HUMPBACK WHALE TAGGING IN SUPPORT OF MARINE MAMMAL MONITORING ACROSS MULTIPLE NAVY TRAINING AREAS IN THE PACIFIC OCEAN

Final Report for Feeding Areas off the US West Coast in Summer-Fall 2017, Including Historical Data from Previous Tagging Efforts

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Commander, U.S. Pacific Fleet and
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14. ABSTRACT
Three Distinct Population Segments (DPSs) of humpback whale (Hawaii, Mexico, and Central America) are found in different proportions along the western coast of North America during the feeding season. In 2017, Oregon State University (OSU) conducted tagging of Eastern North Pacific humpback whales to determine their movement patterns, occurrence, and residence times within US Navy training and testing areas. This report presents detailed results from the tagging, biopsy sampling, and photo-identification efforts conducted off southern and central California in summer and off Oregon in fall, as well as results from previous OSU studies of humpback whales in California, Oregon, Southeast Alaska, and the Aleutian Islands during 1997-2016. Whale use of Navy training and testing areas as well as NMFS-identified Biologically Important Areas (BIAs) is examined and assignment to various DPSs (based on tracking, genetic, and photographic information) is discussed. Fourteen humpback whales (7 Duration Monitoring [DUR] tags, 7 Dive Monitoring [DM] tags) were tagged in California in July-August 2017, and five humpback whales (5 DUR tags) were tagged in Oregon in September-October 2017. Argos locations were received from 18 of 19 tags, tracking duration was 0.3-50.4 days (mean=40.8 d, SD=37.9 d). Sixty-nine humpback whales were tagged in previous ("historical") seasons; 47 in Southeast Alaska in 1997, 2014, and 2015; 15 in California in 2004 and 2005; 5 in the Aleutian Islands in 2008; and 2 in Oregon in 2016. Locations were received for all but 2 of these tags, for 0.2 to 143.9 d (mean=32.9 d, SD=27.2 d).
Tracked humpback whales had an affinity for continental shelf and shelf-edge habitat, as well as off the Columbia River

mouth. The latitudinal range of whales during the feeding season was longest for humpbacks tagged in California, extending from the Southern California Bight to central Oregon, followed by whales tagged in Southeast Alaska, extending from just north of Vancouver Island to Lynn Canal, north of Juneau, Alaska. Feeding-area locations of humpback whales tagged in Oregon extended from Point Arena, central California, to Vancouver Island, British Columbia. Humpback whales tagged off Dutch Harbor, Alaska, had the smallest latitudinal range, with the majority of locations extending from the northeast corner of Umnak Island to just north of Unimak Pass, Alaska. Feeding-area home ranges were smaller for humpback whales tagged in Southeast Alaska in the fall than for whales tagged in California or Oregon, and core areas were smaller for those Southeast Alaska (fall) whales than all other whales. Core areas also were larger for humpback whales tagged in California in 2004-2005 than those tagged in California in 2017. Total distances traveled by individual whales did not differ between whales tagged in California, Oregon, or Alaska; however, distances were longer for whales tagged in Southeast Alaska in the fall than those tagged in the spring, or whales tagged in the Aleutian Islands.

The NWTT was the most heavily used Navy training range by humpback whales, with animals tagged in both California and Oregon having extended residencies there, and whales tagged in Southeast Alaska migrating through the range. Humpback whale locations occurred in the NWTT from August through January. Area W237 of the NWTT was only used by whales tagged in Oregon, or migrating whales from Southeast Alaska, with occurrences during in November and December. Humpback whales tagged in California were the only ones with extended residencies in PT MUGU; however, migrating whales from Oregon and Southeast Alaska also had locations in the range as they traveled south. Locations occurred within PT MUGU from July through December. SOCAL was used by humpback whales tagged in California, as well as by migrating whales from Oregon and Southeast Alaska for very short periods of time. Locations occurred in SOCAL in the months of November, December, and January. Only one humpback whale tagged in southern Oregon transited through the SOAR range in November of 2005. No tagged humpback whales were located in GOA in any of the years covered in this report (1997-2017).

Humpback whales tagged in California predominantly used the Gulf of Farallones to Monterey Bay and the Fort Bragg to Point Arena BIAs. Whales tagged in Oregon predominantly used the Stonewall and Heceta Bank and Point St. George BIAs. There was overlap in use of the Fort Bragg to Point Arena, Point St. George, and Stonewall and Heceta Bank BIAs by whales tagged in both Oregon and California. No whales tagged in California had locations in the Northern Washington BIA or the Olympic Coast NMS, and no whales tagged in Oregon had locations in the Gulf of the Farallones to Monterey Bay, Morro Bay to Point Sal, or Santa Barbara-San Miguel Island BIAs. Seasonal occurrence was longest for the Gulf of the Farallones to Monterey Bay BIA, from July through November, and shortest for the Northern Washington BIA, with locations there only during November. All humpback whales tagged in Southeast Alaska had locations in the Southeast Alaska summer and fall BIAs, from July through November for whales tagged in summer and November through January for whales tagged in fall. All 5 humpback whales tagged out of Dutch Harbor had locations in the Aleutian BIA (September through November) and one of these whales also had locations in the Bristol Bay BIA in October. Dive durations for humpback whales tagged off California in 2017 was 3-6 min, occasionally lasting over 15 min. Maximum dives were to depths <100 m, occasionally exceeding 175 m. Spatial distribution of dive durations was relatively uniform; however, distribution of feeding effort was concentrated in areas furthest from shore, where dive depths also were deepest. The mean maximum dive depth of one DM-tagged whale (Tag #4175) was two times deeper than the other DM tagged whales (89.5 m versus 45.2 m) and it recorded over 3 times as many feeding lunges compared to all other DM-tagged whales combined. Data from this whale appear to have driven the spatial variability of feeding effort. Humpback whales are known to feed on both fish and krill, and we hypothesize that the strong difference in behavior indicates that the whale with Tag #4175 was feeding on krill while the other DM-tagged whales were feeding on fish.DUR tags deployed in 2017 on whales off Oregon recorded dive duration summaries for a mean of 3,367 dives (range=1,808-6,156), representing a mean of 44% of the tracking duration. The majority of dives lasted 3-8 min and occasionally to over 20 min, with a slight diel trend with longer duration dives occurring during the daytime. Dive durations varied spatially, with the longest dives occurring in offshore waters, particularly near Newport, Oregon. These results may be due to the more limited sample size of Oregon whales compared to the California whales; however, it also may be due to behavior differences. Two humpback whales tagged with DM tags in 2016 exhibited behavior similar to the whale with Tag #4175 from California, suggesting they were feeding on krill, which may explain the more localized spatial distribution of dives off Oregon in 2017.

The hSSSMs for the 2017 tracks indicated that 87.2% of the regularized locations were classified as area-restricted searching (ARS; an indication of foraging behavior) off California, while off Oregon 63.2% were classified as ARS. This difference could be an indication of prey types being targeted (fish versus krill), with the associated energetic demands of lunge feeding, but it may also be driven by the small number of animals tracked off Oregon. Among the historical data set, the proportion of SSSM locations classified as ARS was generally high across feeding grounds, with a couple of notable exceptions. One was the very low percentage of locations classified as ARS for whales tagged in Southeast Alaska in 2014 and 2015 (6.9% and 23.7%, respectively), especially when compared to the 1997 season in Southeast Alaska, which yielded the highest proportion of ARS locations among the historical tracks (86.7%). This likely was a reflection of seasonal differences in foraging behavior, prey types, and habitat occupation, since whale distribution in Southeast Alaska was most confined in the fall just prior to migration to winter breeding areas, probably affecting the behavioral classification by the SSSMs. Similarly, there was a relatively low percentage of ARS locations for whales tagged in California in 2005 (56.3%) when compared to 2004 and 2017 (85.0% and 87.2%, respectively). Whales were reported to be widely spread throughout the California Current System in 2005, presumably in response to oceanographic anomalies and dispersed prey resources.

Average SST values at these feeding areas ranged from a low of 7.27°C to a high of 16.18°C, with SST being highest for animals tracked off California and Oregon and lowest for animals tracked in Southeast Alaska and the Aleutian Islands, following the well-known global latitudinal temperature gradient. Average chlorophyll-a values ranged from a low of 0.39 mg m-3 to a high of 4.35 mg m-3, being highest for animals tracked off California and Oregon and lowest for animals tracked in Southeast Alaska and the Aleutian Islands. This pattern reflected the elevated phytoplankton biomass characteristic of the upwelling-driven California Current Ecosystem, and the low biomass characteristic of the downwelling-driven coastal Gulf of Alaska. Average SST values in California provided additional support for the observed behavioral differences between 2004 and 2005 discussed above. In 2005, SST was, on average, 1.65°C warmer than in 2004 and it was spatially more variable (SD=5.21°C), confirming that in 2005 whales off California were foraging in a warmer and more heterogeneous environment.

In terms of seafloor characteristics, average depth was shallowest for animals that did not move much during the tracking period, such as off the Aleutians in 2008 and Oregon in 2016 (131.97 and 133.16 m, respectively), indicating the strong preference for humpback whales to forage over continental shelf habitats. Animals tagged in other feeding areas occupied somewhat deeper depths (246.57 to 738 m) suggesting that foraging over the continental slope was also important, but these averages were also likely affected by movements over deep waters, especially for whales that migrated toward breeding destinations. Average distance to the shelf break in all feeding areas was relatively small (maximum=31.6 km), similarly highlighting the association with the shelf and shelf break for humpback whales.

Average seafloor slope was lowest for animals tagged in Oregon in 2016 (0.59°) and highest for animals tagged in Southeast Alaska in 1997 (2.48°). Except for the very low average slope recorded off Oregon in 2016 (0.59°; which was likely biased by the small sample size and short duration of these tracks), average slope was fairly similar (1.30-2.48°) across foraging sites. Average aspect of the slope faced toward the southeast for animals tagged in Southeast Alaska in 2014 and 2015 (149.26° and 142.33°, respectively), toward the south for animals tagged in Southeast Alaska in 1997 and the Aleutians in 2008 (174.57° and 191.77°, respectively), toward the southwest for animals tagged in California in 2004, 2005, and 2017 (234.53°, 229.73°, and 233.32°), and toward the west-southwest for animals tagged in Oregon in 2016 and 2017 (241.9° and 244.92°). This variation in the aspect of the slope from a predominantly southwest direction for animals tracked off California, to west-southwest for animals tagged in Oregon, to south for animals tagged in Southeast Alaska and the Aleutians, followed the large-scale geometry of the basin, but otherwise did not appear indicative of an ecological relationship.

