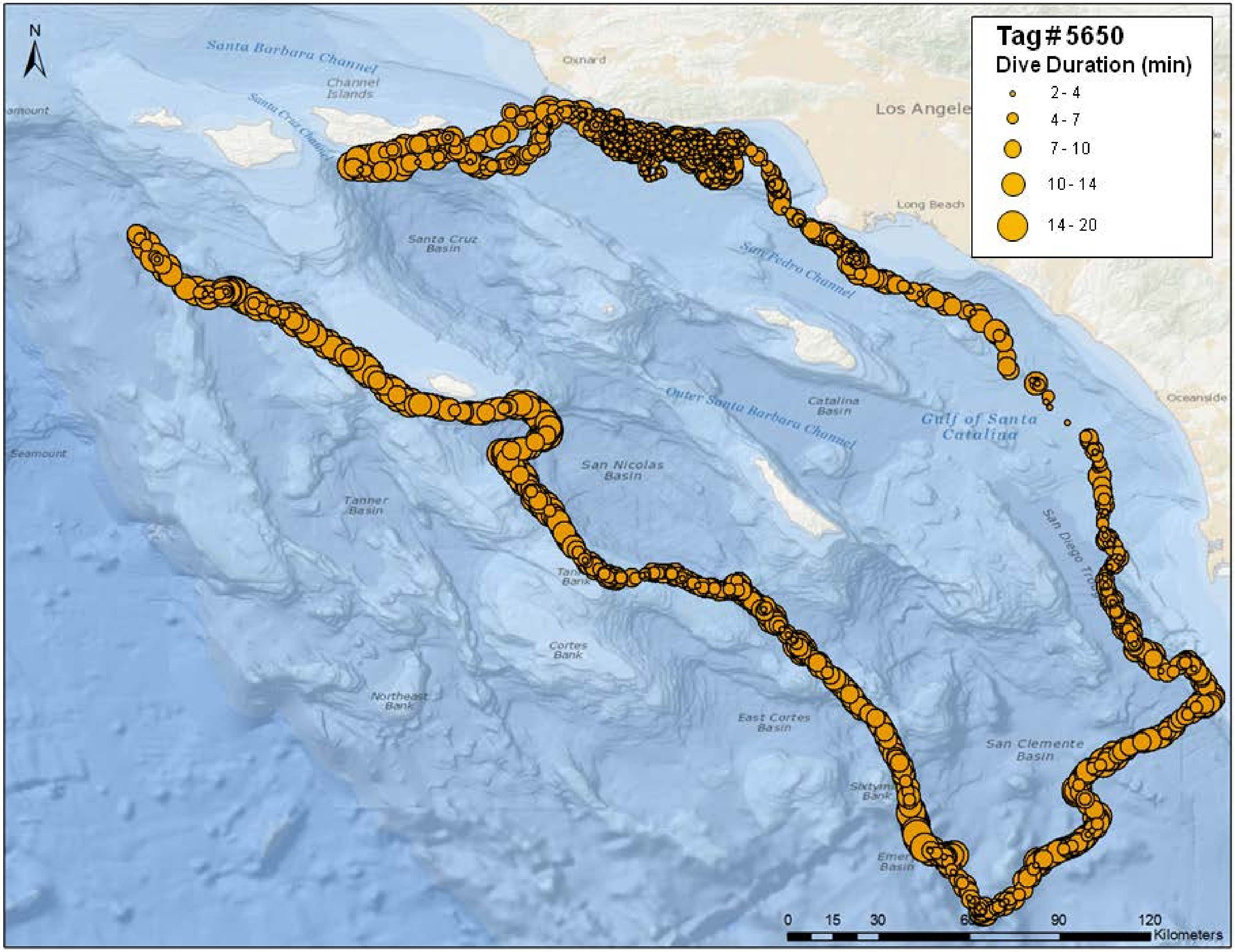

Figure 3-16. Track during 4 to 23 August 2014 of ADB-tagged blue whale #5650 tagged off southern California. Circle size represents the duration of a dive made at that location (*n* dives=2,276).

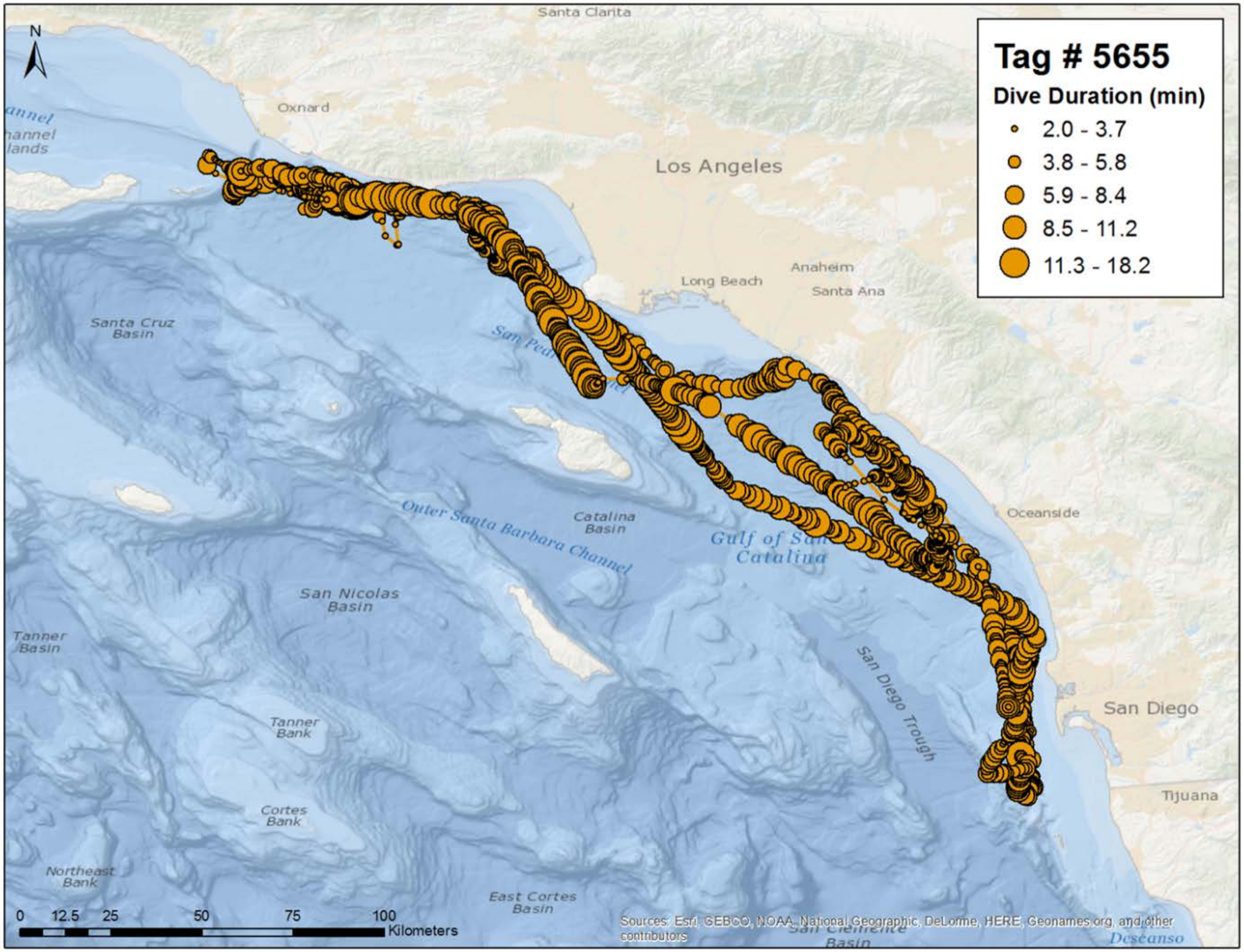

Figure 3-17. Track during 6 to 26 August 2014 of ADB-tagged blue whale #5655 tagged off southern California. Circle size represents the duration of a dive made at that location (*n* dives=2,918).

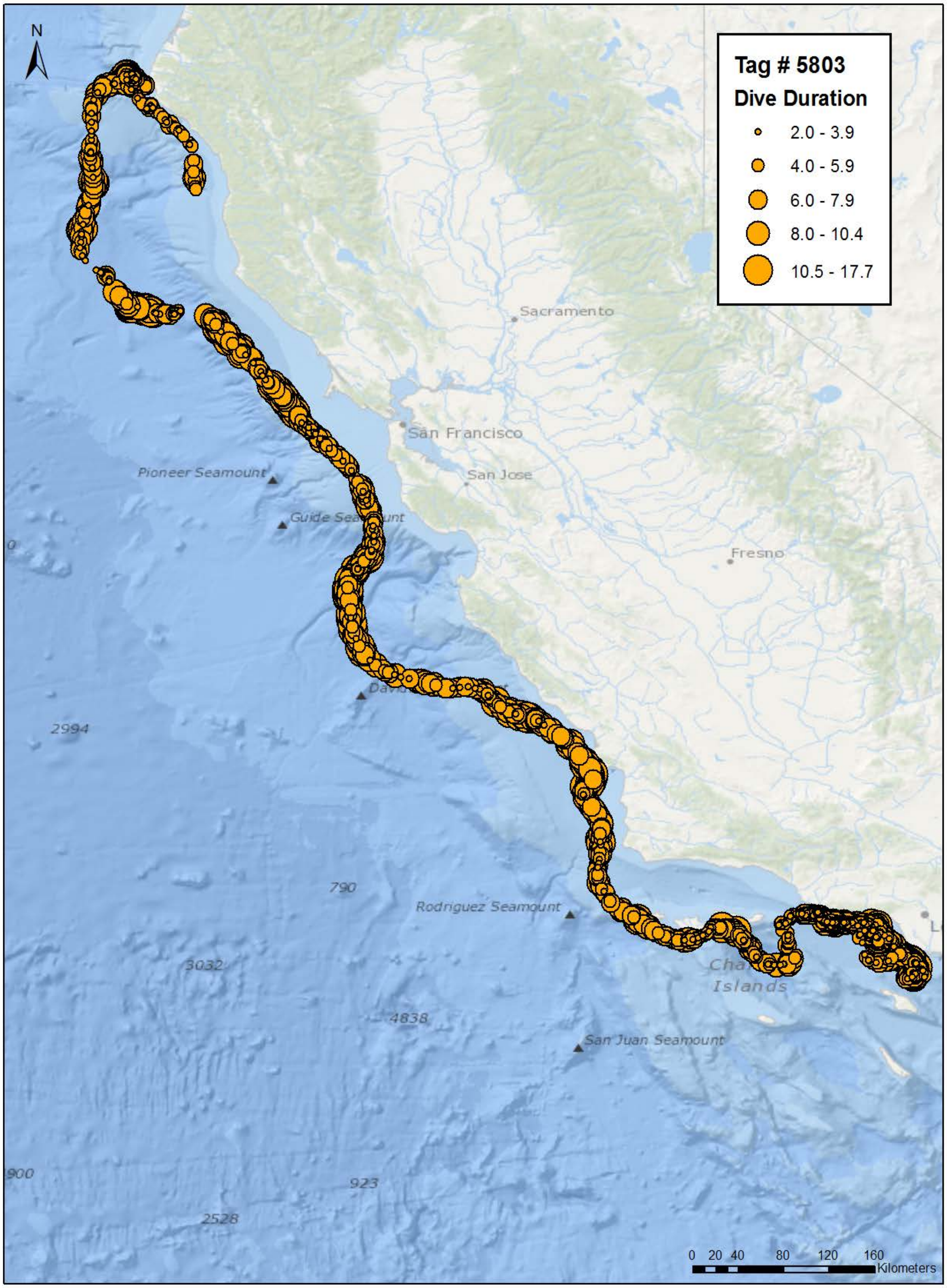

Figure 3-18. Track during 4 to 23 August 2014 of ADB-tagged blue whale #5803 tagged off southern California. Circle size represents the duration of a dive made at that location (*n* dives=1,832).

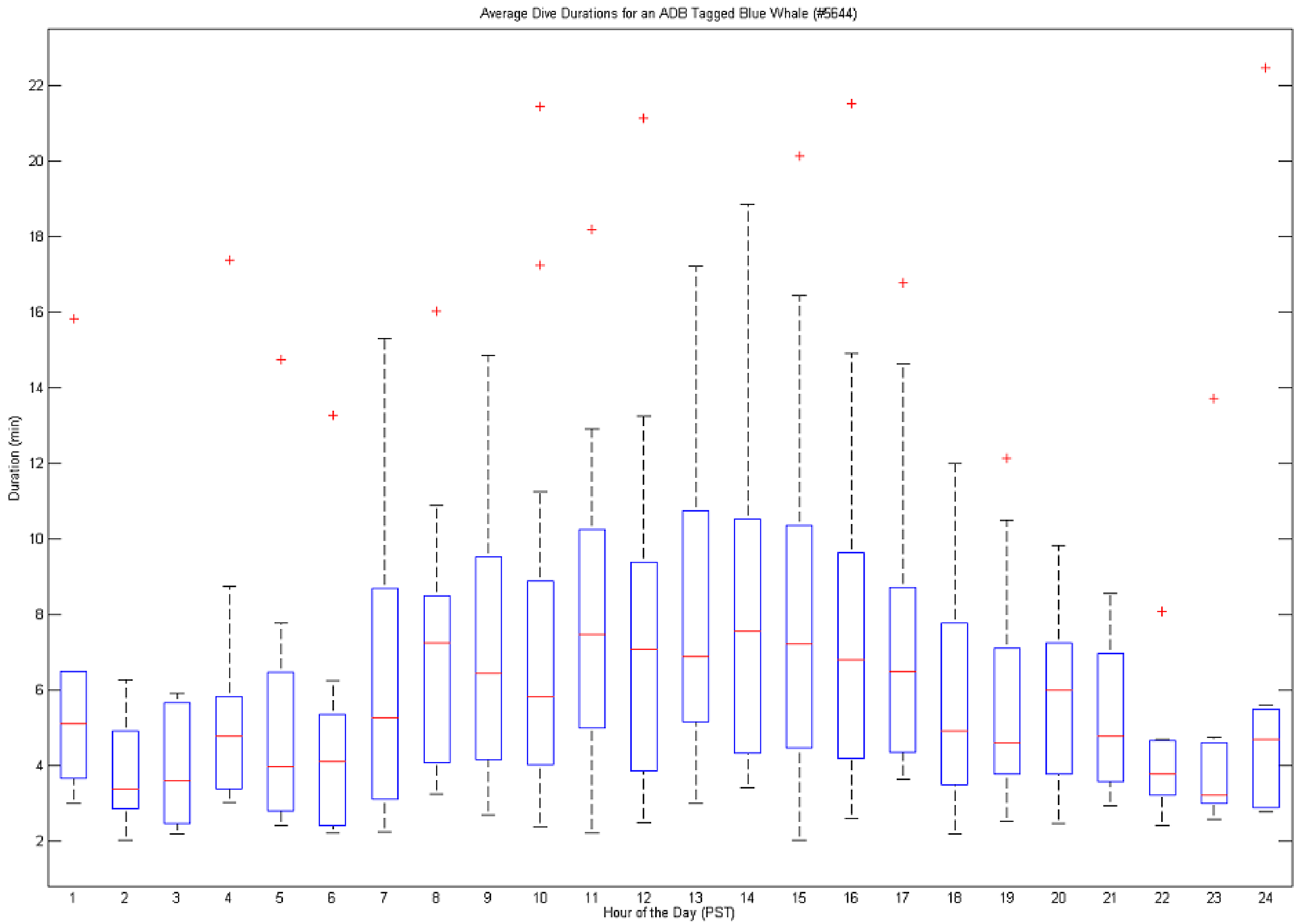

Figure 3-19. The distribution of dive durations for dives made by ADB-tagged blue whale #5644 tagged off southern California during each hour of the day.

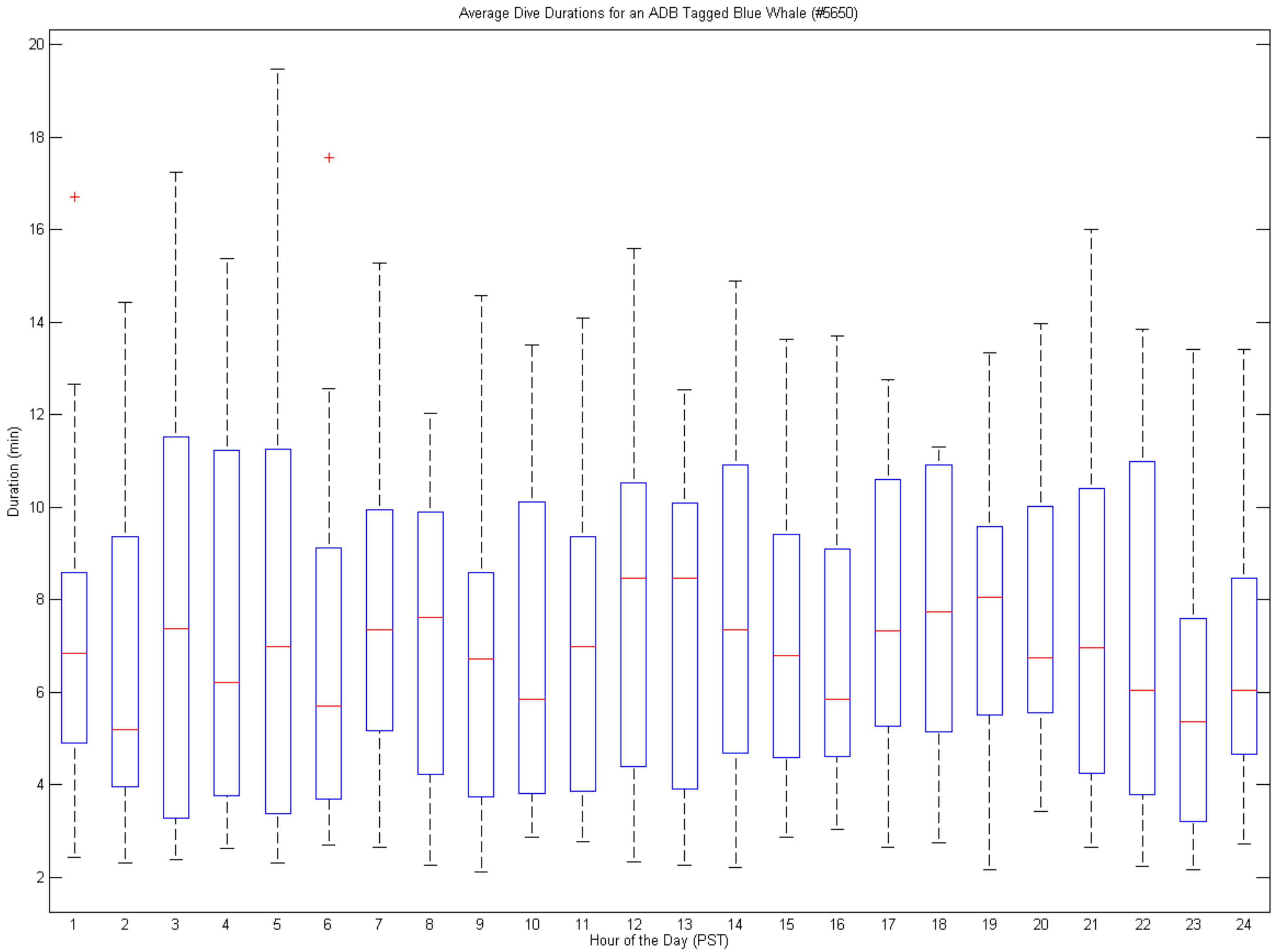

Figure 3-20. The distribution of dive durations for dives made by ADB-tagged blue whale #5650 tagged off southern California during each hour of the day.

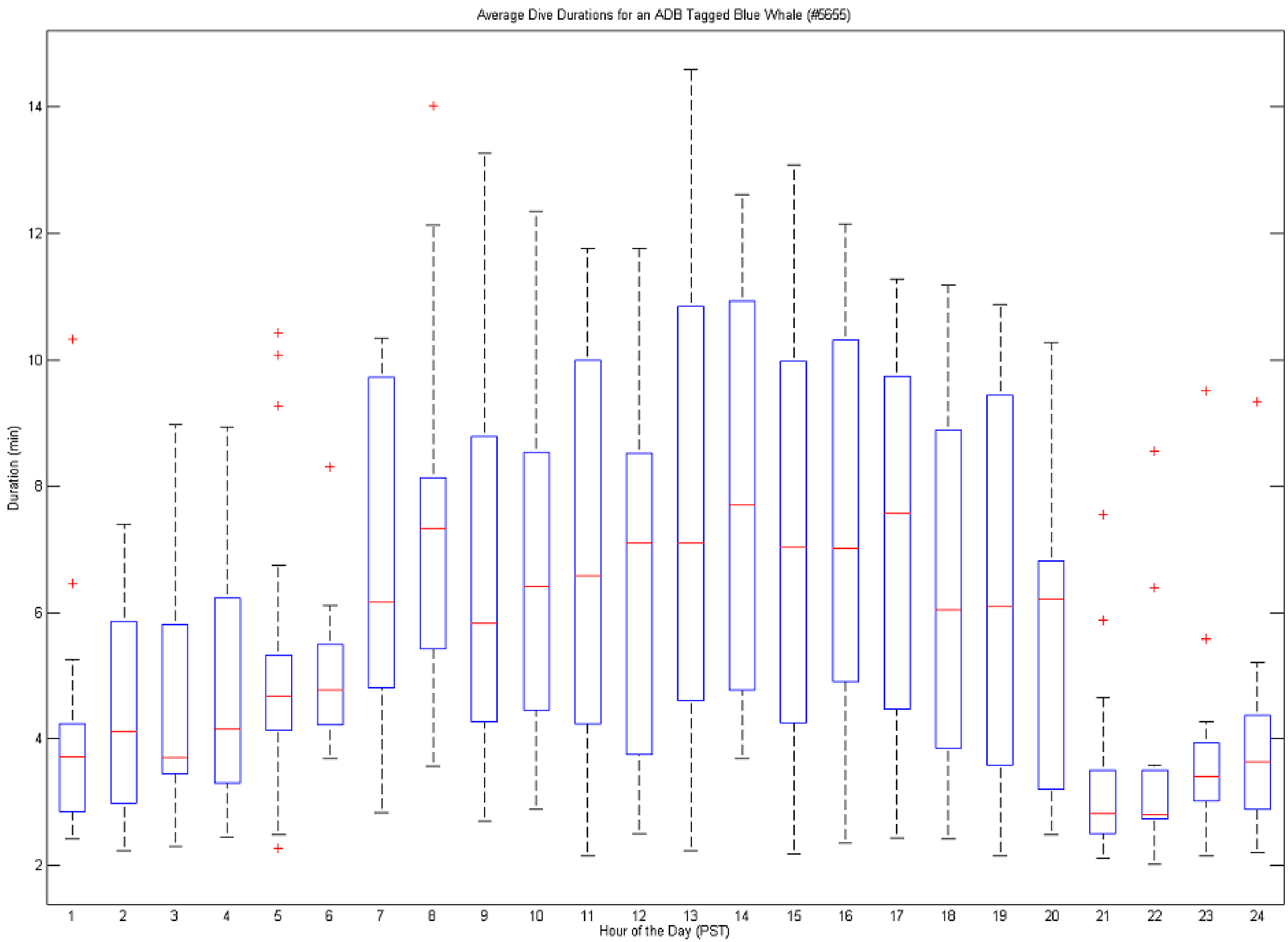

Figure 3-21. The distribution of dive durations for dives made by ADB-tagged blue whale #5655 tagged off southern California during each hour of the day.

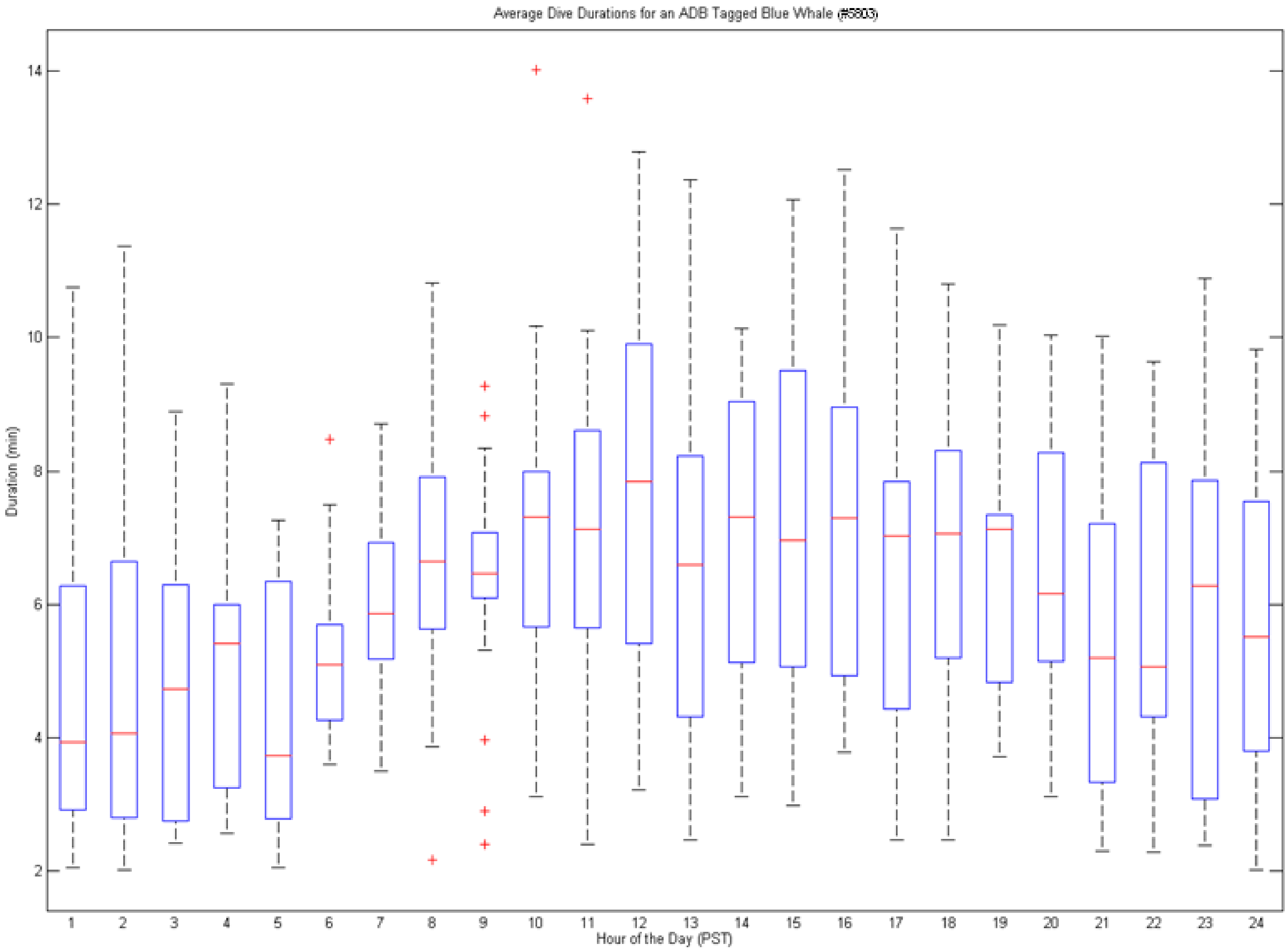

Figure 3-22. The distribution of dive durations for dives made by ADB-tagged blue whale #5803 tagged off southern California during each hour of the day.

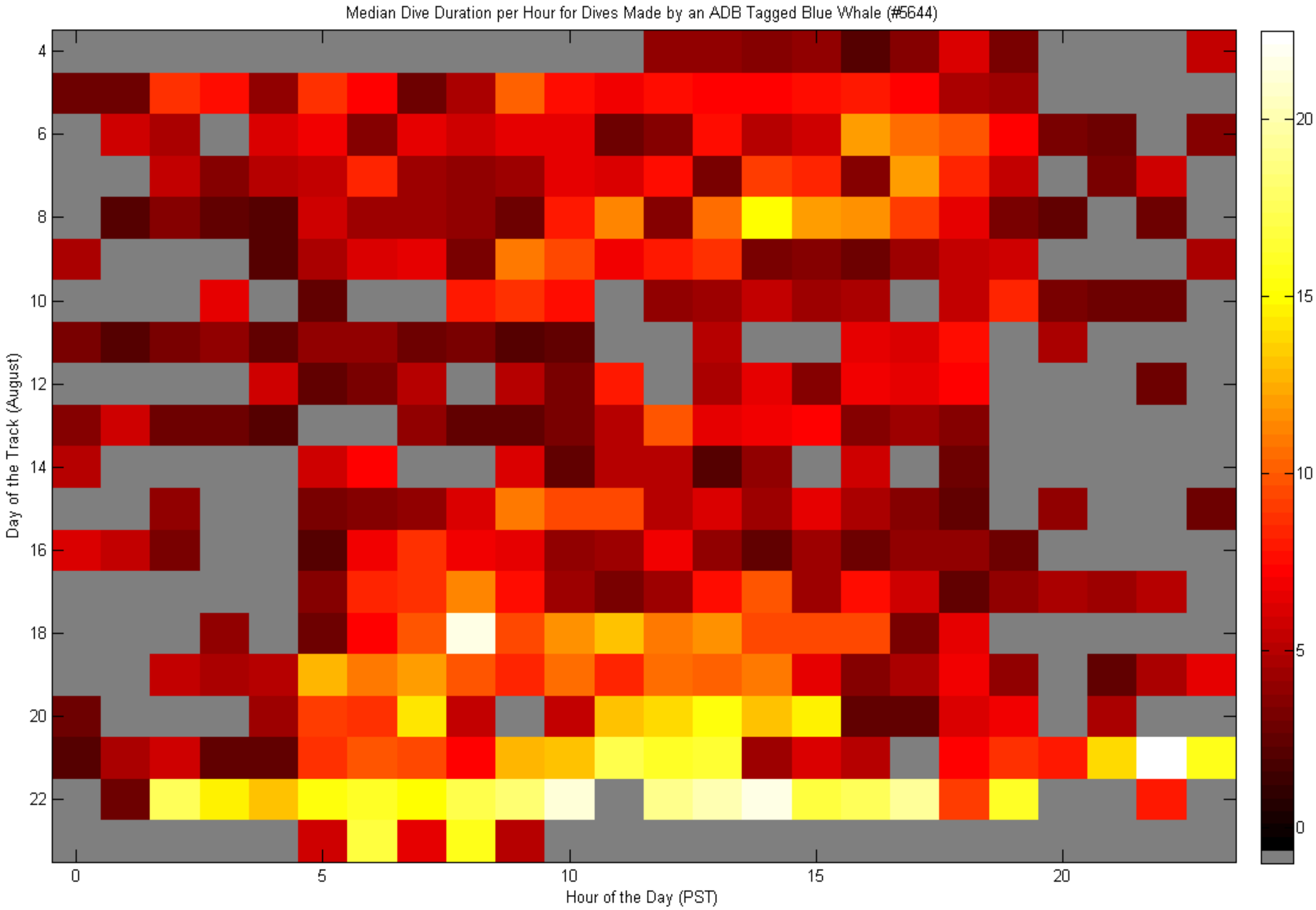

Figure 3-23. Median hourly durations of dives longer than 2 min in duration and greater than 10 m in depth made by ADB-tagged blue whale #5644 tracked off southern California (*n*=1068). Gray color represents hours with no dives meeting the criteria.

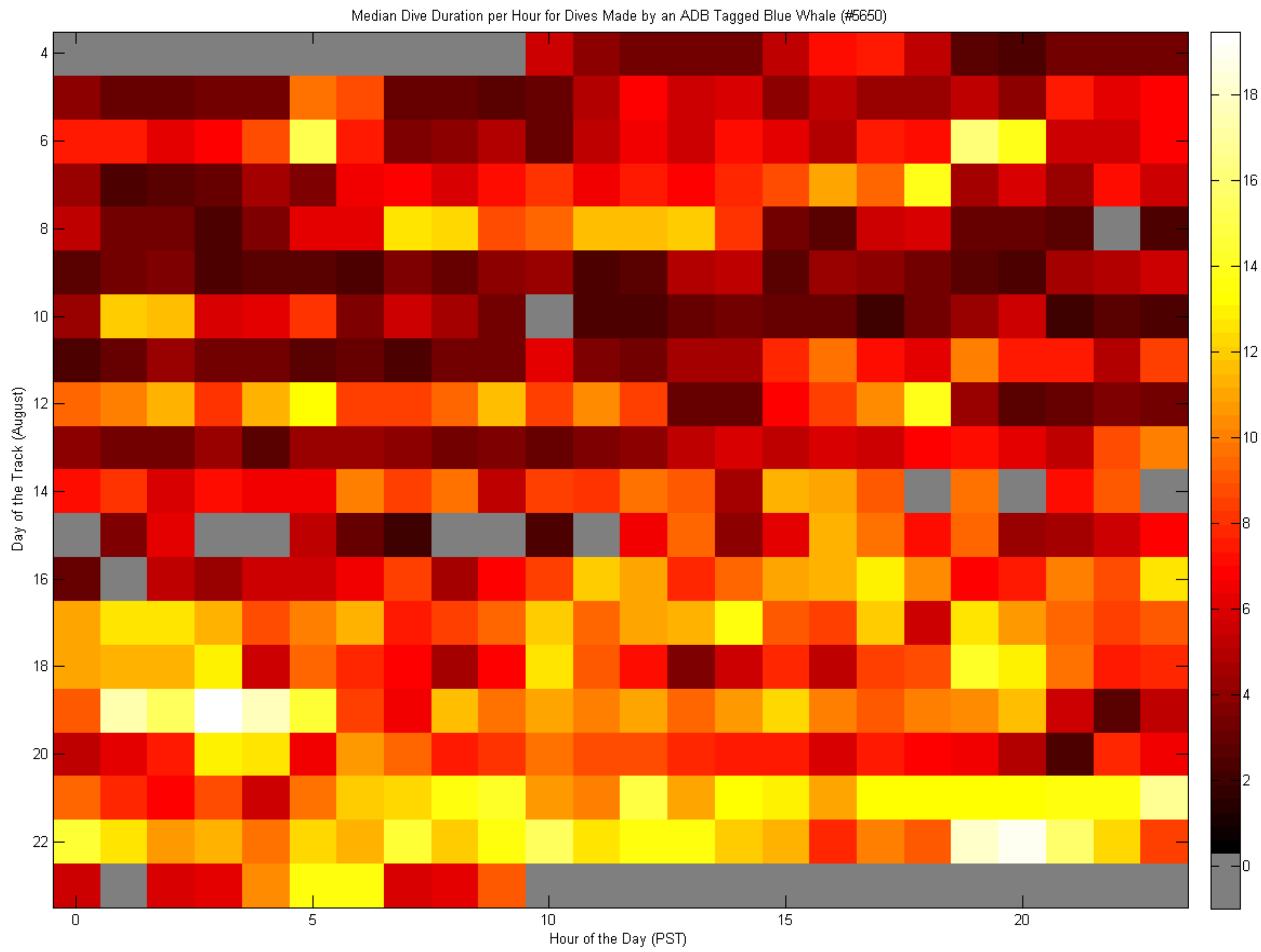

Figure 3-24. Median hourly durations of dives longer than 2 min in duration and greater than 10 m in depth made by ADB-tagged blue whale #5650 tracked off southern California (*n*=2,276). Gray color represents hours with no dives meeting the criteria.

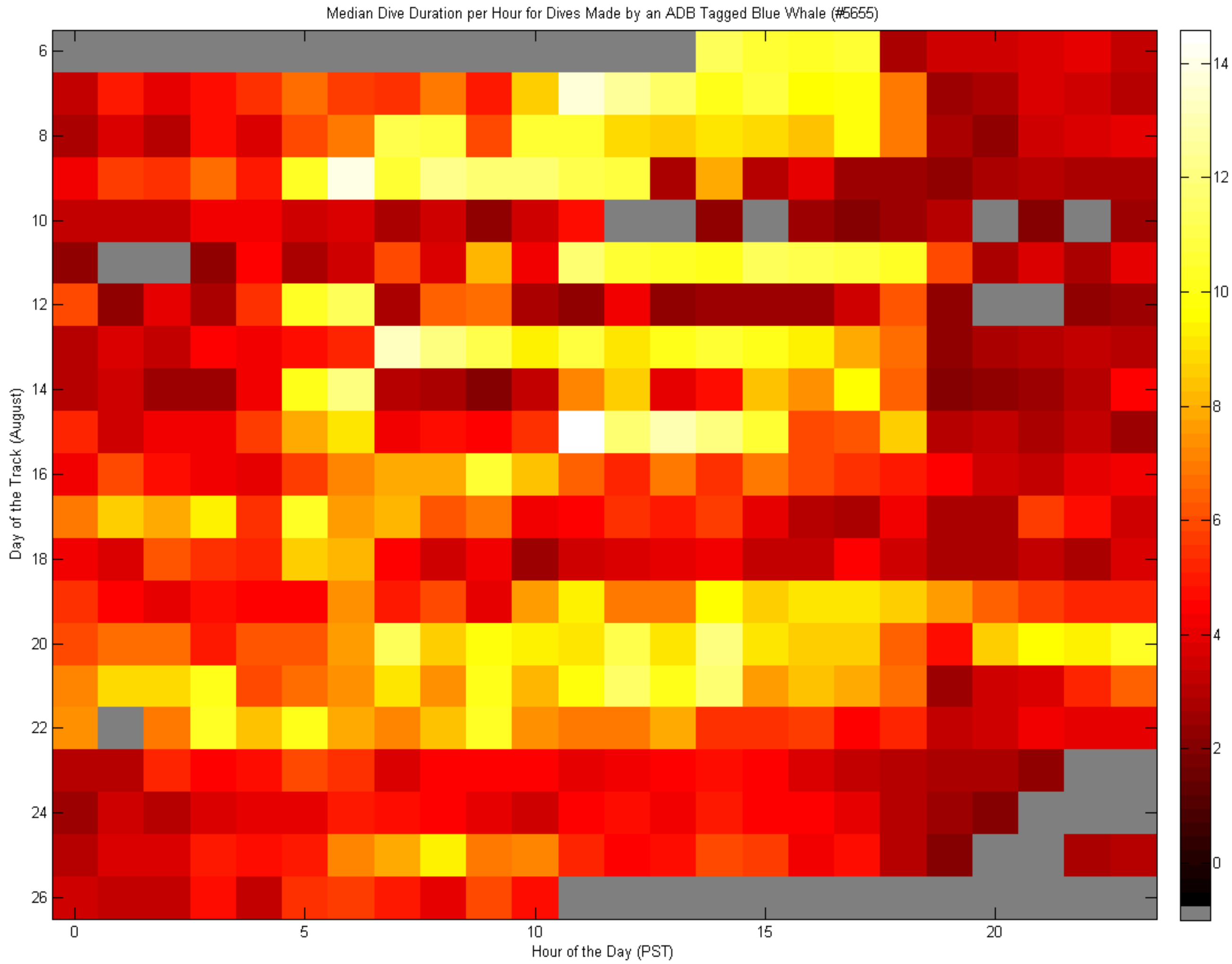

Figure 3-25. Median hourly durations of dives longer than 2 min in duration and greater than 10 m in depth made by ADB-tagged blue whale #5655 tracked off southern California (*n*=2,918). Gray color represents hours with no dives meeting the criteria.

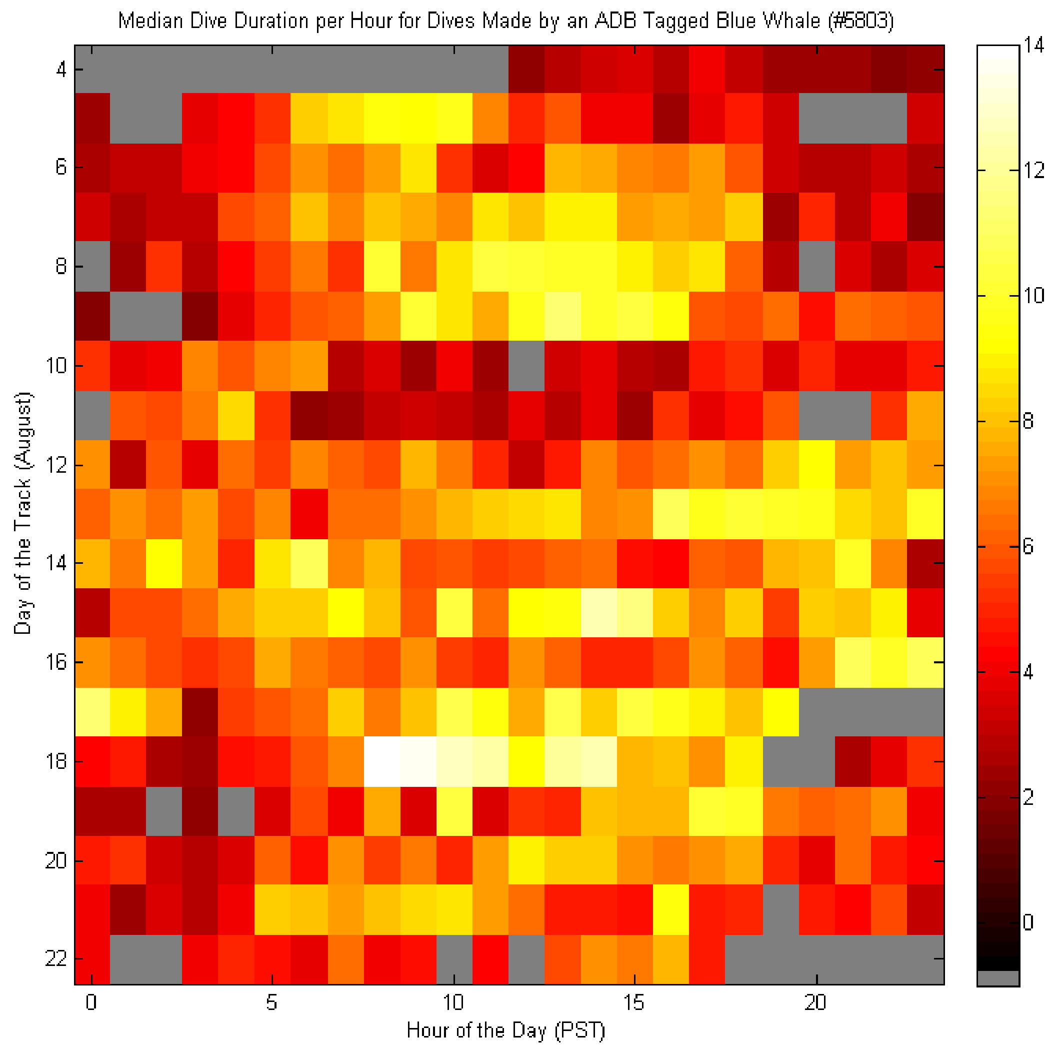

Figure 3-26. Median hourly durations of dives longer than 2 min in duration and greater than 10 m in depth made by ADB-tagged blue whale #5803 tracked off southern California (*n*=1,832). Gray color represents hours with no dives meeting the criteria.