Biopsy samples were collected from all 14 tagged whales (7 males, 7 females) in California in 2017 and from three of the tagged whales in Oregon (plus from three untagged whales) (3 males, 3 females). mtDNA sequences of the samples resolved seven haplotypes for the consensus region of 500 bp for the California samples and three haplotypes for the Oregon samples. All haplotypes have been previously described for North Pacific humpback whales. The DNA profiles of the 20 individuals were compared to the SPLASH reference database (plus 3 individuals sampled by OSU off Oregon in 2016), but no recaptures were detected. For population analyses, data from the 6 individuals sampled during 2017 off Oregon were combined with data from the three 2016 individuals, for a total of 9 individuals representing the Oregon feeding area.The composition of mtDNA haplotype frequencies indicated a significant level of differentiation between the California and Oregon feeding aggregations that was not previously realized, with Oregon animals appearing more similar to the Northern Washington/Southern British Columbia aggregation previously identified during SPLASH. Further, comparisons to the breeding areas defined by SPLASH indicated that the haplotypic composition of California whales was most similar to Central America, while the Oregon whales were most similar in haplotypic composition to those found off Mexico. Individual assignment using the program GeneClass2 for the 14 California samples showed the highest likelihood of assignment to the Central America DPS for 9 individuals, to the Mexico DPS for 2 individuals and to the Hawaii DPS for 2 individuals. One individual was assigned with nearly equal likelihood to both Mexico and Central America DPSs. For the 9 Oregon samples, the individual assignment showed the highest likelihood of assignment to the Central America DPS for two individuals, to the Mexico DPS for two individuals, to the Hawaii DPS for four individuals, and to the Western North Pacific DPS for one individual. Assignments to the Hawaii or the Western North Pacific DPS could suggest changes in the migratory destinations, since some of these animals were tracked and/or photographed in Mexico.

15. SUBJECT TERMS

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Executive Summary

Three of the 14 Distinct Population Segments (DPSs) of humpback whales (*Megaptera novaeangliae*) recently designated worldwide by the National Marine Fisheries Service (NMFS) for listing under the Endangered Species Act (ESA) can be found along the western coast of North America during the feeding season: "Hawaii", "Mexico", and "Central America". This mixing of these DPSs in the feeding areas in different proportions complicates unequivocal assignment of individuals to breeding stock for management purposes without further information. As a result, there is an urgent need for data on occurrence and habitat use by these different DPSs in the feeding grounds, and their overlap with shipping traffic, fishing grounds, and areas of military operation, in order to prioritize management actions and to mitigate the impacts from these activities.

In 2017, Oregon State University (OSU) conducted a tagging and tracking study on Eastern North Pacific humpback whales to determine their movement patterns, occurrence, and residence times within United States (US) Navy training and testing areas along the US West Coast. This work was performed under a Cooperative Ecosystem Studies Unit (CESU) agreement in support of the Navy's efforts to meet regulatory requirements for marine mammal monitoring under the ESA and the US Marine Mammal Protection Act (MMPA). This report presents detailed results from the tagging, biopsy sampling, and photo-identification efforts conducted off the coast of southern and central California in summer and off the coast of Oregon in fall, as well as results from previous OSU studies of humpback whales in California, Oregon, Southeast Alaska, and the Aleutian Islands from 1997 to 2016. Whale use of Navy training and testing areas as well as their use of NMFS-identified Biologically Important Areas (BIAs) is examined and assignment to various DPSs (based on tracking, genetic, and photographic information) is discussed. The following paragraphs in this Executive Summary summarize whale movements, dive behavior, oceanographic data associated with whale locations, as well as results from genetic and photographic-identification analyses.

Two types of fully implantable tags were used: Telonics Duration Monitoring (DUR) tags, providing long-term tracking information via the Argos satellite system and dive duration information, and Telonics Dive Monitoring (DM) tags, providing intermediate duration Argos tracking and dive behavior (duration, depth and number of feeding lunges per dive). Both tag types followed the same design of OSU's earlier Location-Only (LO) tag used during the historic tagging efforts. Fourteen humpback whales (7 DUR tags, 7 DM tags) were tagged in California in July and August 2017 and five humpback whales (5 DUR tags) were tagged in Oregon in September and October 2017. Argos locations were received from 18 of the 19 tags, with tracking periods ranging from 0.3 to 150.4 days (d) (mean = 40.8 d, standard deviation [SD] = 37.9 d). Sixty-nine humpback whales were tagged in previous ("historical") seasons; 47 in Southeast Alaska in 1997, 2014, and 2015; 15 in California in 2004 and 2005; five in the Aleutian Islands of Alaska in 2008; and two in Oregon in 2016. Locations were received for all but two of these tags, with tracking periods ranging from 0.2 to 143.9 d (mean = 32.9 d, SD = 27.2 d). Hierarchical switching state-space models (hSSSM) were applied to the Argos locations from the DUR and DM tags and conventional switching state-space models (SSSM) to the Argos locations from the historical LO tags for the purpose of generating regularly spaced tracks with annotated movement behavior for use in several analyses.

The SSSM/hSSSM locations were used for examining home range, historical comparisons, dive behavior, and ecological relationships.

The distribution of tracked humpback whales aligned well with previously reported humpback sightings, further supporting humpback whale affinity for continental shelf and shelf-edge habitat, and also documented continued use of a recently identified feeding area off the Columbia River mouth. The latitudinal range of whales during the feeding season was longest for humpbacks tagged in California, extending from the Southern California Bight to central Oregon, followed by whales tagged in Southeast Alaska, extending from just north of Vancouver Island to Lynn Canal, north of Juneau, Alaska. Feeding-area locations of humpback whales tagged in Oregon extended from Point Arena, central California, to Vancouver Island, British Columbia, Canada. Humpback whales tagged off Dutch Harbor, Alaska, had the smallest latitudinal range, with the majority of locations extending from the northeast corner of Umnak Island to just north of Unimak Pass, Alaska. Small sample sizes of tagged whales in the latter two areas may have contributed to the smaller latitudinal ranges for these areas. Feeding-area home ranges were smaller for humpback whales tagged in Southeast Alaska in the fall than for whales tagged in California or Oregon, and core areas were smaller for those Southeast Alaska (fall) whales than all other whales. Core areas were also larger for humpback whales tagged in California in 2004-2005 than those tagged in California in 2017. Total distances traveled by individual whales did not differ between whales tagged in California, Oregon, or Alaska; however, distances were longer for whales tagged in Southeast Alaska in the fall than those tagged in the spring, or whales tagged in the Aleutian Islands.

The analyzed Navy areas considered were: the Southern California Range Complex (SOCAL), the Southern California Anti-submarine warfare Offshore Range subarea (SOAR), the Point Mugu Range Complex (PT MUGU), the Northwest Training and Testing Study Area (NWTT), the Warning Area-237 (Area W237) within the NWTT, and the Gulf of Alaska Temporary Maritime Activities Area (GOA). The NWTT was the most heavily used Navy training range by humpback whales, with animals tagged in both California and Oregon having extended residencies there, and whales tagged in Southeast Alaska migrating through the range. Humpback whale locations occurred in the NWTT from August through January. Area W237 of the NWTT range was only used by whales tagged in Oregon, or migrating whales from Southeast Alaska, with occurrences during in November and December. Humpback whales tagged in California were the only ones with extended residencies in PT MUGU; however, migrating whales from Oregon and Southeast Alaska also had locations in the range as they traveled south. Locations occurred within PT MUGU from July through December. SOCAL was used by humpback whales tagged in California, as well as by migrating whales from Oregon and Southeast Alaska for very short periods of time. Locations occurred in SOCAL in the months of November, December, and January. Only one humpback whale tagged in southern Oregon transited through the SOAR range in November of 2005. No tagged humpback whales were located in the GOA training range in any of the years covered in this report (1997-2017).

Humpback whales were found in all BIAs to varying degrees, with whales tagged in California predominantly using the Gulf of Farallones to Monterey Bay and the Fort Bragg to Point Arena BIAs. Whales tagged in Oregon predominantly used the Stonewall and Heceta Bank and Point St. George BIAs. There was overlap in use of the Fort Bragg to Point Arena, Point St. George, and Stonewall and Heceta

Bank BIAs by whales tagged in both Oregon and California. No whales tagged in California had locations in the Northern Washington BIA or the Olympic Coast National Marine Sanctuary, and no whales tagged in Oregon had locations in the Gulf of the Farallones to Monterey Bay, Morro Bay to Point Sal, or Santa Barbara-San Miguel Island BIAs. Seasonal occurrence was longest for the Gulf of the Farallones to Monterey Bay BIA, from July through November, and shortest for the Northern Washington BIA, with locations there only during November. All humpback whales tagged in Southeast Alaska had locations in the Southeast Alaska summer and fall BIAs, with occurrences there from July through November for whales tagged in summer and November through January for whales tagged in fall. All five humpback whales tagged out of Dutch Harbor had locations in the Aleutian BIA (September through November) and one of these whales also had locations in the Bristol Bay BIA in October.

DM and DUR tags deployed during 2017 on whales off California provided a mean of 2,251 dive summaries (range = 33-6,156), which summarized a mean of 48 percent of the tracking duration. Dive durations were similar across all tags ranging from 3-6 minutes (min) in duration with occasional dives lasting over 15 min. Maximum dive depths reported by DM tags were more variable across individuals with most dives occurring to depths < 100 meters (m) and occasional dives exceeding 175 m. Spatial distribution of dive durations was relatively uniform; however, distribution of feeding effort was concentrated in areas furthest from shore, where dive depths were also deepest. The mean maximum dive depth of one DM-tagged whale (Tag #4175) was two times deeper than the other DM tagged whales (89.5 m versus 45.2 m) and it recorded over three times as many feeding lunges compared to all other DM-tagged whales combined. Data from this whale appear to have driven the spatial variability of feeding effort. Humpback whales are known to feed on both fish and krill, and we hypothesize that the strong difference in behavior indicates that the whale with Tag #4175 was feeding on krill while the other DM-tagged whales were feeding on fish.

DUR tags deployed in 2017 on whales off Oregon recorded dive duration summaries for a mean of 3,367 dives (range = 1,808-6,156), representing a mean of 44 percent of the tracking duration. Dive durations were similar across tagged whales with the majority of dives lasting 3-8 min and occasional dives lasting over 20 min and displaying a slight diel trend with longer duration dives occurring during the day. Dive durations varied spatially, with the longest dives occurring in offshore waters, particularly near Newport, Oregon. These results may be due to the more limited sample size of Oregon whales compared to the California whales; however, it also may be due to behavior differences. Two humpback whales tagged with DM tags in 2016 exhibited behavior similar to the whale with Tag #4175 from California, suggesting they were feeding on krill, which may explain the more localized spatial distribution of dives off Oregon in 2017.

These results provide interesting trends for humpback whale diving and feeding behavior and underscore the need for additional DM tag deployments. The addition of dive and lunge-feeding behavior to the dive duration information has the possibility of revealing significant aspects of humpback whale behavior. The ability to distinguish between whales feeding on fish versus krill allows for the exploration of many important questions. Most important to the Navy is whether the movement of whales differs when they are feeding on these two prey types. This could impact how long a whale might stay within a training area and thus be exposed to potential anthropogenic impacts.

The hSSSMs for the 2017 tracks indicated that 87.2 percent of the regularized locations were classified as area-restricted searching (ARS; an indication of foraging behavior) off California, while off Oregon 63.2 percent were classified as ARS. This difference could be an indication of prey types being targeted (fish versus krill), with the associated energetic demands of lunge feeding, but it may also be driven by the small number of animals tracked off Oregon. Among the historical data set, the proportion of SSSM locations classified as ARS was generally high across feeding grounds, with a couple of notable exceptions. One was the very low percentage of locations classified as ARS for whales tagged in Southeast Alaska in 2014 and 2015 (6.9 and 23.7 percent, respectively), especially when compared to the 1997 season in Southeast Alaska, which yielded the highest proportion of ARS locations among the historical tracks (86.7 percent). This likely was a reflection of seasonal differences in foraging behavior, prey types, and habitat occupation, since whale distribution in Southeast Alaska was most confined in the fall just prior to migration to winter breeding areas, probably affecting the behavioral classification by the SSSMs. Similarly, there was a relatively low percentage of ARS locations for whales tagged in California in 2005 (56.3 percent) when compared to 2004 and 2017 (85.0 and 87.2 percent, respectively). Whales were reported to be widely spread throughout the California Current System in 2005, presumably in response to oceanographic anomalies and dispersed prey resources.

Average sea surface temperature values at these feeding areas ranged from a low of 7.27°C to a high of 16.18°C, with sea surface temperature being highest for animals tracked off California and Oregon and lowest for animals tracked in Southeast Alaska and the Aleutian Islands, following the well-known global latitudinal temperature gradient. Average chlorophyll-*a* values ranged from a low of 0.39 mg m^{-3} to a high of 4.35 mg m^{-3}, being highest for animals tracked off California and Oregon and lowest for animals tracked in Southeast Alaska and the Aleutian Islands. This pattern reflected the elevated phytoplankton biomass characteristic of the upwelling-driven California Current Ecosystem, and the low biomass characteristic of the downwelling-driven coastal Gulf of Alaska. Average sea surface temperature values in California provided additional support for the observed behavioral differences between 2004 and 2005 discussed above. In 2005, sea surface temperature was, on average, 1.65°C warmer than in 2004 and it was spatially more variable (SD = 5.21°C), confirming that in 2005 whales off California were foraging in a warmer and more heterogeneous environment.

In terms of seafloor characteristics, average depth was shallowest for animals that did not move much during the tracking period, such as off the Aleutians in 2008 and Oregon in 2016 (131.97 and 133.16 m, respectively), indicating the strong preference for humpback whales to forage over continental shelf habitats. Animals tagged in other feeding areas occupied somewhat deeper depths (246.57 to 738 m) suggesting that foraging over the continental slope was also important, but these averages were also likely affected by movements over deep waters, especially for whales that migrated toward breeding destinations. Average distance to the shelf break (i.e., the 200-m isobath) in all feeding areas was relatively small (maximum = 31.6 km), similarly highlighting the association with the shelf and shelf break for humpback whales.

Average seafloor slope was lowest for animals tagged in Oregon in 2016 (0.59 deg) and highest for animals tagged in Southeast Alaska in 1997 (2.48 deg). Except for the very low average slope recorded off Oregon in 2016 (0.59 deg; which was likely biased by the small sample size and short duration of these tracks), average slope was fairly similar (1.30-2.48 deg) across foraging sites. Average aspect of the slope faced toward the southeast for animals tagged in Southeast Alaska in 2014 and 2015 (149.26 and 142.33 deg, respectively), toward the south for animals tagged in Southeast Alaska in 1997 and the Aleutians in 2008 (174.57 and 191.77 deg, respectively), toward the southwest for animals tagged in California in 2004, 2005, and 2017 (234.53, 229.73, and 233.32 deg), and toward the west-southwest for animals tagged in Oregon in 2016 and 2017 (241.9 and 244.92). This variation in the aspect of the slope from a predominantly southwest direction for animals tracked off California, to west-southwest for animals tagged in Oregon, to south for animals tagged in Southeast Alaska and the Aleutians, followed the large-scale geometry of the basin, but otherwise did not appear indicative of an ecological relationship.

Biopsy samples were collected from all 14 tagged whales in California in 2017 and from three of the tagged whales in Oregon (plus from three untagged whales). Mitochondrial deoxyribonucleic acid (mtDNA) sequences of the samples resolved seven haplotypes for the consensus region of 500 bp for the California samples and three haplotypes for the Oregon samples. All haplotypes have been previously described for North Pacific humpback whales. All samples were represented by a unique multi-locus genotype of at least 15 loci, indicating that each of them represented a unique individual. The 14 California individuals represented seven females and seven males, while the six Oregon individuals represented three females and three males. The DNA profiles of the 20 individuals were compared to a reference database of 1,805 individuals sampled previously in the North Pacific by the program SPLASH (plus three individuals sampled by OSU off the Oregon coast in 2016), but no recaptures were detected. For population analyses, data from the six individuals sampled during 2017 off Oregon were combined with data from the three 2016 individuals, for a total of nine individuals representing the Oregon feeding area.

The composition of mtDNA haplotype frequencies indicated a significant level of differentiation between the California and Oregon feeding aggregations that was not previously realized, with Oregon animals appearing more similar to the Northern Washington/Southern British Columbia aggregation previously identified during SPLASH. Further, comparisons to the breeding areas defined by SPLASH indicated that the haplotypic composition of California whales was most similar to Central America, while the Oregon whales were most similar in haplotypic composition to those found off Mexico.

Individual assignment using the program GeneClass2 for the 14 California samples showed the highest likelihood of assignment to the Central America DPS for nine individuals, to the Mexico DPS for two individuals and to the Hawaii DPS for two individuals. One individual was assigned with nearly equal likelihood to both Mexico and Central America. For the nine Oregon samples, the individual assignment showed the highest likelihood of assignment to the Central America DPS for two individuals, to the Mexico DPS for two individuals, to the Hawaii DPS for four individuals, and to the Western North Pacific DPS for one individual. Assignments to the Hawaii or the Western North Pacific DPS could suggest changes in the migratory destinations, since some of these animals were tracked and/or photographed in Mexico. In interpreting these assignment results, however, it is important to keep in mind that their accuracy is dependent on the quality of the reference data set (which is limited to a relatively small sample size for the Central America DPS), and that assignments also reflect genetic ancestry, including recent historical exchange between breeding areas.

Of the 14 whales tagged in California in 2017, 13 had fluke photos that could be used for identification (ID) purposes. Out of these 13 whales, nine had been previously identified in the HappyWhale photo-ID database (https://happywhale.com). Eight whales had previously been sighted in California before tagging and three were resighted by others in California after tagging. Three whales had been seen previously in Mexico and two were resighted by other researchers there after tagging, one of which was a new record for that location, for a total of four tagged whales that have been sighted in Mexico. All five of the whales tagged in Oregon in 2017 had good fluke photos that could be used for ID purposes. None of the tagged whales were matched to any existing whales in the HappyWhale database, but two tagged individuals were resighted by researchers working off Nayarit, near Puerto Vallarta, Mexico, during February of 2018 and photographs sent to us allowed for their identification and assessment of the tag site.

While tagging can be a useful tool in marine animal population management and conservation, for humpback whales the mixing of DPSs that occurs in the feeding areas poses additional challenges that are best addressed using additional lines of evidence, including hSSSM/SSSM-inferred movement behavior, genetics, and photo-ID. With various levels of confidence, during the first year of this CESU agreement we were able to identify the DPS for several of the whales we tagged in the feeding areas, either through satellite telemetry, photo-ID, genetics, or through the combined information from these sources. We have begun to compile a data set that, with additional years of sampling, offers great potential for addressing current management questions for humpback whale DPSs at the scale of the Eastern North Pacific.