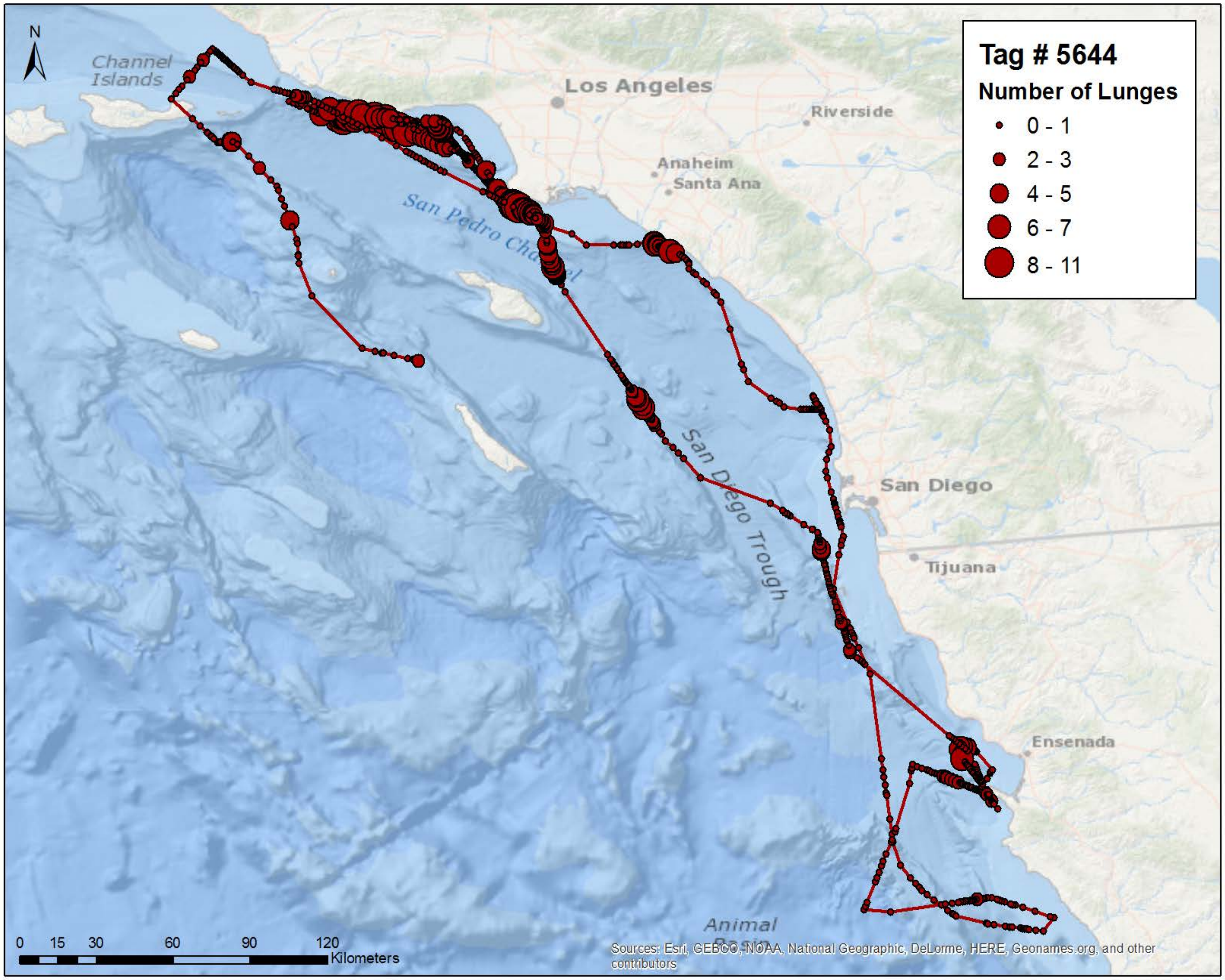

Figure 3-27. Track during 4 to 23 August 2014 of ADB-tagged blue whale #5644 tagged off southern California. Circle size represents the number of feeding lunges made during a dive at that location (*n* dives=1,068).

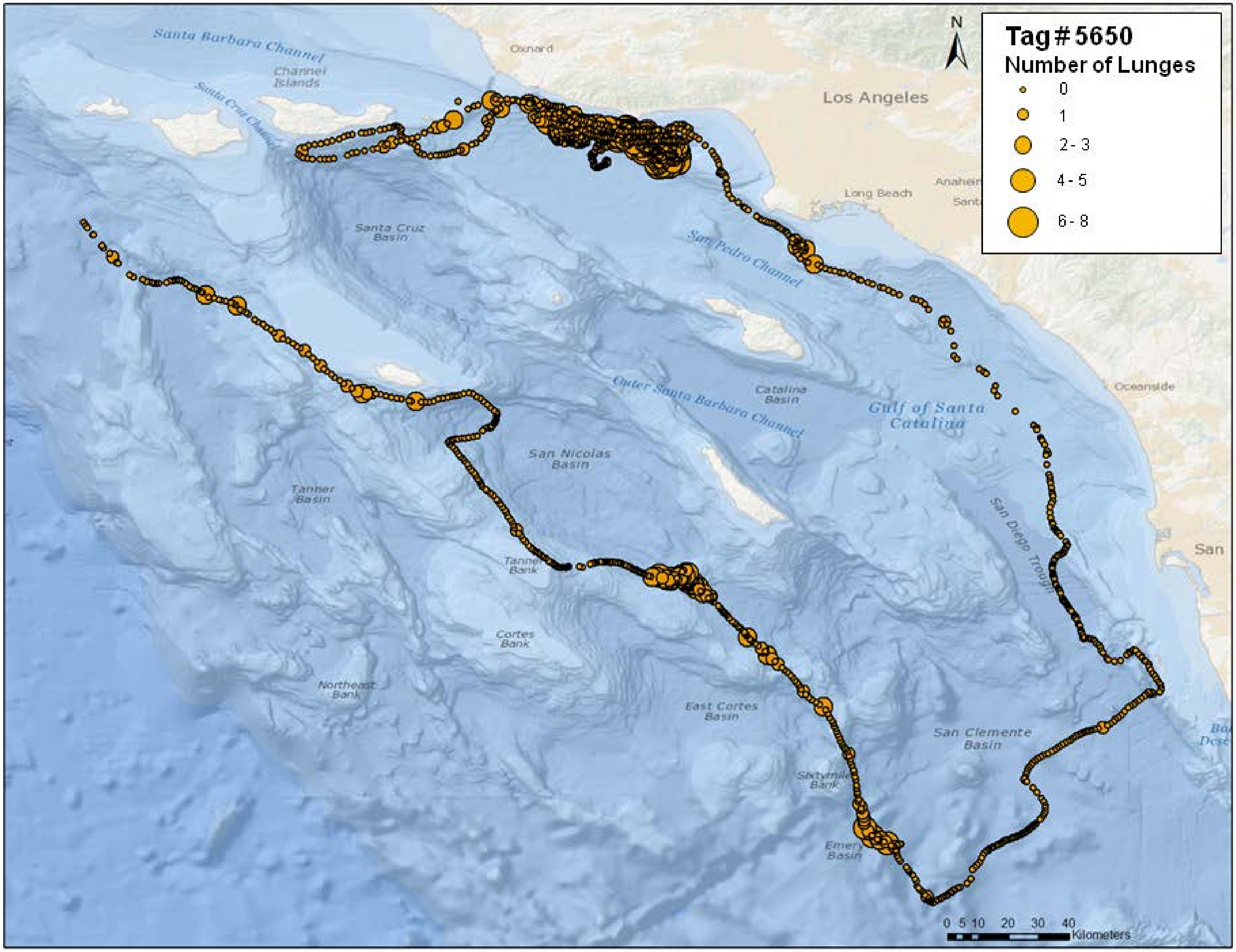

Figure 3-28. Track during 4 to 23 August 2014 of ADB-tagged blue whale #5650 tagged off southern California. Circle size represents the number of feeding lunges made during a dive at that location (*n* dives=1,832).

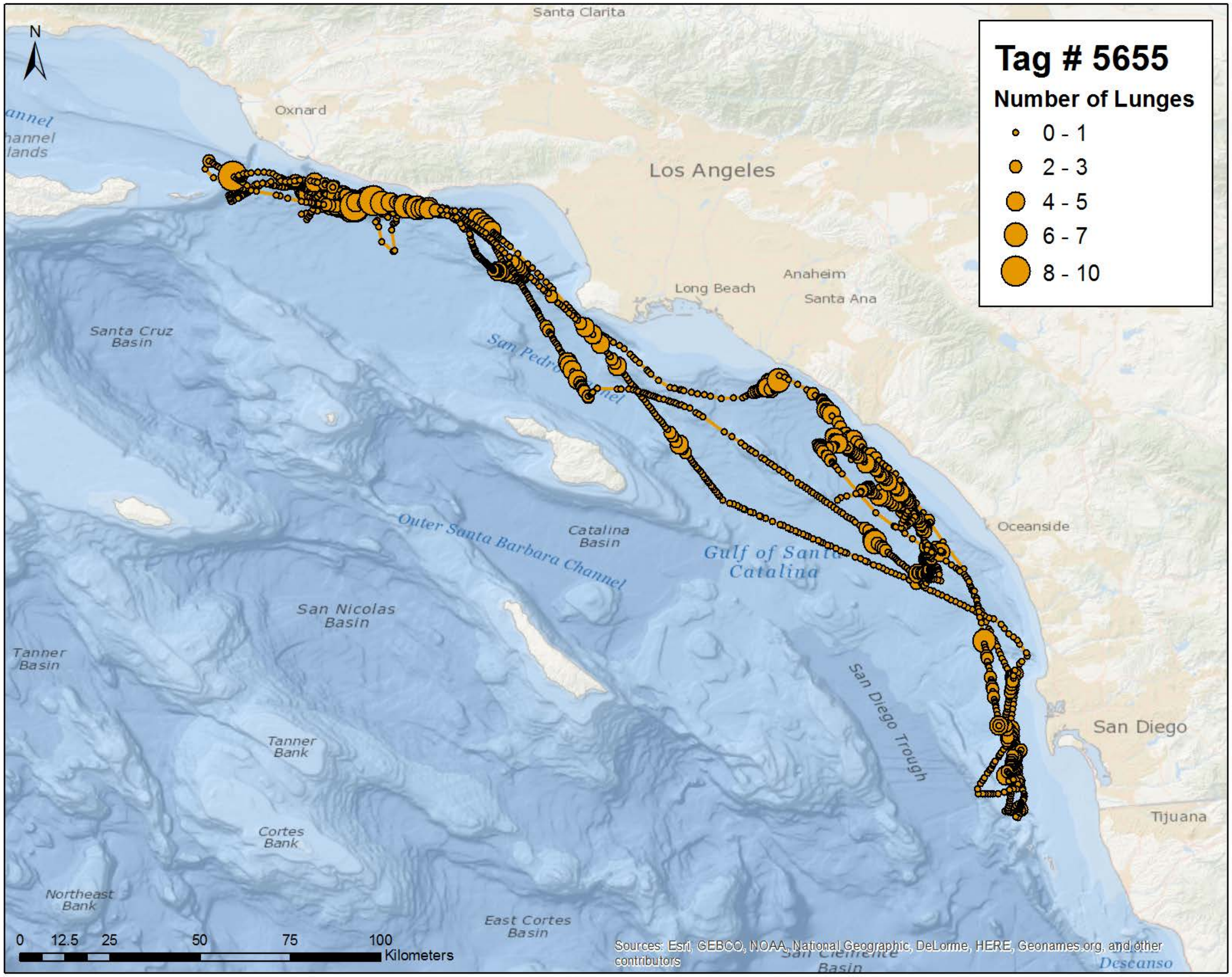

Figure 3-29. Track during 6 to 26 August 2014 of ADB-tagged blue whale #5655 tagged off southern California. Circle size represents the duration of a dive made at that location (*n* dives=2,918).

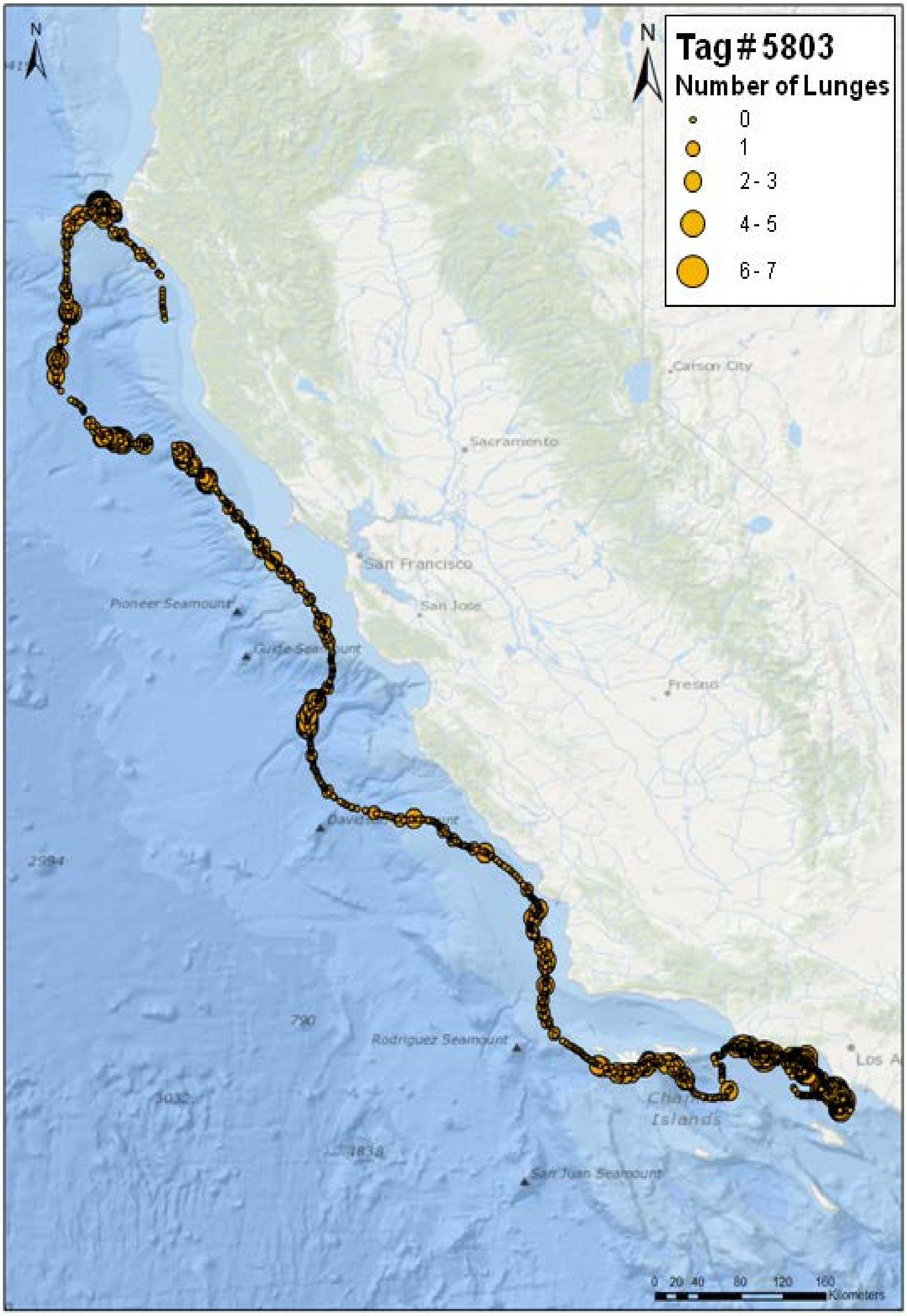

Figure 3-30. Track during 4 to 23 August 2014 of ADB-tagged blue whale #5803 tagged off southern California. Circle size represents the number of feeding lunges made during a dive at that location (*n* dives=1,832).

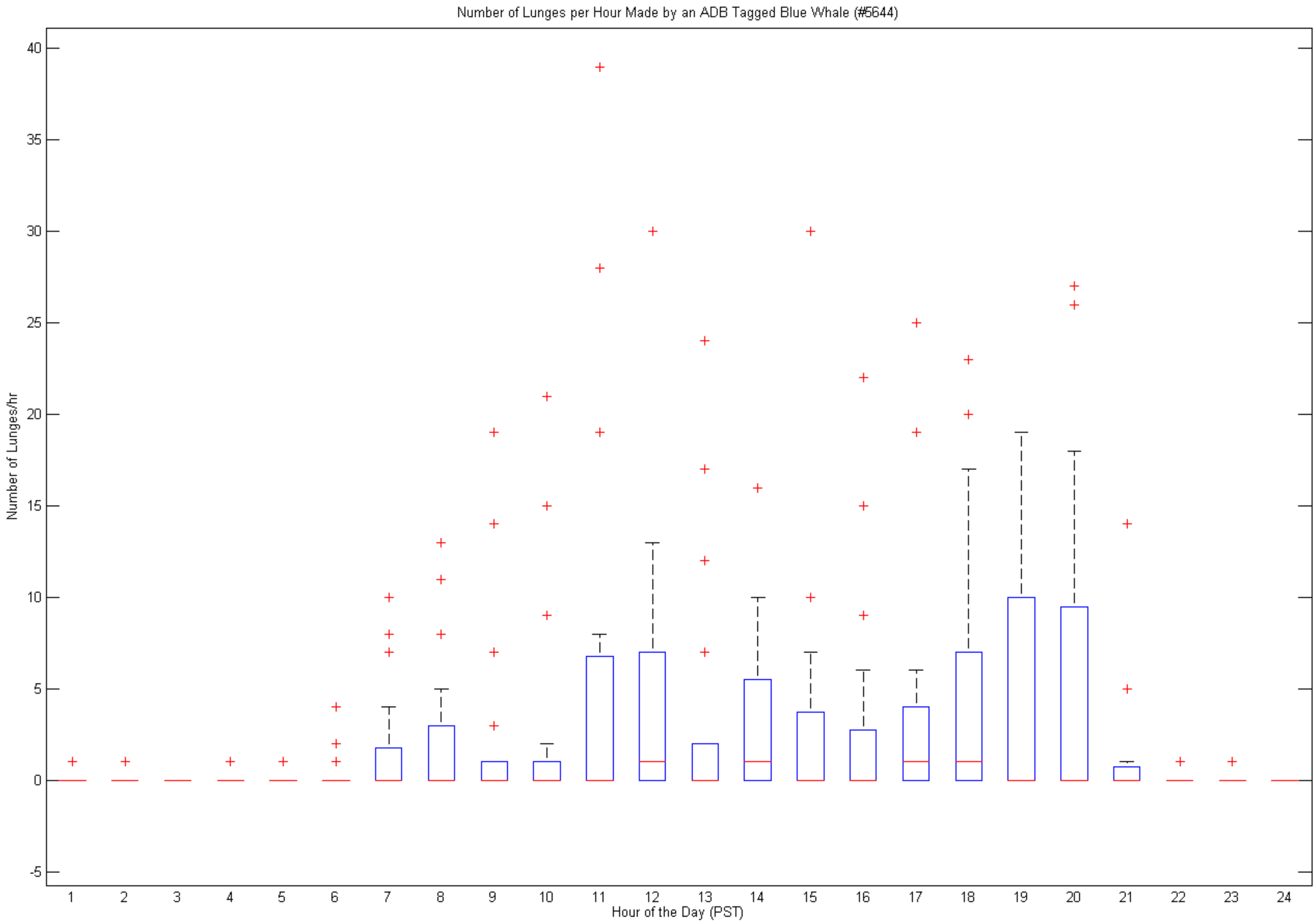

Figure 3-31. The distribution of dive durations for dives made by ADB-tagged blue whale #5644 during each hour of the day.

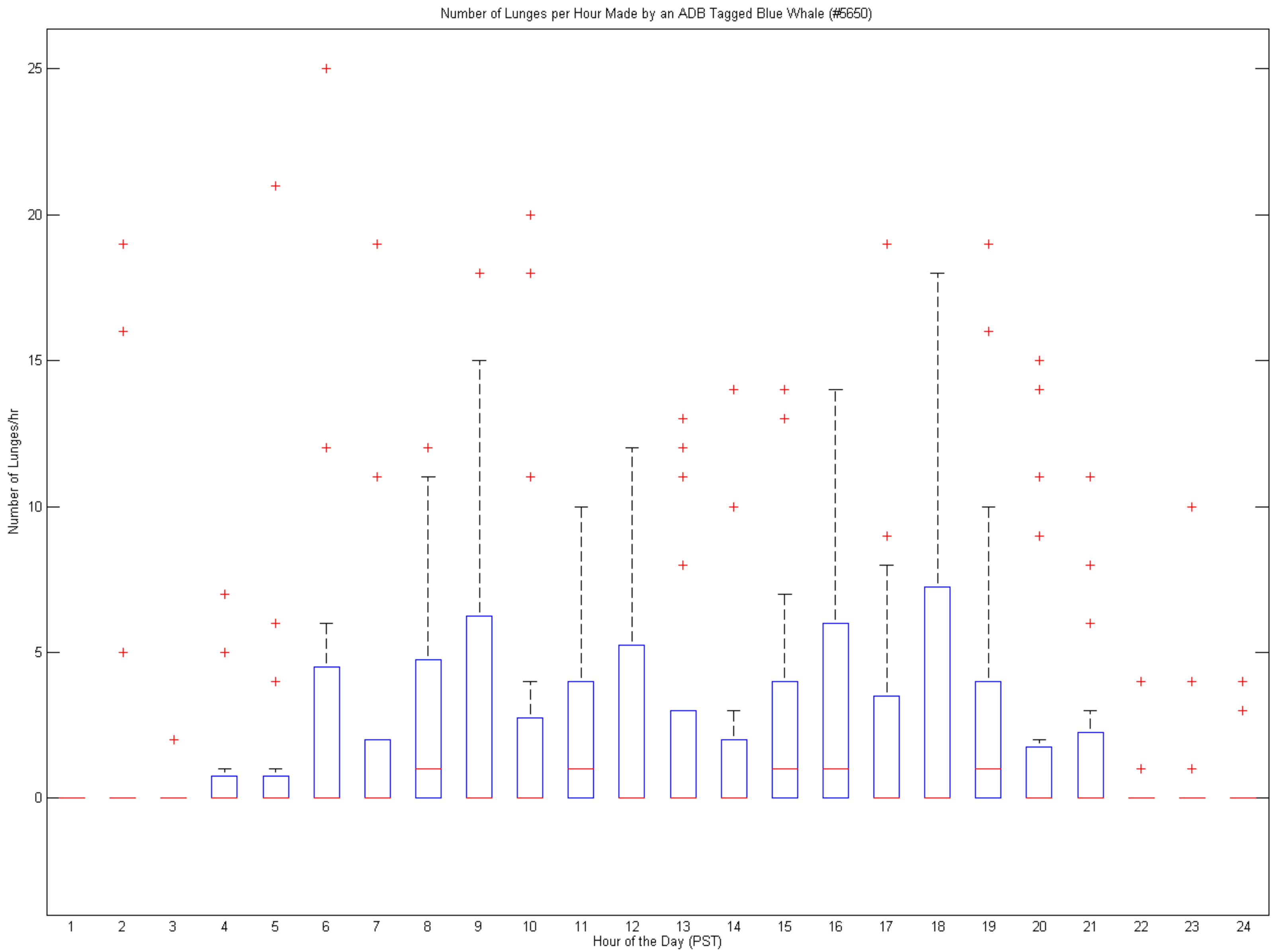

Figure 3-32. The distribution of dive durations for dives made by ADB-tagged blue whale #5650 during each hour of the day.

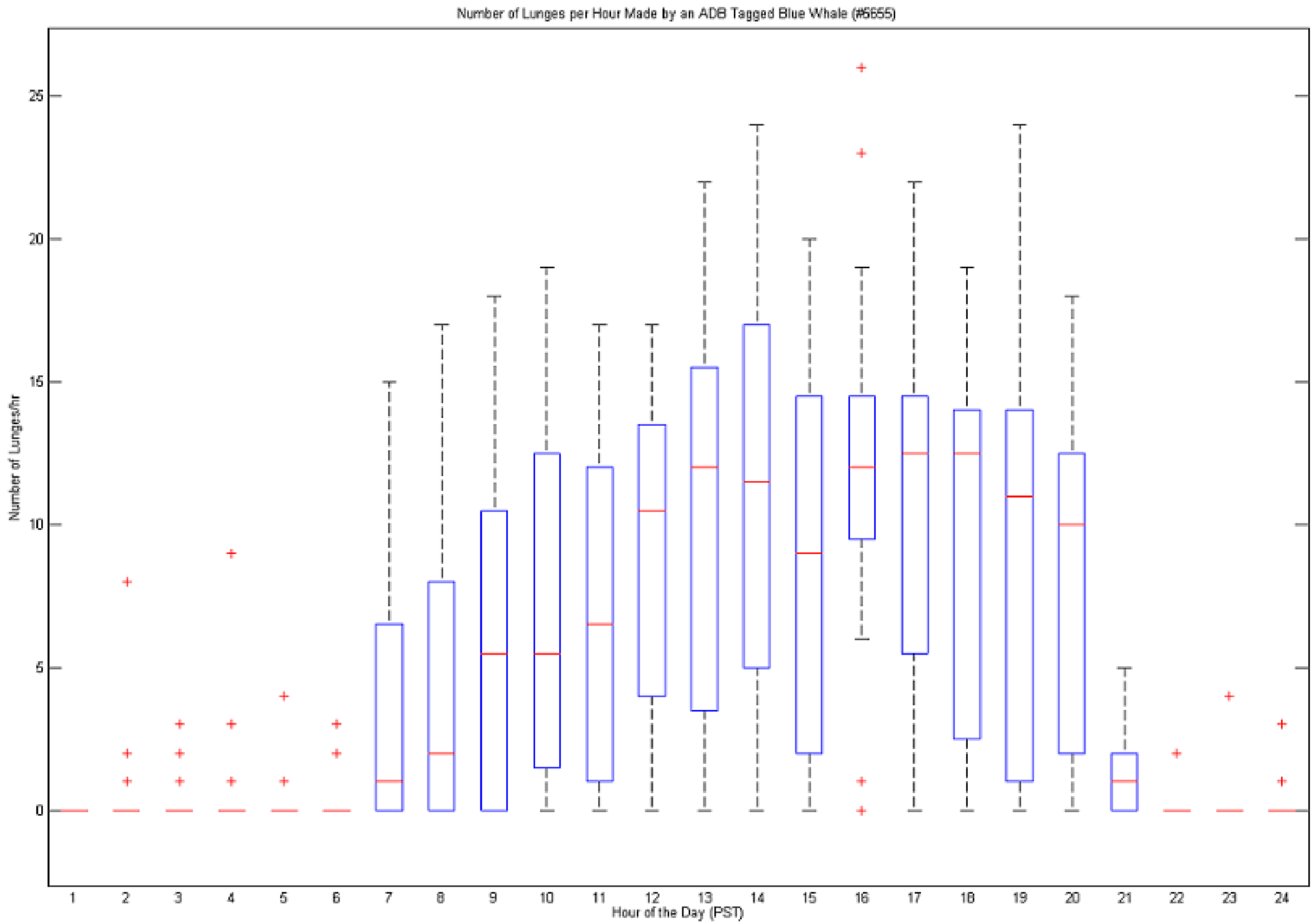

Figure 3-33. The distribution of dive durations for dives made by ADB-tagged blue whale #5655 during each hour of the day.

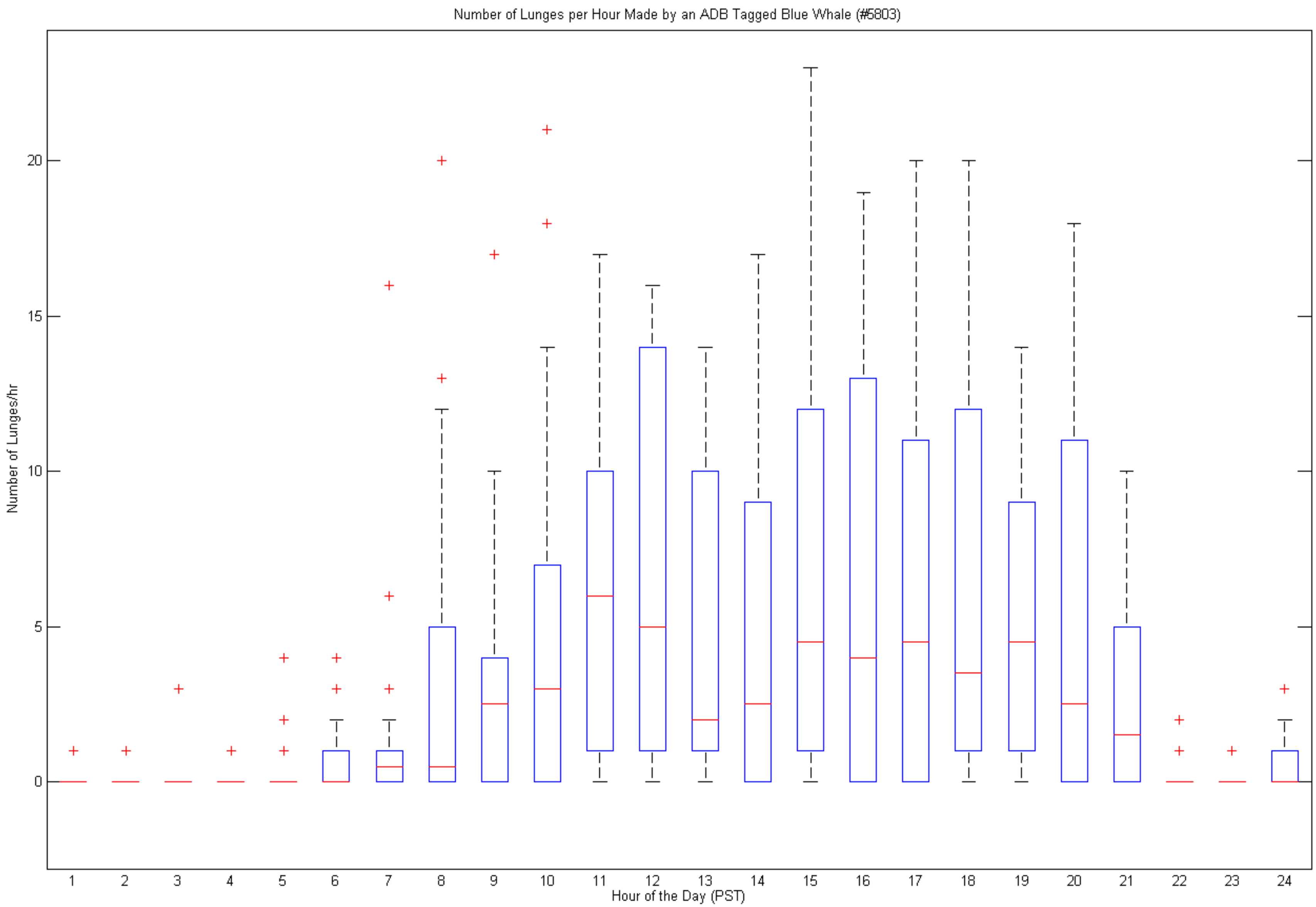

Figure 3-34. The distribution of dive durations for dives made by ADB-tagged blue whale #5803 during each hour of the day.

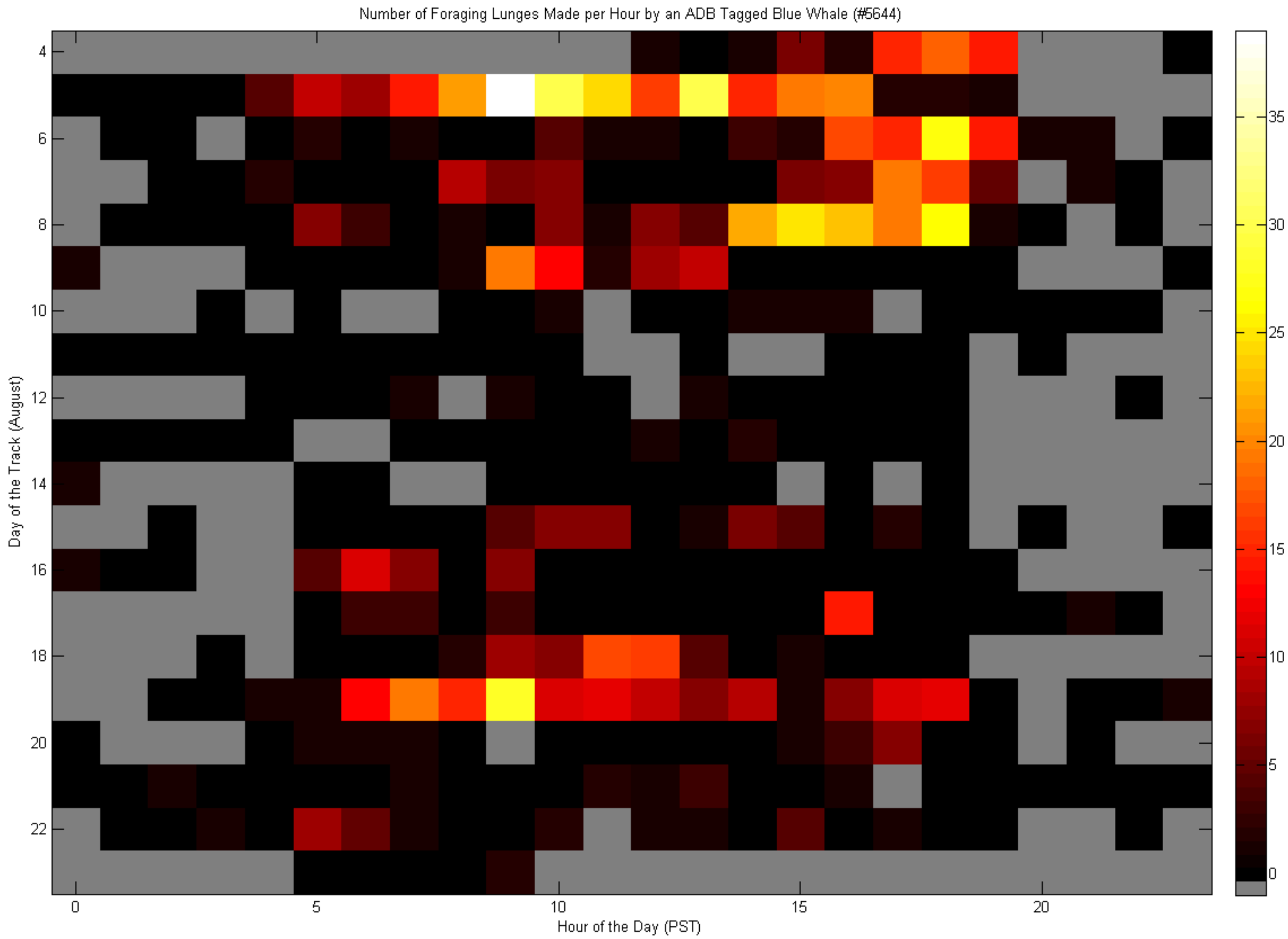

Figure 3-35. Numbers of foraging lunges made per hour during dives longer than 2 min in duration and greater than 10 m in depth by ADB-tagged blue whale #5644 tracked off southern California (*n*=1,068). Gray color represents hours with no dives meeting the criteria.

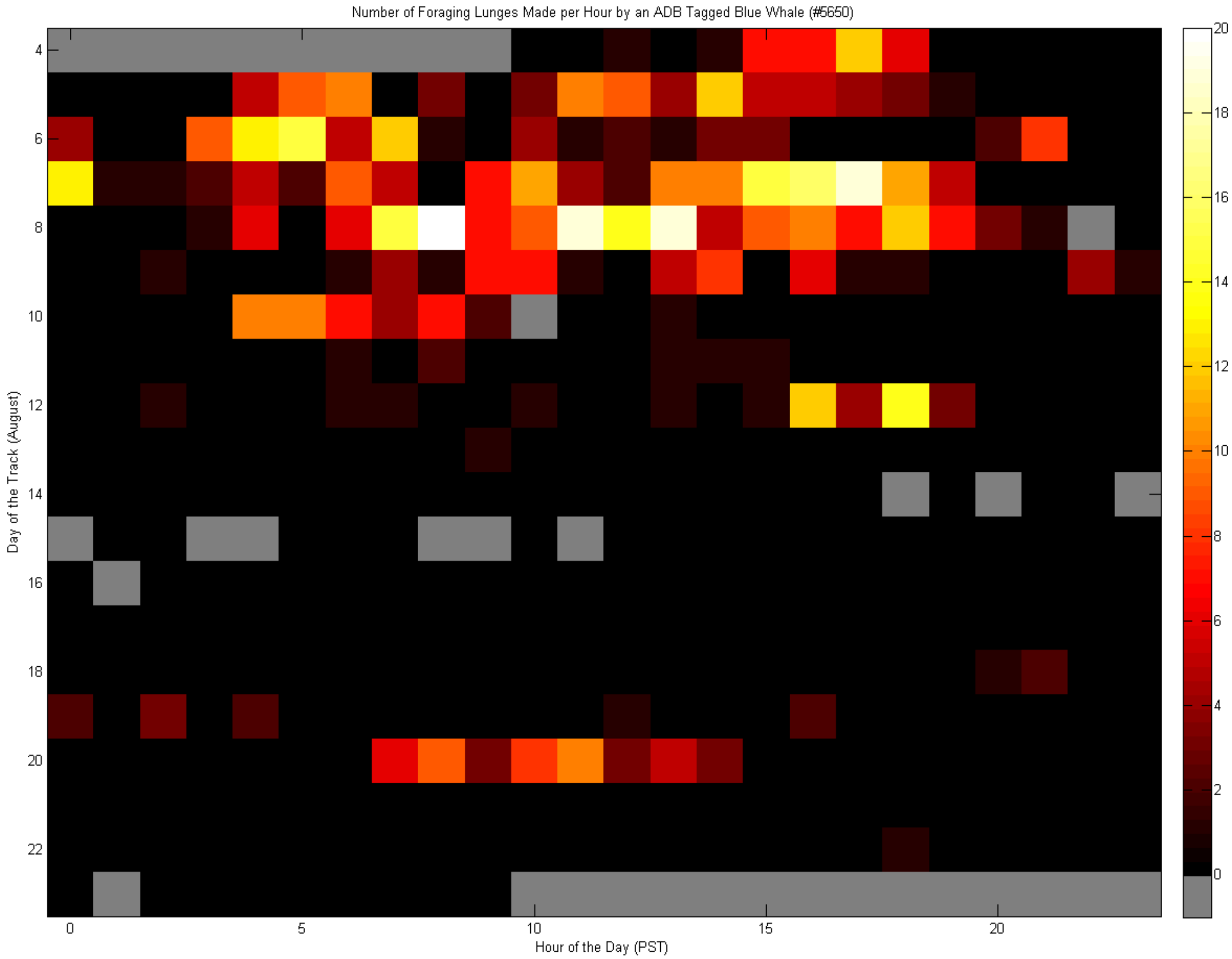

Figure 3-36. Numbers of foraging lunges made per hour during dives longer than 2 min in duration and greater than 10 m in depth by ADB-tagged blue whale #5650 tracked off southern California (*n*=2,276). Gray color represents hours with no dives meeting the criteria.

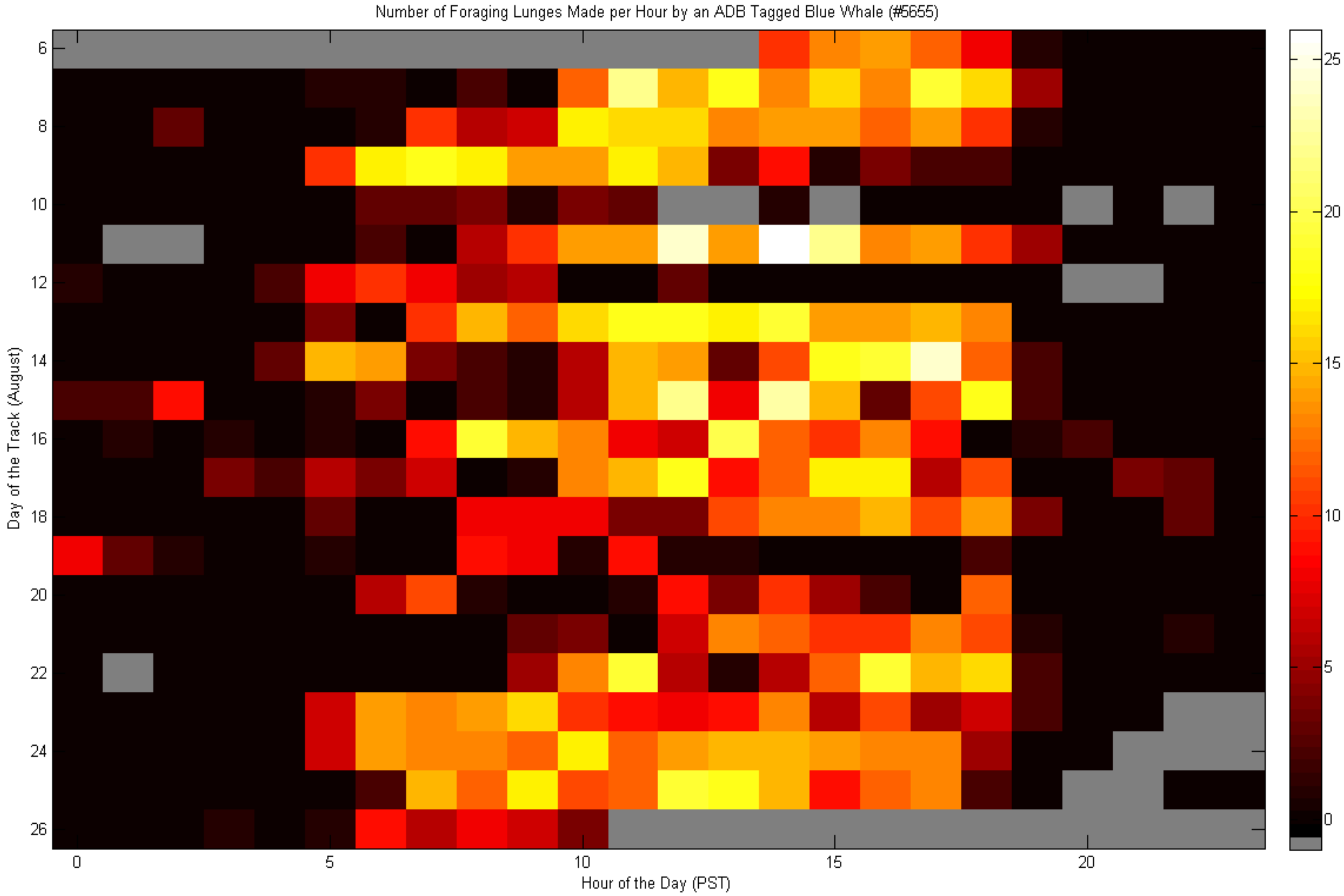

Figure 3-37. Numbers of foraging lunges made per hour during dives longer than 2 min in duration and greater than 10 m in depth by ADB-tagged blue whale #5655 tracked off southern California (*n*=2,918). Gray color represents hours with no dives meeting the criteria.