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Acronyms, Abbreviations, and Units

°C	Degrees Celsius
Aleutian BIA	Aleutian Islands Biologically Important Area
ANOVA	Analysis of variance
Area W237	Warning Area-237 within the Northwest Training and Testing Study Area
ARS	Area-restricted searching
ASPECT	Slope aspect
BIA	Biologically Important Area
bp	Base pair
CA	Core area of utilization
CESU	Cooperative Ecosystem Studies Unit
CHL	Phytoplankton chlorophyll-*a*.
cm	Centimeter
d	Day
deg	Degrees
DEPTH	Depth
DISTSHELF	Distance to the 200-m isobath (or distance to the shelf break)
DM	Dive-Monitoring tag (model Telonics RDW-665)
DNA	Deoxyribonucleic acid
DON	Department of the Navy
DPS	Distinct Population Segment
DUR	Duration-only tag (model Telonics RDW-640)
EEZ	Exclusive Economic Zone
ERDDAP	Environmental Research Division Data Access Program

ESA	Endangered Species Act
Farallones-Monterey BIA	Gulf of the Farallones-Monterey Bay Biologically Important Area
Fort Bragg BIA	Fort Bragg to Point Arena Biologically Important Area
g	Gram
GOA	Gulf of Alaska Temporary Maritime Activities Area
h	Hour
HR	Home range
hSSSM	Hierarchical switching state-space model
IACUC	Institutional Animal Care and Use Committee
ID	Identification
km	Kilometer
LC	Argos location class
LO	Location-Only tag (either model Telonics ST-15, or models Wildlife Computers SPOT6 or SPOT6)
m	Meter
mg m^{-3}	Milligrams per cubic meter
min	Minute
mm	Millimeter
MMPA	Marine Mammal Protection Act
mo	Month
Morro Bay BIA	Morro Bay to Point Sal Biologically Important Area
mtDNA	Mitochondrial deoxyribonucleic acid
NAVFAC	Naval Facilities Engineering Command
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NWA BIA	Northern Washington Biologically Important Area

NWTRC	Northwest Training Range Complex
NWTT	Northwest Training and Testing Study Area
OCNMS	Olympic Coast National Marine Sanctuary
OSU	Oregon State University
PCR	Polymerase chain reaction
PDI	Post-dive interval
PSG BIA	Point St. George Biologically Important Area
PT MUGU	Point Mugu Range Complex
R/V	Research Vessel
s	Second
Santa Barbara BIA	Santa Barbara Channel-San Miguel Biologically Important Area
SD	Standard deviation
SEAK BIA	Summer and fall Southeast Alaska Biologically Important Area
SLOPE	Slope (or depth gradient)
SOAR	Southern California Anti-submarine warfare Offshore Range subarea
SOCAL	Southern California Range Complex
SPLASH	Structure of Populations, Levels of Abundance and Status of Humpbacks program
SSSM	Conventional switching state-space model
SST	Sea surface temperature
Stonewall BIA	Stonewall and Heceta Bank Biologically Important Area
SWS	Saltwater conductivity switch
US	United States
V	Volt

1 Introduction

The purpose of this Cooperative Ecosystem Studies Unit (CESU) agreement between the Department of the Navy (Navy) and Oregon State University (OSU) is to support marine mammal studies in compliance with the Letters of Authorization and Biological Opinions issued by the United States (US) National Marine Fisheries Service (NMFS) to the Navy for activities in all Pacific Ocean testing and training range complexes. With regard to humpback whales (*Megaptera novaeangliae*), in 2016 NMFS divided the global population into 14 Distinct Population Segments (DPSs) for purposes of listing under the United States' (US) Endangered Species Act[1] (ESA). Four DPSs were designated for the North Pacific based on the location of distinct breeding areas (Federal Register 2016a, b): Western North Pacific, Hawaii, Mexico, and Central America. The corresponding ESA status is "Endangered" for both the Western North Pacific (estimated at 1,066 animals; Wade 2017) and the Central America DPSs (estimated at 783 animals; Wade 2017), "Threatened" for the Mexico DPS (estimated at 2,806 animals; Wade 2017), and "Not Listed" for the Hawaii DPS (estimated at 11,571 animals; Wade 2017) (Federal Register 2016a, b).

The available information indicates that three of these DPSs, Hawaii, Mexico, and Central America, are primarily found along the western coast of North America during the summer-fall feeding season. During this season, these DPSs occur in somewhat distinct feeding aggregations, with Hawaii animals being found in Southeast Alaska and northern British Columbia; Mexico animals being found off northern Washington-southern British Columbia; and Central America animals being found off California and Oregon (Bettridge et al. 2015). However, some degree of mixing of DPSs occurs in the feeding areas, with Hawaii whales also being found throughout the Gulf of Alaska, the Aleutian Islands, and eastern Russia; and Mexico whales also being found off California and Oregon, as well as in the northern and western Gulf of Alaska and the Bering Sea (Bettridge et al. 2015). Finally, animals from the Western North Pacific DPS may also be present in small numbers in these areas (Bettridge et al. 2015). This mixing of DPSs in the feeding areas complicates unequivocal assignment of individuals to breeding stock for management purposes without further information. As a result, there is an urgent need for data on occurrence and habitat use by these different DPSs in the feeding grounds, and their overlap with shipping traffic, fishing grounds, and areas of military operation, so that management agencies can prioritize actions and to mitigate potential impacts from these activities.

OSU conducted early tagging efforts in two breeding areas in the North Pacific, Hawaii and Mexico. These studies showed that humpback whales from Hawaii migrate north into the Gulf of Alaska, with some turning west towards Russia and others transiting east towards southeast Alaska (Mate et al. 2007). Tagging in the Revillagigedo Islands off Mexico showed that some of these whales may transit through US West Coast waters while *en route* to migratory destinations in British Columbia (Canada), while others travel through international waters heading toward the Gulf of Alaska and the Aleutian Islands (Lagerquist et al. 2008). These results indicate that North Pacific humpback whales from the Hawaii and Mexico DPSs spend time in Navy activity areas off California, the Pacific Northwest, and the Gulf of Alaska, in addition to activity areas in Hawaii (for Hawaii DPS whales). However, it is unknown

[1] See: "Listing of Humpback Whale Under the ESA" https://www.fisheries.noaa.gov/action/listing-humpback-whale-under-esa

what portion of each DPS is present in these locations or the proportion of time they spend in them (or if other DPSs are also present). In addition, tagging work conducted by others in the feeding area off northwestern Washington State (Schorr et al. 2013) showed humpback whale use of continental shelf and slope waters between Willapa Bay and Cape Flattery, within the Navy's Northwest Training Range Complex. However, the DPS to which these whales belong is unknown, and the short duration of those tag deployments (average = 8.1 days; Schorr et al. 2013) precluded investigation of more extensive area use as well as of long-distance movements.

In addition to monitoring marine mammal occurrence in testing and training range complexes, the Navy is also required to report information for areas of special interest to NMFS, such as the Olympic Coast National Marine Sanctuary or the recently designated Biologically Important Areas (hereafter referred to as BIAs) for humpback whales in waters of the US Exclusive Economic Zone (EEZ; i.e., the ocean waters extending out to 200 nautical miles of the US coastline) (Calambokidis et al. 2015, Ferguson et al. 2015a, b). Through the use of satellite telemetry, genetic analyses, and photo-identification, this CESU agreement seeks to provide greater detail on which humpback whale sub-populations (or DPSs, as delineated under the ESA; Federal Register 2016a, b) use the Navy ranges, BIAs, and adjacent areas in the North Pacific, and to help describe their feeding-season home range, habitat use, and ecological characteristics. In addition, data from tagged whales will provide detail on dive duration, feeding activity, and behavioral characteristics over periods spanning multiple weeks to multiple months. This report covers the results of tagging efforts conducted by OSU in feeding areas off the US West Coast in summer-fall 2017, and also includes analyses of historical data from previous tagging efforts by OSU in these areas. Additional tagging of humpback whales took place off Washington and Oregon in August and September 2018, the details of which will be presented in a separate Preliminary Summary as well as a comprehensive Final Report synthesizing the information from 2017 and 2018. The results of tagging efforts conducted by OSU in Hawaii in spring 2018 that are also part of this CESU agreement will be covered in a separate report focusing on the breeding areas.

2 Methods

2.1 Field Efforts

2.1.1 Tag Deployment

All tagging efforts were conducted from a small, 6.7-m rigid-hulled inflatable boat (RHIB). The tagging crew consisted of a tagger, biopsy darter, photographer, data recorder, and boat driver. Candidate whales for tagging were selected based on visual observation of body condition. No whales were tagged that appeared emaciated or that were extensively covered by external parasites. Satellite tags were deployed using the Air Rocket Transmitter System (Heide-Jørgesen et al. 2001), an air-powered applicator, following the methods described in Mate et al. (2007). Tags were deployed from distances of 1.5 to 5 meter (m) with 90- to 100-pound force per square inch in the applicator's 70-cubic centimeter pressure chamber.

2.1.2 2017 California Tagging

The California humpback whale tagging efforts in 2017 took place off the southern and central coast of the state, during a 16-day (d) cruise aboard the 26-m research vessel (R/V) *Pacific Storm*. The R/V *Pacific Storm* served as a home base and support vessel for the research crew, as well as an additional platform from which to search for whales and conduct visual observations. A crane on the back deck was used to launch and retrieve the 6.7 m tagging RHIB. Aerial observations to locate whales prior to the cruise were conducted during 7 d between 1 and 21 July 2017. The cruise took place from 21 July to 5 August 2017, departing from Santa Barbara, in southern California, and returning to Half Moon Bay, in central California. Tagging efforts were conducted during 7 d due to a combination of weather and concentrations of whales. Tagging activities began off southern California, but switched to central California due to a scarcity of humpback whales in southern California (**Figure 1**).

2.1.3 2017 Oregon Tagging

Humpback whale tagging efforts off Oregon in 2017 were conducted as day trips from ports located along the coast. These trips took place during 7 d, as follows: 2 d out of Newport, in central Oregon; 1 d each out of Charleston, Brookings, and Gold Beach, in southern Oregon; and 2 d out of Ilwaco, in southern Washington (which provided ready access to northern Oregon waters through the mouth of the Columbia River). The location of our field efforts varied due to the changing presence of whales, as reported to us by commercial fishermen and one aerial survey we conducted on 7 October 2017 off central Oregon.

2.1.4 Previous Tagging Efforts

Humpback whales were tagged by OSU during previous field seasons in several feeding areas of the North Pacific (Mate et al. 2007, Palacios et al. 2015). The results of these efforts (referred to hereafter as "historical data") are also presented in this report. For the purpose of this report, the historical field seasons were grouped according to region and time of year, as follows: (1) summer/fall 2004 and 2005 in California (including one whale tagged in southern Oregon in 2005), (2) late summer 2016 in Oregon, (3) summer 1997 in Southeast Alaska, (4) fall 2014 and 2015 in Southeast Alaska, and (5) late summer 2008 in the Aleutian Islands (out of Dutch Harbor), Alaska.

2.2 Satellite Tags

Two types of fully implantable, non-recoverable, Argos-based tags were used in 2017 to track humpback whales: Telonics RDW-640 tags (hereafter referred to as Duration-only or DUR tags) and Telonics RDW-665 tags (hereafter referred to as Dive-Monitoring or DM tags). Both tag types follow the same design of our earlier Location-Only (LO) tag used in previous tagging efforts (Mate et al. 2007, Mate et al. 2017), which is composed of a main body, a penetrating tip, and an anchoring system (**Figure 2**). The main body consisted of a stainless steel cylinder [1.9 centimeter (cm) in diameter × 15.9 cm in length for the DUR tag, and 1.9 cm in diameter × 20.7 cm in length for the DM tag] that houses a certified Argos transmitter and a 6 volt (V) lithium battery pack. A flexible whip antenna (15.8 cm long) and a saltwater conductivity switch (SWS, 2.2 cm long), both constructed of single-strand nitinol [1.27 millimeter (mm) in diameter], were mounted on the distal endcap of this cylinder, while a penetrating tip was screwed onto the other end. The polycarbonate endcap had two perpendicular stops (1.5 cm long × 0.9 cm wide × 0.6 cm thick) extending laterally to prevent tags from embedding too deeply on deployment or from migrating inward after deployment. The penetrating tip consisted of a Delrin® nose cone, into which a ferrule shaft was pressed with four double-edged blades. The anchoring system consisted of two rows of outwardly curved metal strips (each strip is 3.2 cm long × 0.6 cm wide) mounted on the main body at the nose cone (proximal) end. Following the original LO tag design, two of the DUR tags also had eight stainless steel wires (3.5 cm long, 0.9 mm gauge) mounted behind the blades on the penetrating tip for added anchorage, but wires were not used in our current tags. Maximum tag weight was 300 grams (g) for both tag types.

Tag cylinders were partially coated with a long-dispersant polymer matrix (Resomer® or Eudragit®) in which a broad-spectrum antibiotic (gentamicin sulfate) was mixed to allow for a continual release of antibiotic into the tag site for an extended period of time to reduce the chances of infection (Mate et al. 2007). The tags were designed to be almost completely implantable (except for the perpendicular stops, antenna, and SWS), and were ultimately shed from the whale probably due to hydrodynamic drag and/or the natural migration of foreign objects out of the tissue (Mate et al. 2007). The operational duration of these tags was almost always limited by issues related to retention on the whale rather than by battery life. To date, the mean duration of the fully implantable tags deployed by OSU on humpback whales has been 35 d [standard deviation (SD) = 36 d, median = 25.6 d, n = 180], with a maximum duration of 220 d (OSU, unpublished data).

2.2.1 DUR Tag Programing

DUR tags use the status of the SWS (wet/dry) to detect submergence events and to record dive duration for "selected dives". For this study, selected dives were specified as those > 2 minutes (min) in duration. Argos messages for DUR tags consisted of the start time and duration of a variable number of consecutive selected dives, typically four to six dives depending on data compression. The tag maintains an Argos message buffer that holds up to 10 messages in the tag's memory. When enough selected dives are recorded to create a new message it is added to the buffer. If there are already 10 messages in the buffer, the oldest message is discarded to make space for the new message. Every time the tag transmits, it randomly selects one of the messages for transmission from the buffer and every third transmission is a diagnostic message, containing the tag's current temperature and voltage. DUR tags were programmed to transmit during five 1-hour (h) periods per day coinciding with times when satellites were most likely to be overhead. With such a transmission schedule, the life expectancy of the DUR tag's battery was approximately 220 to 290 d.

2.2.2 DM Tag Programing

Telonics RDW-665 DM tags contain a pressure sensor and tri-axial accelerometers, and are able to record dive depth, dive duration, changes in body orientation, and motion while attached to a whale. During a deployment, dive depth was recorded every 5 seconds (s) with 2 m vertical resolution up to a maximum of 511 m. Dive duration was recorded at 1-s resolution up to a maximum of 4,095 s using the tag's SWS. Accelerometer readings were recorded every 0.25 s.

Feeding activity was derived from the motion data for selected dives (i.e., dives > 2 min in duration and 10 m in depth), as follows. For every selected dive, the magnitude of the acceleration vector (A) was calculated as in Simon et al. (2012):

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

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

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

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

Feeding lunges are associated with a peak followed by a minimum in Jerk (Allen et al. 2016), so we identified feeding lunges as instances when the Jerk value exceeded 1.5 SD above the mean, followed by a value less than 1/2 of the mean within 30 s after the Jerk peak. The mean Jerk value was continually updated following each selected dive and therefore represented a "grand mean" across all dives. Acceleration data recorded in the first 5 s or final 5 s of a selected dive were not used in these calculations to eliminate spurious peaks from strong fluking at the start or end of a dive. Lunges for each selected dive were then counted if they occurred more than 35 s from the previous lunge.

Argos messages for DM tags consist of the start date and time of each selected dive, dive duration, maximum depth, and number of lunges for four to six consecutive selected dives, depending on data compression. Details related to the transmit buffer, how a message was selected for transmission, and the frequency of utility message transmission were all the same as described above for DUR tags (see **Section 2.2.1**). The current Jerk mean and SD values were included in the utility message for diagnostic purposes and to monitor for any potential drift in the feeding lunge detection criteria over time. DM tags were programmed to transmit only when out of the water during six 1-h periods every day until 1 September 2017, when they started transmitting for six 1-h periods every other day to prolong battery life. The transmission periods were chosen to coincide with times when satellites were most likely to be overhead. With such a transmission schedule, the life expectancy of the DM tag's battery was approximately 100 to 160 d.

2.3 Tracking Analyses

2.3.1 Argos Track Editing

Tag transmissions are processed by Service Argos using the Kalman filter to calculate locations (Collecte Localisation Satellites 2015). Service Argos assigns a quality to each location, depending, among other things, on the number and temporal distribution of transmissions received per satellite pass (Collecte Localisation Satellites 2015). The accuracy associated with each Argos satellite location is reported as one of six possible location classes (LCs) ranging from less than 200 m (LC = 3) to greater than 5 kilometers (km) (LC = B) (Vincent et al. 2002).

Before generating a complete Argos track, OSU implemented a sequential data editing protocol on the received ("raw") Argos locations from each tag to retain the best locations. First, locations occurring on land were excluded. Then, locations of class Z were removed from analyses because of the unbounded errors (or sometimes invalid locations) associated with them. The remaining locations were further filtered by LC, as follows. 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). Finally, speeds between remaining locations were computed, and if a speed between two locations exceeded 14 kilometers per h (km/h), one of the two locations was removed, with the location resulting in a shorter overall track length being retained. These edited Argos tracks were used for analyses involving calculation of distance from shore and occurrence in Navy areas and BIAs (see **Sections 2.4** and **2.5** below).

2.3.2 Track Regularization and Behavioral Annotation with State-Space Models

Several of the analyses covered by this report, such as home range, historical comparisons, dive behavior, and ecological relationships (see **Sections 2.6-2.9** below), further required that track locations be spaced at regular intervals and have a behavioral mode annotation. For these purposes, the raw Argos locations (i.e., prior to applying the sequential data editing protocol described in **Section 2.3.1**) were used largely unedited (except for the removal of Z-class locations) as input into a Bayesian hierarchical state-space model (hSSSM) (Jonsen 2016) in the software package R v. 3.4.4 using the bsam and rjags libraries (which interfaced with the software package JAGS v. 4.3 to run Markov chain Monte Carlo simulations using the Gibbs sampler). This model is structurally similar to the conventional switching state-space model (SSSM; Jonsen et al. 2005) that has been applied to marine mammal tracking data for many years (e.g., Bailey et al. 2009, Irvine et al. 2014). However, the estimates for parameters driving different behavioral modes are generated from all tracks simultaneously rather than separately, as with the conventional SSSM. This process assumes that all tracks share an underlying set of movement parameters, which can be used to derive behavioral modes for each individual. Using multiple tracks simultaneously allows for greater precision when estimating behavior modes and for scaling individual movements up to the population level to better examine individual variation in foraging behavior and environmental characteristics (Jonsen 2016).

The model output provided a regularized track with three estimated locations per day, after accounting for Argos satellite location errors (based on Vincent et al. 2002) and movement dynamics of the animals. The hSSSM ran two Markov chain Monte Carlo simulations each for 60,000 iterations, with the first 40,000 iterations being discarded as a burn-in and the remaining iterations being thinned by removing every 20th to reduce autocorrelation, yielding a final 2,000 samples to be used (Jonsen 2016). 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 behavioral state value from 1 to 2 (Jonsen 2016). As in Bailey et al. (2009) and Irvine et al. (2014), we chose behavioral state values greater than 1.75 to represent ARS locations and values lower than 1.25 to represent transiting. Locations with behavioral state values in between were considered "uncertain".

For the analysis of historical data from previous tagging efforts, fewer transmission periods were scheduled per day to prolong battery life (see Mate et al. 2007), and thus fewer locations were received per day than for the 2017 tags. For this reason, conventional SSMs (Jonsen et al. 2005) were applied to the historical tracks to produce regularized tracks with only one estimated location per day (Bailey et al. 2009, Irvine et al. 2014, Mate et al. 2017).

2.4 Calculation of Distance from Shore

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

2.5 Occurrence in Navy Areas and BIAs

The number of filtered locations occurring inside versus outside Navy areas was computed for each Argos track, with the percentage of locations inside reported as a proportion of the total number of locations obtained for each whale. The Navy areas considered (per this CESU agreement) were: (1) the Southern California Range Complex (SOCAL), (2) the Southern California Anti-submarine warfare Offshore Range subarea (SOAR), (3) the Point Mugu Range Complex (PT MUGU), (4) the Northwest Training and Testing Study Area (NWTT), (5) the Warning Area-237 (Area W237) within the NWTT, and (6) the Gulf of Alaska Temporary Maritime Activities Area (GOA; **Figure 3**).