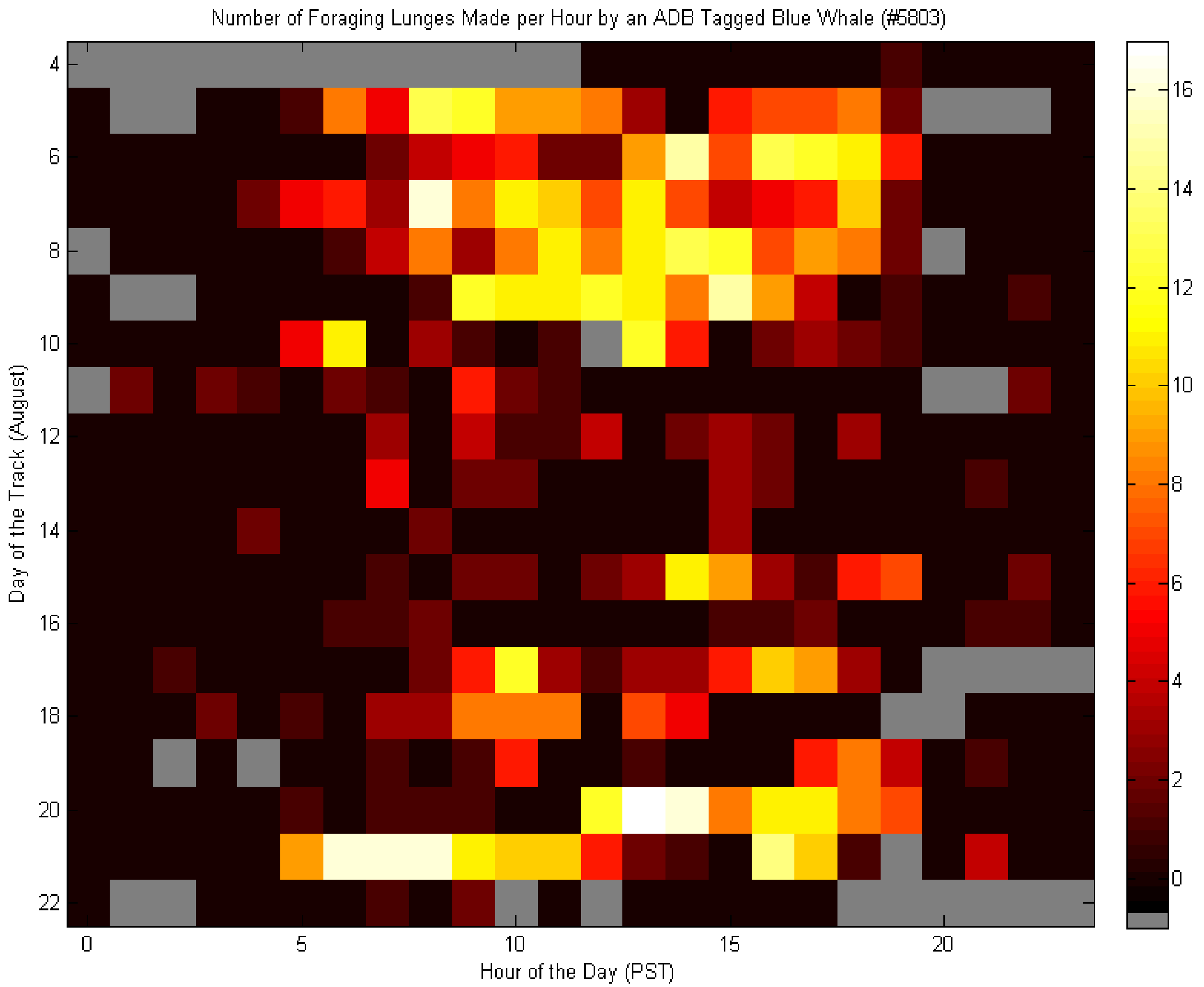

Figure 3-38. Number of foraging lunges made per hour during dives longer than 2 min in duration and greater than 10 m in depth by ADB-tagged blue whale #5803 tracked off southern California (*n*=1,832). Gray color represents hours with no dives meeting the criteria.

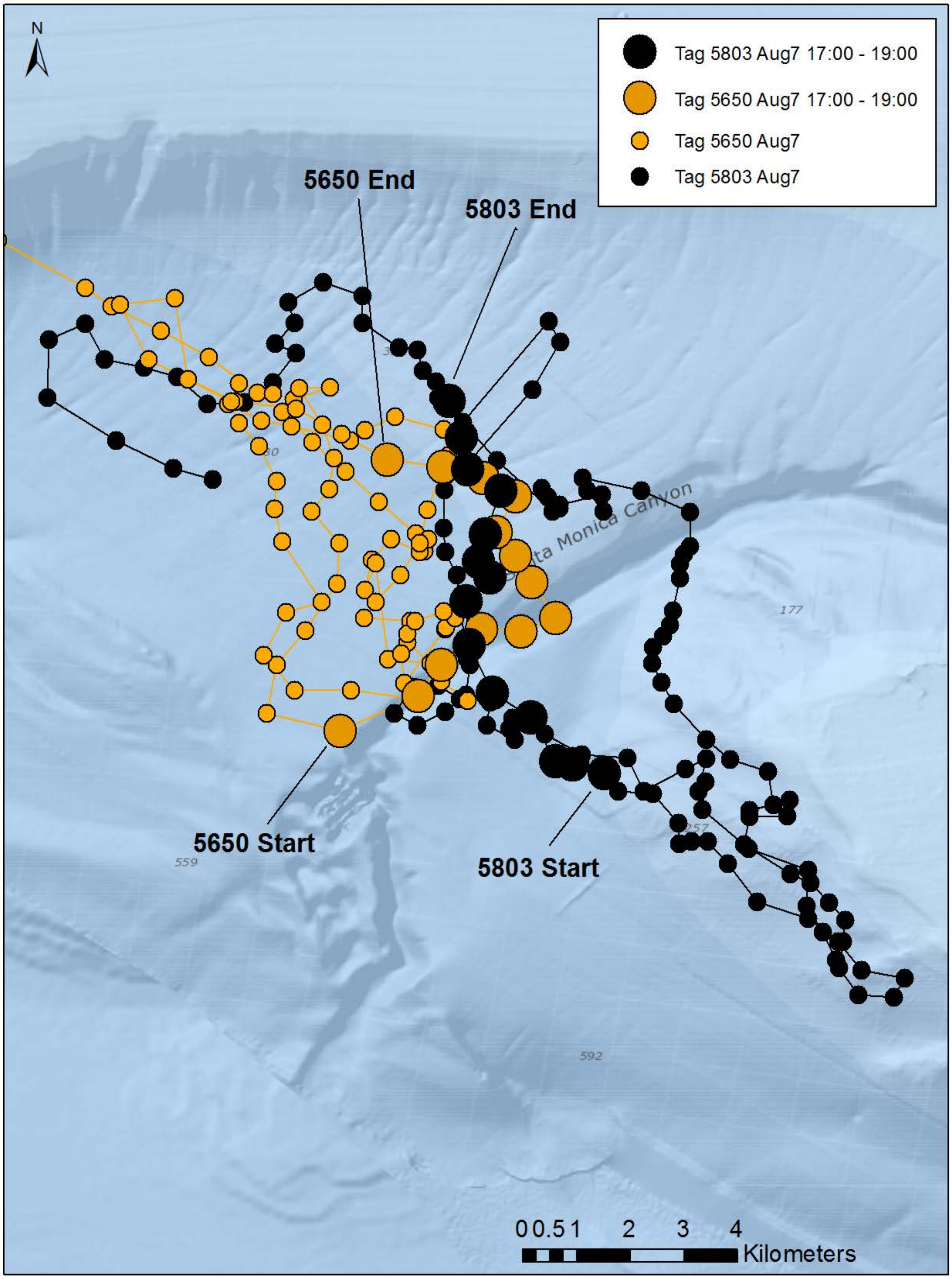

Figure 3-39. The tracks of two ADB-tagged blue whales on 7 August 2014. Larger circles show portions of the tracks were they were in very close proximity to one another (less than 0.5 km) at 17:00–19:00 GMT.

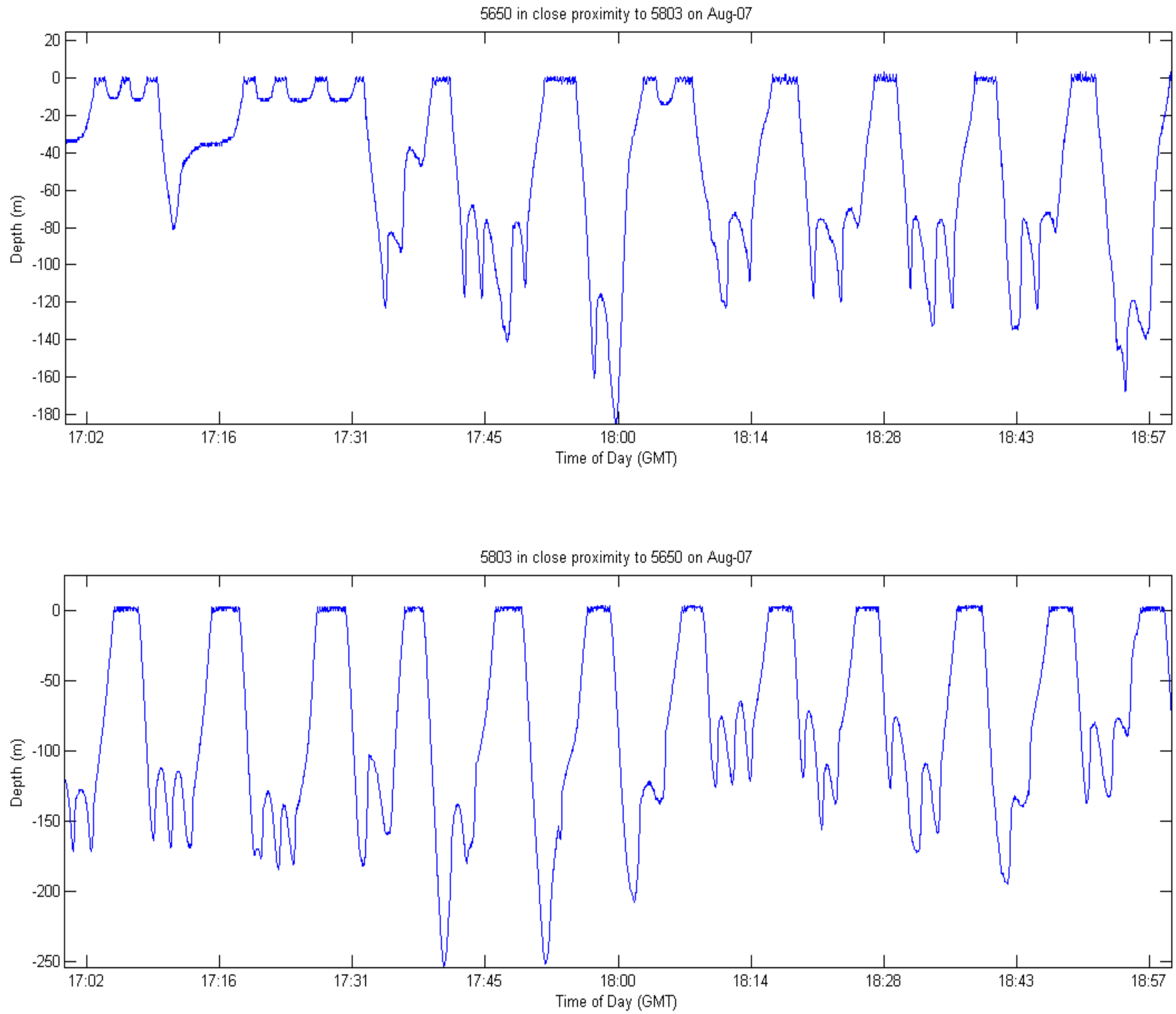

Figure 3-40. Dive profiles for ADB-tagged blue whales #5650 (top panel) and #5803 (bottom panel) when they were in close proximity to one another at 17:00-19:00 GMT on 7 August 2014 off southern California.

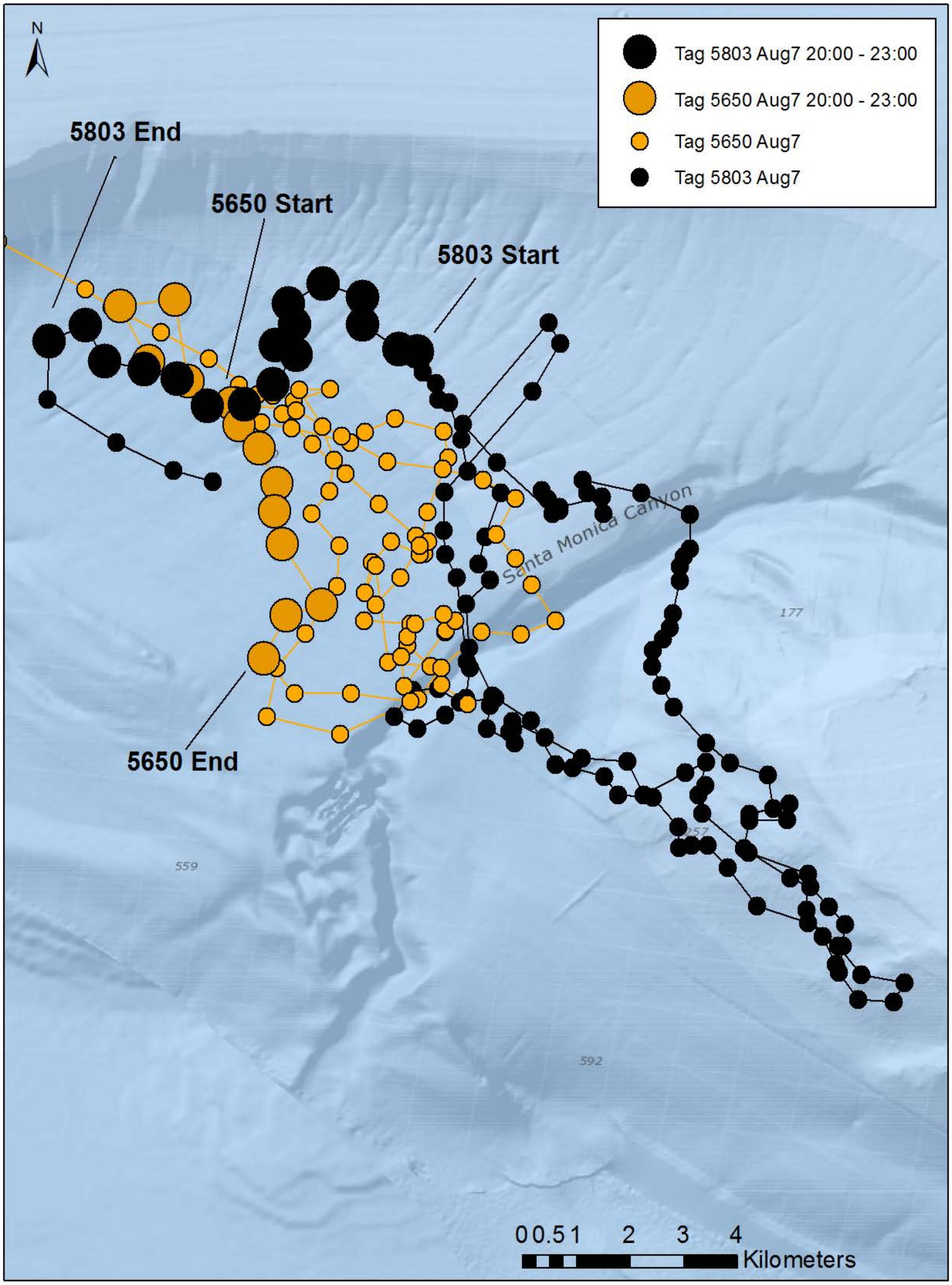

Figure 3-41. The tracks of two ADB-tagged blue whales on 7 August 2014. Larger circles show portions of the tracks were they were in very close proximity to one another (less than 0.5 km) at 20:00–23:00 GMT.

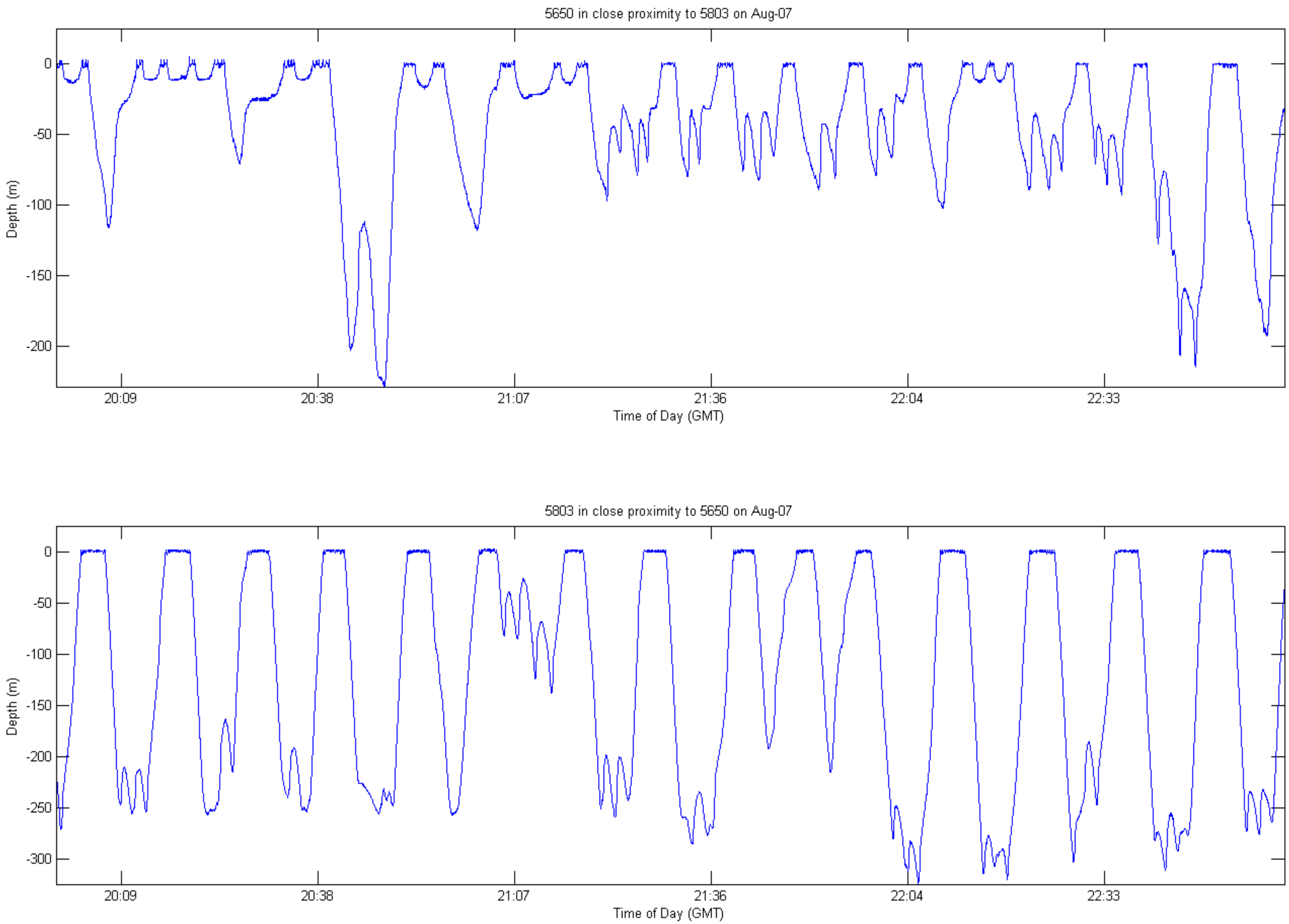

Figure 3-42. Dive profiles for ADB-tagged blue whales #5650 (top panel) and #5803 (bottom panel) when they were in close proximity to one another at 20:00-23:00 GMT on 7 August 2014 off southern California.

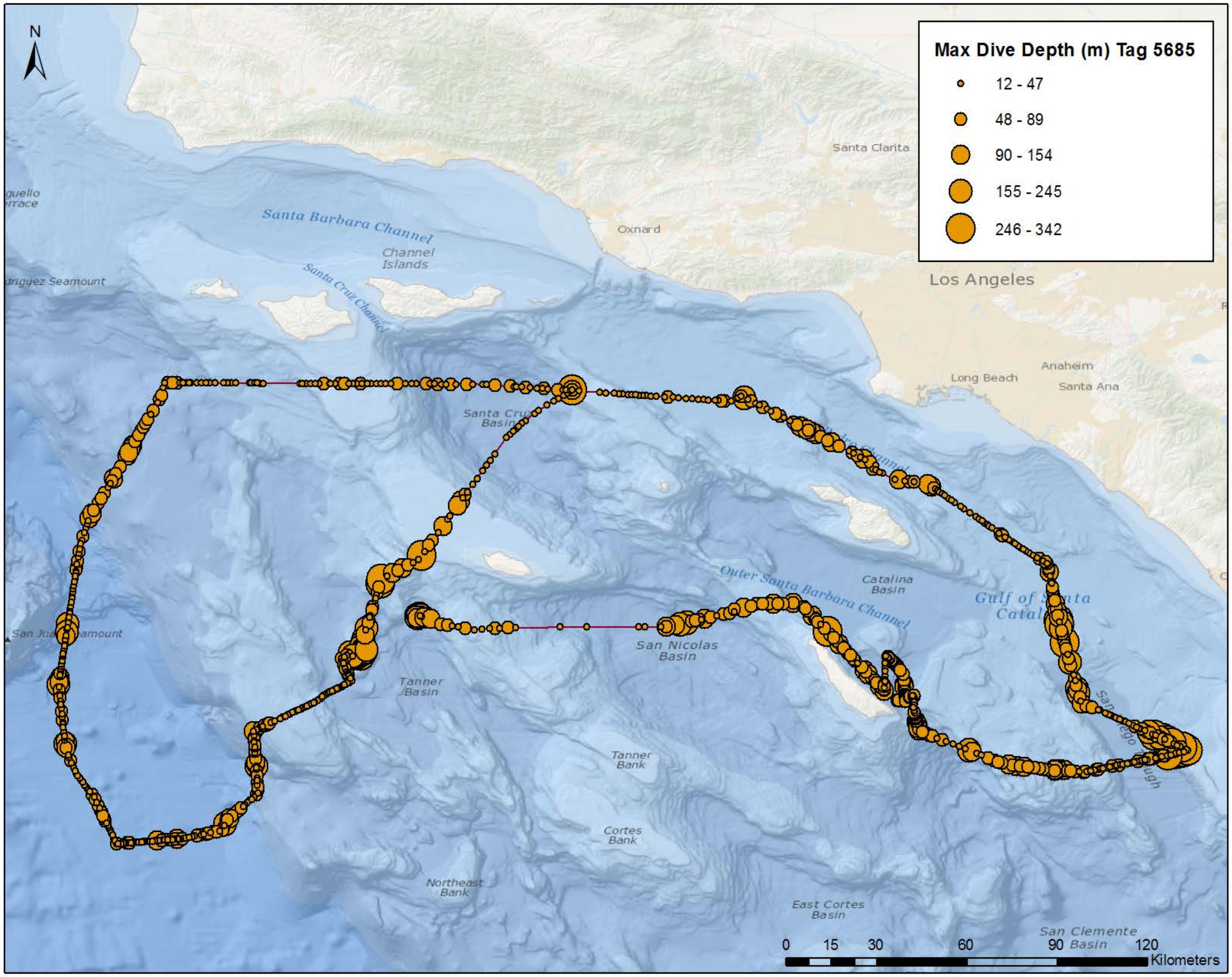

Figure 3-43. Track during 6 to 21 August 2014 of ADB-tagged fin whale #5685 tagged off southern California. Circle size represents the maximum dive depth of a dive made at that location (*n* dives=1,140).

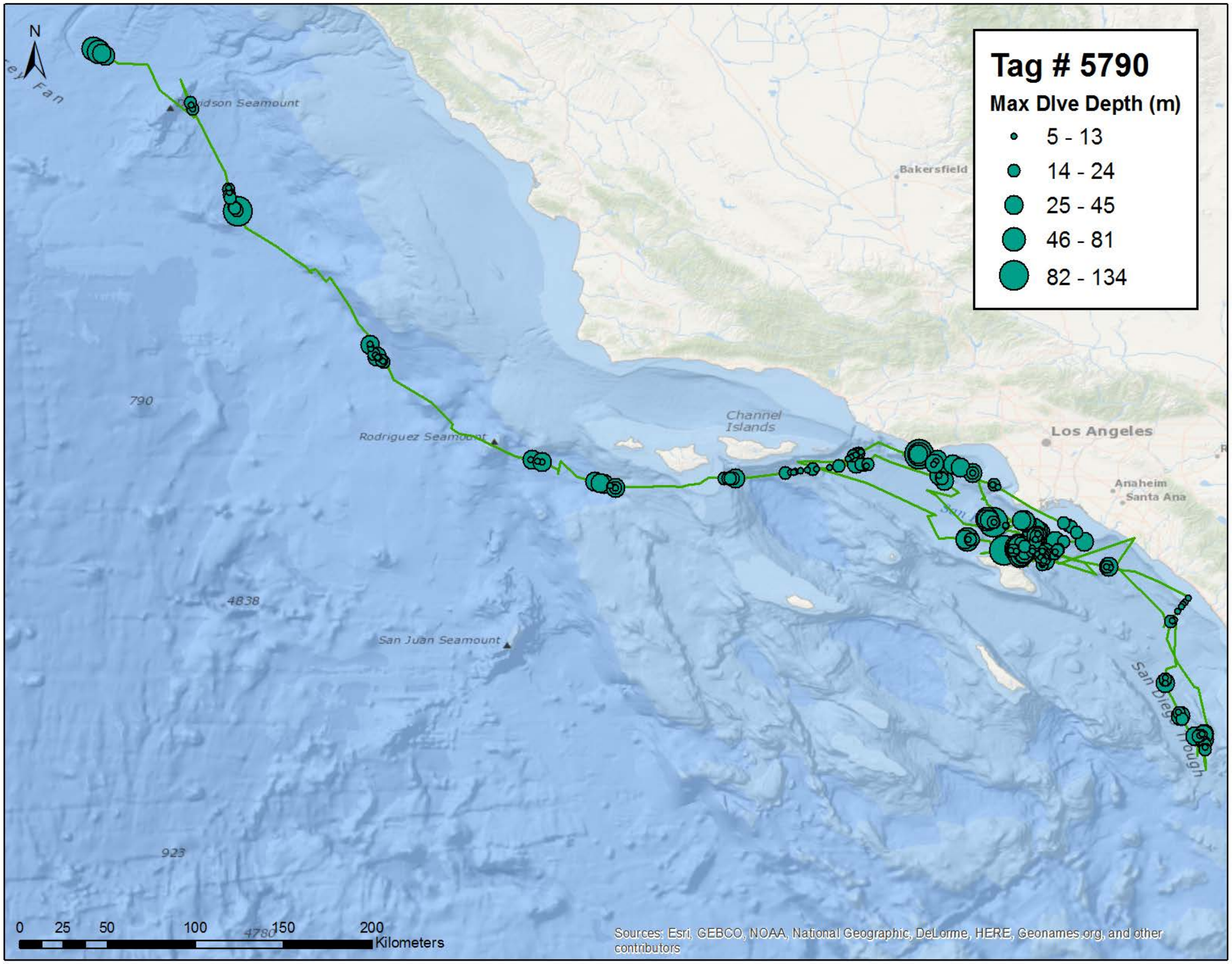

Figure 3-44. Track during 11 to 25 August 2014 of ADB-tagged fin whale #5790 tagged off southern California using both Argos and GPS locations. Circle size represents the maximum dive depth of a dive made at that location (*n* dives=279).

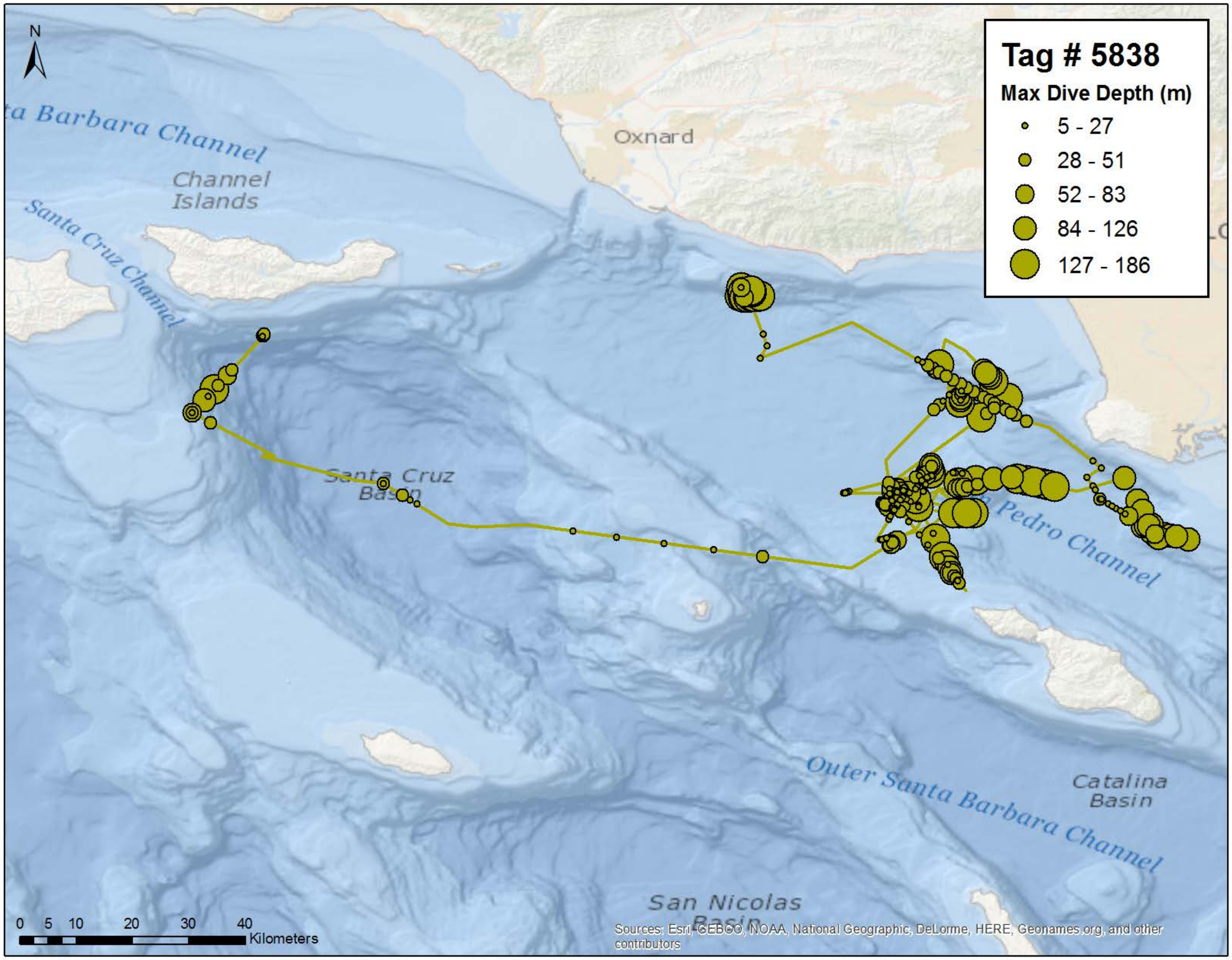

Figure 3-45. Track during 11 to 16 August 2014 of ADB-tagged fin whale #5838 tagged off southern California using both Argos and GPS locations. Circle size represents the maximum dive depth of a dive made at that location (*n* dives=289).

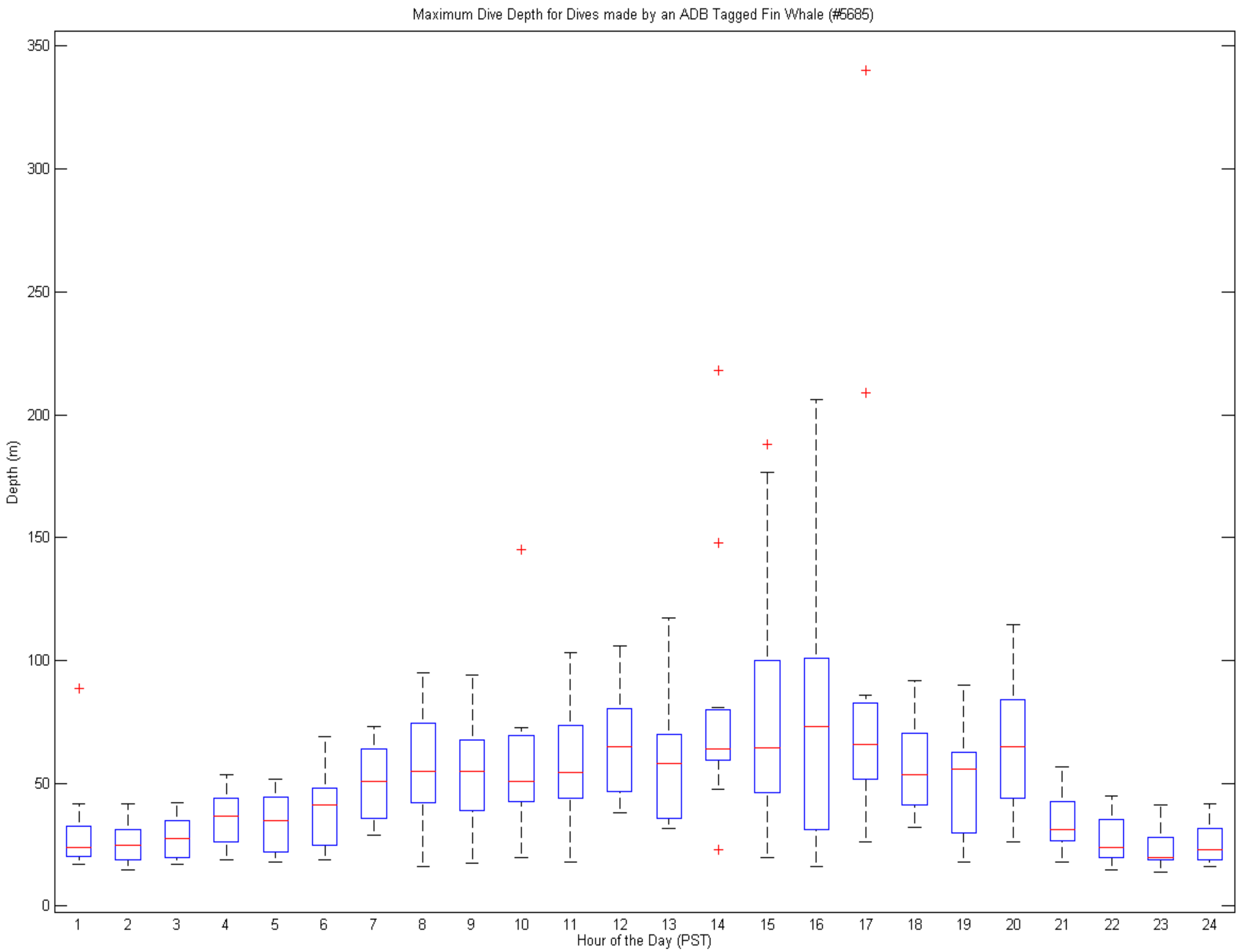

Figure 3-46. The distribution of maximum dive depths for dives made by ADB-tagged fin whale #5685 during each hour of the day.

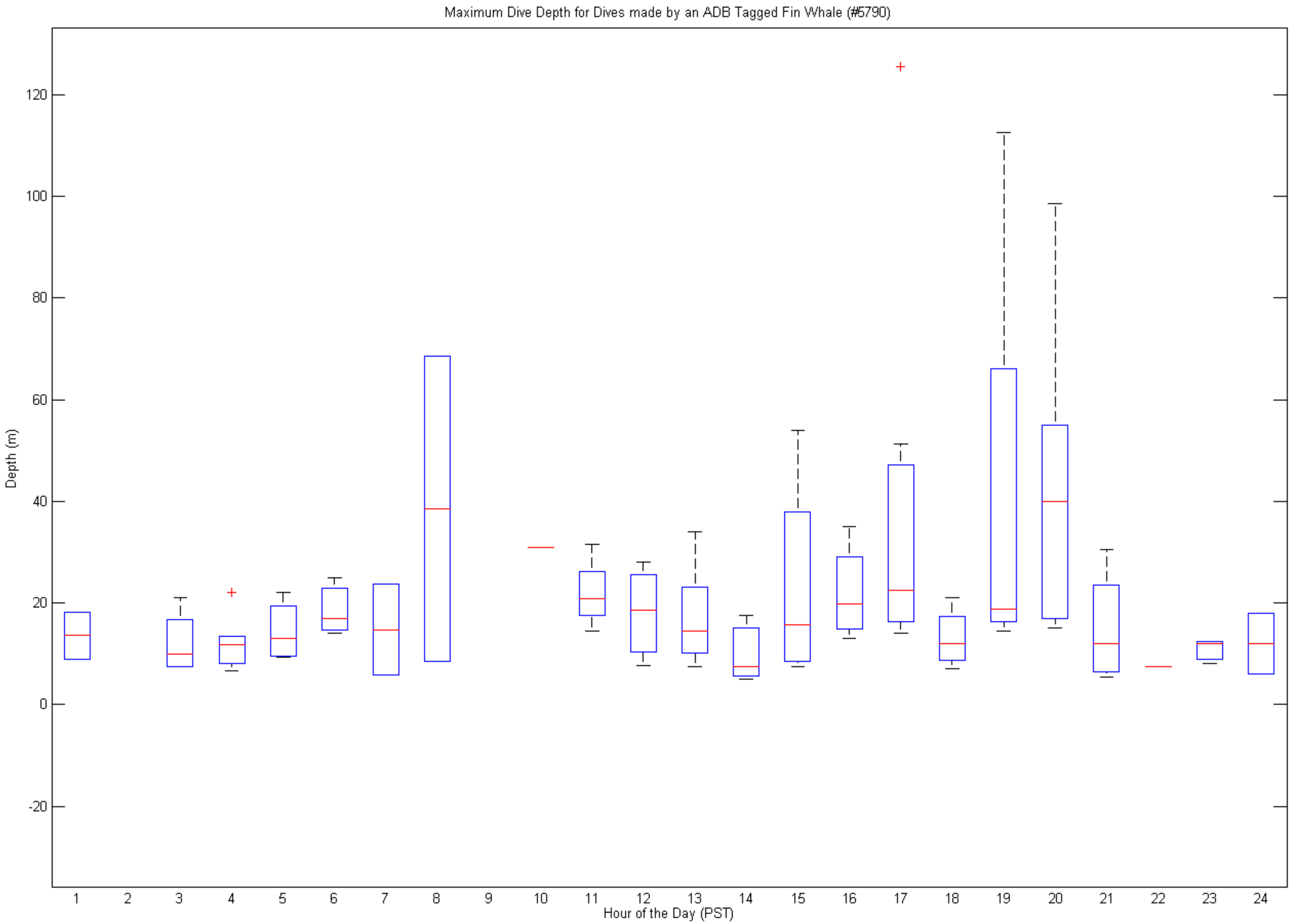

Figure 3-47. The distribution of maximum dive depths for dives made by ADB-tagged fin whale #5790 during each hour of the day.

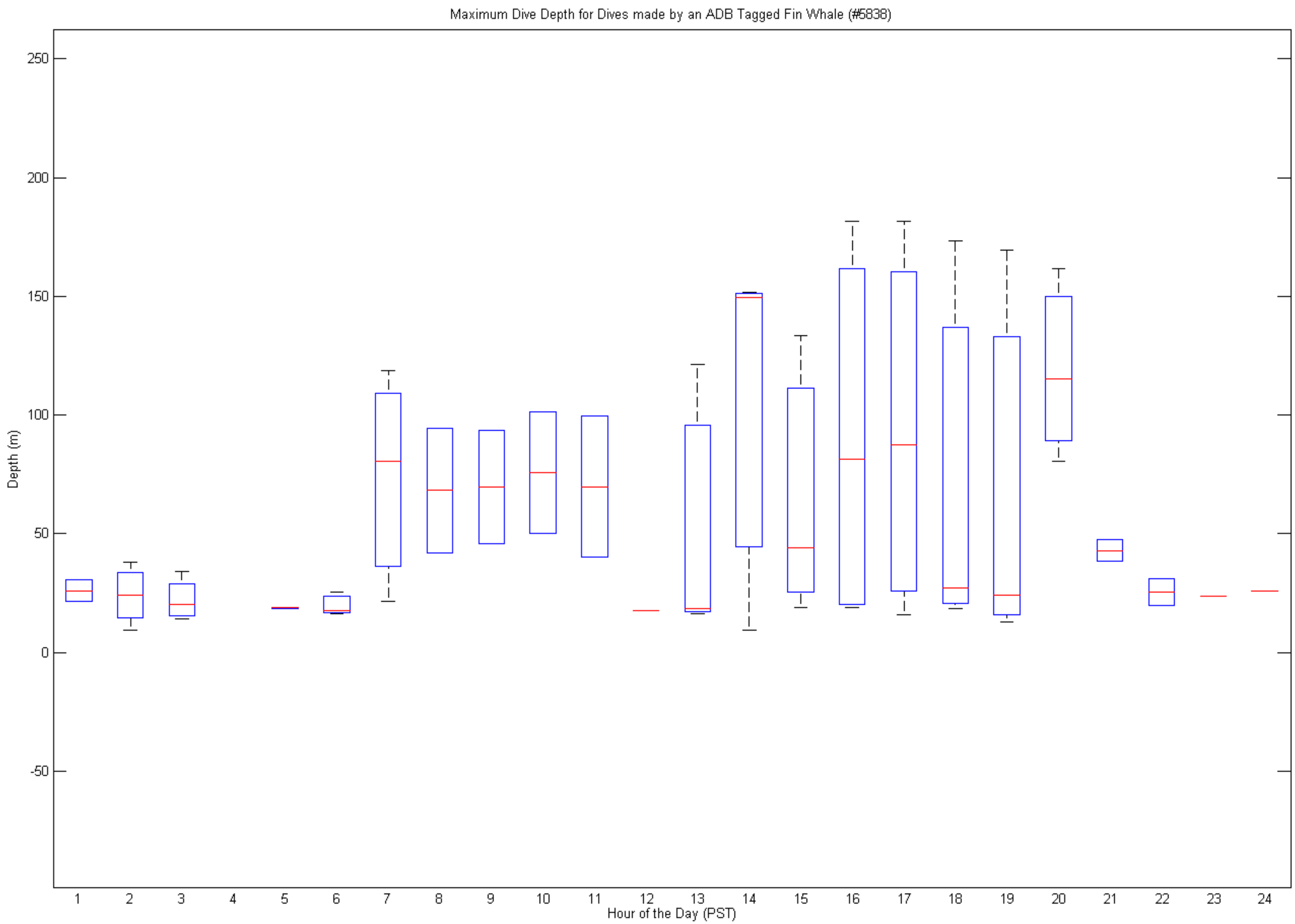

Figure 3-48. The distribution of maximum dive depths for dives made by ADB-tagged fin whale #5838 during each hour of the day.

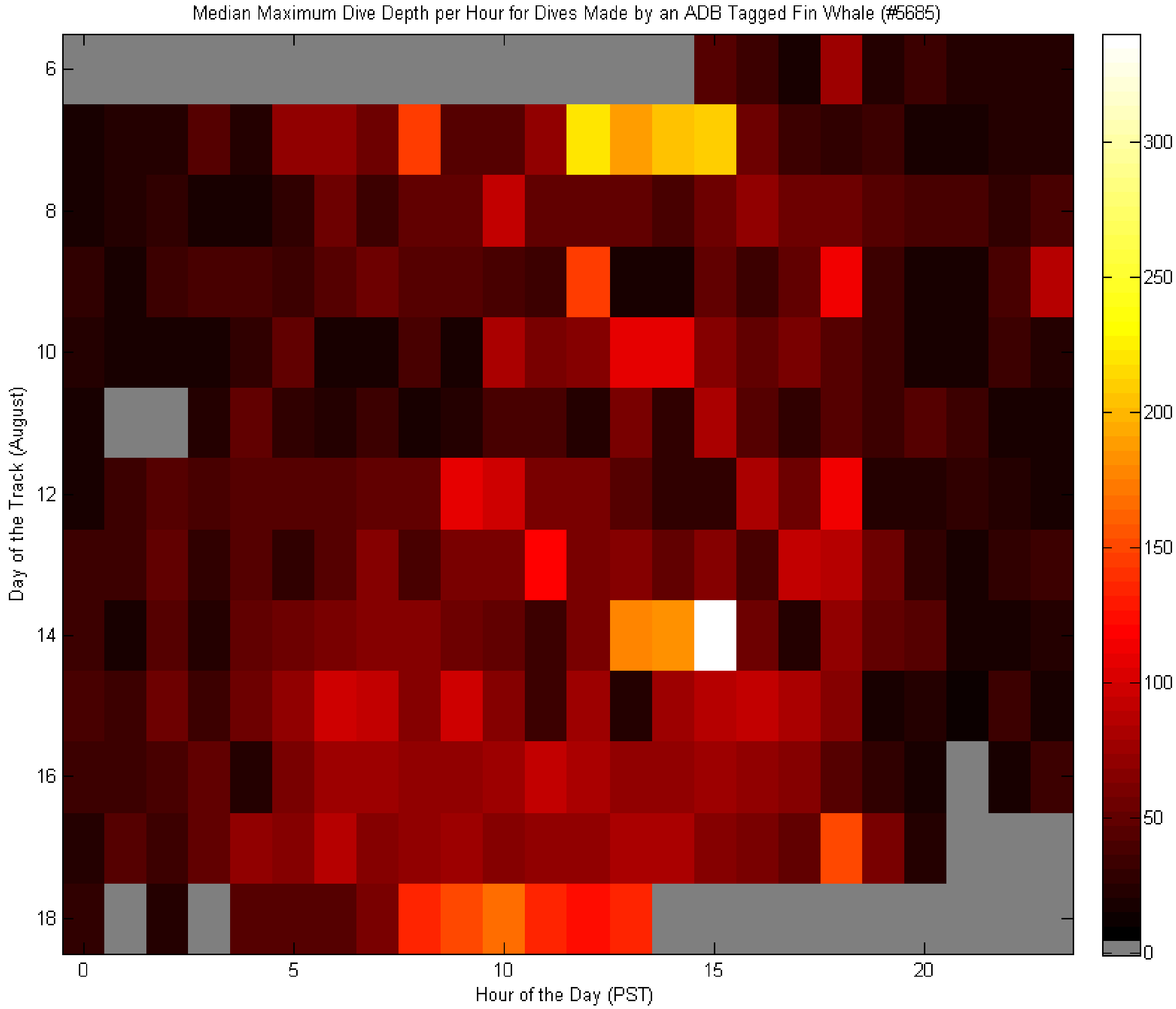

Figure 3-49. Median maximum dive depth per hour for dives made by ADB-tagged fin whale #5685 tracked off southern California (*n*=1,140). Gray color represents hours with no dives meeting the criteria.