The number of locations and corresponding percentages were also computed for areas of interest to NMFS, such as the Olympic Coast National Marine Sanctuary and the BIAs that were identified for humpback whales in US waters of the Pacific Ocean (Calambokidis et al. 2015, Ferguson et al. 2015a, b). The BIAs considered for this report (per our CESU agreement) were: (1) Santa Barbara Channel-San Miguel (Santa Barbara BIA), (2) Morro Bay to Point Sal (Morro Bay BIA), (3) Gulf of the Farallones-Monterey Bay (Farallones-Monterey BIA), (4) Fort Bragg to Point Arena (Fort Bragg BIA), (5) Point St. George (PSG BIA), (6) Stonewall and Heceta Bank (Stonewall BIA), (7) Northern Washington (NWA BIA), (8) summer and fall Southeast Alaska (SEAK BIA), (9) Bristol Bay, and (10) Aleutian Islands (Aleutian BIA; **Figure 4**). We note that the summer and fall Southeast Alaska BIAs identified in Ferguson et al. (2015a) were combined for this report due to their substantial overlap and the fact that some humpback whales were tracked in the area in both summer and fall. The Olympic Coast National Marine Sanctuary (OCNMS) was also included with the BIAs in these residency analyses.

To compute estimates of residence time inside Navy areas and BIAs, interpolated locations were derived from the edited Argos tracks at 10 min intervals between locations, assuming a linear track and a constant speed. These interpolated locations provided evenly spaced time segments from which reasonable estimates of residence time could be generated, especially within the smaller Navy areas and BIAs. Residence time was calculated as the sum of all 10-min segments from the interpolated tracks that were completely within each area of interest. The amount of time spent inside these areas was expressed as the number of days as well as the proportion (percentage) of the total track duration. The number of edited Argos locations inside these areas was also reported, as well as the proportion (percentage) of the total number of edited Argos locations per track.

2.6 Home Range Analysis

The focus of this section was on feeding-season occupation, so we sought to remove the migration portion of the tracks. For this purpose, the migration portion was established as the segment of each hSSSM or conventional SSSM track where behavioral state values remained less than 1.25 (indicative of transiting) during southward movement after which tags either stopped transmitting or reached a breeding area. After removing the migration portion, we created feeding-area kernel home ranges for the remaining portions of tracks that contained at least 30 d of estimated locations (Seaman et al. 1999), using the least-squares cross-validation bandwidth selection method (Worton 1995, Powell 2000), as implemented in the R package by the adehabitatHR library (Calenge 2006, 2017). The 90 percent (home range, HR) and 50 percent (core area of utilization, CA) isopleths were produced for each track and isopleth portions that overlapped land were removed. The areas of each whale's HR and CA were then calculated in ESRI® ArcMap v.10.3.

2.7 Historical Comparisons

Comparisons between the historical tagging seasons/years and the 2017 seasons were conducted for tracking duration, total distance traveled for each whale, as well as HR and CA size using the STATGRAPHICS® Centurion XVI v. 16.1.03 software package. Analysis of variance (ANOVA) was used to test whether there were any significant differences in the season/year mean values, and multiple range tests using the Fisher's least significant difference procedure determined which means were significantly different from one another. Test results were reported as ANOVA *p*-values because multiple range tests in STATGRAPHICS® only report a 95 percent significance level, rather than an exact *p*-value.

2.8 Dive Behavior Analyses

The goals of the analyses in this section were to characterize the diving and feeding behavior of tagged whales over their tracked duration (weeks to months) and to examine how it changed temporally and spatially, using the dive data from the DUR and DM tags. As described in **Section 2.2**, both tag types had a similar design but the earlier DUR tag lacked the pressure sensor and accelerometer of the later DM tag, so it was only capable of reporting submergence events and dive duration.

2.8.1 DUR Tag Analysis

The percent of the tracking duration summarized by reported dives[2] from the DUR tags was calculated as the sum of all received dive durations plus the sum of all received post-dive intervals (PDI; i.e., the time between the end of one selected dive and the start of the next one). We only calculated PDI for dives reported within the same transmission because we could not be sure dives were sequential from one transmission to the next (e.g., if there was a 15-min time difference between the end of the last dive in one received transmission and the start of the first dive of the next received transmission, it is

[2] DUR and DM tags occasionally reported abnormally long-duration ("anomalous") dives lasting from 44 min up to the maximum possible value recorded by the tag (4,095 s or 68.3 min). Such instances were limited to 15 dives across all tags (nine dives for DUR tags and six for DM tags), and were excluded from the analyses. While it is possible these represent true dives, the durations would be well outside typical dive durations for humpback whales on the feeding grounds, and no other dives > 26.5 min were recorded. These anomalous dives could be related to times when the whales surfaced in such a way that the tag was not lifted out of the water (e.g., when the whales surface to breathe or rest at the surface). At such times the tag's SWS could remain submerged, causing multiple dives to be combined.

possible the whale made no selected dives during that time, or made a series of short-duration selected dives that were packaged into a transmission that was not received).

Summary plots showing dive duration versus time and versus time of day were generated for each individual tag and for all tags combined to visualize temporal and diel trends in the dive data. Due to the large number of plots generated, only the plots aggregating all tag data are presented to illustrate the trends that are described in the results.

Each reported dive was assigned a location along the track by linear interpolation, using the proportional time difference between the start of each dive and the two temporally closest hSSSM locations (i.e., before and after the start of the dive) to determine where on the line the dive should fall. The dives for each whale were then mapped onto a 0.15-degree hexagonal grid and the median dive durations were calculated for all dives occurring in each cell. This process was repeated for each tagged whale, and then the value of each grid cell was averaged across all tagged whales to produce a map showing the spatial distribution of dive durations after accounting for day-to-day differences in the number of dives, both within and between whales. Cells that averaged data from a greater number of whales are more likely to be representative of the overall behavior occurring in that cell so the gridded map of dive durations is presented with a corresponding gridded map showing the number of DUR-tagged whales that occupied each grid cell. This map indicates where DUR-tagged whales spent more time diving.

2.8.2 DM Tag Analysis

The percentage of the tracking period summarized by the tag was calculated and an interpolated location was assigned to each dive[2] as described for DUR tags. The dive duration summary plots described for DUR tags above (**Section 2.5.1**) were also generated from DM tag data, with additional plots showing dive depth and number of feeding lunges. The number of feeding lunges for each whale was then mapped onto a 0.15-degree hexagonal grid so that each grid cell contained the total number of lunges that occurred within that cell for one whale. The number of lunges in each cell was then divided by the sum of the dive durations for all dives occurring in the cell (i.e., the total time spent diving in that cell) to get the number of lunges per h reported for each grid cell. This process was repeated for each DM-tagged whale, and then the value of each grid cell was averaged across all whales and relativized so that all values fell from 0 to 1. The result shows the spatial distribution of relative feeding effort after accounting for day-to-day differences in the number of dives, both within and between whales. A corresponding gridded map showing the number of DM-tagged whales that occupied each grid cell was also generated as described for DUR tags. A similar gridded representation was conducted using the average daytime maximum dive depth recorded in each grid cell to examine spatial differences in dive depth across whales.

2.9 Ecological Relationships

In order to provide an environmental context to the tracking data, we obtained relevant variables for the SSSM (historical data) and hSSSM (2017 data) tracks from remotely sensed measurements acquired by oceanographic satellites and from digital elevation models of seafloor relief. The environmental data products are available through the web service Environmental Research Division Data Access Program

(ERDDAP), hosted by the National Oceanic and Atmospheric Administration's (NOAA's) NMFS/Southwest Fisheries Science Center (http://coastwatch.pfeg.noaa.gov/erddap/index.html). The extraction process was automated using the R package xtractomatic v. 3.4.1 (Mendelssohn 2018), a collection of functions that permit client-side access to the data sets served by ERDDAP.

The oceanographic variables extracted included: sea surface temperature (SST) and phytoplankton chlorophyll-*a* (CHL). Variables describing the seafloor relief were depth (DEPTH), slope (or depth gradient, SLOPE), aspect (ASPECT, the directional facing of the slope), and distance to the 200-m isobath (or distance to the shelf break, DISTSHELF). Finally, the distance to the nearest shoreline (DISTSHORE) was also computed for each SSSM/hSSSM location (**Table 1**). Considering that the environmental data products had a temporal resolution of 1 d or coarser (**Table 1**), and to avoid pseudo-replication, prior to extraction the hSSSM tracks were decimated from three to one location per day (keeping only the first estimated location of each day). We also excluded SSSM/hSSSM locations that were estimated on land. We further excluded locations with 95 percent credible limits exceeding 1 degree in longitude and/or in latitude from the analyses to reduce the bias introduced by locations with large estimation uncertainty.

The xtractomatic functions permit the use of a box of arbitrary size to extract the underlying data around each location. In order to account for the uncertainty in the location estimation by the SSSM/hSSSM, we obtained the median value for the environmental variables closest in time and space to each location occurring within a box defined by the 95 percent credible limits in longitude and in latitude, respectively. The number of values used in this computation was dependent not only on the extent of the credible limits around each location, but also on the spatial resolution of the environmental products used, which varied from 1.11 km (for SST) to 4.63 km (for CHL) (**Table 1**). In addition to reflecting the uncertainty in location estimation, this approach had the benefit of minimizing the number of locations with missing environmental values due to cloud cover in some of the products had we simply obtained the single pixel value nearest to a location. In this way, we generated fully annotated SSSM/hSSSM tracks with behavioral mode and a suite of environmental variables associated with each estimated location.

2.10 Genetics

2.10.1 DNA Extraction and mtDNA Sequencing

Total genomic deoxyribonucleic acid (DNA) was extracted from skin tissue following standard proteinase K digestion and phenol/chloroform methods (Sambrook et al. 1989) as modified for small samples by Baker et al. (1994). An approximate 800-base-pair (bp) fragment of the mitochondrial deoxyribonucleic acid (mtDNA) control region was amplified with the forward primer M13Dlp1.5 and reverse primer Dlp8G (Dalebout et al. 2004) under standard conditions (Baker et al. 2013). Control region sequences were edited and trimmed to a 500-bp consensus region in Sequencher v. 4.6. Unique haplotypes were then aligned with previously published haplotypes downloaded from GenBank® (Baker et al. 2013).

2.10.2 Microsatellite Genotypes

Up to 16 microsatellite loci were also amplified for each sample using previously published conditions (Baker et al. 2013). These included the following loci: EV1, EV14, EV21, EV37, EV94, EV96, EV104

(Valsecchi and Amos 1996); GATA28, GATA417 (Palsbøll et al. 1997); rw31, rw4-10, rw48 (Waldick et al. 1999); GT211, GT23, GT575 (Bérubé et al. 2000); and 464/465 (Schlötterer et al. 1991). Microsatellite loci were amplified individually in 10-microliter reactions and co-loaded in four sets for automated sizing on an ABI3730xl (Applied Biosystems™). Microsatellite alleles were sized and binned using Genemapper v. 4.0 (Applied Biosystems™) and all peaks were visually inspected.

2.10.3 Sex Determination

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

2.10.4 Individual Identification

Individual whales were identified from the multi-locus genotypes using CERVUS v. 3.0.3 (Marshall et al. 1998). Mismatches of up to three loci were allowed as a precaution against false exclusion due to allelic dropout and other genotyping errors (Waits and Leberg 2000, Waits et al. 2001). Electropherograms from mismatching loci were reviewed and corrected or repeated. A final "DNA profile" for each sample included up to 16 microsatellite genotypes, sex, and mtDNA control region sequence or haplotype. The expected probability of identity (P_{ID}) for a given number of loci was calculated with GenAlex (Peakall and Smouse 2006). The P_{ID} reflects the probability of a pair of individuals sharing a multi-locus genotype by chance given the frequency of alleles at each microsatellite locus. This probability is typically very low for the loci chosen in this study, providing confidence in the identification of individuals (Baker et al. 2013).

2.10.5 Species and Stock Identification

Species identity from field observations was confirmed by submitting mtDNA sequences to the web-based program *DNA-surveillance* (Ross et al. 2003) and by Basic Local Alignment Search Tool (BLAST) search of GenBank®.

For humpback whales, there is a large "DNA register" (DeSalle and Amato 2004, Haaland et al. 2011) available from the ocean-wide survey referred to as the Structure of Populations, Levels of Abundance and Status of Humpbacks program, or SPLASH. This register includes mtDNA haplotypes, sex, and microsatellite genotypes at 10 loci, sufficient for individual identification of 1,805 individuals sampled in all known breeding and feeding grounds in the North Pacific Ocean (Baker et al. 2013). Consequently, the mtDNA of tagged humpback whales can be compared to haplotype frequencies from any selected regions of the North Pacific and microsatellite genotypes can be used to match for individual identification with the DNA register.

Tests of differentiation in mtDNA haplotype frequencies between the two tagging datasets and the 18 populations defined during SPLASH (Baker et al. 2013) were conducted (using a significance threshold of 0.05) with the program Arlequin (Excoffier and Lischer 2010). Assignment of individuals from the tagging dataset to the four DPSs, as recognized by the ESA (Federal Register 2016a, b), was based on multi-locus genotyping using the population assignment procedure implemented in the program GeneClass2 (Piry et al. 2004). This program uses multi-locus genotypes and haplotypes to calculate the relative likelihood of an individual originating from alternate populations given the frequencies of alleles from a reference dataset representing those populations. For the purposes of this report, reference samples for the four DPSs came from one or more of the eight breeding ground strata defined by SPLASH (Baker et al. 2013), and were combined in the following way: "Western North Pacific" included all individuals sampled from Okinawa, Ogasawara and the Philippines, for a total of n = 245 individuals; "Mexico" included all individuals sampled from the Mexican mainland (MX-ML) and the offshore Revillagigedo Archipelago (MX-AR), for a total of n = 176 individuals; and "Hawaii" and "Central America" were kept as reported in Baker et al. (2013), for a total of n = 230 and n = 39, respectively. The individuals sampled from a third Mexican region, Baja California, were not included in this reference database as this region is considered an area of mixing between a local breeding population and migrating animals from other Mexican breeding areas and the Central American breeding area. The reference data set for the DPSs (i.e., the revised stratification of the SPLASH DNA register) included up to 10 microsatellite loci and mtDNA haplotype where available for each individual.

2.11 Photo-identification

Photographs of the whales' tail flukes and dorsal fins were taken during field efforts for identification (ID) purposes, as well as to document tag placement, wound condition, and to identify previously tagged whales to examine wound healing. Besides tagged whales, photographs were taken of all other whales seen while tagging for ID purposes and to examine for tag wounds or scars. Each individual whale that had a recognizable fluke was compared to our existing OSU photo catalog to determine if it had previously been identified. If not in the catalog, it was given a unique ID number and the best fluke photo was added.

Once this process is completed, our photo-IDs are submitted to other researchers to compare with their photo-ID catalogs to determine if there are matches that can show us the sighting histories of tagged whales. OSU is also in the process of uploading our catalog to the online resource "HappyWhale" (http://happywhale.com), a global database of photo-IDs contributed by the public that provides automated matching using state-of-the-art algorithms and machine learning, which will allow us to know where many of our tagged whales have been seen historically as well as where and when they are resighted in the future.

3 Results

3.1 Tagging Rates

A total of 173 humpback whales were approached during 7 d of tagging efforts in California in 2017, and 14 tags were deployed (**Table 2**). Off Oregon, 105 whales were approached in 7 d of tagging and five tags were deployed (**Table 2**). On average, the rate for humpbacks tagged in Oregon (0.7 tags per day) was almost one third of the tagging rate off California (two tags per day) with the same number of days of effort, due to fewer whales being encountered in Oregon than in California.

3.2 Behavioral Responses to Tagging

All 14 of the humpback whales tagged in California and four of the five humpbacks tagged off Oregon in 2017 exhibited short-term startle responses to the tagging/biopsy process. These responses consisted of mild to moderate tail flicks, tail lifts, or tail slaps (**Table 3**). A tail flick is defined here as a swift or abrupt movement of the tail flukes dorso-ventrally (up and down). The level of response follows definitions described in Weinrich et al. (1992), Hooker et al. (2001), and Baumgartner et al. (2015), with "moderate" referring to relatively forceful modifications to behavior (such as hard tail flicks) with no prolonged evidence of behavioral disturbance.

3.3 Wound Healing

Only two humpback whales were resighted on subsequent days after tagging during the field efforts. One was resighted 3 d after tagging (California DM Tag #840, a male) and the second 4 d after tagging (California DUR Tag #10842, a female). No swelling or other abnormalities were seen around the tag sites on these animals.

Two tagged whales were seen in February 2018 off the Nayarit coast, Mexico, by local researchers. The first of these whales (Oregon DUR Tag #1387, a male tagged off Newport) was seen again 148 d after tagging and 4 d after its tag last transmitted. The tag was still attached at this time, with an approximately 10-cm diameter and 3-cm deep divot surrounding it. Divots of this nature are common around tag sites and are a normal and inconsequential result from implant tags according to experienced marine mammal veterinarians with whom we consult. There was also a scrape running vertically downward from the divot, approximately 17-cm long, as well as another scrape running horizontally below the tag approximately 75 cm long. These may have been caused by contact with other whales during competitive behaviors common to the breeding season. This whale was resighted in the same area a second time 7 d later (i.e., 155 d after tagging and 11 d after the tag stopped transmitting).

The second resighted whale (Oregon DUR Tag #4174, a female tagged off Port Orford) was seen with a calf 145 d after tagging and 115 d after its last tag transmission. It was also seen off Nayarit, near Puerto Vallarta, Mexico. The tag's antenna was no longer present. The tag was protruding approximately 6 cm from the whale's back, with a circular divot around the tag approximately 10 cm in diameter and 2 cm deep. This whale was not accompanied by a calf when it was tagged on 27 September 2017, indicating that the calf was born sometime after tagging and before the pair was sighted off the Nayarit coast.

3.4 2017 California Tagging

3.4.1 Tracked Movements

Fourteen tags (seven DM and seven DUR) were deployed on humpback whales in California between 21 July and 4 August 2017; one in the Santa Barbara Channel off southern California, and 13 off central California between San Francisco and Santa Cruz. Locations were received from all 14 tags, with tracking durations for both tag types combined ranging from 0.3 to 84.7 d (**Table 4**). Tracking durations averaged 12.8 d (SD = 17.9 d) for DM tags and 56.8 d (SD = 22 d) for DUR tags. Distance traveled averaged 489 km (SD = 495 km) for DM tags and 2,061 km (SD = 879 km) for DUR tags (**Table 4**).

The DM tags did not transmit as long as DUR tags (ANOVA p-value = 0.001), nor as long as DM tags deployed in the past on blue (average 73.2 d) and fin whales (average 38.6 d) (Mate et al. 2017), prompting us to send the remaining, un-deployed tags of this type back to the manufacturer (Telonics) for assessment. Telonics discovered minute amounts of water inside the tags (presumably from pre-field pressure testing), which were attributed to failure in the O-ring seals of the antenna and SWS. This failure was due in part to the pressure transducer occupying a large portion of the endcap, creating very tight tolerances to fit the antenna and SWS. These tolerances were such that extremely small variations in O-ring diameter (within specifications) were enough to slightly contact the endcap walls as the antenna or SWS was inserted, and damage the O-ring, resulting in leakage. The leakage of saltwater into the tag was so slight that it took varying lengths of time (up to 10 d after deployment) to result in tag failure. This was why it was undetected during our pressure testing before deployment. This led to a new endcap design as well as new testing procedures by Telonics for each individual endcap before additional or re-built tags were assembled. Despite these failures, three of the seven DM tags contributed 10 d or more of tracking data (maximum = 51.6 d). These tag issues resulted in the overall duration of averages for the DM tags to be so much lower than the DUR tags.

Locations for humpback whales tagged off California ranged over 11 degrees of latitude, from the Santa Barbara Channel to Pacific City on the central Oregon coast (**Figure 5**). The individual with the longest range (DUR Tag #10822, a male) was tracked between Pigeon Point, central California, and Pacific City, Oregon, with a distance between northern and southern most locations of more than 900 km. The humpback whale tagged in the Santa Barbara Channel in southern California remained in the Channel for the first 8 d of its tracking period, then moved back and forth from the Santa Barbara Channel to slope waters between Point Conception and Point Buchon over a period of 15 d. The last 11 d of its tracking period were spent in outer slope waters off Morro Bay. This whale's 44-d track did not intersect with those of other tagged humpbacks in central California or Oregon. The majority of humpback whale locations for whales tagged in central California occurred between Año Nuevo Point and Bodega Bay on the central California coast, and were located primarily over continental shelf waters. The humpback whale that traveled to the central Oregon coast (Tag #10822) took an offshore route on the way north, over continental slope and abyssal plain waters, and a more inshore route on the way south back to California, mainly over continental slope and continental rise (the region between the continental slope and the abyssal plain) waters. This whale reached a maximum distance offshore of approximately 200 km, during the northbound portion of its track. While in Oregon, this whale spent 4 d off Pacific City and 5 d off the southern Oregon coast between Cape Blanco and Brookings.