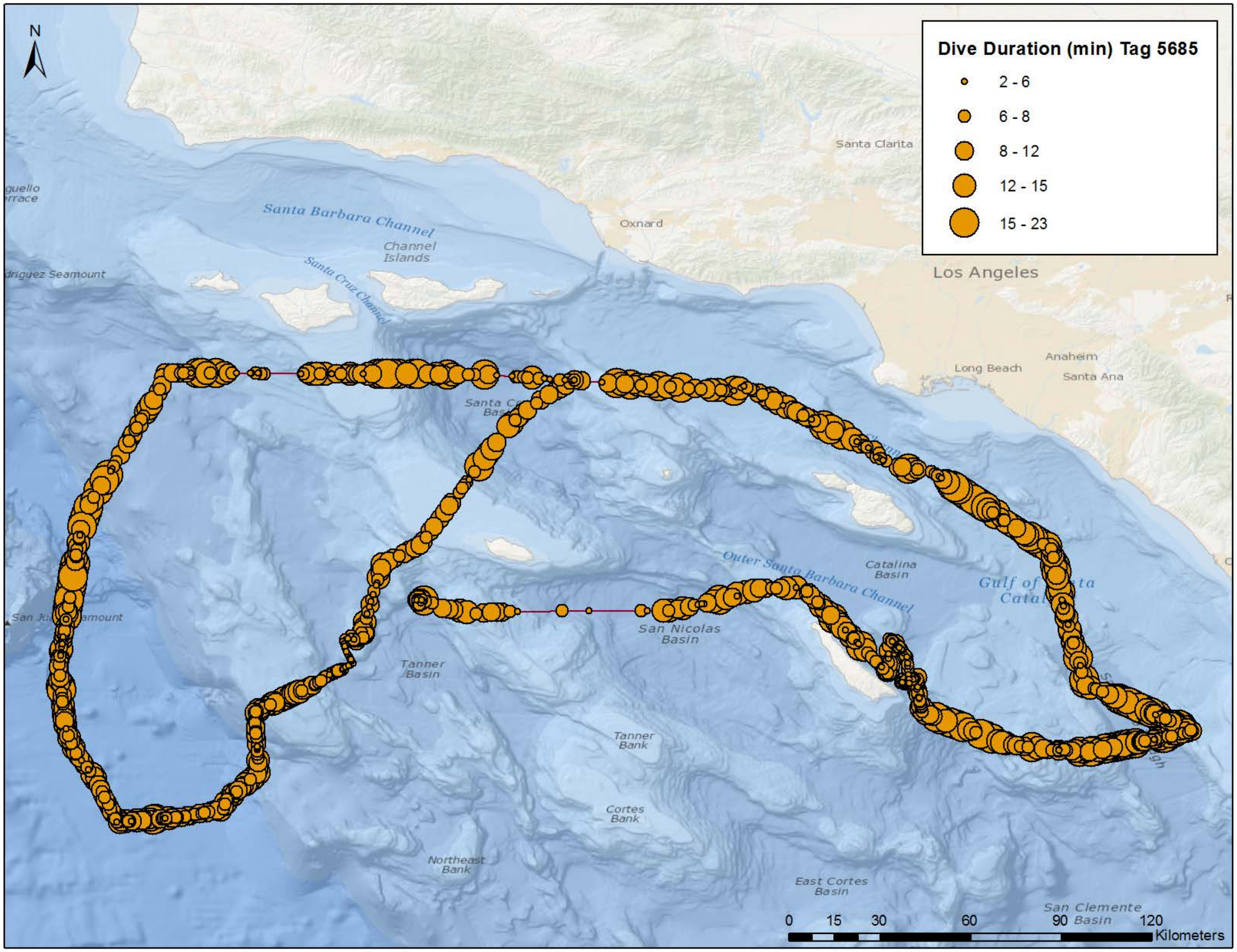

Figure 3-50. Track during 6 to 21 August 2014 of ADB-tagged fin whale #5685 tagged off southern California. Circle size represents the duration of a dive made at that location (*n* dives=1,140).

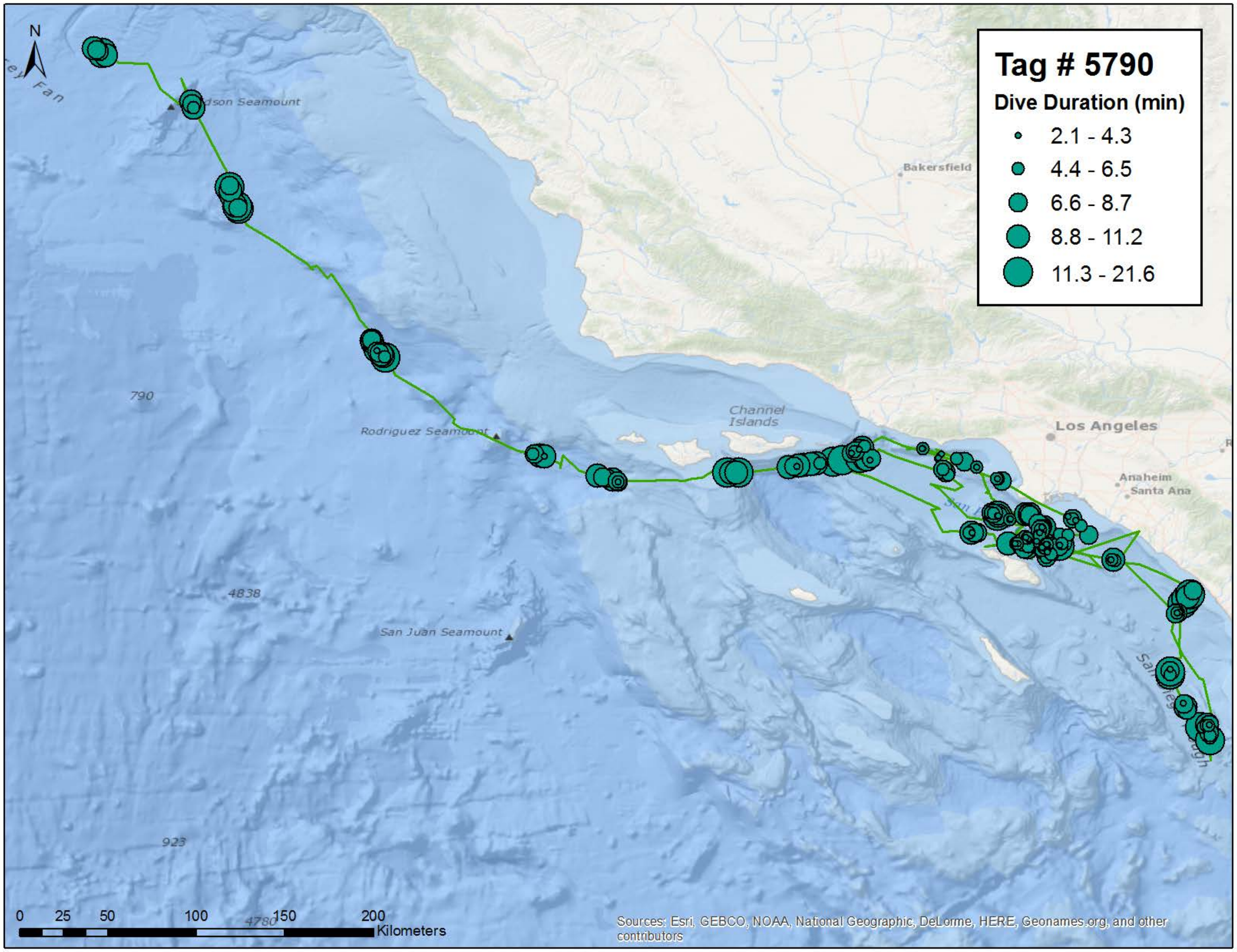

Figure 3-51. Track during 11 to 25 August 2014 of ADB-tagged fin whale #5790 tracked off southern California using both Argos and GPS locations. Circle size represents the duration of a dive made at that location (*n* dives=279).

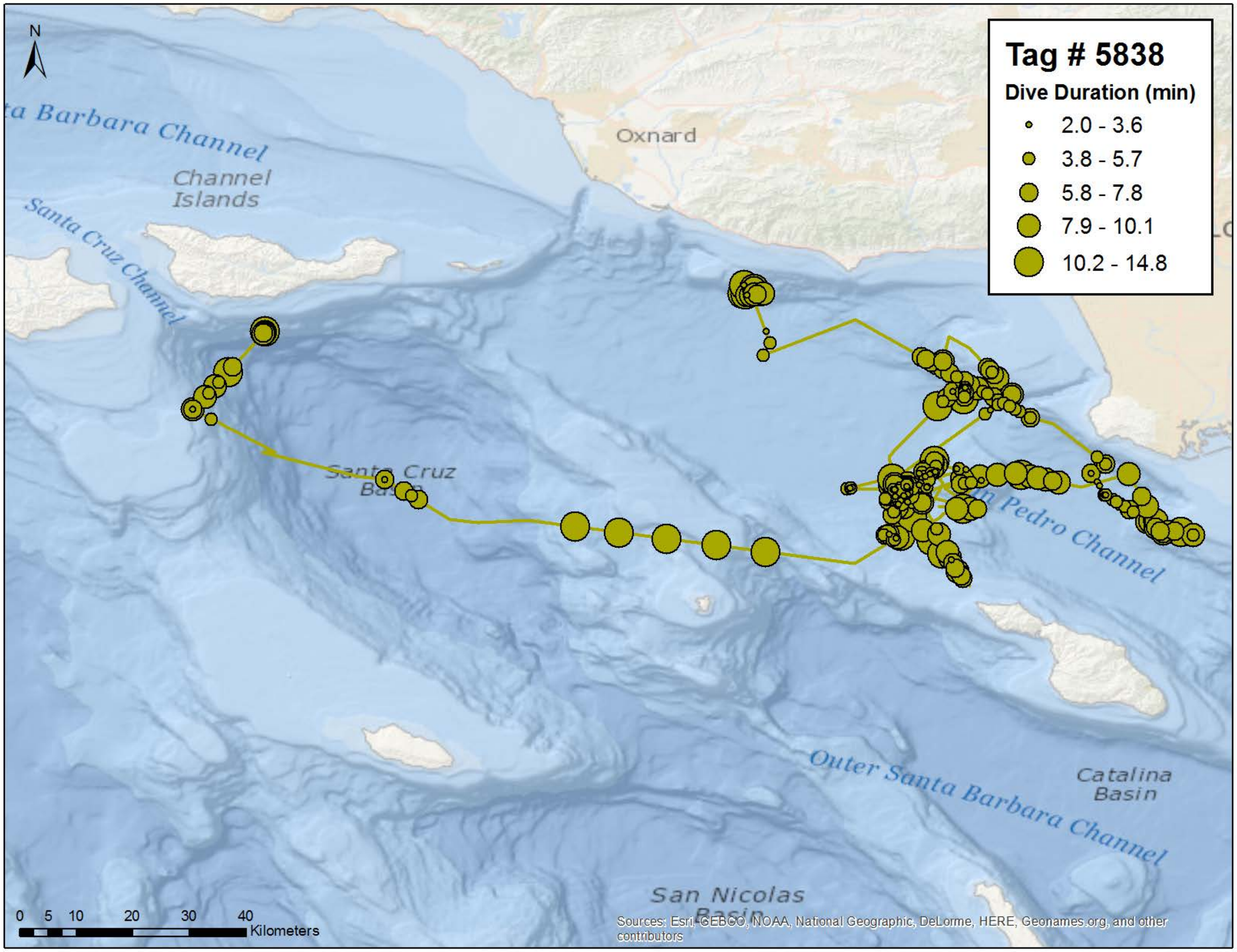

Figure 3-52. Track during 11 to 16 August 2014 of ADB-tagged fin whale #5838 tagged off southern California using both Argos and GPS locations. Circle size represents the duration of a dive made at that location (*n* dives=289).

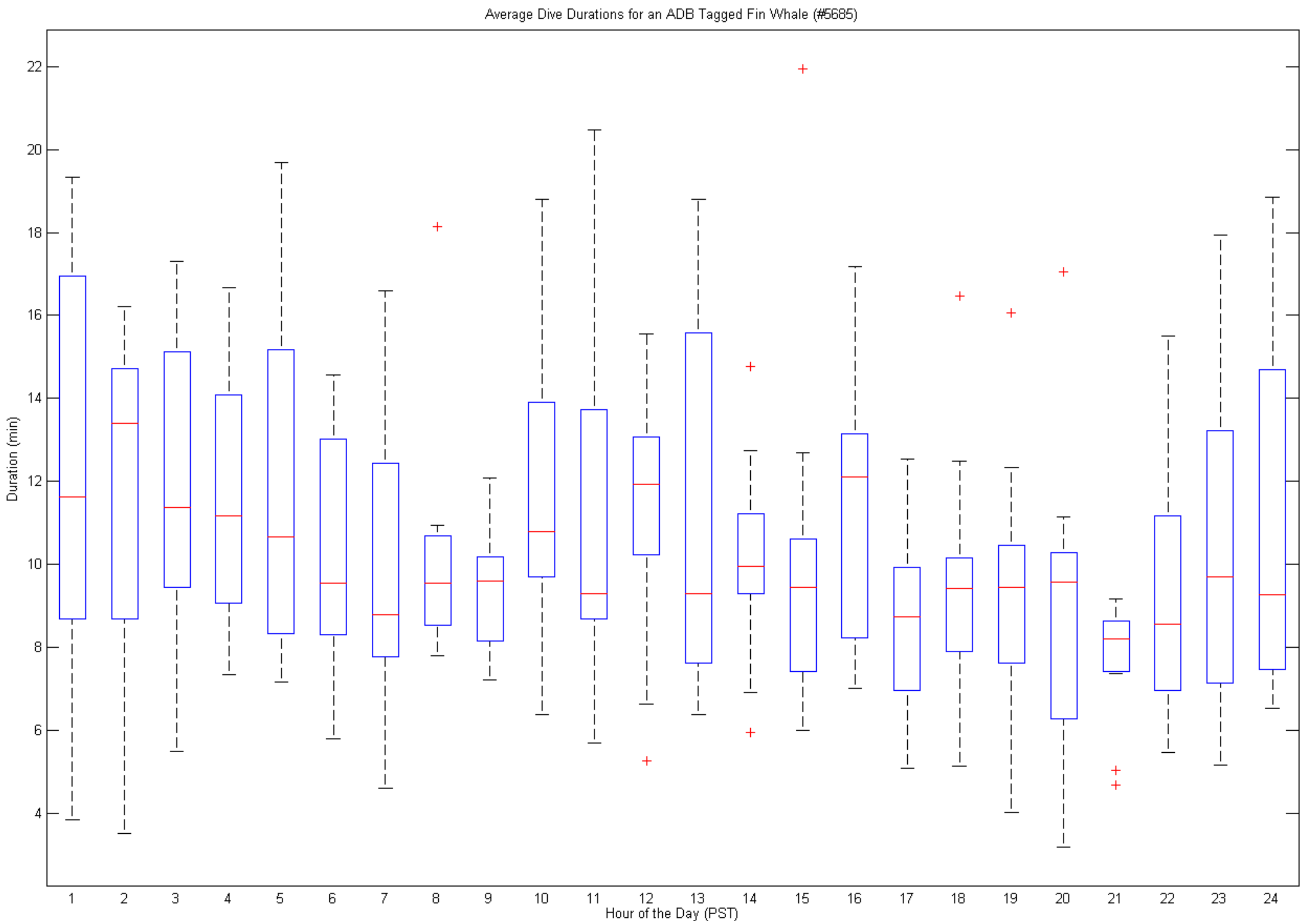

Figure 3-53. The distribution of durations for dives made by ADB-tagged fin whale #5685 during each hour of the day.

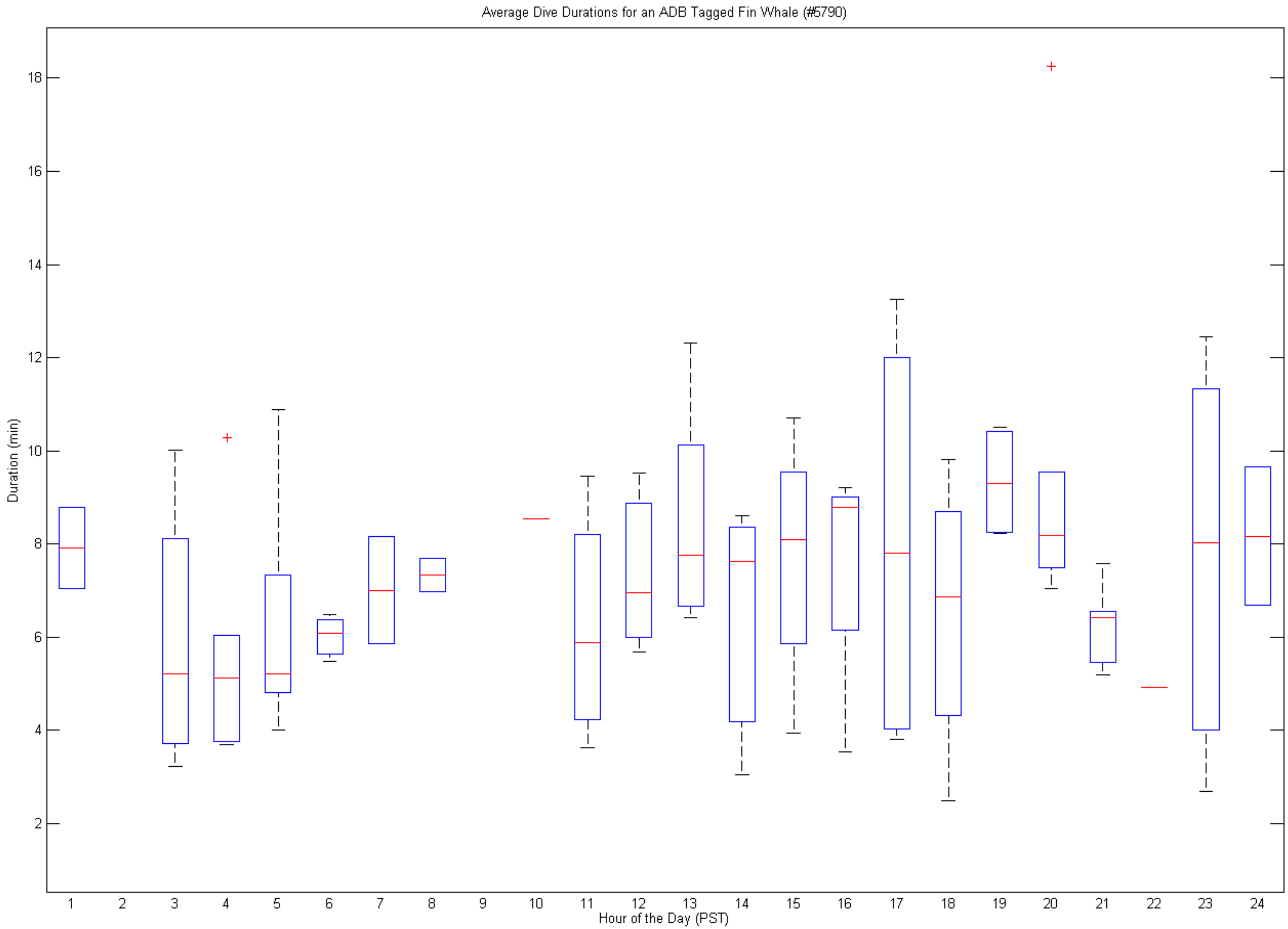

Figure 3-54. The distribution of durations for dives made by ADB-tagged fin whale #5790 during each hour of the day.

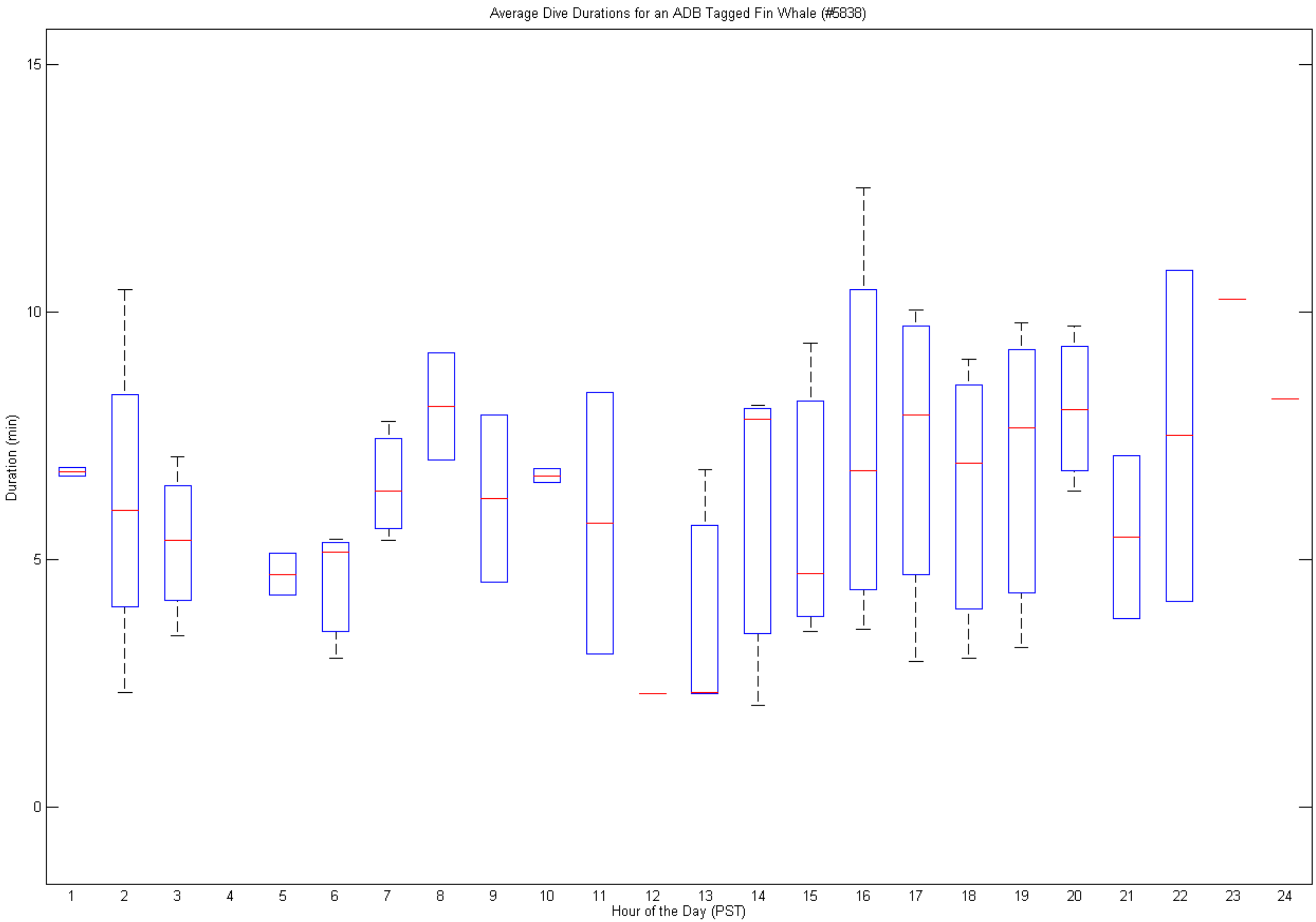

Figure 3-55. The distribution of durations for dives made by ADB-tagged fin whale #5838 during each hour of the day.

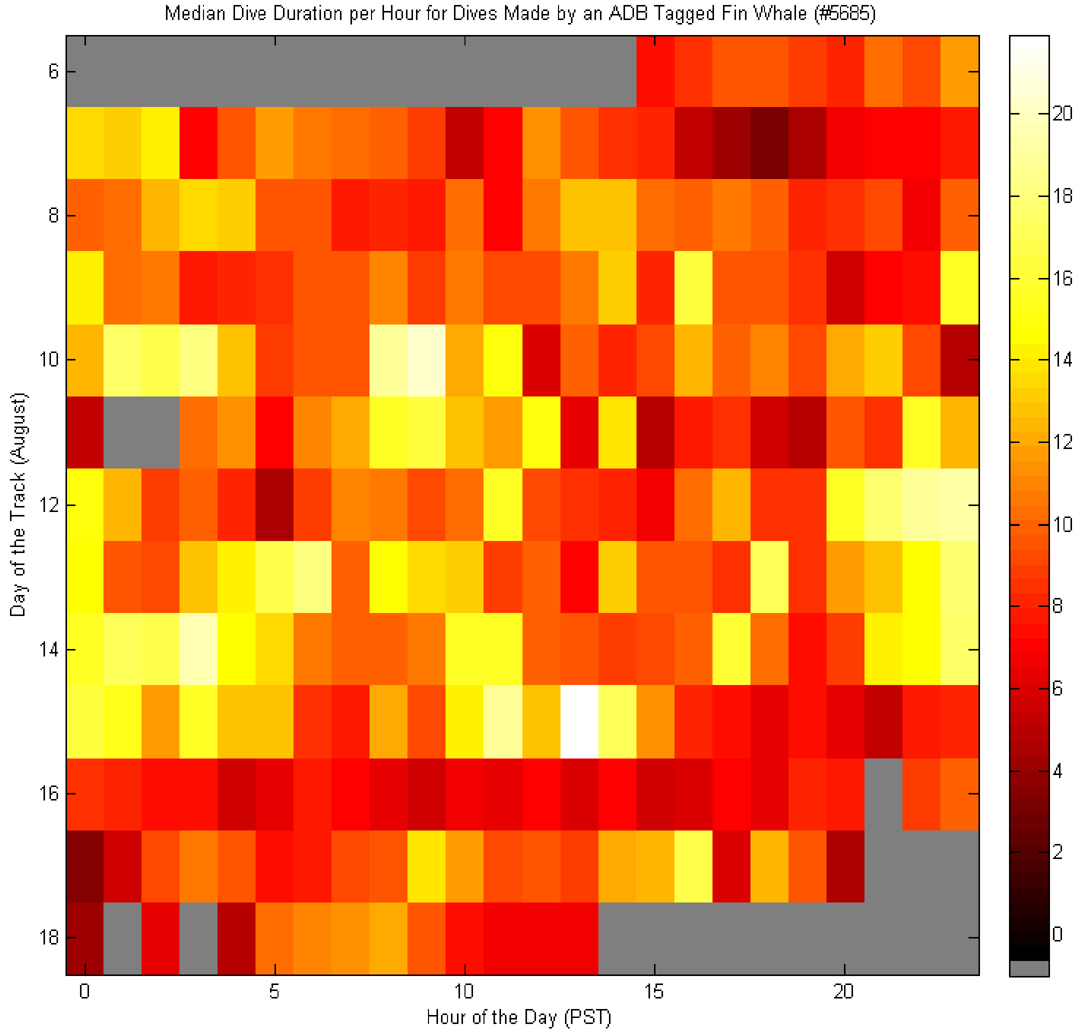

Figure 3-56. Median hourly dive durations for dives made by ADB-tagged fin whale #5685 tracked off southern California (*n*=1,140). Gray color represents hours with no dives meeting the criteria.

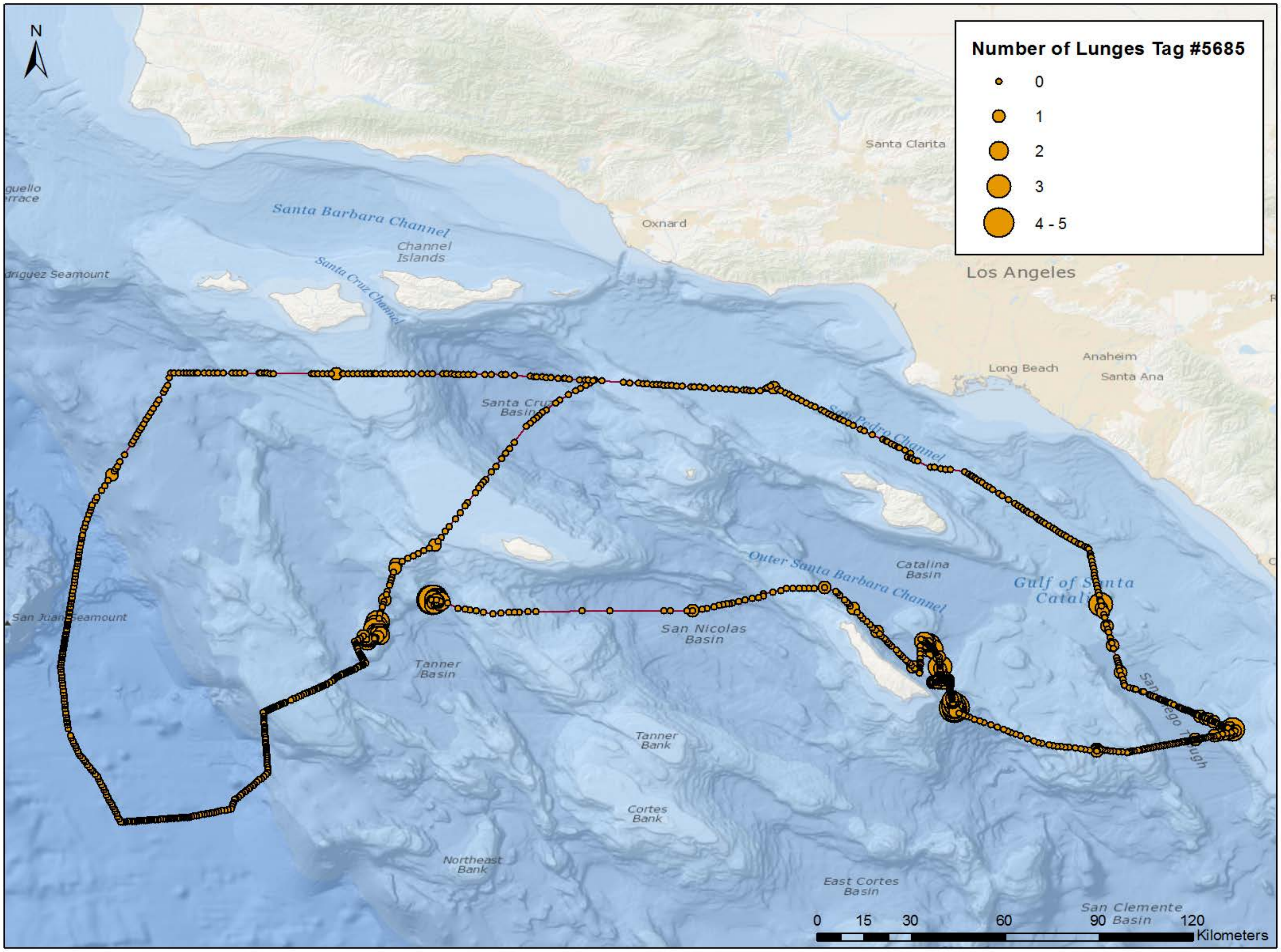

Figure 3-57. Track during 6 to 21 August 2014 of ADB-tagged fin whale #5685 tagged off southern California. Circle size represents the number of lunges made during a dive at that location (*n* dives=1,140).

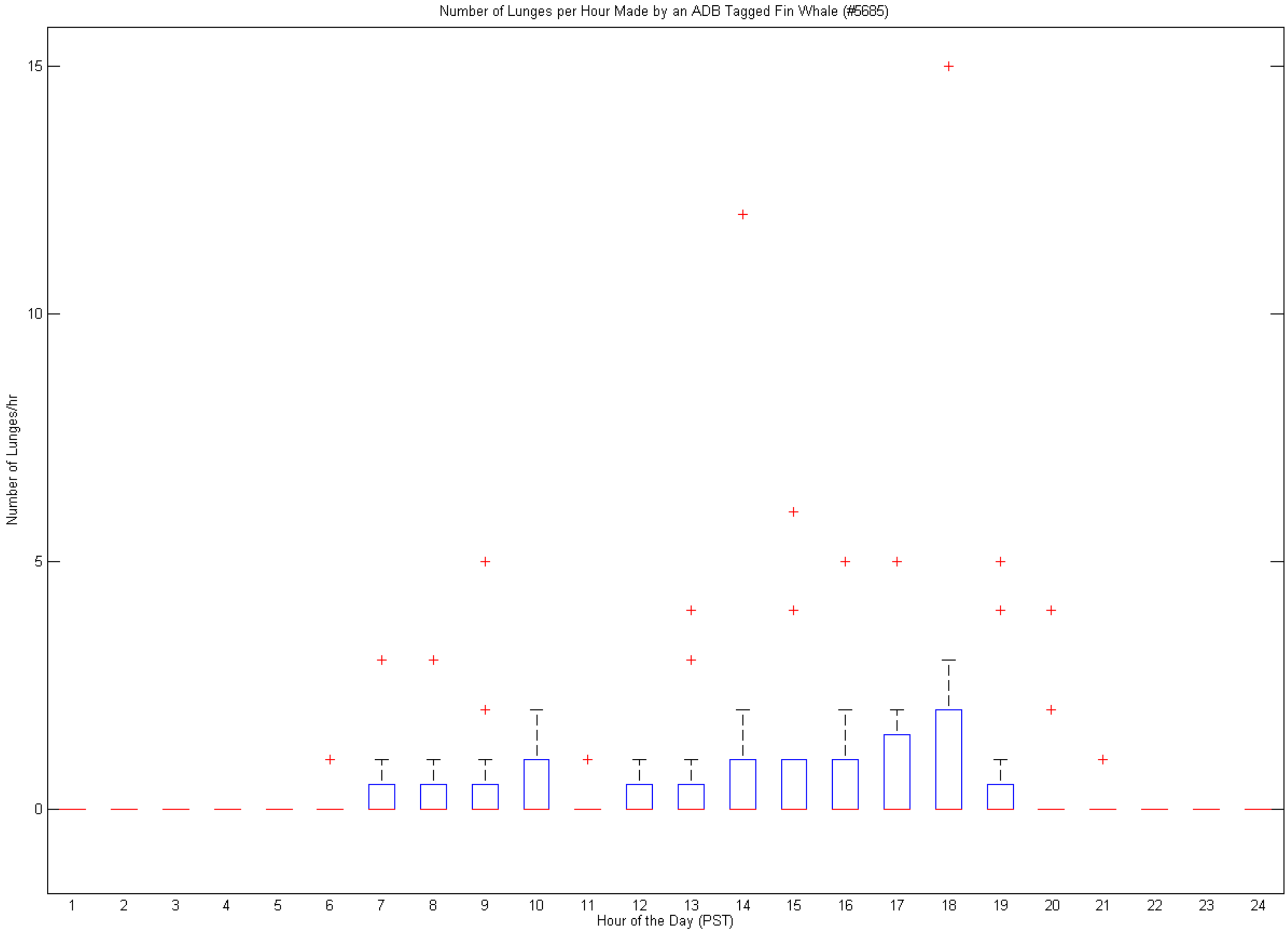

Figure 3-58. The distribution of durations for dives made by ADB-tagged fin whale #5685 during each hour of the day.

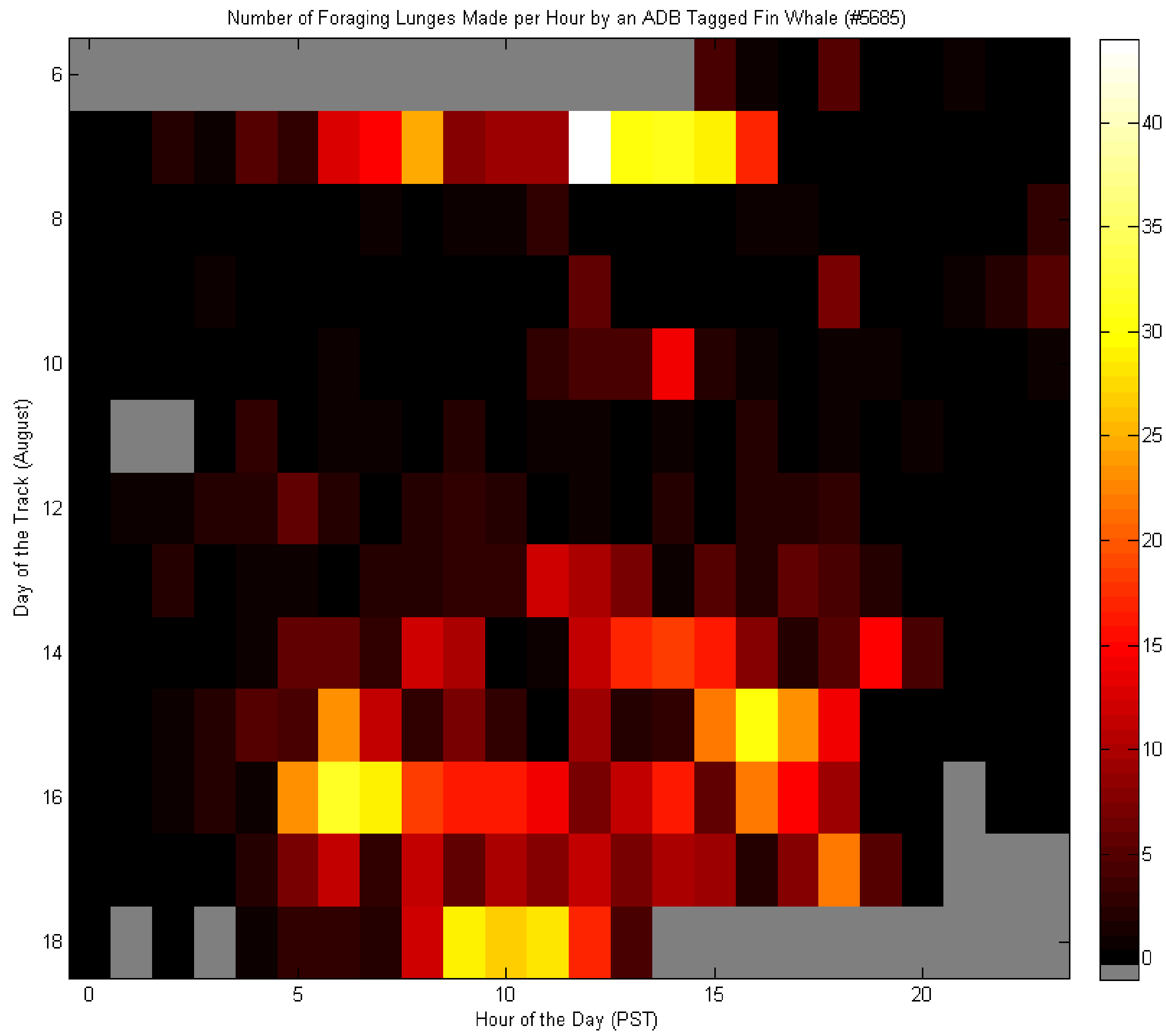

Figure 3-59. Numbers of foraging lunges made per hour made by ADB-tagged fin whale #5685 tracked off southern California (*n*=1,140). Gray color represents hours with no dives meeting the criteria.

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Chapter 3 Appendix - Additional ADB Tables and Figures

Table 3-5. Summary of dives occurring during 'foraging bouts' made by an ADB-tagged blue whale (#5644) tagged off southern California in August 2014. Foraging bouts are sequences of dives with no more than three dives in a row with no recorded foraging lunges.

Bout Start	Bout End	Bout Duration (h)	# of Dives	Ave Max Dive Depth (m)	Ave Dive Duration (min)	Ave # Lunges/ Dive	Dives With No Lunges	Area Of Bout (km^2)	Time to Next Bout (h)
8/4/14 23:07	8/5/14 0:50	1.7	9	66.3	3.5	0.9	4	0.5	0.6
8/5/14 1:26	8/5/14 3:30	2.1	17	100.6	4.9	2.8	2	2.8	9.5
8/5/14 12:58	8/6/14 1:15	12.3	68	109.8	7.1	3.7	14	70.2	21.3
8/6/14 22:31	8/7/14 3:55	5.4	24	119.7	8.7	3.3	5	0.0	12.2
8/7/14 16:09	8/7/14 18:17	2.1	15	88.3	5.3	1.5	7	3.5	6.3
8/8/14 0:35	8/8/14 5:14	4.7	14	126.3	8.2	3.4	5	5.1	8.1
8/8/14 13:23	8/8/14 14:47	1.4	6	124.3	5.8	1.7	1	2.8	3.4
8/8/14 18:11	8/8/14 19:19	1.1	6	105.0	7.8	1.3	2	0.0	1.0
8/8/14 20:20	8/9/14 3:06	6.8	26	166.2	10.0	4.9	2	15.3	13.8
8/9/14 16:52	8/9/14 19:14	2.4	10	169.8	9.5	3.5	1	0.0	1.5
8/9/14 20:43	8/9/14 21:58	1.3	5	160.8	7.9	3.6	1	0.0	24.9
8/10/14 22:51	8/11/14 0:32	1.7	7	68.1	5.0	0.4	4	0.5	38.5
8/12/14 15:03	8/12/14 21:18	6.3	6	65.7	5.2	0.5	3	12.9	68.3
8/15/14 17:39	8/15/14 19:50	2.2	10	84.0	10.2	1.8	0	0.0	2.1
8/15/14 21:58	8/15/14 23:39	1.7	13	71.6	6.0	0.8	4	1.5	14.1
8/16/14 13:46	8/16/14 15:57	2.2	11	55.5	8.8	2.0	4	1.7	22.1
8/17/14 14:03	8/17/14 16:07	2.1	7	93.0	8.0	0.9	3	3.7	8.1
8/18/14 0:14	8/18/14 1:07	0.9	5	75.8	8.6	2.8	1	0.0	15.5
8/18/14 16:40	8/18/14 21:30	4.8	19	131.4	12.0	2.8	4	0.0	16.4
8/19/14 13:54	8/19/14 23:14	9.3	44	110.4	9.6	2.9	10	5.8	1.8
8/20/14 0:59	8/20/14 2:57	2.0	16	67.3	5.2	1.7	5	2.4	10.6
8/20/14 13:34	8/20/14 15:19	1.7	7	99.4	10.3	0.4	4	0.0	7.9
8/20/14 23:14	8/21/14 1:43	2.5	13	33.2	5.1	0.8	6	3.1	17.7
8/21/14 19:25	8/22/14 0:10	4.8	10	55.1	12.3	0.7	5	0.0	13.0
8/22/14 13:09	8/23/14 1:27	12.3	20	117.6	17.3	1.2	10	111.6	0.0
	median	2.2	11	99.4	8.0	1.7	4	1.7	10.6
	min	0.9	5	33.2	3.5	0.4	0	0.0	0.0
	max	12.3	68	169.8	17.3	4.9	14	111.6	68.3

Table 3-6. Summary of dives occurring during 'foraging bouts' made by an ADB-tagged blue whale (#5650) tagged off southern California in August 2014. Foraging bouts are sequences of dives with no more than three dives in a row with no recorded foraging lunges.

Bout Start	Bout End	Bout Duration (h)	# of Dives	Ave Max Dive Depth (m)	Ave Dive Duration (min)	Ave # Lunges/Dive	Dives With No Lunges	Area Of Bout (km^2)	Time to Next Bout (h)
8/4/14 22:58	8/5/14 2:45	3.8	26	88.2	5.9	1.3	9	2.5	10.0
8/5/14 12:48	8/5/14 14:48	2.0	9	166.8	8.6	2.7	2	1.1	1.3
8/5/14 16:04	8/5/14 16:36	0.5	5	34.2	3.2	0.6	3	0.4	2.0
8/5/14 18:39	8/5/14 23:24	4.7	31	103.6	6.3	1.4	10	18.3	0.6
8/5/14 23:58	8/6/14 1:36	1.6	13	98.7	5.1	0.8	8	8.1	0.5
8/6/14 2:07	8/6/14 2:41	0.6	4	113.3	6.3	0.8	2	0.4	8.7
8/6/14 11:22	8/6/14 14:36	3.2	17	100.4	9.6	2.5	2	5.3	0.8
8/6/14 15:21	8/6/14 16:05	0.7	7	75.1	4.6	1.9	1	0.3	6.7
8/6/14 22:47	8/6/14 23:51	1.1	6	114.7	8.7	1.0	3	2.6	5.0
8/7/14 4:52	8/7/14 5:51	1.0	7	67.3	6.9	1.4	0	0.0	2.2
8/7/14 8:03	8/7/14 9:22	1.3	10	34.6	4.6	1.4	3	0.4	1.5
8/7/14 10:51	8/7/14 12:29	1.6	10	32.3	4.2	0.8	4	0.9	1.3
8/7/14 13:48	8/7/14 15:31	1.7	10	123.0	6.8	1.6	2	1.2	2.0
8/7/14 17:32	8/8/14 3:46	10.2	52	141.4	8.3	2.1	13	54.9	8.0
8/8/14 11:48	8/8/14 12:24	0.6	7	27.7	3.5	1.0	2	0.1	2.5
8/8/14 14:52	8/8/14 23:36	8.7	32	244.2	11.0	3.8	5	15.8	1.3
8/9/14 0:55	8/9/14 5:07	4.2	23	87.0	5.2	1.5	8	5.0	9.3
8/9/14 14:25	8/9/14 15:39	1.2	6	83.2	4.5	0.8	3	1.4	1.1
8/9/14 16:47	8/9/14 18:39	1.9	12	76.8	4.8	1.3	3	2.2	3.0
8/9/14 21:41	8/9/14 23:05	1.4	7	145.4	7.0	1.9	1	0.2	2.7
8/10/14 1:44	8/10/14 2:38	0.9	4	113.3	5.2	0.5	2	0.9	9.8
8/10/14 12:29	8/10/14 14:46	2.3	15	85.7	6.3	1.8	6	3.7	1.4
8/10/14 16:11	8/10/14 16:49	0.6	5	91.6	6.3	1.4	2	0.2	46.1
8/12/14 14:58	8/12/14 15:38	0.7	4	66.5	8.0	0.5	2	0.5	8.3
8/12/14 23:56	8/13/14 3:34	3.6	15	179.7	10.6	2.3	3	3.4	179.6
8/20/14 15:07	8/20/14 16:58	1.8	11	64.3	8.2	1.4	3	1.8	0.7
8/20/14 17:38	8/20/14 22:29	4.9	28	72.3	8.2	1.1	12	19.5	0.0
	median	1.6	10	88.2	6.3	1.4	3	1.4	2.2
	max	10.2	52	244.2	11.0	3.8	13	54.9	179.6
	min	0.5	4	27.7	3.2	0.5	0	0.0	0.0

Table 3-7. Summary of dives occurring during 'foraging bouts' made by an ADB-tagged blue whale (#5655) tagged off southern California in August 2014. Foraging bouts are sequences of dives with no more than three dives in a row with no recorded foraging lunges.

Bout Start	Bout End	Bout Duration (h)	# of Dives	Ave Max Dive Depth (m)	Ave Dive Duration (min)	Ave # Lunges/Dive	Dives With No Lunges	Area Of Bout (km^2)	Time to Next Bout (h)
8/7/14 18:13	8/8/14 3:16	9.0	42	233.1	9.8	3.5	1	6.2	7.4
8/8/14 10:37	8/8/14 11:04	0.4	4	36.5	5.3	0.8	1	0.0	3.8
8/8/14 14:54	8/8/14 16:49	1.9	9	152.0	10.5	1.9	1	0.0	0.6
8/8/14 17:27	8/9/14 3:07	9.7	50	195.3	9.0	2.7	1	0.0	10.1
8/9/14 13:13	8/9/14 21:38	8.4	35	238.5	10.7	3.6	2	2.0	4.8
8/10/14 2:24	8/10/14 2:58	0.6	5	61.6	3.9	0.4	3	0.0	11.6
8/10/14 14:32	8/10/14 15:40	1.1	7	59.9	3.3	0.9	3	0.5	25.0
8/11/14 16:42	8/12/14 3:19	10.6	52	238.4	9.2	3.3	5	20.3	9.7
8/12/14 12:59	8/12/14 15:29	2.5	14	178.6	8.0	1.7	4	0.0	21.8
8/13/14 13:16	8/13/14 13:50	0.6	4	200.3	6.6	1.0	1	1.1	1.4
8/13/14 15:14	8/14/14 2:52	11.6	55	212.6	9.8	3.3	4	3.7	10.1
8/14/14 12:55	8/14/14 15:20	2.4	11	166.0	10.5	3.3	1	0.0	3.1
8/14/14 18:26	8/14/14 22:08	3.7	20	160.5	5.8	2.1	7	9.1	0.5
8/14/14 22:36	8/15/14 3:08	4.5	26	195.1	7.4	3.2	3	9.6	10.6
8/15/14 13:45	8/15/14 15:13	1.5	7	247.3	9.5	0.7	2	0.1	3.1
8/15/14 18:19	8/16/14 0:55	6.6	31	195.5	9.9	3.0	5	64.3	0.6
8/16/14 1:30	8/16/14 3:07	1.6	9	176.8	7.6	3.3	0	0.0	12.5
8/16/14 15:34	8/16/14 19:21	3.8	20	220.7	8.9	3.2	1	10.0	0.9
8/16/14 20:18	8/17/14 1:52	5.6	41	145.2	6.0	1.7	10	76.8	1.6
8/17/14 3:31	8/17/14 4:23	0.9	4	47.0	5.4	0.8	2	0.0	8.4
8/17/14 12:47	8/17/14 15:39	2.9	15	154.9	9.5	1.3	5	0.0	2.3
8/17/14 17:56	8/18/14 2:54	9.0	69	96.8	4.6	1.7	7	9.4	2.7
8/18/14 5:36	8/18/14 6:22	0.8	7	47.1	5.4	1.0	2	0.0	6.9
8/18/14 13:19	8/18/14 13:56	0.6	4	149.8	8.2	0.8	1	0.0	2.2
8/18/14 16:07	8/19/14 2:49	10.7	82	66.0	3.9	1.3	16	10.2	5.3

Bout Start	Bout End	Bout Duration (h)	# of Dives	Ave Max Dive Depth (m)	Ave Dive Duration (min)	Ave # Lunges/Dive	Dives With No Lunges	Area Of Bout (km^2)	Time to Next Bout (h)
8/19/14 8:05	8/19/14 9:30	1.4	12	42.3	5.8	0.9	3	0.0	6.8
8/19/14 16:20	8/19/14 17:51	1.5	13	85.4	5.1	1.3	3	1.0	1.0
8/19/14 18:50	8/19/14 19:57	1.1	6	170.0	9.1	1.7	1	0.0	18.5
8/20/14 14:24	8/20/14 16:27	2.0	10	177.6	10.3	1.8	2	0.0	5.3
8/20/14 21:44	8/20/14 23:47	2.0	10	147.1	10.3	1.9	1	1.6	2.6
8/21/14 2:23	8/21/14 3:00	0.6	5	75.0	6.3	2.4	0	0.0	14.8
8/21/14 17:49	8/21/14 18:37	0.8	4	180.0	9.5	1.8	1	0.0	1.9
8/21/14 20:33	8/22/14 3:14	6.7	36	146.7	8.8	2.1	3	4.9	14.4
8/22/14 17:37	8/22/14 20:42	3.1	19	120.9	8.0	2.3	1	5.9	1.3
8/22/14 21:57	8/23/14 3:28	5.5	47	92.5	5.5	1.5	6	5.4	9.7
8/23/14 13:12	8/24/14 2:30	13.3	125	87.3	4.3	1.1	38	8.6	0.3
8/24/14 2:49	8/24/14 3:14	0.4	4	31.5	2.7	1.0	1	0.0	10.2
8/24/14 13:26	8/25/14 2:35	13.1	123	91.7	4.3	1.4	27	39.4	12.0
8/25/14 14:35	8/26/14 2:14	11.6	91	111.3	5.9	1.7	14	94.7	12.7
8/26/14 14:58	8/26/14 16:42	1.7	16	43.9	4.4	1.0	9	0.0	0.0
	median	2.5	14.5	148.4	7.5	1.7	2.5	0.7	5.3
	max	13.3	125	247.3	10.7	3.6	38	94.7	25.0
	min	0.4	4	31.5	2.7	0.4	0	0.0	0.0

Table 3-8. Summary of dives occurring during 'foraging bouts' made by an ADB-tagged blue whale (#5803) tagged off southern California in August 2014. Foraging bouts are sequences of dives with no more than three dives in a row with no recorded foraging lunges.

Bout Start	Bout End	Bout Duration (h)	# of Dives	Ave Max Dive Depth (m)	Ave Dive Duration (min)	Ave # Lunges/Dive	Dives With No Lunges	Area Of Bout (km^2)	Time to Next Bout (h)
8/5/14 13:57	8/5/14 21:46	7.8	40.0	246.7	7.8	1.7	8.0	5.2	1.8
8/5/14 23:37	8/6/14 0:28	0.8	5.0	78.6	3.5	1.8	1.0	0.1	0.5
8/6/14 0:57	8/6/14 2:08	1.2	11.0	109.6	4.3	1.2	5.0	4.7	0.7
8/6/14 2:48	8/6/14 3:23	0.6	5.0	85.2	5.3	1.6	1.0	0.2	12.2
8/6/14 15:34	8/6/14 16:33	1.0	6.0	134.2	7.1	1.0	2.0	1.5	0.9
8/6/14 17:25	8/6/14 18:16	0.9	4.0	195.3	10.4	1.8	0.0	0.1	0.6
8/6/14 18:54	8/6/14 20:00	1.1	7.0	91.3	4.0	0.9	4.0	0.6	0.9
8/6/14 20:54	8/7/14 3:34	6.7	42.0	173.5	6.6	1.8	5.0	8.8	10.1
8/7/14 13:40	8/7/14 15:12	1.5	9.0	163.8	7.8	1.3	2.0	1.1	0.6
8/7/14 15:51	8/8/14 3:08	11.3	62.0	220.5	7.8	1.6	14.0	41.2	12.5
8/8/14 15:38	8/8/14 17:17	1.6	8.0	201.8	9.8	1.8	0.0	1.5	0.7
8/8/14 17:58	8/9/14 3:05	9.1	46.0	212.6	8.8	2.0	2.0	12.5	13.8
8/9/14 16:51	8/10/14 1:35	8.7	44.0	204.7	8.9	2.1	4.0	80.9	12.8
8/10/14 14:26	8/10/14 15:03	0.6	4.0	161.8	7.3	2.8	0.0	0.0	1.5
8/10/14 16:32	8/10/14 17:03	0.5	5.0	69.6	3.3	0.8	1.0	0.3	2.5
8/10/14 19:32	8/10/14 22:41	3.2	14.0	95.0	3.7	1.4	7.0	10.6	12.6
8/11/14 11:16	8/11/14 12:26	1.2	7.0	179.7	7.4	0.4	4.0	0.1	1.6
8/11/14 14:03	8/11/14 17:20	3.3	12.0	56.3	2.8	0.8	6.0	2.0	1.2
8/11/14 18:29	8/11/14 19:13	0.7	5.0	47.6	3.7	0.6	3.0	0.7	22.0
8/12/14 17:11	8/12/14 18:43	1.5	9.0	97.0	8.0	0.6	5.0	6.7	1.5
8/12/14 20:14	8/12/14 20:50	0.6	6.0	26.3	3.5	0.7	3.0	0.6	1.4
8/12/14 22:17	8/13/14 0:42	2.4	15.0	66.3	6.2	0.5	10.0	17.8	1.4
8/13/14 2:08	8/13/14 2:48	0.7	4.0	60.8	6.9	0.8	2.0	0.4	12.4
8/13/14 15:11	8/13/14 15:45	0.6	4.0	84.5	6.5	1.3	1.0	0.2	1.6
8/13/14 17:20	8/13/14 18:51	1.5	8.0	83.6	7.2	0.5	4.0	2.8	46.8

Bout Start	Bout End	Bout Duration (h)	# of Dives	Ave Max Dive Depth (m)	Ave Dive Duration (min)	Ave # Lunges/Dive	Dives With No Lunges	Area Of Bout (km^2)	Time to Next Bout (h)
8/15/14 17:38	8/15/14 18:19	0.7	4.0	117.0	6.9	1.0	2.0	0.5	3.1
8/15/14 21:26	8/16/14 3:36	6.2	30.0	149.0	9.3	1.3	9.0	69.5	10.9
8/16/14 14:29	8/16/14 15:30	1.0	5.0	52.8	5.9	0.4	3.0	0.3	24.6
8/17/14 16:06	8/17/14 19:46	3.7	16.0	157.1	8.7	1.4	1.0	11.6	1.1
8/17/14 20:51	8/17/14 22:30	1.7	8.0	137.8	9.6	0.9	3.0	3.1	0.9
8/17/14 23:26	8/18/14 2:52	3.4	17.0	160.9	9.0	1.6	3.0	11.4	13.0
8/18/14 15:52	8/18/14 19:51	4.0	14.0	251.1	13.2	2.1	2.0	5.1	1.2
8/18/14 21:01	8/18/14 23:09	2.1	8.0	243.6	12.1	1.5	1.0	1.5	18.5
8/19/14 17:41	8/19/14 18:44	1.0	4.0	222.5	13.1	1.8	0.0	0.1	6.3
8/20/14 1:02	8/20/14 5:38	4.6	17.0	126.7	8.1	1.1	7.0	13.8	14.8
8/20/14 20:26	8/21/14 3:44	7.3	45.0	109.1	7.3	2.0	11.0	13.5	9.5
8/21/14 13:11	8/21/14 20:18	7.1	40.0	141.6	7.9	2.4	1.0	6.1	4.0
8/22/14 0:16	8/22/14 1:53	1.6	10.0	129.0	7.0	2.4	3.0	1.2	0.0
	median	1.6	8.5	131.6	7.3	1.3	3.0	1.8	2.2
	max	11.3	62.0	251.1	13.2	2.8	14.0	80.9	46.8
	min	0.5	4.0	26.3	2.8	0.4	0.0	0.0	0.0

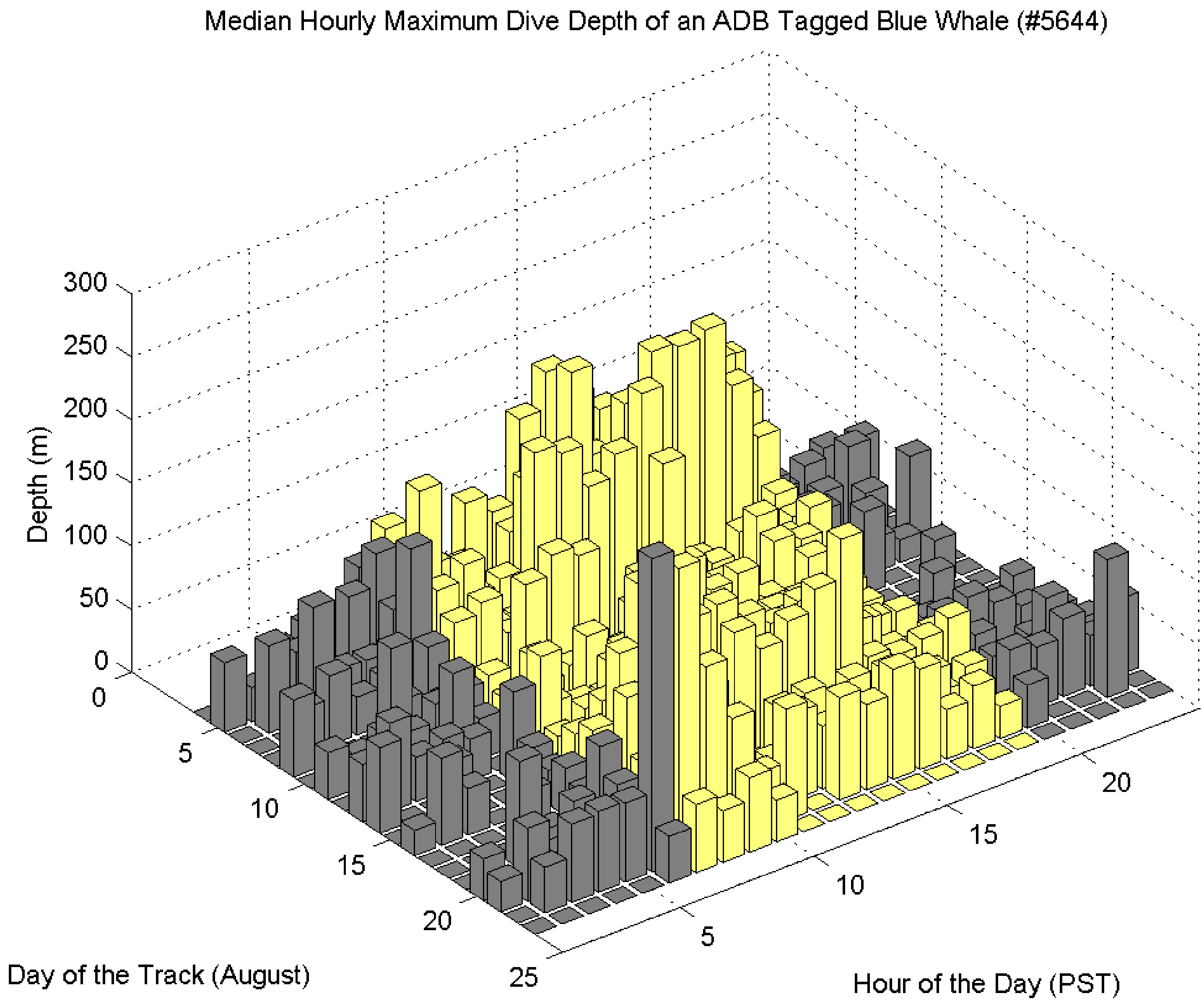

Figure 3-60. A plot showing the median maximum dive depth for each hour of the track of dives made by ADB-tagged blue whale #5644. Yellow bars are daytime and gray bars are nighttime. (N dives=1,068).

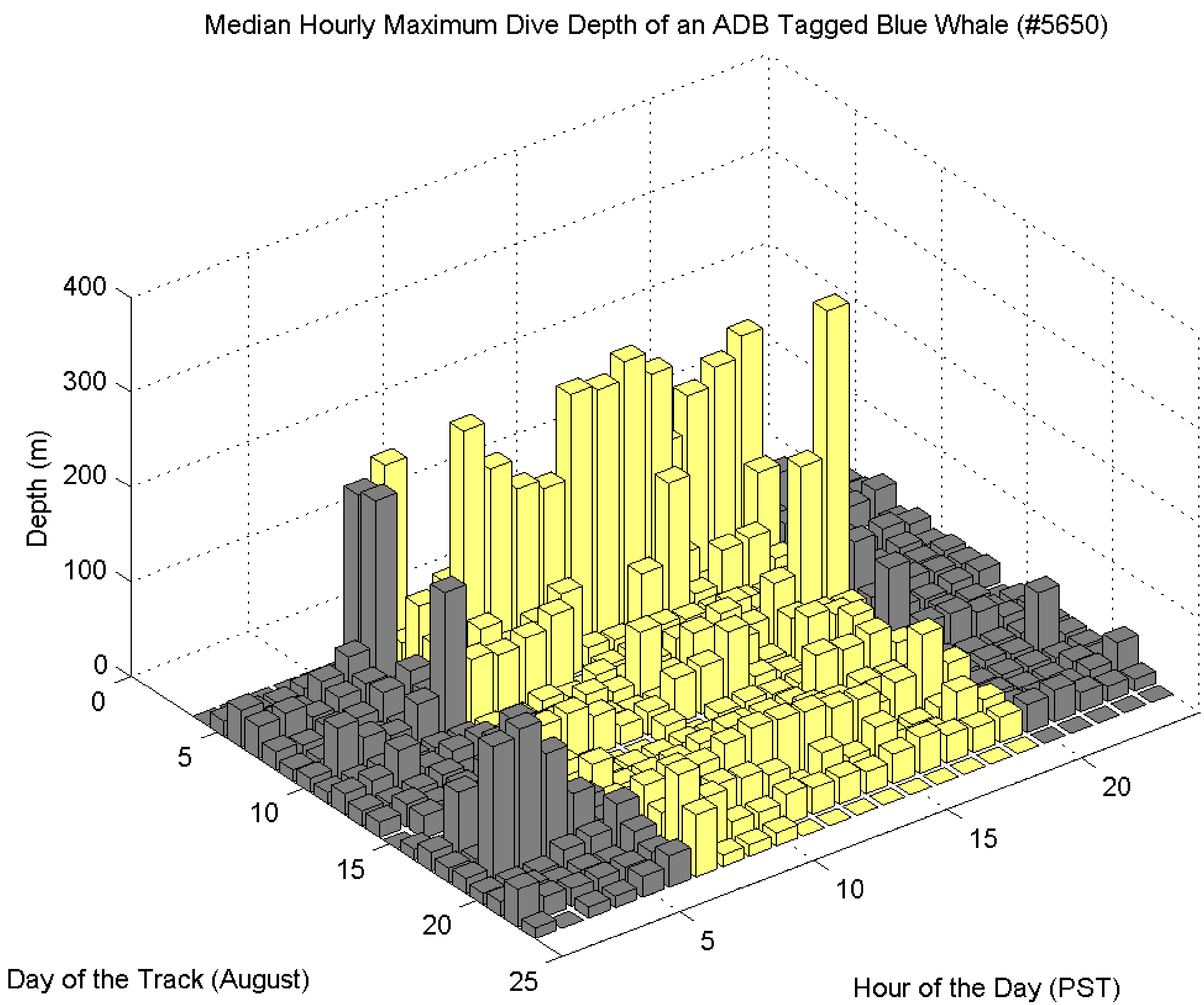

Figure 3-61. A plot showing the median maximum dive depth for each hour of the track of dives made by ADB-tagged blue whale #5650). Yellow bars are daytime and gray bars are nighttime. (N dives=2,276).

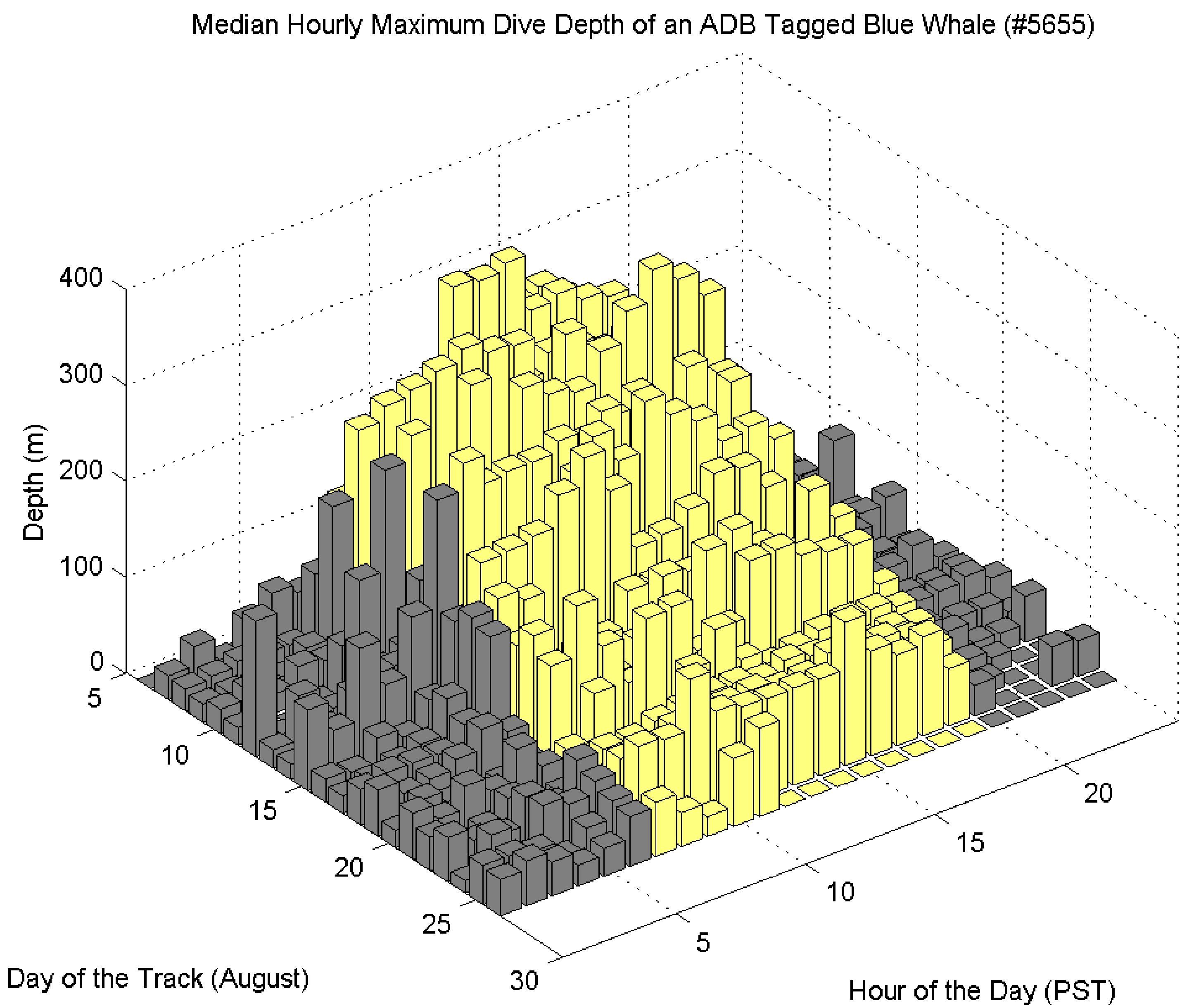

Figure 3-62. A plot showing the median maximum dive depth for each hour of the track of dives made by ADB-tagged blue whale #5655. Yellow bars are daytime and gray bars are nighttime. (N dives=2,918).

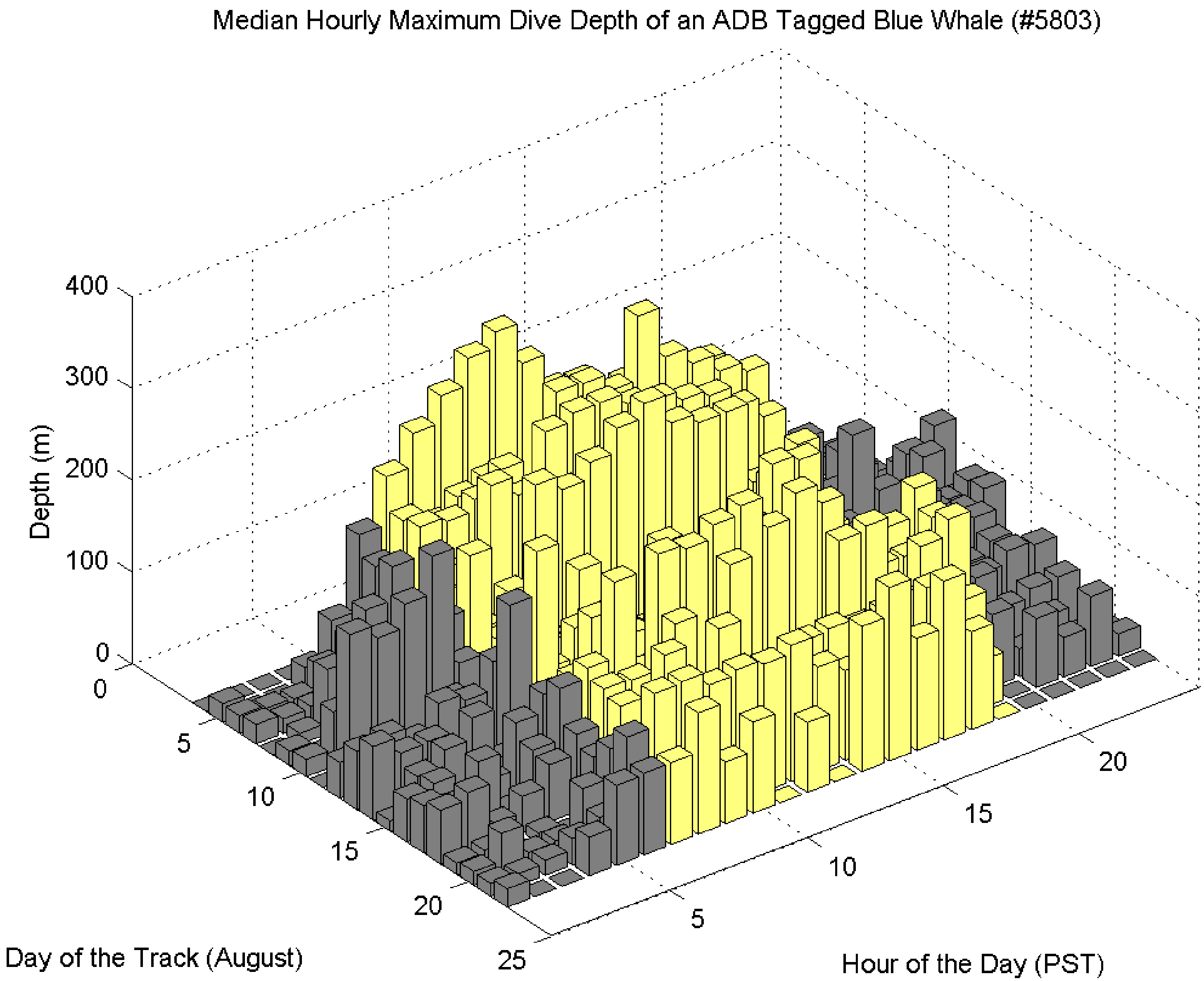

Figure 3-63. A plot showing the median maximum dive depth for each hour of the track of dives made by ADB-tagged blue whale #5803. Yellow bars are daytime and gray bars are nighttime. (N dives=1,832).

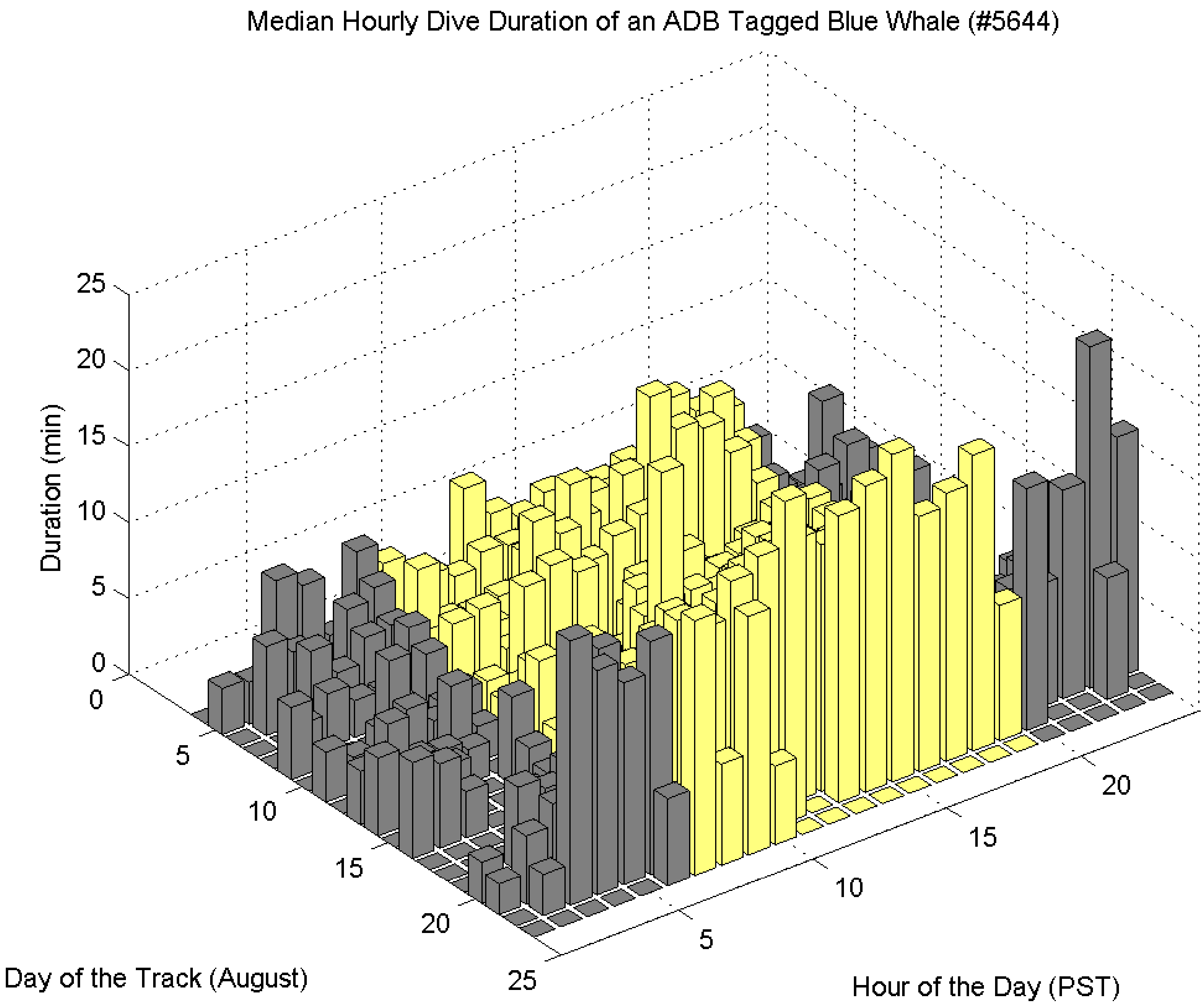

Figure 3-64. A plot showing the median dive duration for each hour of the track of dives made by ADB-tagged blue whale #5644. Yellow bars are daytime and gray bars are nighttime. (N dives=1,068).

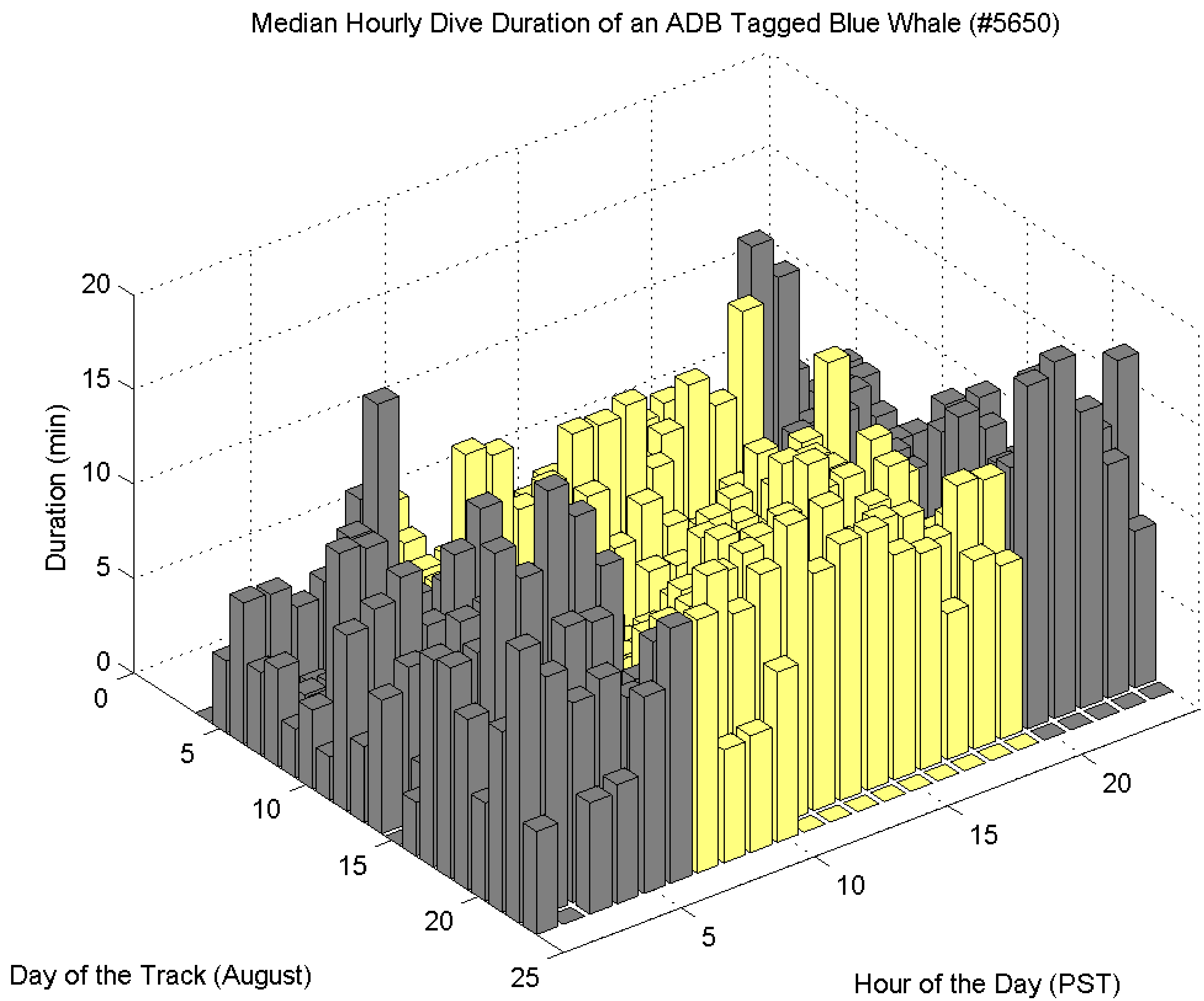

Figure 3-65. A plot showing the median dive duration for each hour of the track of dives made by ADB-tagged blue whale #5650. Yellow bars are daytime and gray bars are nighttime. (N dives=2,276).

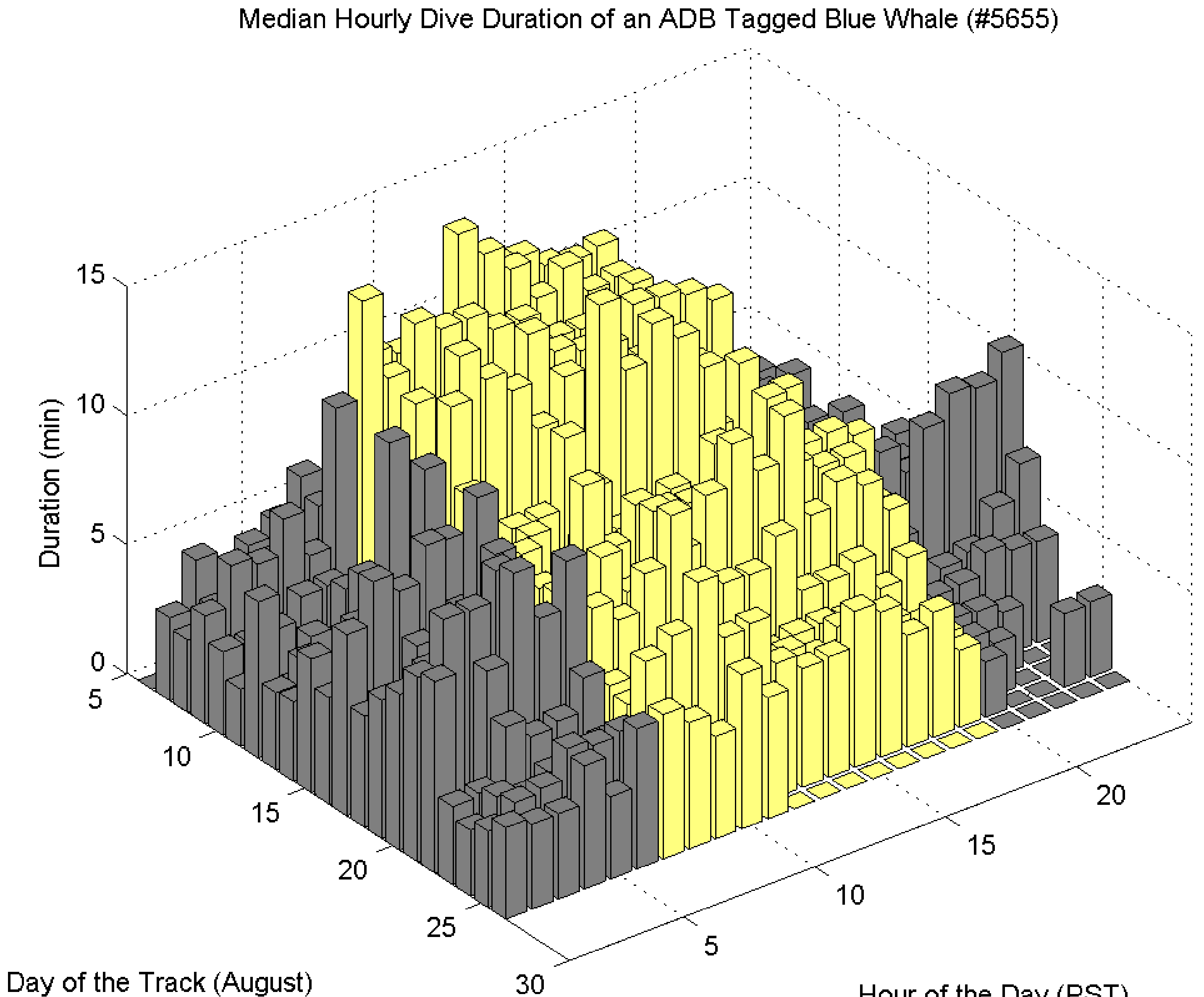

Figure 3-66. A plot showing the median dive duration for each hour of the track of dives made by an ADB-tagged blue whale #5655. Yellow bars are daytime and gray bars are nighttime. (N dives=2,918).

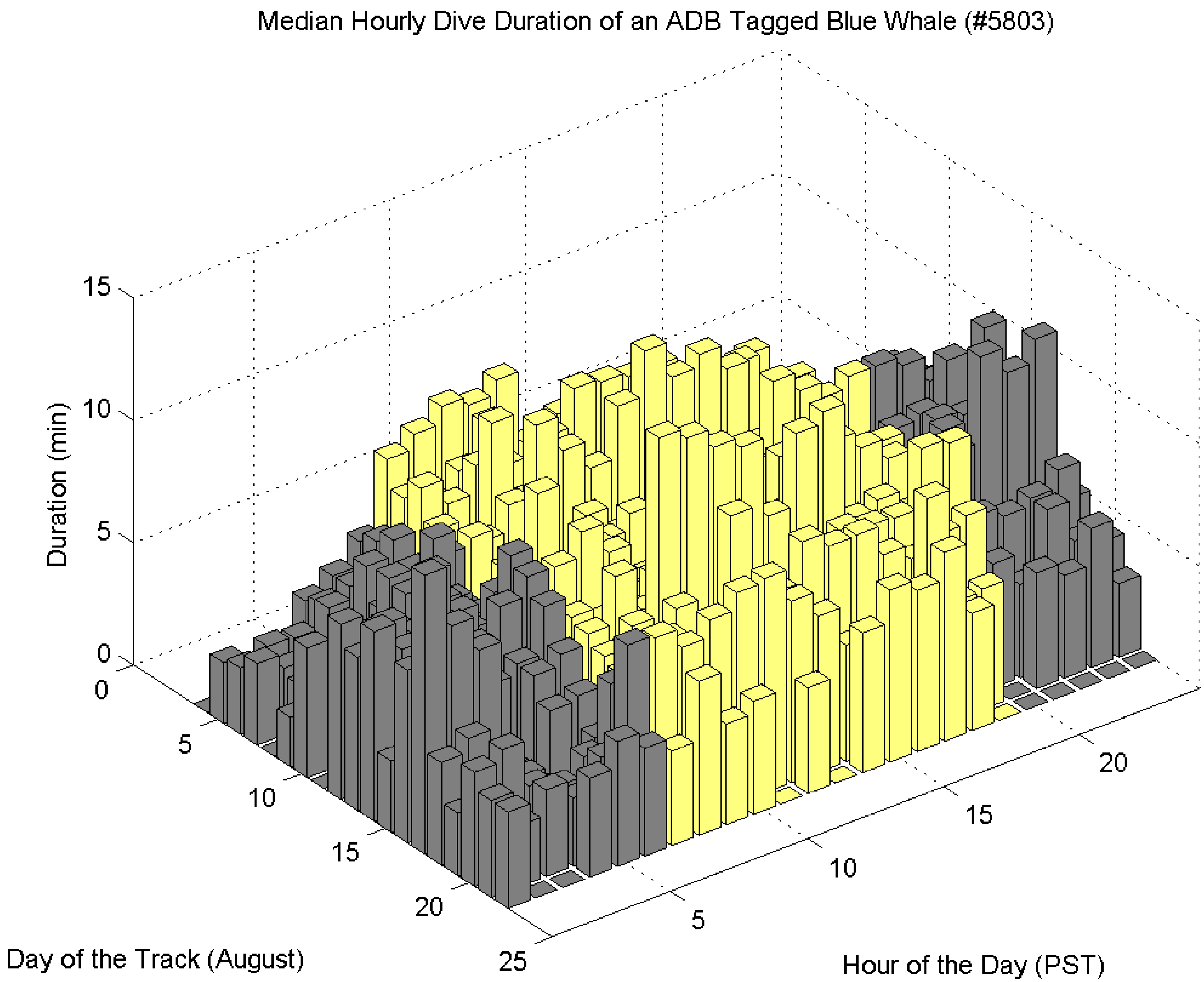

Figure 3-67. A plot showing the median dive duration for each hour of the track of dives made by ADB-tagged blue whale #5803. Yellow bars are daytime and gray bars are nighttime. (N dives=1,832).

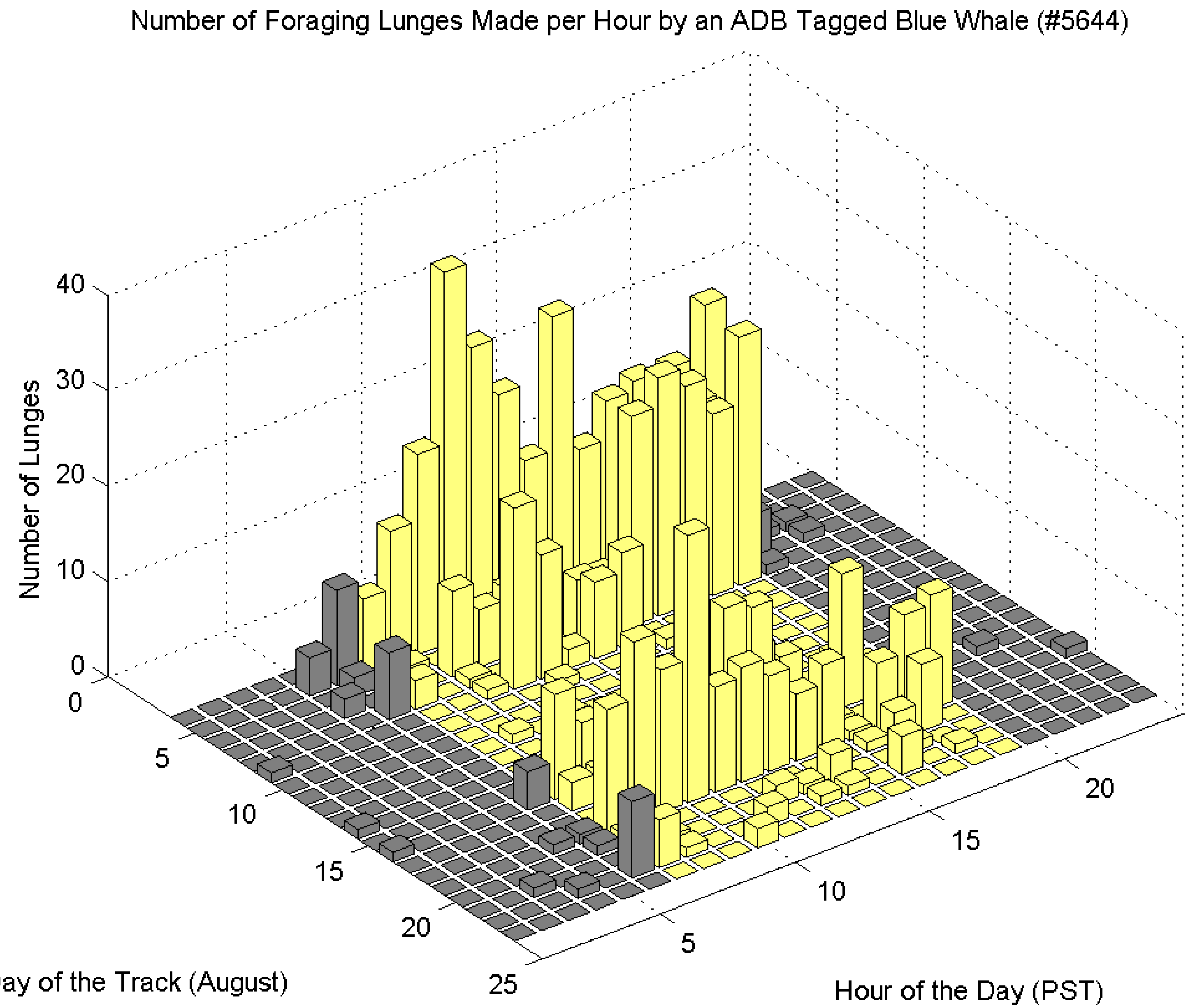

Figure 3-68. A plot showing the number of feeding lunges per dive for each hour of the track made by ADB-tagged blue whale #5644. Yellow bars are daytime and gray bars are nighttime. (N dives=1,068).

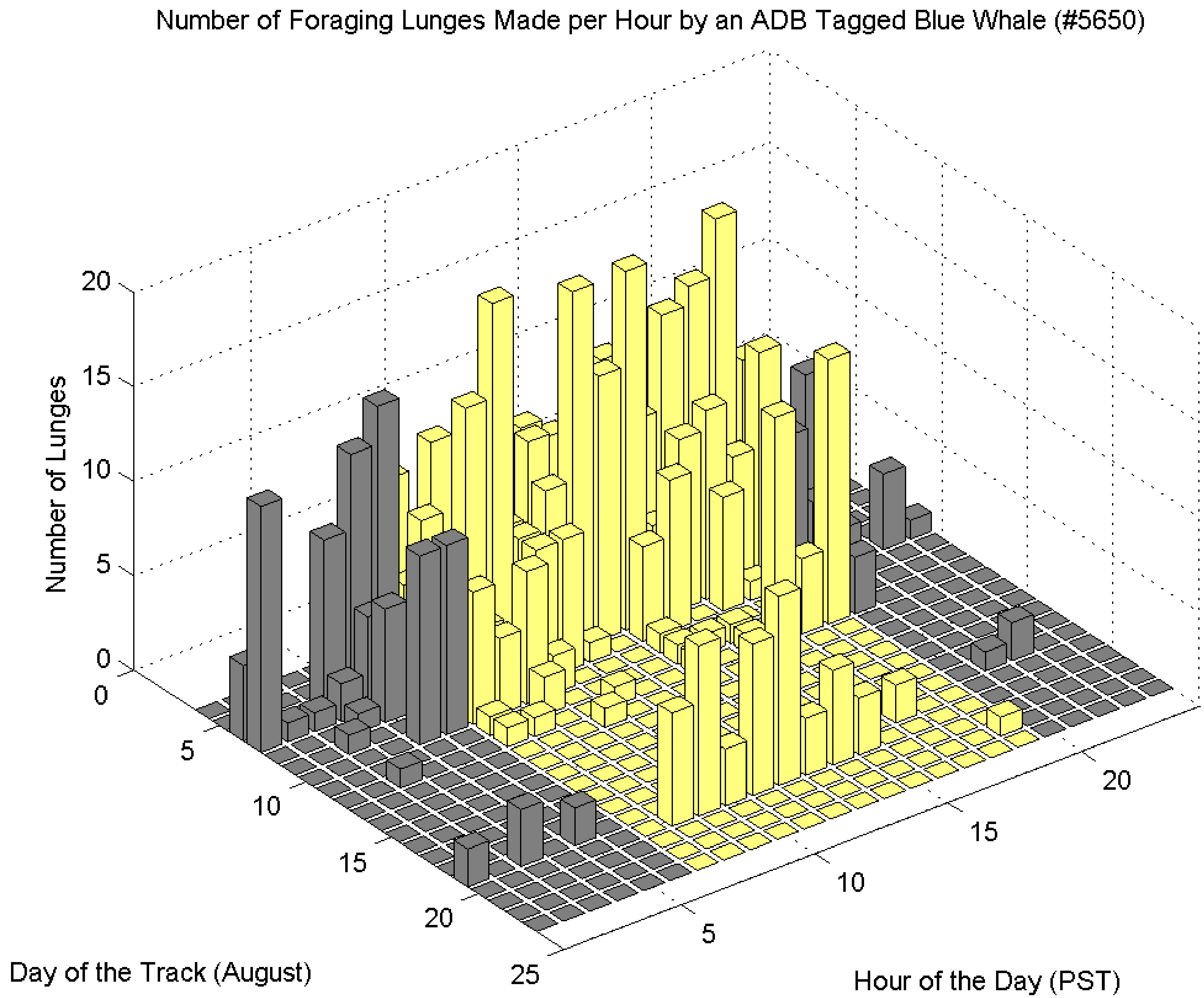

Figure 3-69. A plot showing the number of feeding lunges per dive for each hour of the track made by ADB-tagged blue whale #5650. Yellow bars are daytime and gray bars are nighttime. (N dives=2,276).

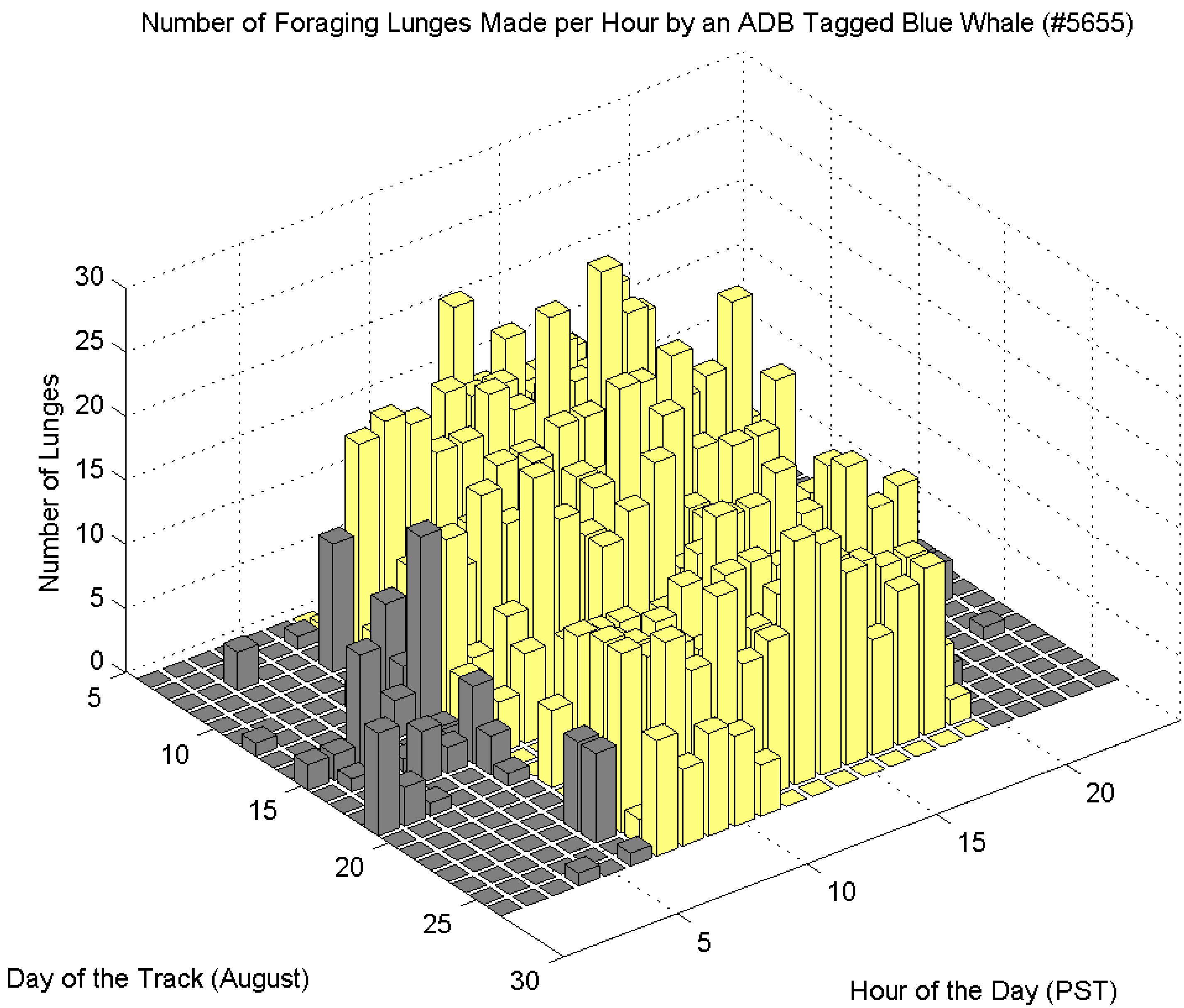

Figure 3-70. A plot showing the number of feeding lunges per dive for each hour of the track made by –ADB-tagged blue whale #5655. Yellow bars are daytime and gray bars are nighttime. (N dives=2,918).

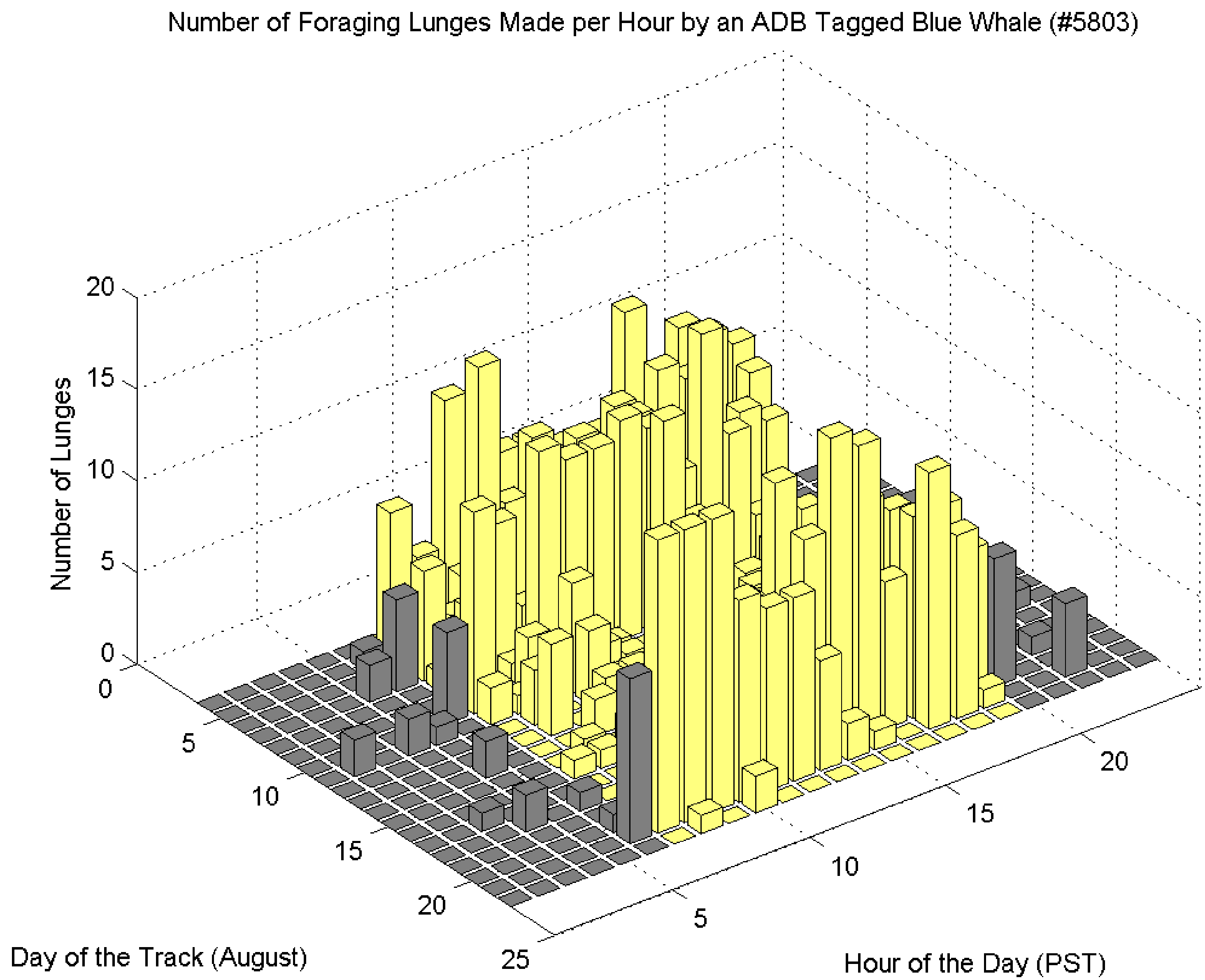

Figure 3-71. A plot showing the number of feeding lunges per dive for each hour of the track made by ADB-tagged blue whale #5803. Yellow bars are daytime and gray bars are nighttime. (N dives=1,832).

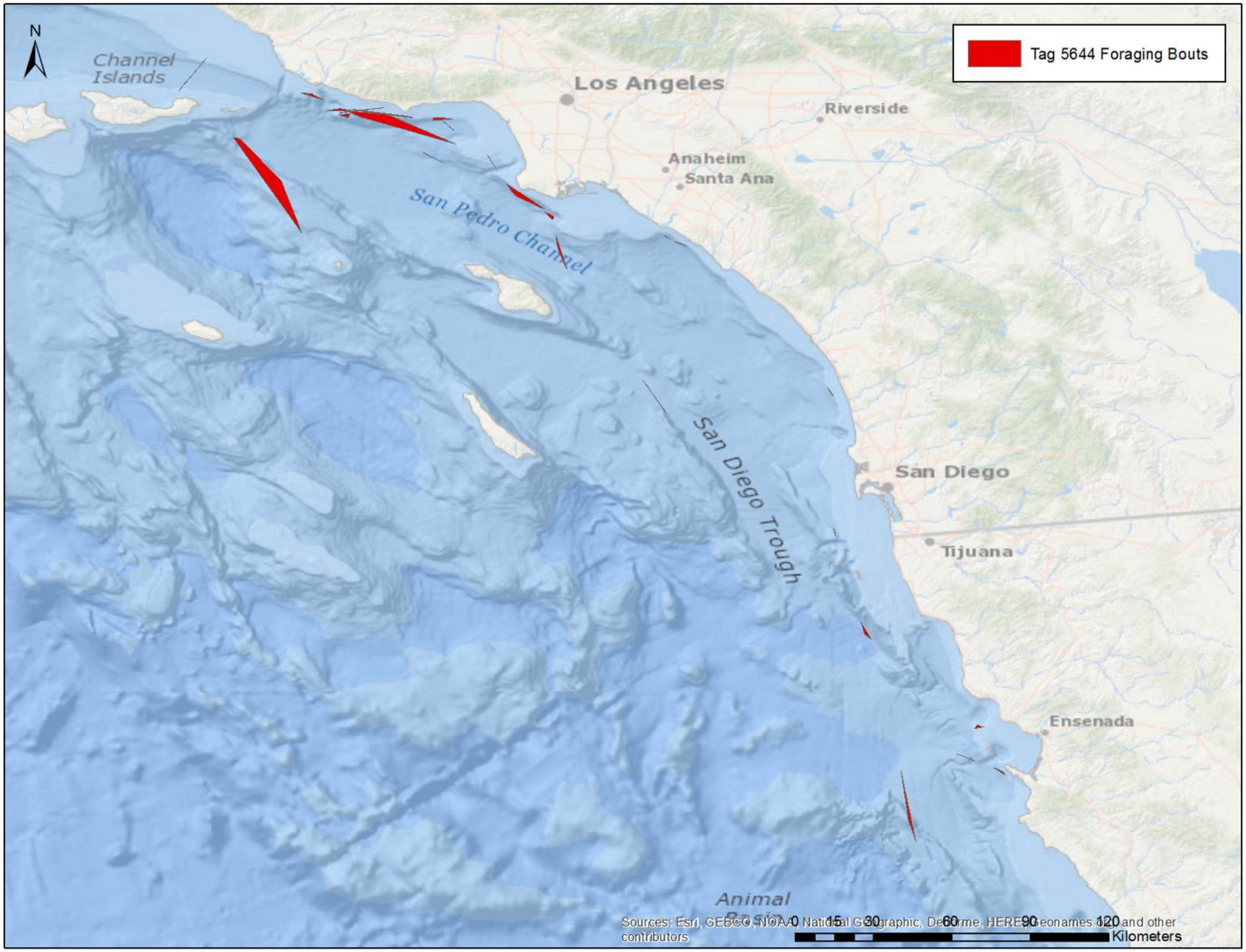

Figure 3-72. Locations of foraging bouts made by ADB-tagged blue whale #5644 during 4 to 23 August 2014 off southern California. Foraging bouts are sequences of dives with no more than three dives in a row with no recorded foraging lunges.

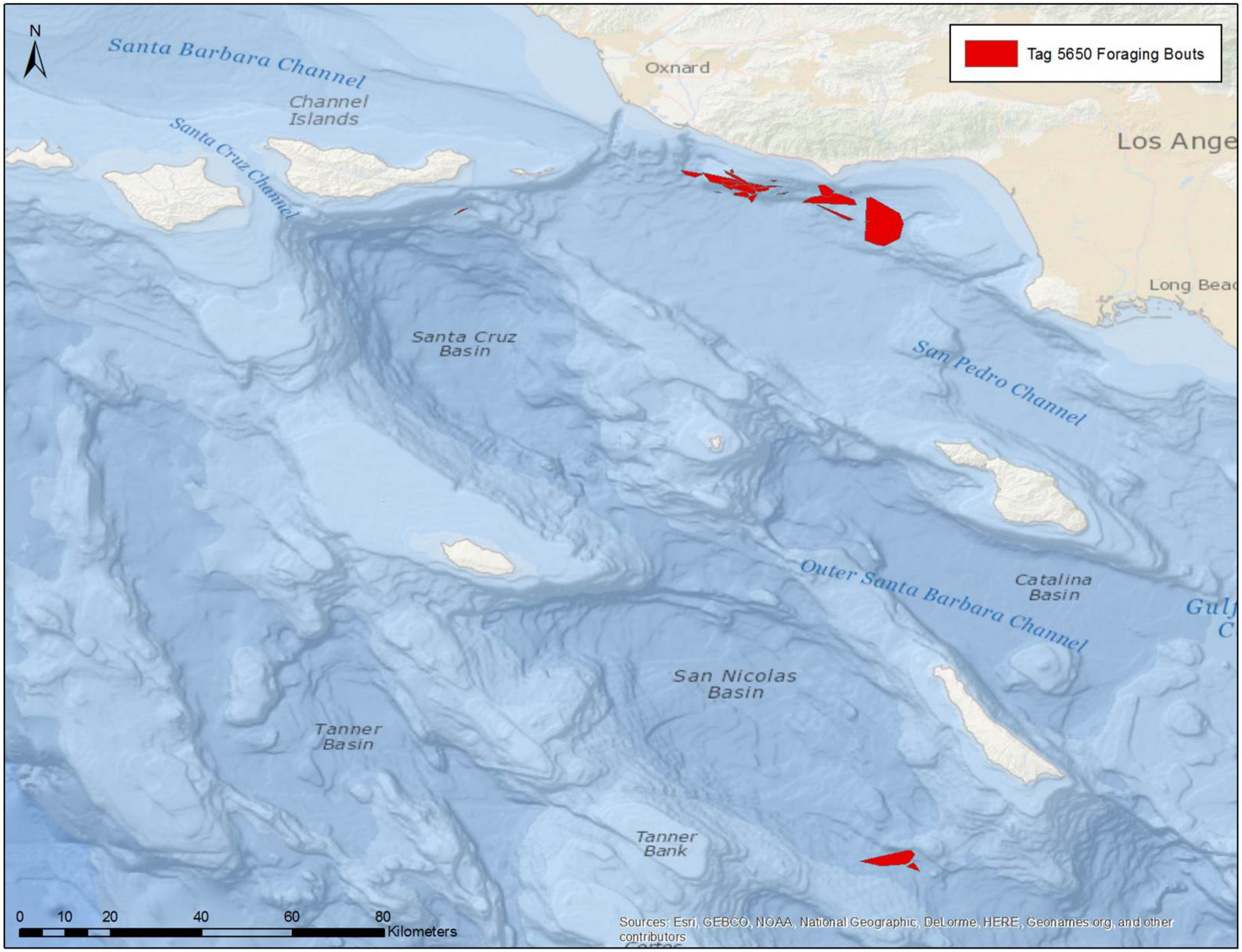

Figure 3-73. Locations of foraging bouts made by ADB-tagged blue whale #5650 during 4 to 23 August 2014 off southern California. Foraging bouts are sequences of dives with no more than three dives in a row with no recorded foraging lunges.

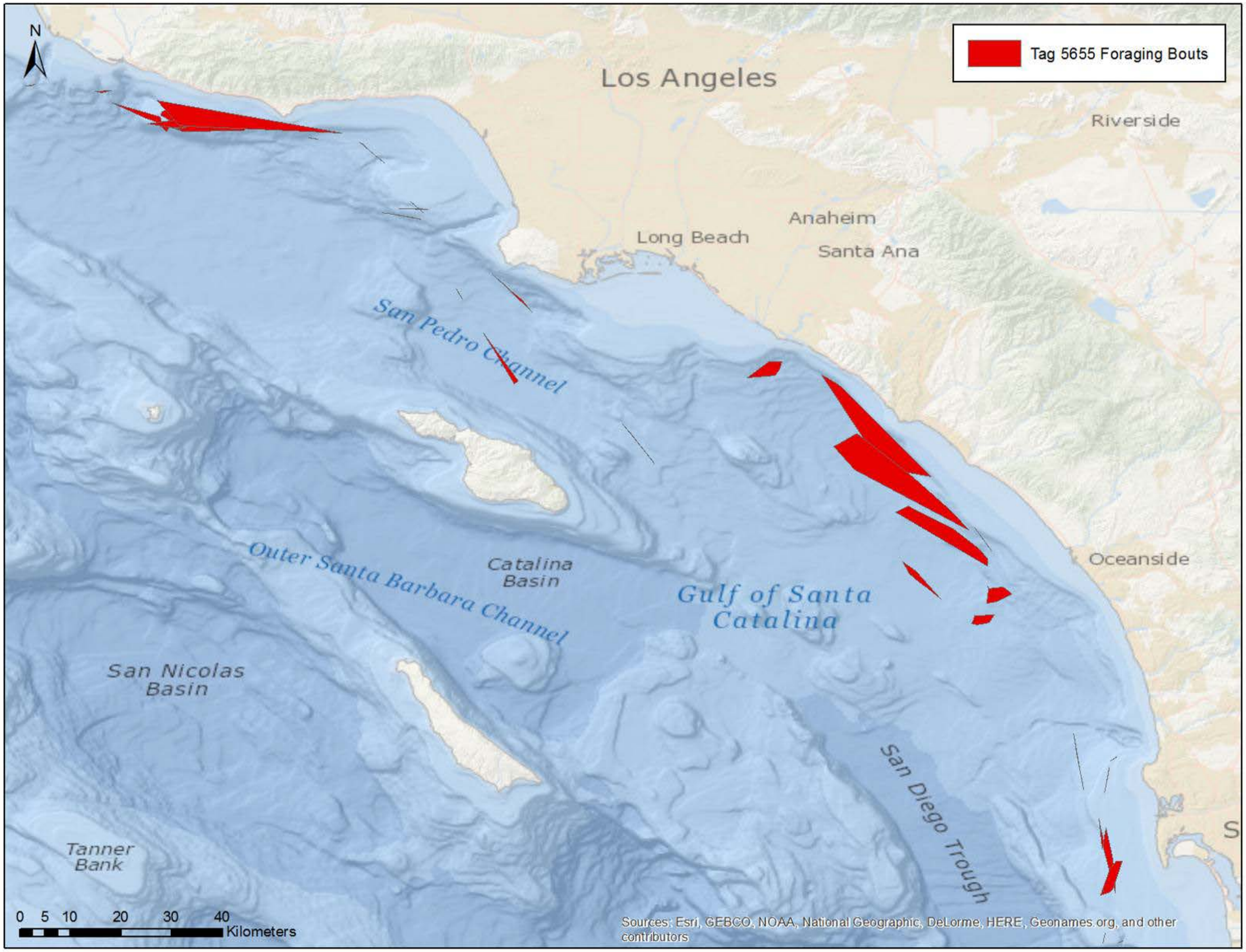

Figure 3-74. Locations of foraging bouts made by ADB-tagged blue whale #5655 during 6 to 26 August 2014 off southern California. Foraging bouts are sequences of dives with no more than three dives in a row with no recorded foraging lunges.

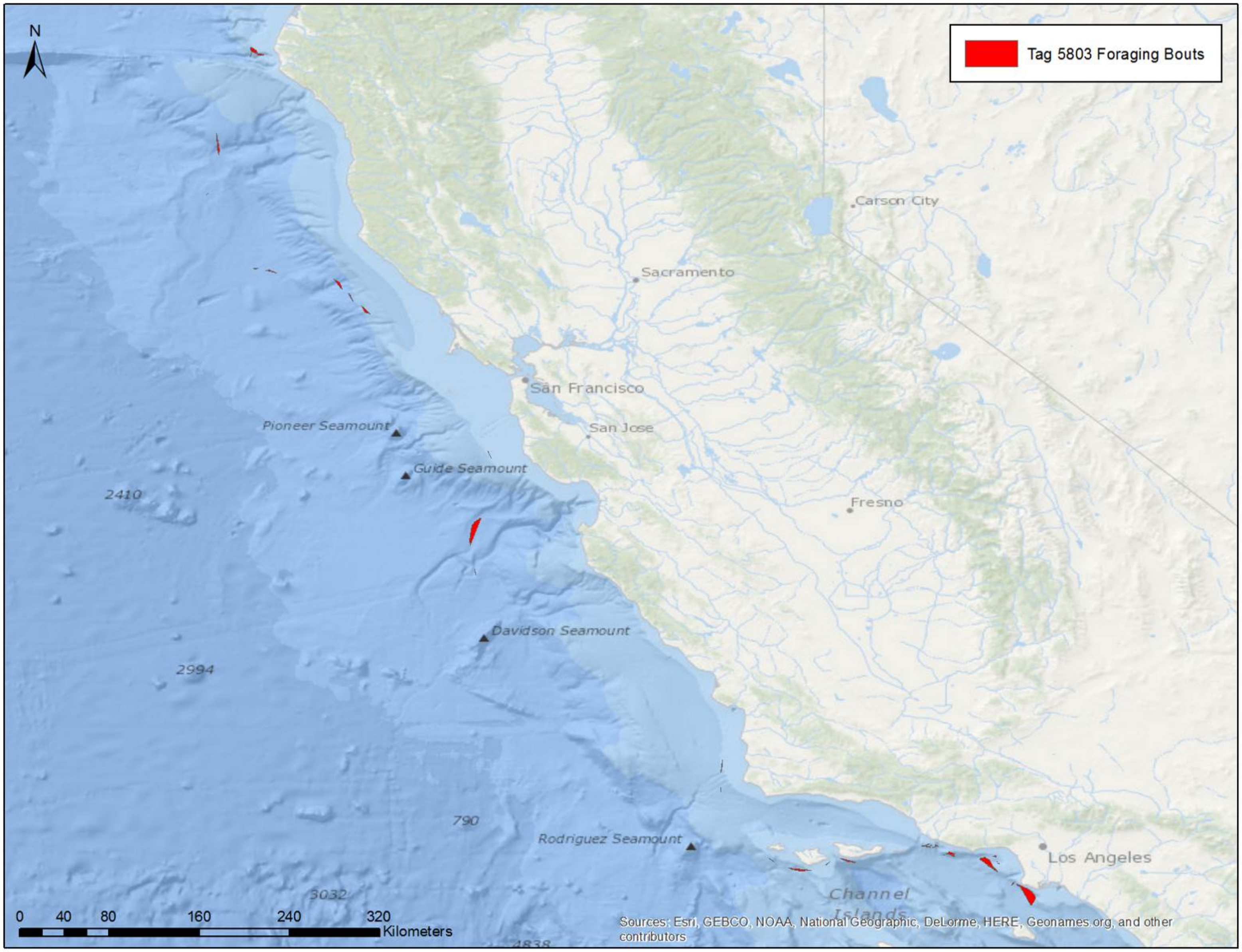

Figure 3-75. Locations of foraging bouts made by ADB-tagged blue whale #5803 during 4 to 23 August 2014 off southern California. Foraging bouts are sequences of dives with no more than three dives in a row with no recorded foraging lunges.

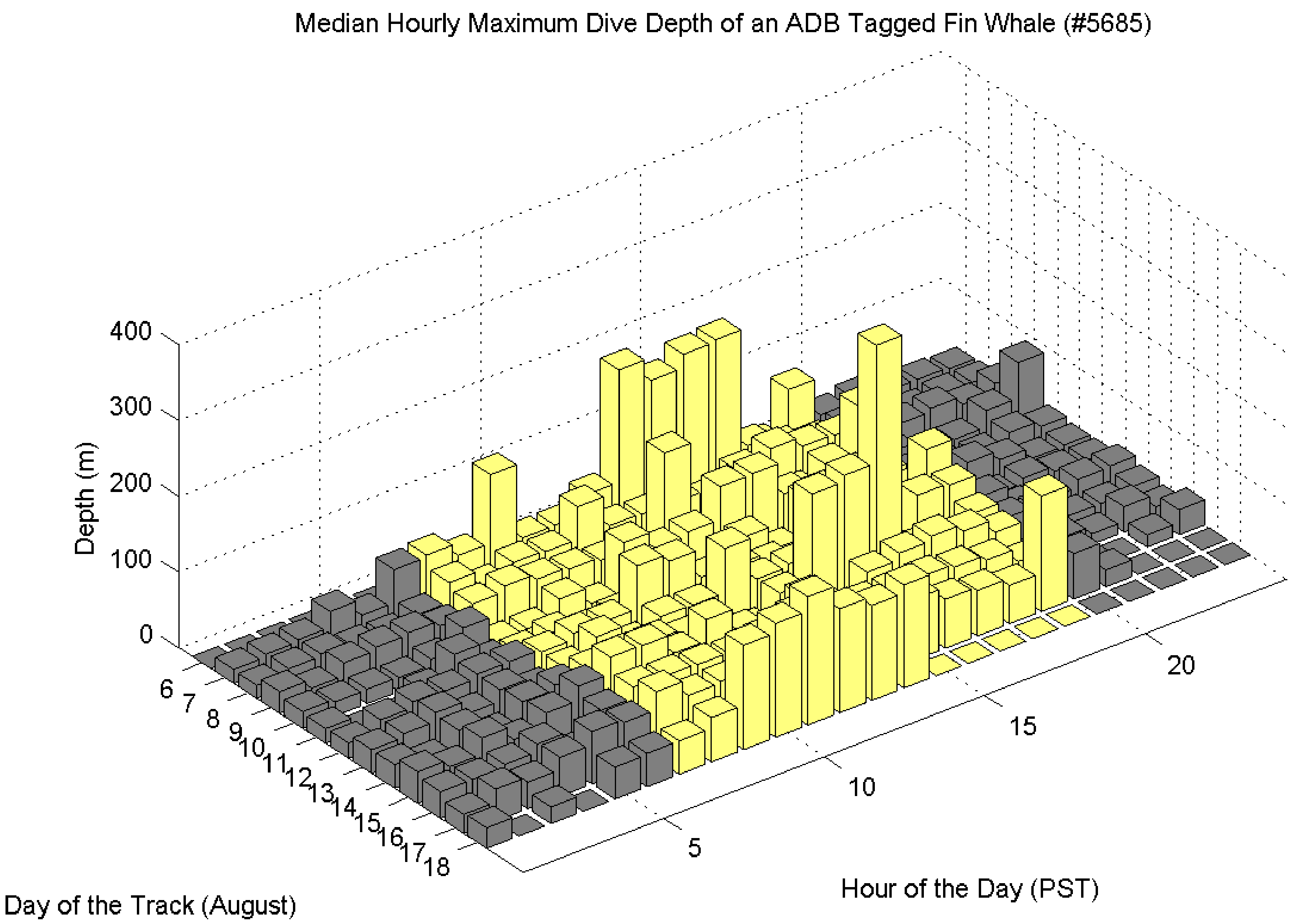

Figure 3-76. A plot showing the median maximum dive depth for each hour of the track of dives made by ADB-tagged fin whale #5685. Yellow bars are daytime and gray bars are nighttime. (N dives=1,140).

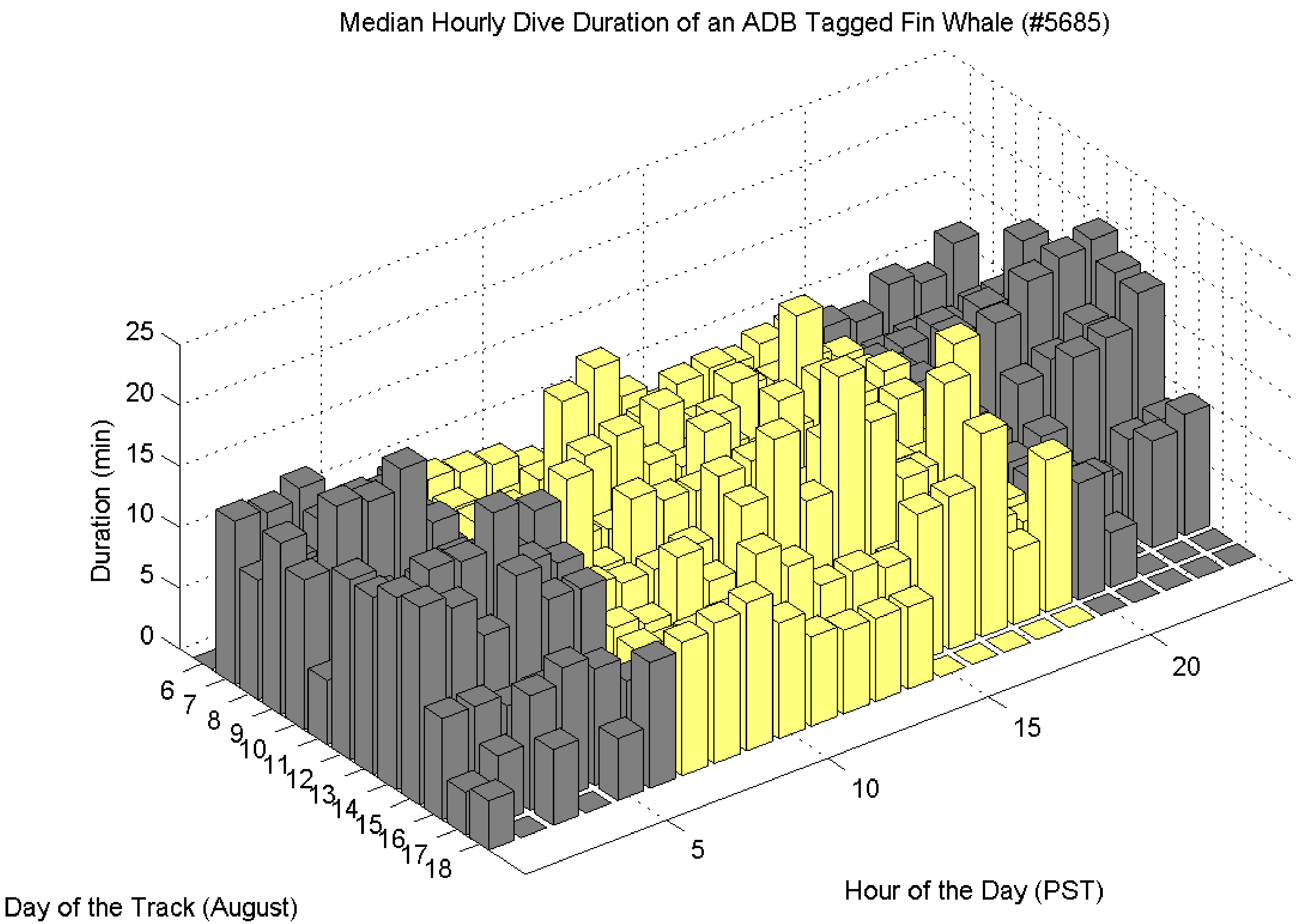

Figure 3-77. A plot showing the median dive duration for each hour of the track of dives made by ADB-tagged fin whale #5685. Yellow bars are daytime and gray bars are nighttime. (N dives=1,140).

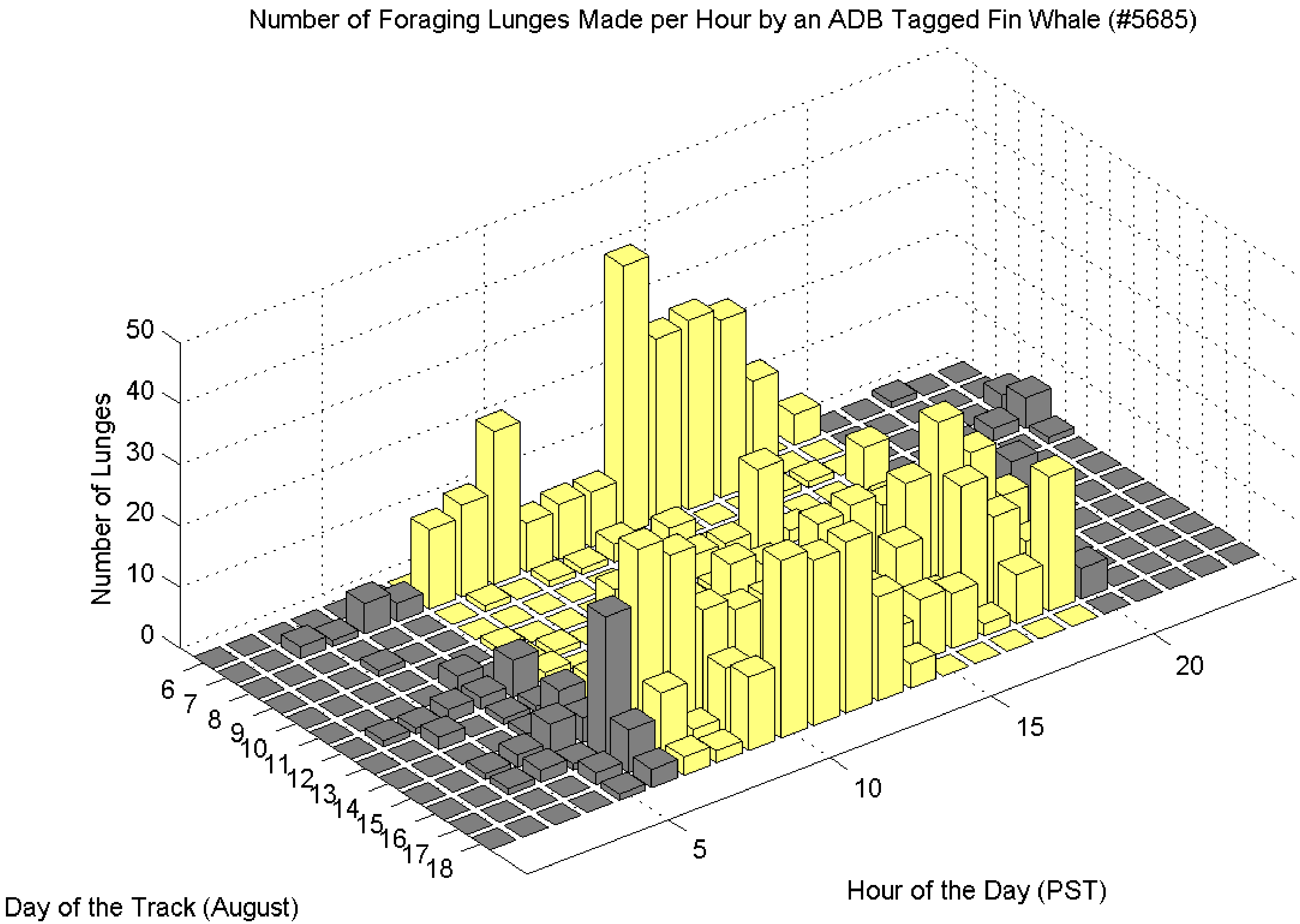

Figure 3-78. A plot showing the number of feeding lunges per dive for each hour of the track made by ADB-tagged fin whale #5685. Yellow bars are daytime and gray bars are nighttime. (N dives=1,140).

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4. Historical Analysis on Previously Deployed Blue Whale Tag Data

4.1 Introduction

A general picture of the status and distributional range of the population of blue whales inhabiting the Eastern North Pacific Ocean has gradually emerged in the past four decades. Presently numbering about 2,000 animals and thought to be increasing after depletion by commercial whaling in the first two-thirds of the twentieth century (Monnahan et al. 2014), this population is known to occur from the eastern Gulf of Alaska to the eastern tropical Pacific, including the Gulf of California (Rice 1974, 1978, Leatherwood et al. 1988, Reilly and Thayer 1990, Barlow and Forney 2002, Calambokidis et al. 2009). Occupation of parts of this range follows a seasonal pattern, with animals being found in northern areas off California, British Columbia, and the Gulf of Alaska in summer and fall, and in southern areas off Baja California, the Gulf of California, and the eastern tropical Pacific in winter and spring (Leatherwood et al. 1988, Larkman and Veit 1998, Stafford et al. 1999, Burtenshaw et al. 2004).

However, we have only recently been able to obtain a refined view of the migratory movements of the Eastern North Pacific blue whale population due to a satellite-tagging and tracking program by Oregon State University’s Marine Mammal Institute (MMI) that began in 1993 and that extended through 2008 (Mate et al. 2007, Bailey et al. 2010). Over this 16-year period, 182 satellite tags were deployed, representing the largest tracking data set in existence for any whale population to date. Portions of these data have been used in several studies (Fiedler et al. 1998, Mate et al. 1999, Lagerquist et al. 2000, Etnoyer et al. 2004, 2006, Mate et al. 2007, Bailey et al. 2010, Irvine et al. 2014), but an analysis encompassing the complete set of tracks has not been undertaken. This chapter presents an historical analysis of this tracking data set as part of our characterization of blue whale migration and foraging areas along the U.S. West Coast in relation to the Navy’s training and testing areas and NOAA’s BIAs (Calambokidis et al. 2015). For the analyses performed here we: a) apply state-space models to regularize the tracks, improve location estimates, and classify movement behavior; b) estimate home ranges using fixed-kernel density approaches to determine the areas of highest use by blue whales, and their degree of overlap with Navy areas and BIAs; c) provide a biogeographic context for blue whale distribution in the Eastern North Pacific; and d) examine the tracking data in combination with a suite of environmental variables to characterize whale distribution in relation to habitat variability within the main biogeographic provinces they occupy.

4.2 Methods

4.2.1 Tagging and Tracking

A tracking study of Eastern North Pacific blue whales using Argos-linked satellite tags was begun by the MMI in 1993 and extended through 2008. Fieldwork was conducted every year except for 1996, 1997, and 2003, amounting to 13 tagging years over this 16-year period.

Tagging occurred at five locations along the range, from north to south: Cape Mendocino, Gulf of the Farallones, Santa Barbara Channel, Gulf of California, and Costa Rica Dome.

The tags were attached 1 to 4 m forward of the whale's dorsal fin from a small (5- to 7-m) rigid-hulled inflatable boat. Prior to 1998 surface-mounted tags were based on Telonics transmitters (ST-6 or ST-10) housed in stainless-steel cylinders attached to the whale's back with two sub-dermal anchors to hold them in the blubber layer (Mate et al. 1999). Later, smaller Telonics ST-15 transmitters were used that could be housed in an implantable stainless-steel cylinder partly covered with a long-term dispersant antibiotic coating (Mate et al. 2007). Until 2002, tags were applied with a 68-kg Barnett compound crossbow. Subsequently they were applied using a modified version of the Air Rocket Transmitter System (ARTS), a pneumatic applicator for projectile tags with adjustable pressure (Heide-Jørgensen et al. 2001). Further details about tag design and deployment methods can be found in Mate et al. (2007).

4.2.2 State-Space Modeling

We applied Bayesian state-space models (SSMs) to the raw Argos locations of tracks that lasted more than 7 d to generate improved location estimates at uniformly spaced intervals (one location per day), as described in **Section 2.1.5**. Output from the SSMs included estimates of uncertainty around each location, as described by the 95 percent credible limits in longitude and latitude. The SSMs also classified movement behavior at each location according to two behavioral modes, transiting or area-restricted searching (ARS), based on a continuous "behavioral state" scale ranging from 1 to 2 (corresponding to the mean values of two Markov Chain Monte Carlo simulations; see **Section 2.1.5)**. Arbitrary values along this scale are conventionally used to assign behavioral mode as either transiting (values lower than 1.25) or ARS (values greater than 1.75) (Bailey et al. 2010). However, instead of using this discrete behavioral mode classification, we used the full range of the behavioral state scale as a continuous response variable (BSTATE, after re-scaling it from 0 to 1 for ease in visualization) for quantitative comparison with environmental variables.

4.2.3 Occurrence in Navy Areas and BIAs

For each one of the SSM-derived tracks we determined the number of locations and the number of days occurring inside the Navy areas and the BIAs in each year, and report them in terms of percentages of these totals. To compute estimates of residence time inside Navy areas and overlapping BIAs, interpolated locations were derived at 1-h intervals between SSM locations, assuming a linear track and constant speed. These interpolated locations provided evenly spaced time segments from which reasonable estimates of residence times could be generated for areas of widely different size, and were especially useful when tracks crossed Navy area or BIA boundaries. Residence time was calculated as the sum of all 1-h 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 for each year.

4.2.4 Home Range Analysis

We used SSM-derived tracks that had 30 or more locations within U.S. EEZ waters to estimate the HR and CA as the 90 percent and 50 percent fixed-kernel density distributions, respectively, for each track, as described in **Section 2.1.6**. We used the number of overlapping individual HRs and CAs to identify areas of highest use.

4.2.5 Biogeographic Context

Considering the vast range in the Eastern North Pacific occupied by the whales tracked during this study, we examined whale occurrence in the context of regional ecology. We followed Longhurst's (1998, 2006) biogeochemical province designations to investigate the occurrence of blue whales within these provinces. Digital boundaries for these provinces were obtained as shapefiles from VLIZ (version 2; 2009). The study area comprised eight biogeographic provinces: Alaska Downwelling Coastal Province, 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, and Central American Coastal Province (CAMR). The boundaries of two of these provinces were slightly modified to better reflect blue whale distribution, as follows. First, the jagged offshore edge of the CCAL boundary was straightened to avoid interrupting some of the 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 blue whales did occur, by slightly altering the boundaries of CCAL and PNEC, and did not further consider the rest of CAMR in this study. The percentage of SSM-derived locations occurring in each province was calculated to assess blue whale regional biogeography.

A number of biogeographic classifications of the global oceans have been advanced, each with advantages and drawbacks, as reviewed by Vierros et al. (2009) and Gregr et al. (2012). We chose the framework assembled by Longhurst (1998, 2006) in his *Ecological Geography of the Sea* for its objective and consistent designation of global biogeochemical provinces in the open ocean based on physiognomic and ecological considerations. We note that the Convention on Biological Diversity more recently advanced the Global Open Oceans and Deep Seabed approach to biogeographic classification (Vierros et al. 2009), which is also appealing for this purpose. However, in our view Longhurst's approach offers a more consistent consideration of the ecological factors and a more thorough validation of the identified provinces, several drawbacks notwithstanding. We also note that subsequent analyses of remote sensing data have proposed refinements to Longhurst's classification (Esaias et al. 2000, Hardman-Mountford et al. 2008, Oliver and Irwin 2008), but they remain to be validated with *in-situ* observations of biological community structure. Other existing frameworks like Sherman and Alexander's (1989) Large Marine Ecosystems or Spalding et al.'s (2007) Marine Ecoregions of the World, while popular among management and conservation practitioners, were not suitable for our purpose because they are largely restricted to shelf areas and because they are at least partly determined by geopolitical considerations. Further to the literature cited above, read Watson et al. (2003) for additional background and consideration of biogeographic classification systems in fishery management applications.

4.2.6 Habitat Characterization

In order to provide an improved understanding of blue whale distribution in relation to habitat variability, the SSM-generated daily locations were analyzed in relation to environmental conditions. We obtained relevant environmental variables from remotely sensed measurements collected by oceanographic satellites and from digital databases of bottom relief. These variables included: vertical upwelling velocity (or Ekman pumping, WEKM), sea surface height (SSH, a measure of the ocean's surface topography that we used as a proxy for thermocline depth), sea surface temperature (SST), and phytoplankton chlorophyll-*a* concentration (CHL). Variables describing the bottom relief were depth (DEPTH), aspect (expressed in northness and eastness), slope (SLOPE, or depth gradient), and horizontal distance to the 200-m isobath (distShelf, i.e., the approximate location of the continental shelf break).

In order to account for the uncertainty in the location estimation by the SSMs, we obtained the median values for the environmental variables closest in time and space to each location occurring within an ellipse defined by the radii corresponding to the 95 percent credibility limits in longitude and in latitude, respectively, output by the SSMs. This process was automated using the xtract-o-matic.m script (available from http://coastwatch.pfel.noaa.gov/xtracto/), a Matlab® routine that permits client-side access to the environmental data sets served by the Thematic Real-time Environmental Distributed Data System at NOAA's Southwest Fisheries Science Center/Environmental Research Division ERDDAP service (http://coastwatch.pfel.noaa.gov/erddap/index.html). 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 km (for DEPTH) to 37.4 km (for SSH). 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 value nearest to a location.

4.3 Results

4.3.1 Tagging and Tracking

A summary of the yearly tagging effort is presented in **Table 4-1**. The operational duration for the 182 tags deployed is depicted on a yearly basis in **Figure 4-1a** and as an empirical probability distribution in **Figure 4-1b**. The improved tag retention and tag performance observable over the course of the study is attributable to changes in: a) tag size (from large, surface-mounted tags to smaller implant tags in 1998), allowing sub-dermal attachment and reduced hydrodynamic drag, and b) delivery method (from fixed-energy crossbow deployments to adjustable air-powered applicator deployments in 2004) (see **Tables 4-1 and 4-2**, and **Figure 4-1**).

4.3.2 State-Space Modeling and Occurrence within Navy Areas and BIAs

Of the 182 tags deployed, 128 transmitted successfully for any length of time, and 104 transmitted for more than 7 d. Bayesian SSMs were applied to the 104 tracks lasting more than 7 d, covering the period from 14 September 1994 through 9 April 2009. These tracks are shown on a map in **Figure 4-2** and summary information is given in **Table 4-2**. The mean duration for this set of tags was 102.5 d (range = 7–505 d, median = 81 d, SD = 85.4 d). The mean distance covered was 4,625.6 km (range = 104.2–19,203.3 km, median = 3,316.4 km, SD = 3,859.9 km). The mean speed of travel was 2 km/h (range = 0.4-4.2 km/h, median = 1.9 km/h, SD = 0.8 km/h). Sex was determined genetically from skin biopsies for 12 females and 12 males in this set; the sex of the remaining animals was unknown (**Table 4-2**).

The SSMs generated 10,664 daily locations from this set of tracks. The numbers of locations and the numbers of days in each year are reported in **Table 4-3**. From these numbers, we calculated the percentages occurring inside the Navy areas and the BIAs. Overall for the Navy areas, 6.7 percent of the total locations occurred within SOCAL, 2.8 percent in NWTRC, and 0.4 percent in W237 for all years. For the BIAs, 0.1 percent occurred in the San Diego BIA, 0.3 percent in the Santa Monica Bay to Long Beach BIA, and 0.1 percent in the Tanner-Cortez BIA for all years. In individual years, these values ranged between 3.1 and 16.3 percent of the total locations for those years for SOCAL, 0.1 and 8.6 percent for NWTRC, and 0.3 and 1.7 percent for W237 (**Table 4-3**). For the BIAs, these values ranged between 0.1 and 0.5 percent for the San Diego BIA, 0.1 and 0.9 percent for the San Nicolas BIA, 0.5 and 1.8 percent for the Santa Monica Bay to Long Beach BIA, and 0.2 and 0.5 percent for the Tanner-Cortez BIA (**Table 4-3**).

4.3.3 Home Range Analysis

Blue whales occupied the U.S. EEZ in late summer and early fall (July to October). Sizes of the HR and CA were estimated using kernel density analysis for 53 tracks with 30 or more SSM-derived locations inside the US EEZ spanning the period 1998 to 2008 (**Table 4-4**). The numbers of locations for this analysis ranged between 31 and 178 per track (mean=68.8, median=62, SD=31.6). The smallest HR was 3,342.7 km^2 and the largest one was 286,414.5 km^2 (mean=61,783 km^2, median=42,299.4 km^2, SD=61,253.81 km^2). The smallest CA was 299.6 km^2 and the largest one was 73,252.5 km^2 (mean=13,424 km^2, median=7,827.1 km^2, SD=15,872.3 km^2) (**Table 4-4**).

We used the numbers of overlapping individual HRs and CAs to identify areas of highest use inside the U.S. EEZ. Two areas were most heavily used: as many as 40 blue-whale-HRs overlapped in the area at the western end of the Santa Barbara Channel in southern California, and as many as 32 blue-whale-HRs overlapped in the Gulf of the Farallones, off central California (**Figure 4-3a**). Of the 53 eligible 53 whale tracks, 26 blue-whale-CAs overlapped in the area at the western end of the Santa Barbara Channel and 21 blue-whale-CAs overlapped in the Gulf of the Farallones (**Figure 4-3b**).

None of the two areas of highest HR use overlapped with the Navy areas. Eight HRs extended into SOCAL. Sixteen HRs occurred along the southeastern border of the NWTRC, but only eight HRs included most of this range. Eight HRs extended into area W237 (**Figure 4-3a**). None of the two areas of highest CAs overlapped with the Navy areas. Six CAs included SOCAL. Eleven CAs occurred along the southeastern border of the NWTRC, but only six CAs included most of this training range. Six CAs included area W237 (**Figure 4-3b**).

4.3.4 Biogeographic Context

The 104 blue whale tracks analyzed for this report ranged from the Gulf of Alaska (approximately 143°W, 53°N) to the north, the eastern tropical Pacific (approximately 87°W, 5°N) to the southeast, and almost to Hawaii (approximately 152°W, 32°N) to the west (**Figure 4-2**). Considering this vast range, we examined whale occurrence in a biogeographic context following Longhurst's (1998, 2006) province designations (after slight modification to the boundaries as described in **Section 4.2.5**) to partition the SSM-derived locations within these provinces (**Figure 4-4a**).

The SSMs generated 10,664 daily locations from the set of 104 tracks. The vast majority of these locations occurred in CCAL (74.4 percent), PNEC (15.9 percent), and GUCA (6.9 percent), while very few occurred in PSAE (0.7 percent), NPPF (1.3 percent), or NPTG (0.8 percent). No locations were recorded in Alaska Downwelling Coastal Province or Pacific Equatorial Divergence Province. While undoubtedly GUCA is an important wintering area for Eastern North Pacific blue whales (Costa-Urrutia et al. 2013, Pardo et al. 2013), given the comparatively much lower occurrence of tagged whales in this province as well as in PSAE, NPPF, and NPTG, for the remainder of this report we focus on the results from CCAL and PNEC only.

From a seasonal perspective, CCAL was occupied in all months of the year, although use shifted from central and southern California (U.S.) in the summer-fall months (**Figure 4-4b**) to the southern part (along the Baja California Peninsula, Mexico) in the winter-spring months (**Figure 4-4c**). PNEC was primarily occupied in the winter-spring months (**Figure 4-4c**).

For each location, the SSMs also generated a continuous behavioral state variable (BSTATE) ranging from 0 to 1 (after re-scaling), with values close to 0 being interpreted as pure transiting and values close to 1 being interpreted as pure ARS (see **Section 4.2.2**). This behavioral classification is presented in map form in **Figure 4-5**. High values of BSTATE, indicative of ARS behavior, occurred in both CCAL and PNEC. Within CCAL, high values of BSTATE occurred along the coast, while in PNEC high values of BSTATE occurred at the southeastern terminus of the winter-spring migration near the Costa Rica Dome (**Figure 4-5**).

4.3.5 Habitat Characterization

We obtained relevant environmental variables for the 10,664 daily locations estimated by the SSMs as described in **Section 4.2.6**. Complete details for each variable, including sources, satellite platforms and sensors, and the temporal and spatial resolution of the products used are provided in **Table 4-5**. The oceanographic and bottom relief variables are shown in map form in **Figures 4-6 and 4-7**, respectively. Low values of SSH, generally corresponding to a shallow thermocline, occurred along the coast in CCAL, especially toward the north, and near the Costa Rica Dome in PNEC (**Figure 4-6**). These areas, identified in the previous section as having the highest BSTATE, also were characterized by strongly positive values of WEKM and elevated values of CHL, revealing that blue whales foraged in the most productive habitats in the Eastern North Pacific. While the similarities among these variables point to a tight physical-biological coupling, it is interesting to note that SST, being primarily driven by the latitudinal gradient in incoming solar radiation and only secondarily by local upwelling signatures, is a poor predictor of blue whale movement behavior at the large scale of this study (**Figure 4-6**).

Within CCAL, blue whales selected bottom relief variables characterized by shallow and intermediate depths, near the shelf break, and with gentle to intermediate slopes (**Figure 4-7**). Additionally, areas of intense ARS behavior appeared to occur on south-westward-facing slopes (**Figure 4-7**), suggesting that bottom relief also plays a role in blue whale habitat selection, at least in CCAL.

The scatterplot matrices in **Figures 4-8 and 4-9** provide the univariate representations of the oceanographic and bottom relief variables, respectively, in relation to province, season, and behavioral state along the diagonal of the matrix. In terms of movement behavior, low values of BSTATE, indicating transiting, were most common during winter-spring in PNEC and in CCAL, while high BSTATE values were most common during summer-fall in CCAL (**Figures 4-8 and 4-9**). These univariate distributions also indicate that blue whales had distinct optima along most environmental gradients within the two main biogeographic provinces they occupied (CCAL and PNEC). In CCAL, the optima remained generally the same across season, except for CHL and DEPTH. The CHL optimum was markedly higher in summer-fall than in winter-spring (**Figure 4-8**). The DEPTH optimum shifted to shallower depths in winter-spring (**Figure 4-9**).

The bivariate relationships among the oceanographic and bottom relief variables can also be visualized in **Figures 4-8 and 4-9**, respectively. Although the maps in **Figures 4-6 and 4-7** suggested visual correspondences between movement behavior and several of the environmental variables, no discernible pattern is readily evident in the “more objective” scatterplots between BSTATE and any of the environmental variables (second row of panels from the bottom in **Figures 4-8 and 4-9**).

4.4 Discussion

An earlier analysis of a subset of the tracks presented here using SSMs by Bailey et al. (2010) has given us insight into the migration routes of this population, showing that animals are generally found close to the continental margin in summer and fall, follow direct routes during the southward winter migration, and make extended stops off the Baja California coast during the northward spring migration. Movement behavior along the both the north and south migration routes alternate between transiting (fast, directed, approximately 3.70 km/h) and ARS (slower, localized, non-directed, approximately 1.05 km/h), with animals spending approximately 29 percent of their time in ARS (Bailey et al. 2010). ARS behavior is thought to represent foraging and animals may engage in ARS intermittently or in persistent bouts for portions of a track; the areas where the latter occur are approximately 50 km in radius (range=10 to 360 km) and animals spend approximately 21 d in them (range=3 to 115 d), presumably in extended foraging (Bailey et al. 2010).

The complete analysis of the 104 tracks presented here extends this knowledge in several ways. The home range analysis indicated that two areas were most heavily used: the area at the western end of the Santa Barbara Channel in southern California and the Gulf of the Farallones, off central California. As discussed in Irvine et al. (2014), these areas are close to large human population centers and busy port terminals. Regular shipping traffic through them puts the whales at increased risk of fatal collisions with commercial vessels. We note that the home range analysis did not extend beyond the limits of the U.S. EEZ. We also caution that the identification of persistent areas of highest use (HRs or CAs) was only possible through the combined use of 53 of the tracks from 8 years that had more than 30 locations within the U.S. EEZ spanning the period 1998 to 2008 (Irvine et al. 2014), and may not reflect the actual pattern on any given year.

At the regional scale, the vast majority of locations occurred in just two (CCAL and PNEC) of the eight biogeographic provinces comprising the Eastern North Pacific. However, it must be pointed out that while the combined tracking data have shown us which provinces were occupied by blue whales, bias in the observed pattern of biogeographic occupation is present because most tags were deployed in CCAL (*n*=99), while only a few were deployed in other provinces (*n*=2 in PNEC and *n*=3 in GUCA). From a seasonal perspective, CCAL was occupied year-round, but use shifted from central and southern California (U.S.) in summer and fall to the Baja California Peninsula (Mexico) in winter and spring. PNEC was primarily occupied in winter and spring. Blue whales displayed high BSTATE values in both CCAL and PNEC, suggesting that they forage throughout their primary distribution range. Within CCAL, high BSTATE values occurred along the coast, where upwelling is strong and productivity is high, while in PNEC high BSTATE values occurred at the southeastern terminus of the winter-spring migration near the Costa Rica Dome, an oceanic upwelling feature well known for its productivity (Fiedler 2002). However, the PNEC occupation coincides with the blue whale calving and mating season, so the elevated BSTATE values may be due to the limited mobility of mothers with calves or adults of both sexes circulating in limited areas for courtship/breeding.

The extensive ARS behavior along the continental margin in CCAL agrees with the “feeding area” designation for all nine BIAs identified by NOAA for blue whales in U.S. waters (Calambokidis et al. 2015). Similarly, while the offshore extents of CCAL were broadly classified as transiting (low BSTATE values), no clear “migratory corridors” were apparent in the tracking data, indicating that within CCAL blue whales travel between foraging patches (cf. Bailey et al. 2010) and that they may also undertake excursions into offshore waters (**Figure 4-5**). The historical tracking data indicate a migratory corridor (low BSTATE values) to and from the southeastern-most terminus of the migration cycle in PNEC near the Costa Rica Dome, but this occurs outside U.S. waters (**Figure 4-5**). The pattern of movement behavior and association with environmental variables indicates that blue whales foraged in the most productive habitats in the Eastern North Pacific, where their krill prey was presumably available at the high densities required to sustain them. While krill data are not available at the spatial extent or temporal coverage of the historical blue whale data set, the associations with environmental variables identified in this analysis point to a strong physical-biological linkage that could be formally explored within the framework of a statistical habitat model, especially considering the low signal-to-noise ratio in some of these relationships.

Blue whales showed distinct optima in relation to the environmental gradients examined within the two main biogeographic provinces they occupied seasonally, CCAL and PNEC. While these optima remained generally the same across seasons in CCAL, there was evidence of greater use of the deeper offshore waters in summer-fall, probably in relation to elevated chlorophyll-*a* levels and to an expanded productive habitat during this season. Movement behavior also showed seasonal shifts, with low BSTATE values (transiting) being more common during winter-spring in PNEC and in CCAL (during the reproductive season when less food is available), while elevated BSTATE values (ARS) were more common during summer-fall in CCAL (when upwelling and productivity are at their peak). As with the home range analysis, we caution that the patterns of biogeographic occupation and environmental associations identified in the combined historical data set may not reflect the actual pattern on any given year. Although between-year differences are expected over the 16-yr period of this study (see Bailey et al. 2010), qualitative comparisons are difficult due to several confounding factors including: a) changes in tag design and attachment methods over the course of the study, b) variation in field timing and tagging effort, and c) individual variation in tracking duration across tags.

The broad analyses of the historical tracking data set performed here have identified several important issues and knowledge gaps that could be addressed with further attention to better inform managers. The apparent foraging behavior in PNEC in winter and spring is confounded with behavior that may be ascribable to reproductive activities. Incorporating sex information to the analyses, especially with a larger sample size from the 2014- and 2015-tagged whales, might help resolve this question. Additionally, the excursions into offshore waters in CCAL, while indicating transiting behavior by the SSMs, may be related to foraging if the whales switch to a movement strategy that is not resolved by the SSMs. A more detailed examination of year-to-year environmental variables in these offshore waters may resolve how these areas are potentially favorable for foraging even without ARS signatures identified with the current resolution of summarized satellite data and the SSM trackings. Consideration of data from individual years may be required to address these questions. Because of multiple confounding factors, these issues would be more appropriately explored within the framework of a statistical model that could explicitly account for them. The next step in these analyses would be the formulation of such a model, which was not possible during this add-on project due to time and funding constraints. We believe the additional modeling work suggested here could resolve these issues if the Navy is interested.

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Table 4-1. Summary of MMI's tagging effort on blue whales by year between 1993 and 2008 off the U.S. West Coast. Also listed is the number of tracks derived from SSMs for analysis. Major changes in tag design or tag delivery method are indicated in the Notes column, as described in Section 4.2.1. ARTS=Air Rocket Transmitter System.

Year	No. tags	No. SSM tracks	Notes
1993	10	0	Tag type: surface-mounted Delivery method: crossbow Mean duration=7.6 d (SD=15.1 d)
1994	17	2	
1995	26	8	
1998	9	6	Tag type: implantable Delivery method: crossbow Mean duration=68.9 d (SD=78.1 d)
1999	23	16	
2000	13	6	
2001	4	1	
2002	2	2	
2004	20	16	Tag type: implantable Delivery method: ARTS Mean duration=102.9 d (SD=93.7 d)
2005	15	14	
2006	12	7	
2007	16	14	
2008	15	12	
Total	**182**	**104**	

Table 4-2. Summary statistics for 104 blue whale tracks for which SSMs were generated for use in this study, covering the period 14 September 1994–9 April 2009. Each tag's identification code (Tag #) is made up of its Argos-assigned Platform Transmitter Terminal (PTT) and a two-digit prefix to resolve duplicate PTT #s. Dates of initial and final location correspond to the dates output by the SSM and may not correspond to the dates of tag deployment and last transmission. The duration, distance traveled, and average speed are given for each track. The total number of tags deployed at each location was: Santa Barbara Channel, *n*=65; Gulf of the Farallones, *n*=32; Gulf of California, *n*=3; Costa Rica Dome, *n*=2; Cape Mendocino, *n*=2. Sex was determined genetically from skin biopsies when available, resulting in: female, *n*=12; male, *n*=12; unknown, *n*=80.

Tag #	Date Initial Location	Date Final Location	Duration (d)	Distance (km)	Speed (km/h)	Deployment Location	Sex
210823	1994-09-14	1994-09-23	10	270.93	1.25	Gulf of the Farallones	Unknown
210828	1994-10-01	1994-10-14	14	1,018.55	3.26	Gulf of the Farallones	Unknown
300837	1995-09-19	1995-09-29	11	569.52	2.37	Santa Barbara Channel	Unknown
300841	1995-09-10	1995-09-25	16	372.29	1.03	Santa Barbara Channel	Unknown
304172	1995-08-23	1995-09-10	19	1,253.04	2.9	Santa Barbara Channel	Unknown
304173	1995-09-18	1995-10-05	18	1,667.52	4.09	Santa Barbara Channel	Unknown
304176	1995-10-02	1995-11-14	44	2,582.39	2.5	Santa Barbara Channel	Unknown
323040	1995-09-18	1995-12-07	81	5,386.07	2.81	Santa Barbara Channel	Unknown
323041	1995-09-10	1995-09-20	11	365.38	1.52	Santa Barbara Channel	Unknown
323042	1995-08-23	1995-09-10	19	1,506.02	3.49	Santa Barbara Channel	Unknown
400823	1998-10-10	1998-12-09	61	3,335.92	2.32	Cape Mendocino	Unknown
400824	1999-03-14	1999-04-09	27	2,376.62	3.81	Gulf of the Farallones	Unknown
400826	1998-08-12	1998-09-17	37	1,354.03	1.57	Gulf of the Farallones	Unknown
400833	1998-08-24	1998-09-08	16	585.46	1.63	Santa Barbara Channel	Unknown
404174	1998-08-24	1998-11-06	75	2,950.89	1.66	Santa Barbara Channel	Unknown
404175	1998-10-10	1998-12-09	61	4,807.67	3.34	Cape Mendocino	Unknown
410823	1998-08-31	1999-01-04	127	9,267.18	3.06	Santa Barbara Channel	Unknown
500830	1999-07-21	1999-08-21	32	1,532.42	2.06	Santa Barbara Channel	Unknown
500834	1999-07-29	1999-11-21	116	5,453.99	1.98	Santa Barbara Channel	Unknown
500837	1999-08-01	1999-10-01	62	2,422.32	1.65	Santa Barbara Channel	Unknown
510824	1999-08-10	1999-11-16	99	4,410.1	1.88	Santa Barbara Channel	Unknown
523033	1999-07-20	1999-08-27	39	2618	2.87	Santa Barbara Channel	Unknown
523038	1999-07-22	1999-09-03	44	1,468.79	1.42	Santa Barbara Channel	Unknown
523043	1999-07-22	1999-12-17	149	8,243.65	2.32	Santa Barbara Channel	Unknown

Tag #	Date Initial Location	Date Final Location	Duration (d)	Distance (km)	Speed (km/h)	Deployment Location	Sex
600838	1999-10-02	2000-05-17	229	8,542.96	1.56	Santa Barbara Channel	Unknown
602082	1999-10-03	1999-11-02	31	1,115.53	1.55	Santa Barbara Channel	Unknown
604172	1999-10-08	2000-01-09	94	6,337.92	2.84	Santa Barbara Channel	Unknown
604173	1999-10-02	2000-02-10	132	2,411.14	0.77	Santa Barbara Channel	Unknown
604176	1999-10-03	2000-05-04	215	9,009.61	1.75	Santa Barbara Channel	Unknown
610821	1999-11-12	1999-11-30	19	1,474.16	3.41	Santa Barbara Channel	Unknown
623030	1999-10-08	2000-03-27	172	7,229	1.76	Santa Barbara Channel	Unknown
623031	1999-10-03	1999-11-23	52	3,250.8	2.66	Santa Barbara Channel	Unknown
701386	2000-10-05	2001-02-08	127	6,563.04	2.17	Gulf of the Farallones	Unknown
701390	2000-12-01	2001-07-08	220	8,311.66	1.58	Gulf of the Farallones	Unknown
710825	2000-10-06	2000-10-23	18	805.36	1.97	Gulf of the Farallones	Unknown
710828	2000-10-05	2000-12-02	59	4,479.58	3.22	Gulf of the Farallones	Unknown
710832	2000-11-10	2001-07-16	249	10,054.01	1.69	Gulf of the Farallones	Unknown
723029	2000-10-06	2000-12-03	59	4,955.97	3.56	Gulf of the Farallones	Unknown
1910831	2001-03-26	2001-10-25	214	7,646.72	1.5	Gulf of California	Female
2300837	2002-04-07	2002-06-28	83	5,138.98	2.61	Gulf of California	Unknown
2300840	2002-03-21	2002-09-30	194	7,391.54	1.6	Gulf of California	Unknown
3300832	2004-07-29	2004-08-08	11	313.41	1.31	Gulf of the Farallones	Unknown
3300834	2004-08-12	2004-10-22	72	2,777.1	1.63	Santa Barbara Channel	Unknown
3300840	2004-08-20	2006-01-06	505	19,203.25	1.59	Gulf of the Farallones	Unknown
3300849	2004-08-12	2004-11-12	93	3,833.32	1.74	Santa Barbara Channel	Unknown
3301389	2004-08-13	2004-11-09	89	2,171.41	1.03	Santa Barbara Channel	Unknown
3304175	2004-08-20	2004-12-03	106	6,049.43	2.4	Gulf of the Farallones	Unknown
3310820	2004-08-12	2004-09-01	21	904.17	1.88	Santa Barbara Channel	Unknown
3310821	2004-08-12	2005-01-24	166	7,879.03	1.99	Santa Barbara Channel	Unknown
3310825	2004-08-19	2004-08-25	7	325.05	2.26	Gulf of the Farallones	Unknown
3310831	2004-08-19	2004-10-04	47	1,981.28	1.79	Gulf of the Farallones	Unknown
3310833	2004-08-02	2004-10-21	81	3,005.62	1.57	Gulf of the Farallones	Unknown
3310834	2004-08-12	2004-11-04	85	3,296.77	1.64	Santa Barbara Channel	Unknown
3310843	2004-08-03	2005-01-01	152	7,984.66	2.2	Gulf of the Farallones	Unknown

Tag #	Date Initial Location	Date Final Location	Duration (d)	Distance (km)	Speed (km/h)	Deployment Location	Sex
3323030	2004-08-13	2004-08-25	13	727.27	2.53	Santa Barbara Channel	Unknown
3323034	2004-08-03	2005-01-15	166	3,764.4	0.95	Gulf of the Farallones	Unknown
3323043	2004-08-07	2004-10-21	76	1,466.12	0.81	Santa Barbara Channel	Unknown
3800834	2005-08-19	2005-11-21	95	4,861.52	2.15	Gulf of the Farallones	Female
3800845	2005-08-16	2005-09-11	27	1,842.45	2.95	Gulf of the Farallones	Female
3800849	2005-08-14	2005-10-03	51	1,702.25	1.42	Gulf of the Farallones	Unknown
3801388	2005-08-15	2005-09-26	43	1,956.71	1.94	Gulf of the Farallones	Male
3801389	2005-08-14	2005-10-21	69	2,884.61	1.77	Gulf of the Farallones	Unknown
3801390	2005-08-18	2006-04-10	236	1,1237.3	1.99	Gulf of the Farallones	Male
3802082	2005-08-19	2005-08-29	11	1,016.31	4.23	Gulf of the Farallones	Unknown
3810820	2005-08-15	2005-09-24	41	3,236.57	3.37	Gulf of the Farallones	Unknown
3810821	2005-08-14	2006-02-18	189	10,392.02	2.3	Gulf of the Farallones	Unknown
3810823	2005-08-15	2005-11-17	95	3,563.19	1.58	Gulf of the Farallones	Unknown
3810826	2005-08-16	2005-10-25	71	2,140.67	1.27	Gulf of the Farallones	Male
3810829	2005-08-07	2006-02-17	195	9,824.46	2.11	Gulf of the Farallones	Unknown
3810830	2005-08-14	2005-12-01	110	2,689.36	1.03	Gulf of the Farallones	Unknown
3810833	2005-08-06	2005-10-24	80	2,191.6	1.16	Gulf of the Farallones	Unknown
4200832	2006-09-12	2006-12-08	88	4,544.94	2.18	Santa Barbara Channel	Unknown
4200838	2006-09-12	2006-11-07	57	2,872.61	2.14	Santa Barbara Channel	Unknown
4202083	2006-09-14	2007-06-28	288	1,6397.3	2.38	Santa Barbara Channel	Female
4204175	2006-12-20	2007-08-05	229	7,040.27	1.29	Santa Barbara Channel	Male
4210831	2006-09-14	2007-06-14	274	12,029.46	1.84	Santa Barbara Channel	Unknown
4210839	2006-09-14	2006-10-21	38	2,851.96	3.21	Santa Barbara Channel	Male
4210840	2006-09-14	2007-04-13	212	7,342.28	1.45	Santa Barbara Channel	Unknown
4500831	2007-09-07	2008-02-04	151	3,759.48	1.04	Santa Barbara Channel	Male
4500835	2007-09-09	2007-10-14	36	2,229.29	2.65	Santa Barbara Channel	Female
4500836	2007-09-17	2007-11-05	50	1,910.58	1.62	Santa Barbara Channel	Unknown
4500847	2007-12-02	2008-01-04	34	1,603.01	2.02	Santa Barbara Channel	Male
4501385	2007-09-07	2008-03-26	202	11,618.8	2.41	Santa Barbara Channel	Female
4504172	2007-09-06	2007-10-04	29	848.38	1.26	Santa Barbara Channel	Male

Tag #	Date Initial Location	Date Final Location	Duration (d)	Distance (km)	Speed (km/h)	Deployment Location	Sex
4504174	2007-09-06	2008-04-14	222	8,768.33	1.65	Santa Barbara Channel	Female
4505670	2007-10-16	2008-01-19	96	4,208.89	1.85	Santa Barbara Channel	Unknown
4505801	2007-09-17	2008-02-15	152	6,531.82	1.8	Santa Barbara Channel	Unknown
4510836	2007-09-08	2008-04-14	220	6,618.86	1.26	Santa Barbara Channel	Female
4510838	2007-09-07	2008-03-01	177	8,475.99	2.01	Santa Barbara Channel	Female
4510842	2007-09-06	2007-09-17	12	138.25	0.52	Santa Barbara Channel	Unknown
4523034	2007-10-26	2007-11-05	11	104.25	0.43	Santa Barbara Channel	Female
4523043	2007-09-06	2008-02-01	149	6,255.62	1.76	Santa Barbara Channel	Female
4600846	2008-01-17	2008-07-30	196	8,663.71	1.85	Costa Rica Dome	Unknown
4601388	2008-01-14	2008-06-13	152	8,497.28	2.34	Costa Rica Dome	Male
4900825	2008-07-24	2009-04-09	260	12,617.2	2.03	Santa Barbara Channel	Female
4900830	2008-07-25	2008-11-12	111	4,974.19	1.88	Santa Barbara Channel	Male
4900840	2008-07-27	2008-11-01	98	3,550.37	1.53	Santa Barbara Channel	Unknown
4901386	2008-07-27	2009-02-24	213	10,112.47	1.99	Santa Barbara Channel	Unknown
4904176	2008-07-27	2009-03-17	234	16,256.89	2.91	Santa Barbara Channel	Unknown
4904177	2008-07-27	2008-10-21	87	3,174.19	1.54	Santa Barbara Channel	Unknown
4905644	2008-07-26	2008-09-03	40	2,561.43	2.74	Santa Barbara Channel	Unknown
4905878	2008-07-27	2008-08-26	31	870.62	1.21	Santa Barbara Channel	Unknown
4910821	2008-07-28	2008-10-31	96	4,484.23	1.97	Santa Barbara Channel	Male
4910839	2008-07-28	2008-09-26	61	3,388.33	2.35	Santa Barbara Channel	Male
		Mean	**102.54**	**4,625.57**	**2.03**		
		Median	**81**	**3,316.35**	**1.88**		
		SD	**85.43**	**3,859.85**	**0.75**		
		Range	**[7 - 505]**	**[104.24 - 19,203.25]**	**[0.43, 4.23]**		

Table 4-3. Quantification of the percent time spent in the Navy training areas and the BIAs compared to the total time for 104 tracks in the historical blue whale data set (1994-2008). Data are regularized tracks (one location per day) from SSMs, and are summarized by year. The number of tracks in each year is indicated by *n*.

Year	Total No.		Percentage in Navy Training Areas						Percentage in BIAs							
			SOCAL		NWTRC		W237		San Diego		San Nicolas		Santa Monica		Tanner-Cortez	
	Locs	Days	Locs	Days	Locs	Days	Locs	Days	Locs	Days	Locs	Days	Locs	Days	Locs	Days
1994	*n*=1		*n*=1													
	24	30	12.5	10.7												
1995	*n*=8		*n*=6						*n*=2		*n*=2				*n*=1	
avg	27	26	21.2	20.2					1.2	0.7	5.3	6.5			5.3	1.9
min	11	10	9.9	9.4					1.2	0.7	5.3	5.1			5.3	1.9
max	81	80	27.3	24.8					1.2	0.7	5.3	7.9			5.3	1.9
1998	*n*=7		*n*=7		*n*=1						*n*=2				*n*=2	
avg	58	57	22.3	22.4	14.8	13.5					1.1	0.4			1.1	0.6
min	16	15	1.6	2.1	14.8	13.5					0.8	0.3			0.8	0.4
max	127	126	87.5	86.1	14.8	13.5					1.3	0.5			1.3	0.7
1999	*n*=7		*n*=6								*n*=1					
avg	77	76	10.3	10.2							11.4	10.4				
min	32	31	1.3	1.7							11.4	10.4				
max	149	148	29.5	28.9							11.4	10.4				
2000	*n*=8		*n*=7						*n*=1		*n*=1				*n*=3	
avg	118	117	5.1	4.6					0.4	2.4	1.1	0.8			1.9	0.8
min	19	18	1.7	1.7					0.4	2.4	1.1	0.8			0.5	0.1
max	229	228	12.9	10.4					0.4	2.4	1.1	0.8			3.2	1.7
2001	*n*=7		*n*=5		*n*=1											
avg	135	134	3.5	3.8	7.1	6.7										
min	18	17	2.3	2.4	7.1	6.7										
max	249	248	5.6	5.8	7.1	6.7										
2002	*n*=2		*n*=2													
avg	139	138	6.8	6.7												
min	83	82	1.5	1.8												
max	194	193	12.0	11.6												

Year	Total No.		Percentage in Navy Training Areas						Percentage in BIAs							
			SOCAL		NWTRC		W237		San Diego		San Nicolas		Santa Monica		Tanner-Cortez	
	Locs	Days	Locs	Days	Locs	Days	Locs	Days	Locs	Days	Locs	Days	Locs	Days	Locs	Days
2004	*n*=16		*n*=4		*n*=6		*n*=1									
avg	106	105	6.1	6.1	14.3	13.5	6.2	4.9								
min	7	6	1.5	1.8	2.4	2.6	6.2	4.9								
max	505	504	12.0	11.6	21.7	20.3	6.2	4.9								
2005	*n*=14		*n*=6		*n*=5		*n*=1				*n*=1				*n*=1	
avg	94	93	11.8	11.3	13.0	13.4	6.7	7.3			1.4	0.8			8.5	8.2
min	11	10	0.8	0.8	1.1	0.8	6.7	7.3			1.4	0.8			8.5	8.2
max	236	235	33.8	34.2	30.9	30.7	6.7	7.3			1.4	0.8			8.5	8.2
2006	*n*=7		*n*=6		*n*=1				*n*=1						*n*=1	
avg	169	168	15.5	15.8	2.6	0.2			0.4	0.1					0.9	0.8
min	38	37	4.5	4.7	2.6	0.2			0.4	0.1					0.9	0.8
max	288	287	38.4	38.8	2.6	0.2			0.4	0.1					0.9	0.8
2007	*n*=14		*n*=10		*n*=1								*n*=1			
avg	110	109	15.3	15.0	5.0	4.7							5.3	4.8		
min	11	10	1.3	1.6	5.0	4.7							5.3	4.8		
max	222	221	100.0	100.0	5.0	4.7							5.3	4.8		
2008	*n*=12		*n*=8		*n*=2		*n*=1		*n*=1		*n*=1		*n*=3			
avg	132	131	16.2	16.9	20.5	20.1	28.1	29.4	5.1	1.5	0.4	0.1	11.1	12.0		
min	31	30	1.9	1.9	0.4	0.1	28.1	29.4	5.1	1.5	0.4	0.1	0.9	0.3		
max	260	259	48.0	49.2	40.6	40.1	28.1	29.4	5.1	1.5	0.4	0.1	19.4	22.0		
Total	**10,664**	**10,568**	**6.7**	**6.7**	**2.8**	**2.8**	**0.4**	**0.4**	**0.1**	**0.1**	**0.1**	**0.1**	**0.3**	**0.4**	**0.1**	**0.1**

Table 4-4. Size of the HR and CA estimated for 53 tracks with 30 or more SSM-derived locations inside the U.S. EEZ in the historical blue whale data set (1998–2008). Each tag's identification code (Tag #) is made up of its Argos-assigned PTT and a two-digit prefix to resolve duplicate PTT #s.

Tag #	Year	No. locs	HR (km^2)	CA (km^2)
400826	1998	37	42,613.70	13,267.56
404175	1998	36	11,3902.65	16,568.97
410823	1998	55	31,719.75	5,748.50
500834	1999	59	52,190.91	6,603.83
500837	1999	62	73,894.86	17,735.58
510824	1999	62	11,741.11	1,846.34
523038	1999	44	19,524.19	4,787.78
523043	1999	96	40,491.63	7,351.46
600838	1999	45	5,870.38	1,293.15
604172	1999	31	15,567.56	3,730.14
701386	2000	51	69,591.69	11,567.49
3300840	2004	92	39,709.11	6,796.32
3300849	2004	93	41,058.20	7,827.11
3301389	2004	89	46,155.61	14,307.16
3304175	2004	85	70,277.59	15,971.89
3310821	2004	108	81,646.96	13,272.56
3310831	2004	47	93,356.46	30,235.12
3310833	2004	75	70,652.50	14,801.02
3310834	2004	85	58,715.30	11,833.58
3310843	2004	112	154,055.78	22,210.32
3323034	2004	162	3,342.69	299.61
3323043	2004	76	3,672.84	669.44
3300840	2005	178	111,983.35	19,815.41
3800834	2005	83	41,311.51	7,463.05
3800849	2005	51	66,036.74	20,056.66
3801388	2005	42	67,016.20	18,930.69
3801389	2005	69	58,825.43	12,197.97
3801390	2005	59	34,552.54	8,121.28
3810820	2005	41	209,845.97	53,352.16
3810823	2005	72	78,866.44	13,856.33
3810826	2005	70	43,172.08	10,297.10
3810829	2005	141	192,823.92	27,508.56
3810830	2005	110	85,945.27	18,528.97
3810833	2005	80	16,854.77	3,393.61
4200832	2006	40	22,820.70	5,334.78
4210831	2006	51	42,299.43	7,033.13
4500831	2007	51	5,701.11	1521.42

Tag #	Year	No. locs	HR (km^2)	CA (km^2)
4500835	2007	36	212,636.68	73,252.53
4500836	2007	48	25,841.11	3,365.90
4504174	2007	33	5,395.09	1,334.08
4505801	2007	51	3,905.49	902.44
4510838	2007	62	30,138.36	4,000.45
4523043	2007	33	4,111.95	1,156.01
4900825	2008	73	54,926.75	10,357.94
4900830	2008	61	22,545.73	3,677.39
4900840	2008	59	19,826.56	3,183.05
4901386	2008	101	26,848.91	5,699.48
4904176	2008	71	105,297.21	14,522.24
4904177	2008	63	28,305.94	3,192.43
4905644	2008	39	186,098.91	52,430.32
4905878	2008	31	13,635.69	3,141.47
4910821	2008	88	286,414.49	6,8761.15
4910839	2008	58	30,763.49	6,358.64
	Mean	**68.81**	**61,783.00**	**13,423.99**
	Median	**62.00**	**42,299.43**	**7,827.11**
	SD	**31.58**	**61,253.81**	**15,872.28**
	Range	**[31 - 178]**	**[3,342.69 - 286,414.49]**	**[299.61 - 73,252.53]**

Table 4-5. Satellite data products, resolution, time periods covered, and source.

Variable	Product/Sensor	Grid Resolution	Temporal Resolution	Temporal Coverage	Source
Sea surface height	Merged (Topex/Poseidon, ERS-1/-2, Geosat, GFO, Envisat, Jason-1/-2)	0.3333 deg	1 day	[14-Sep-94 9-Apr-09]	AVISO
Ekman upwelling	Seawinds/QuikSCAT	12.5 km	8 day	[1-Aug-99 9-Apr-09]	NASA/JPL
Sea surface temperature	AVHRR Pathfinder v. 5 (day and night)	4.4 km	5 day	[15-Sep-94 9-Apr-09]	NOAA/NESDIS
	Blended (AVHRR/POES, Imager/GOES, MODIS/Aqua, AMSR-E/Aqua)	11 km	5 day	[4-Jul-02 9-Apr-09]	NOAA/NESDIS
Chlorophyll-*a* concentration	SeaWiFS/Orbview-2	8.8 km	8 day	[9-Aug-98 10-Apr-08]	NASA/GSFC
	MODIS/Aqua	4.4 km	8 day	[7-Jul-02 9-Apr-09]	NASA/GSFC
Bottom depth	SRTM30_PLUS v.6.0 digital bathymetry	0.0083 deg	--	Fixed	UCSD/SIO
Bottom slope	Derived from bottom depth	0.0083 deg	--	Fixed	UCSD/SIO
Bottom aspect (northness, eastness)	Derived from bottom depth	0.0083 deg	--	Fixed	UCSD/SIO
Distance to shelf break (200-m isobath)	ETOPO2 v.2g	0.0333 deg	--	Fixed	NOAA/NGDC

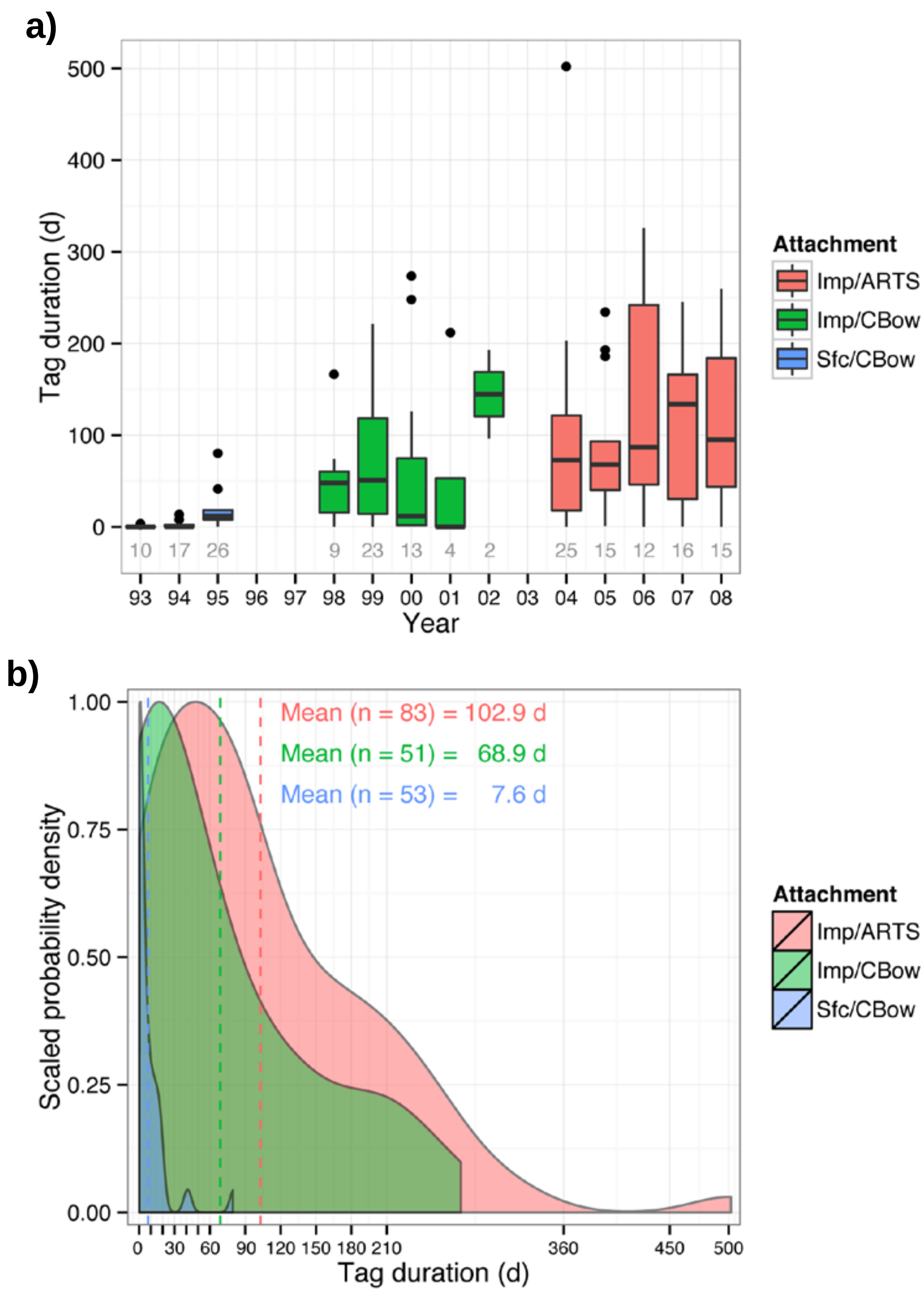

Figure 4-1**. Examination of the operational duration for 182 Argos-linked tags deployed on blue whales by the MMI between 1993 and 2008 in the Eastern North Pacific Ocean. Colors indicate periods of different tag attachment (design and delivery method) used, as described in Section 4.2.1 and Table 4-1 (Sfc/CBow=surface-mounted design delivered with crossbow, Imp/CBow=implantable design delivered with crossbow, and Imp/ARTS=implantable design delivered with the Air Rocket Transmitter System (ARTS)). a) Yearly boxplots of tag duration with the number of tags deployed in each year indicated by the gray number below the box.**
b) Empirical probability distribution of tag duration. Curves are scaled to unity for ease in interpretation. Separate curves are drawn for each period, with vertical dashed lines indicating the mean tag duration as reported in Table 4-1.

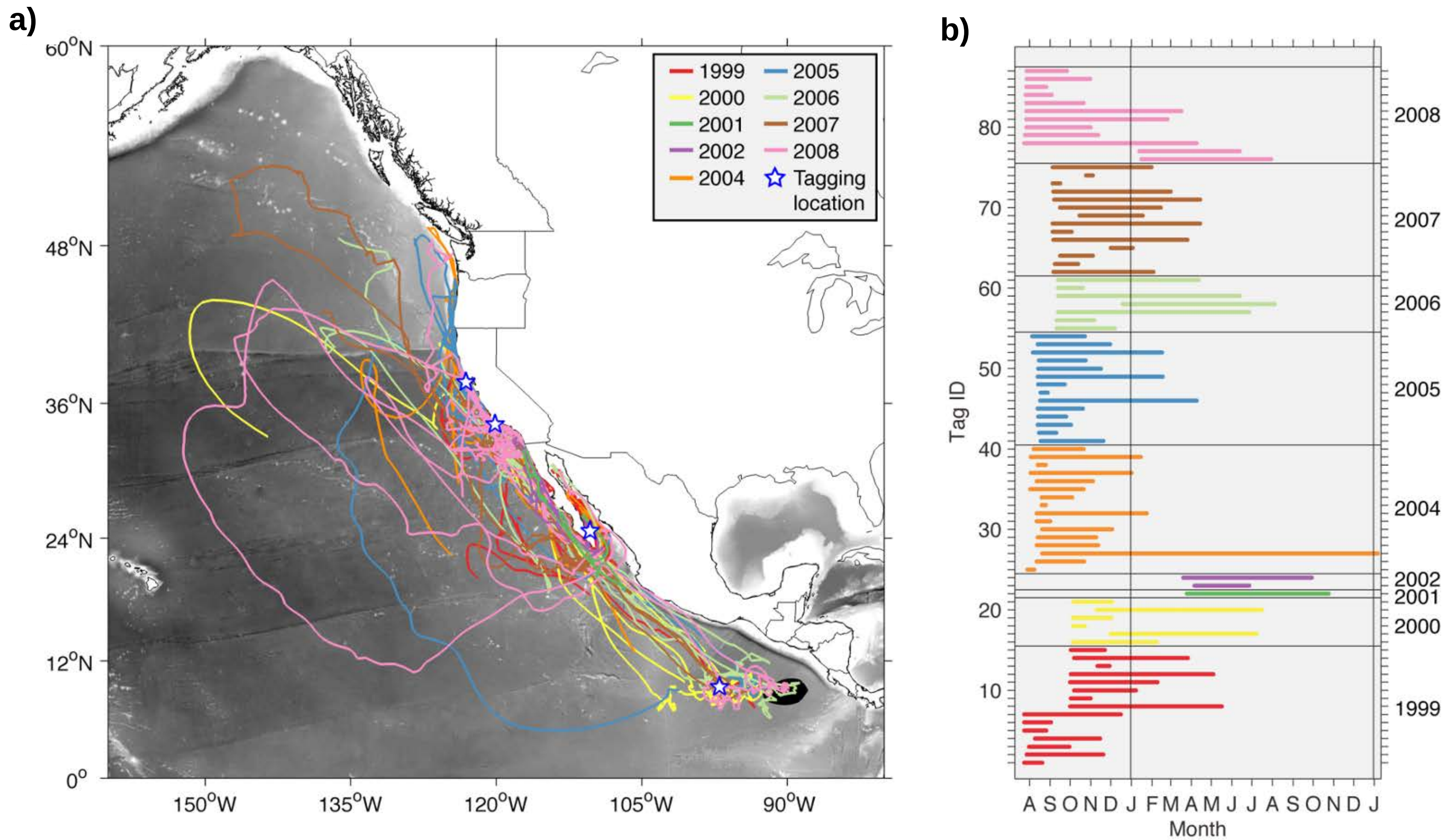

Figure 4-2. a) SSM tracks of 104 blue whales in the Eastern North Pacific instrumented with satellite-monitored radio tags over the period 1993–2008, color-coded by year. Tagging locations, indicated by white stars with blue outline, from north to south were: Cape Mendocino, Gulf of the Farallones, Santa Barbara Channel, Gulf of California, and Costa Rica Dome. b) Timeline of tag duration starting in August of each year. Tags were deployed in late summer and early fall, except in 2001 and 2002, when tagging was done in April in the Gulf of California. No tagging occurred in 1996, 1997, and 2003.

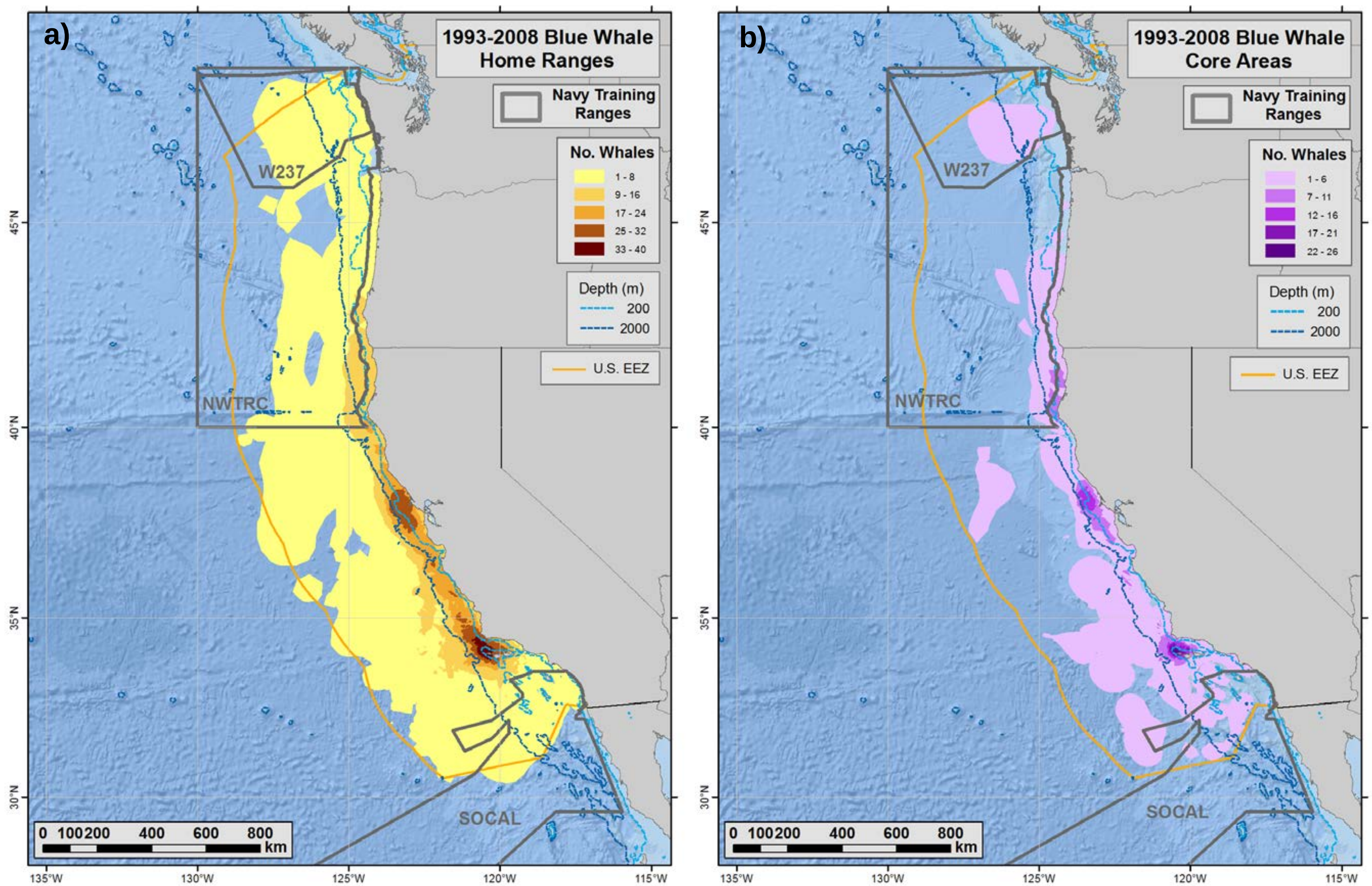

Figure 4-3. Number of individual overlapping areas within the U.S. EEZ estimated from 53 kernel home ranges for blue whales satellite-tagged between 1998 and 2008 with tracks ≥ 30 daily locations: a) 90% HRs, and b) 50% CAs.

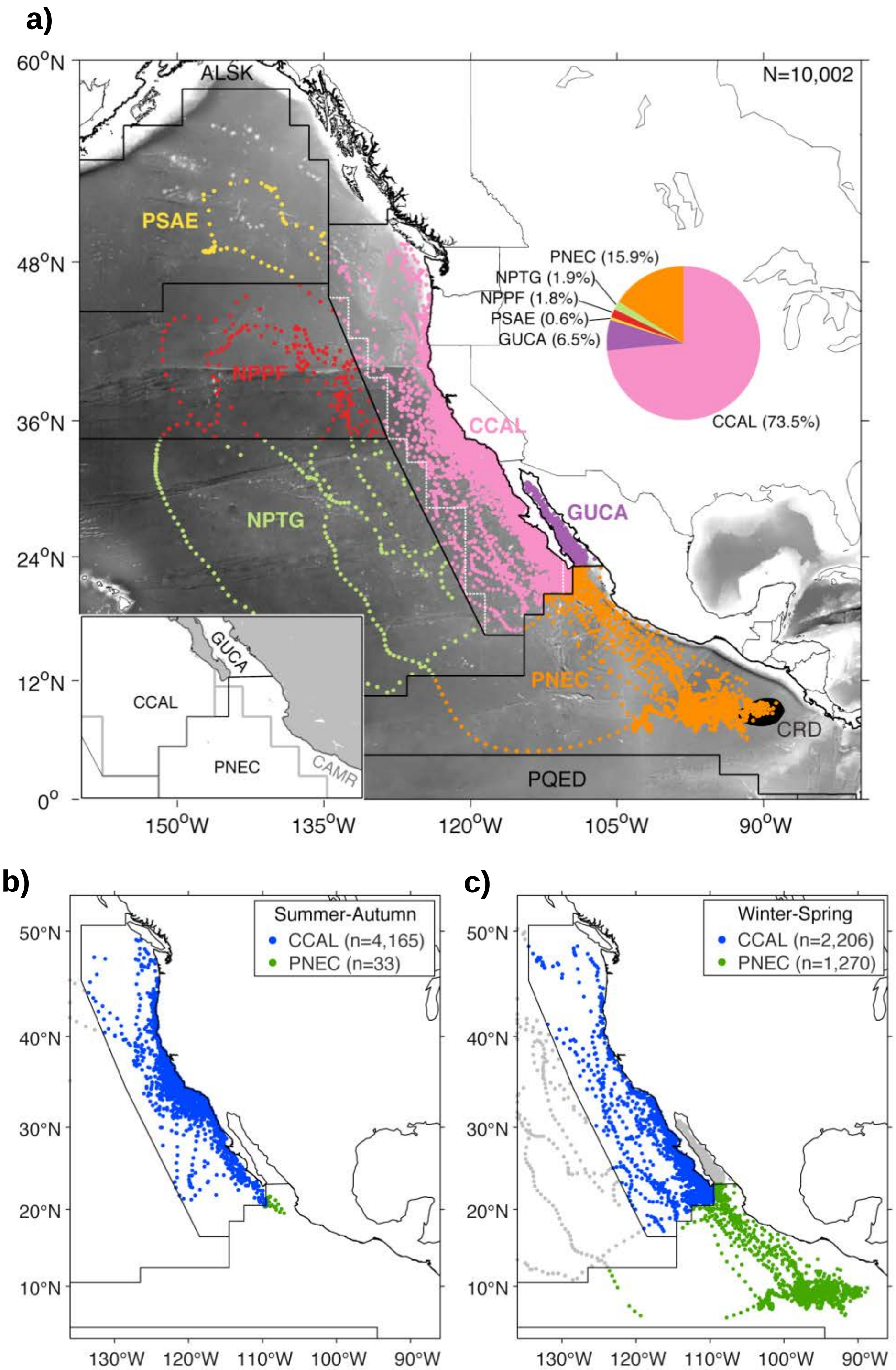

Figure 4-4. a) SSM locations from 104 blue whales tagged and tracked in the Eastern North Pacific over the period 14 September 1994 to 9 April 2009, color-coded by biogeographic province (full name of province abbreviations are given in Section 4.2.5 of the text, following Longhurst (1998, 2006)). Inset shows the modifications made to the province boundaries. Black, oval-shaped contour in PNEC represents the mean position of the Costa Rica Dome (CRD) as represented by the location of the depth of the 20 degrees Celsius isotherm (from Fiedler [2002]). b) Positions in CCAL and PNEC in summer-fall (June–October), and c) in winter-spring (November–May).

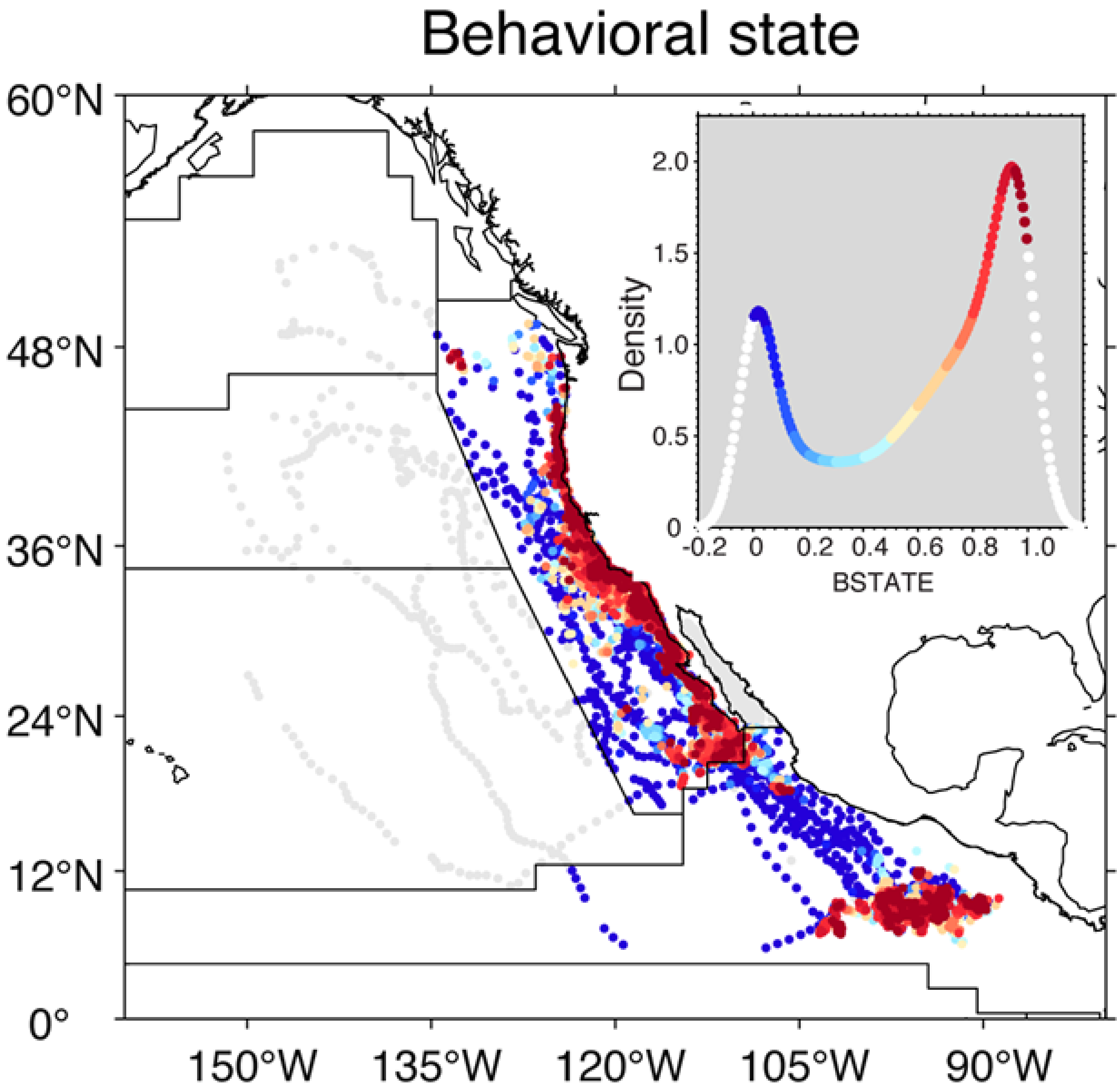

Figure 4-5. Mean behavioral state estimated by SSMs for each location. Color scale ranges between 0 and 1 (pure transiting to pure ARS) as shown by the x-axis in the inset and as described in the text.

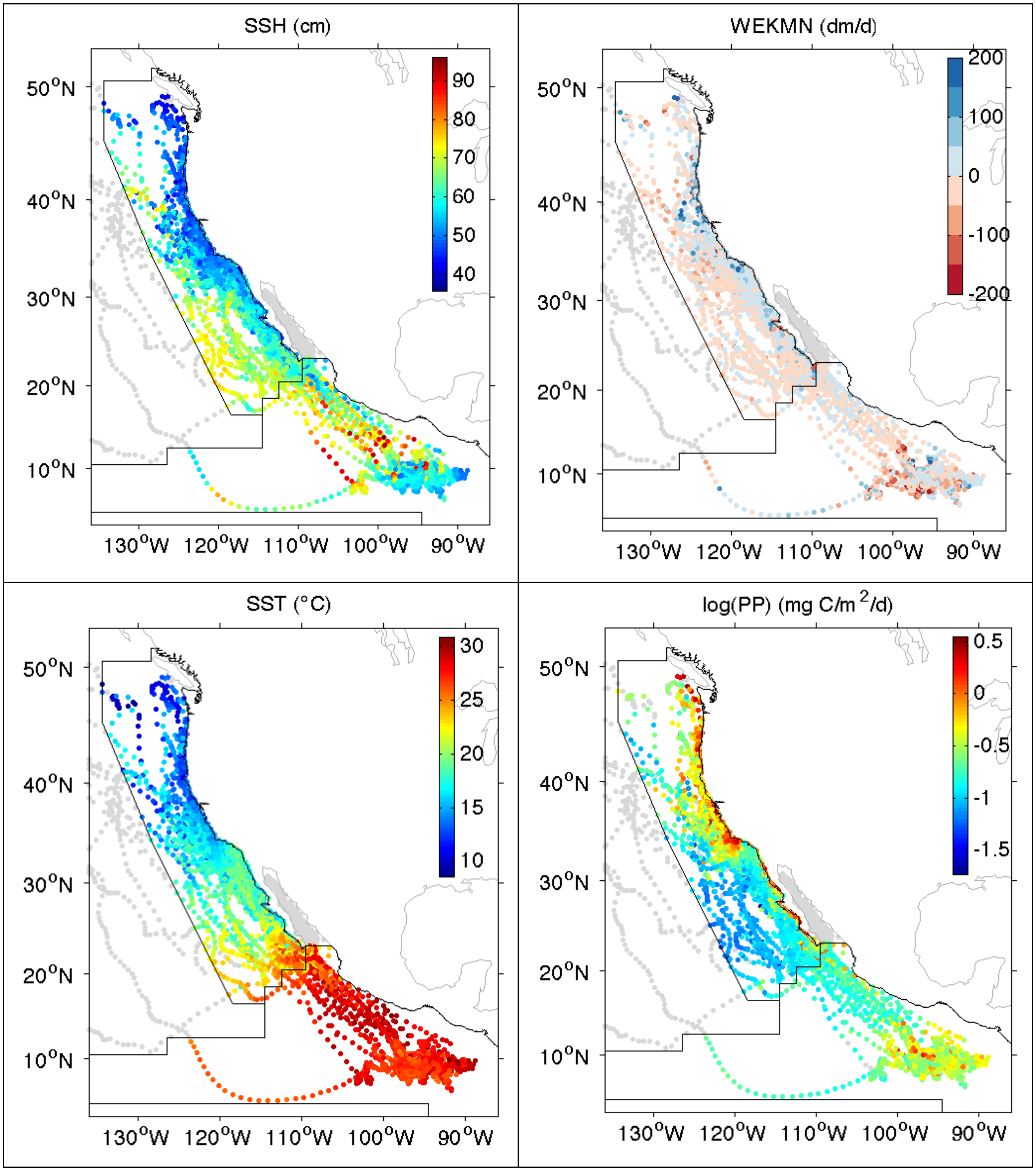

Figure 4-6. Map representations of four oceanographic variables obtained from satellite remote sensing around each blue whale location: a) sea surface height (SSH), b) vertical upwelling velocity (WEKM), c) sea surface temperature (SST), and d) chlorophyll-*a* concentration (CHL, log-transformed.

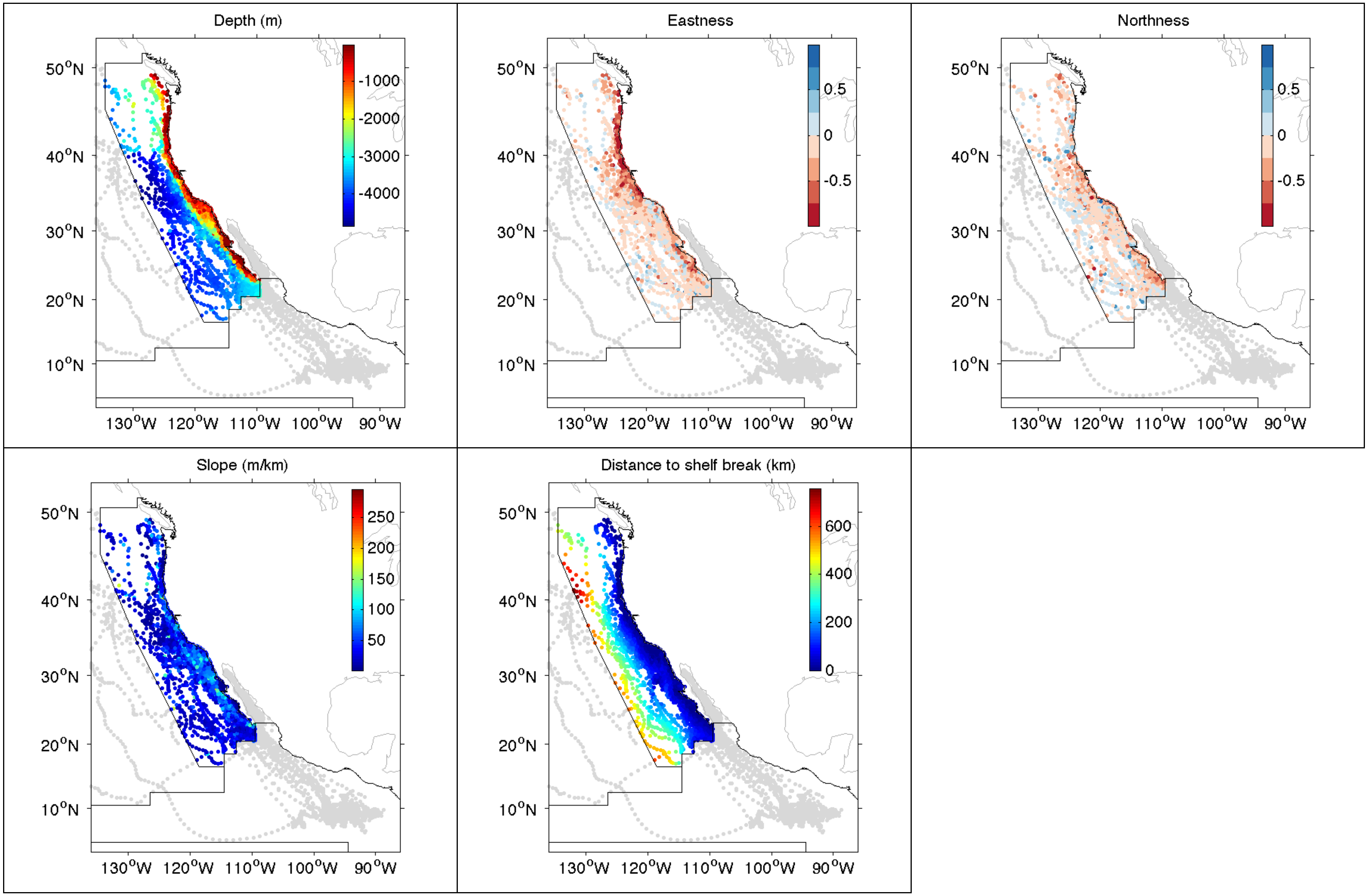

Figure 4-7. Map representations of five variables describing the bottom relief around each blue whale location: a) depth, b) eastness, c) northness, d) slope, and e) distance to the 200-m isobath. Data are only shown for CCAL, where blue whales occur nearshore; bottom relief variables are not thought to influence blue whale distribution in PNEC, where whales occur in very deep, offshore waters.

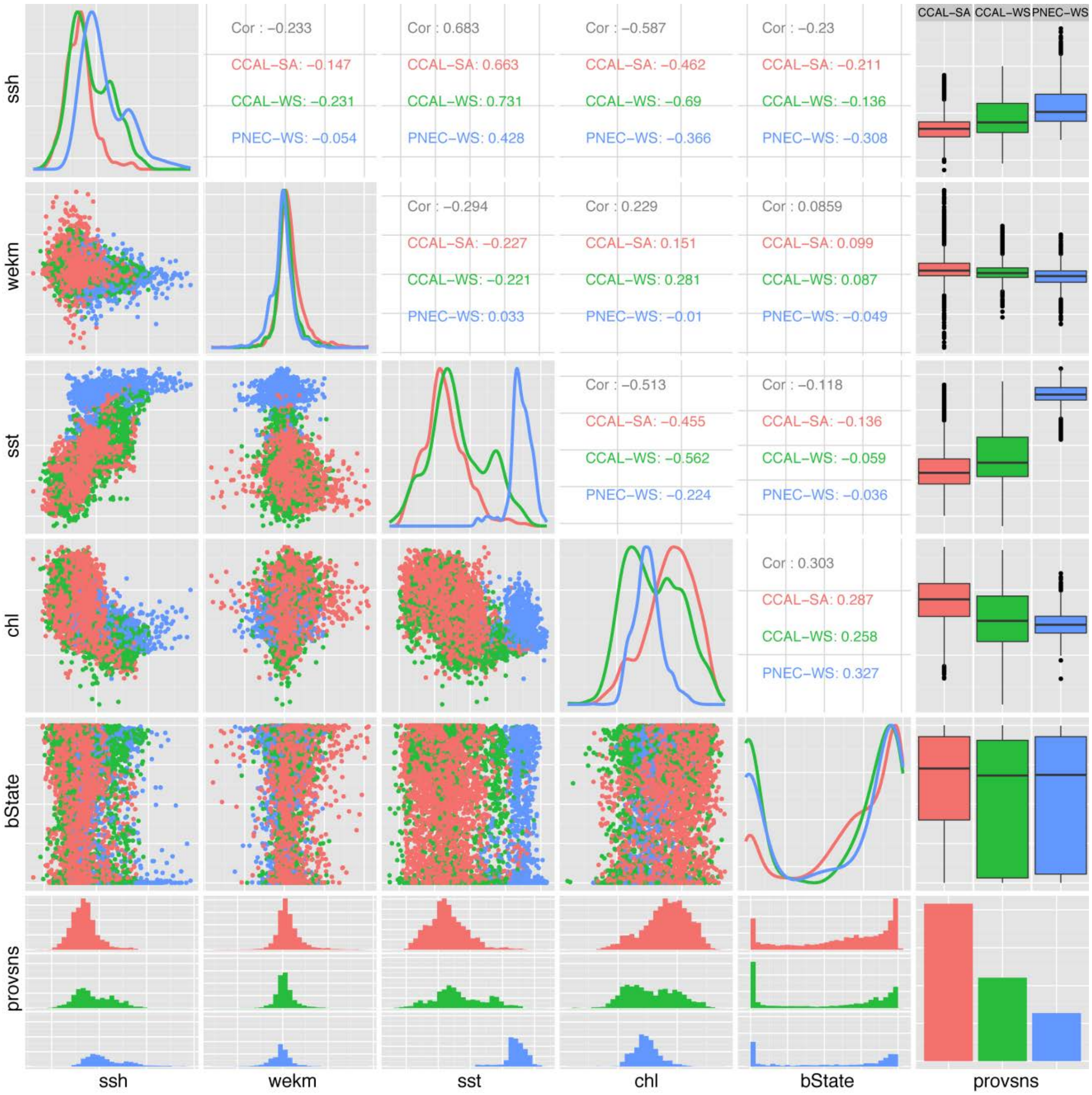

Figure 4-8. Matrix of scatterplots for the four variables describing oceanographic conditions around each blue whale location (SSH, vertical upwelling velocity, SST, CHL) relative to behavioral state. Data are color-coded by province-season combination (red=summer-fall in CCAL; green=winter-spring in CCAL; blue=winter-spring in PNEC). The univariate probability density distributions are shown along the diagonal. Scatterplots in the lower triangle of the matrix depict the bivariate relationships, also indicated by the Pearson correlation coefficient in the upper triangle. Marginal plots along the bottom row and the right-hand column depict the univariate frequency distributions and boxplots, respectively. CHL has been log-transformed.

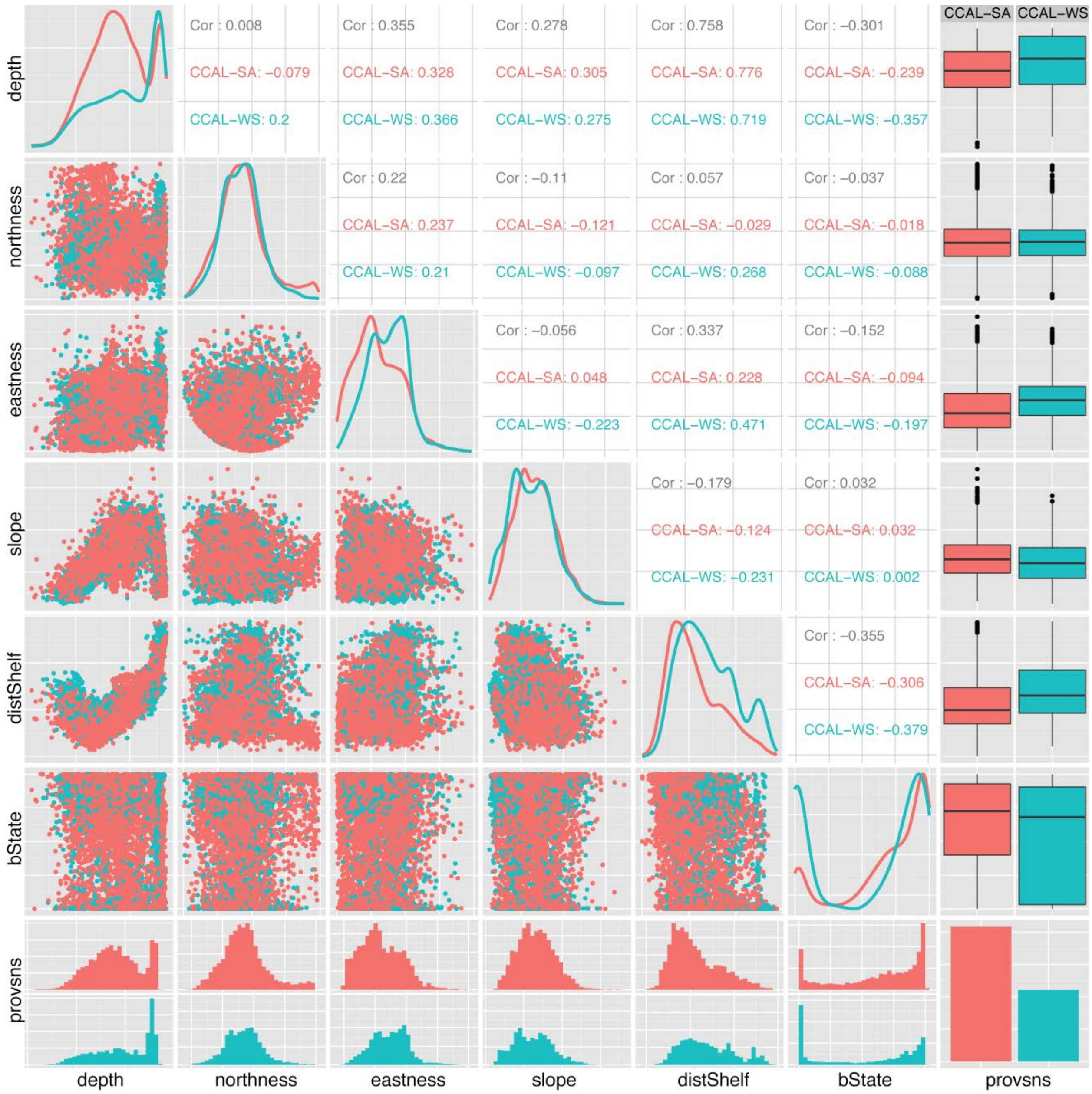

Figure 4-9. Matrix of scatterplots for the five variables describing the bottom relief around each blue whale location (depth, eastness, northness, slope, distance to the 200-m isobath) relative to behavioral state in CCAL. Data are color-coded by season (red=summer-fall; blue=winter-spring). The univariate probability density distributions are shown along the diagonal. Scatterplots in the lower triangle of the matrix depict the bivariate relationships, also indicated by the Pearson correlation coefficient in the upper triangle. Marginal plots along the bottom row and the right-hand column depict the univariate frequency distributions and boxplots, respectively. Depth and distance to the 200-m isobath have been log-transformed and slope has been square-root transformed. Data are only shown for CCAL, where blue whales occur nearshore; bottom relief variables are not thought to influence blue whale distribution in PNEC, where whales occur in very deep, offshore waters.

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5. Acknowledgements

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