3.4.2 Use of Navy Training Areas

Only two of the humpback whales tagged off California in 2017 had locations in Navy training areas. One whale (Tag #830) had 50 percent of its locations and 51 percent of its total tracking period (23 d) within PT MUGU (**Table 5, Figure 6**). Another whale (Tag #10822) had 46 percent of its locations and 33 percent of its total tracking period (28 d) within the NWTT (**Table 5, Figure 7**). Distances to shore in PT MUGU for Tag #830 averaged 34 km (SD = 22.7 km, maximum = 98 km; **Table 6**). Distances to shore in the NWTT for Tag #10822 averaged 88 km (SD = 49.7 km, maximum = 201 km; **Table 6**). Humpback whale locations occurred in PT MUGU during three months (July through September), and during two months in the

NWTT (August and September). None of the tagged humpback whales from 2017 were tracked within SOCAL, SOAR, Area W237 (encompassing approximately the northern third of the NWTT), or the GOA areas.

3.4.3 Use of West Coast BIAs

The amount of time spent in US West Coast BIAs (including the OCNMS) by humpback whales tagged off California ranged from < 1 to 100 percent of their total tracking periods (**Table 7**). The most heavily used BIA, in terms of number of whales having locations there, was the Farallones-Monterey BIA, with 13 humpback whales having 33 to 100 percent of their total locations there (**Figure 8**). This represented 36 to 100 percent of their total tracking durations, or < 1 to 84 d (**Table 7**). Humpback whale locations occurred in the Farallones-Monterey BIA over 4 mo (July through October). Two of these humpback whales (Tag #s 834 and 1390) also had locations in the Fort Bragg BIA (4 to 9 percent of their total locations), representing 3 to 7 percent of their total tracking periods, or 1 to 4 d (**Figure 9**). The track of one other humpback whale (Tag #10822) crossed the Fort Bragg BIA (but there were no locations inside the BIA), representing 1 percent of this whale's tracking period (1 d). This latter whale also had 2 percent of its locations and 1 percent of its tracking period (1 d) within the Stonewall BIA, off central Oregon (**Table 7, Figure 10**). Humpback whale locations occurred in the Fort Bragg BIA during 2 mo (August and September) and in the Stonewall BIA in August. The humpback whale tagged in southern California (Tag #830) had locations in the Santa Barbara BIA as well as the Morro Bay BIA, with 10 and 15 percent of its total number of locations in each BIA, respectively (**Figures 11 and 12**). This represented 8 and 15 percent of the total tracking period for this whale, or 3 and 7 d, respectively (**Table 7**). Humpback whale locations occurred in the Santa Barbara BIA during July and August and in the Morro Bay BIA in August. None of the humpback whales tagged in California in 2017 had locations in the NWA or PSG BIAs, or the OCNMS.

3.4.4 Home Ranges and Core Areas

Seven of the humpback whales tagged in California in 2017 provided enough locations (i.e., non-migrating portions of track with at least 30 d of estimated locations) to calculate feeding area HRs and CAs (**Table 8, Figures 13 and 14**). HR sizes ranged from 1,720 to 101,188 square kilometers (km^2) (mean = 17,684.4 km^2; SD = 36,848.8 km^2) and extended along the US West Coast from the Channel Islands in southern California to central Oregon. The densest location of HRs occurred off central California, where most of the whales were tagged, from Año Nuevo Point to just south of Point Arena, with HRs overlapping for up to six whales in scattered locations along the outer edge of the continental shelf. CAs ranged in size from 156 to 6,033 km^2 (mean = 1,296.2 km^2, SD = 2,104.7 km^2), with the southernmost one off Point Conception, southern California, and the northernmost one off central Oregon. The area of highest use, with overlapping CAs for four humpback whales, was Cordell Bank, off Point Reyes, extending to 55 km offshore. There was no relationship between the number of days used in the analysis and the size of either HRs or CAs (linear regression of log-transformed variables, p-value $\geq$ 0.42).

3.4.5 Dive Behavior

DUR and DM tags provided a mean of 2,251 dive summaries (range = 33-6,156; **Table 9**). The number of dives reported summarized a mean of 47.9 percent of the tracking duration (range = 6.7-91.7 percent). DM Tag #840 did not provide any dive data. The remaining five DM tags reported fewer dives than DUR tags (mean = 1,010 versus 2,676) but summarized a larger percentage of the tracking period (76.6 versus 32.9 percent). Dive durations were approximately equal across both DUR and DM tags, generally ranging from 3-6 min in duration with occasional dives lasting over 15 min and very little variation throughout the day (**Figures 15 and 16**).

A diel trend was present in the maximum dive depth data from DM tags, with deeper dives and more feeding lunges occurring during the day (**Figure 17**). Maximum dive depths were more variable across individuals with most dives occurring to depths < 100 m. However, four of the five tagged whales made dives exceeding 175 m with a maximum depth of 319 m (**Figure 18**). The mean maximum dive depth of Tag #4175 (a female) was two times deeper than the other DM tagged whales (89.5 versus 45.2 m) and recorded over three times as many feeding lunges compared to all other DM-tagged whales combined (**Figure 19**). Lunges were most often recorded singularly (mean = 1.1 lunges per feeding dive) for all tagged whales except Tag #4175, which made a mean of 2.2 lunges per feeding dive.

Dive depths were deeper for dives occurring during ARS behavior (as identified by hSSSMs); however, this was almost entirely driven by Tag #4175 (**Figure 20**). There was no difference in the dive duration across behavioral modes for all tags (DUR and DM). However, Tag #10822 (a male), which moved the furthest of all tags, recorded the shortest duration of dives during ARS behavior (**Figure 21**). The spatial distribution of dive durations was relatively uniform, with longer duration dives occurring offshore of Cape Blanco, Oregon (**Figure 22**). Feeding effort (derived from the number of lunges recorded) was concentrated in areas furthest from shore, where median dive depths were also deepest (**Figure 23**).

3.4.6 Ecological Relationships

The hSSSMs generated regularized locations for 13 humpback whales tagged in California in 2017, resulting in 476 daily estimated locations with annotated behavioral mode and environmental values (**Table 10**). Of this total, 87.2 percent were classified as ARS, 6.5 percent as transiting, and 6.3 percent as uncertain (**Table 10**). The behavioral classification for each location is shown in the map in **Figure 24**.

Details of the environmental variables examined are provided in **Table 1**. Summary statistics for these variables obtained for the hSSSM locations are reported in **Tables 11 and 12**. For the 13 humpback whales tagged in California in 2017, average SST was 15.59 degrees Celsius (°C) (SD = 1.40°C), and average CHL was 3.40 milligrams per cubic meter (mg m^{-3}) (SD = 4.70 mg m^{-3}) (**Table 11**). In terms of seafloor characteristics, in 2017 humpback whales occurred in areas with an average DEPTH of 301.55 m (SD = 582.08 m), average DISTSHELF of 13.67 km (SD = 19.15 km), and average DISTSHORE of 30.32 km (SD = 22.80 km). The average SLOPE in these areas was 1.3 deg (SD = 2.12 deg) and faced toward the southwest (average ASPECT = 233.21 deg, SD = 60.99 deg) (**Table 12**).

3.4.7 Genetics

Biopsy samples were collected from all 14 tagged whales and all samples provided DNA profiles sufficient for subsequent analyses. The mtDNA sequences of the 14 samples resolved seven haplotypes for the consensus region of 500 bp (**Table 13**). Based on submission to *DNA-surveillance* and a BLAST search of GenBank®, all of the mtDNA haplotypes were consistent with field identification of humpback whales. All haplotypes have been previously described for North Pacific humpback whales (Baker et al. 2013) and so are in the public domain (**see Table 13**).

The 14 samples were represented by a unique multi-locus genotype of at least 15 loci with an average of 15.86 loci across the dataset. The probability of identity for any given set of 15 loci ranged from P_{ID} = 3.7 x 10^{-13} to 1.1 x 10^{-14}, providing confidence that the 14 unique multi-locus genotypes represent 14 individual whales. These 14 individuals included seven females and seven males. The DNA profiles of the 14 individuals were compared to a reference database of 1,805 individuals sampled previously in the North Pacific by the program SPLASH as reported in Baker et al. (2013), but no recaptures were detected.

Pairwise comparisons of mtDNA haplotype frequencies showed significant differentiation (F_{ST} *p*-values ranging from < 0.0001 to 0.0021) to all of the 10 SPLASH feeding areas described in Baker et al. (2013) with the exception of California/Oregon and the Western Aleutians (likely due to the small sample size for the Western Aleutians; **Table 14**). The California tagging samples also differed significantly (F_{ST} *p*-values ranging from < 0.0001 to 0.0037) from all eight SPLASH breeding grounds described in Baker et al. (2013) with the exception of Central America (**Table 14**).

Individual assignment using the program GeneClass2 showed the highest likelihood of assignment to the Central America DPS for nine individuals, to the Mexico DPS for two individuals and to the Hawaii DPS for two individuals (**Table 15, Figure 25**). One individual was assigned with nearly equal likelihood to both Mexico and Central America.

3.4.8 Photo-identification

A total of 10,982 photographs were taken of humpback whales in California during the 2017 field season. From these photographs a total of 142 individuals were identified and added to the photo-ID catalog (**Table 16**). Of the 14 whales tagged, 13 had fluke photos that could be used for ID purposes. Out of these 13 whales, nine had been previously identified in the HappyWhale photo-ID database. Eight whales had previously been sighted in California before tagging and three were resighted by others in California after tagging. Three whales had been seen previously in Mexico (DM Tag #833, a male; DUR Tag #10822, a male; and DUR Tag #1389, a female) and two were resighted by other researchers there after tagging (DUR Tag #834, a female, and DUR Tag #1389, a female), one of which was a new record for that location (Tag #834), for a total of four tagged whales that have been sighted in Mexico. For untagged whales that were assigned an ID, HappyWhale has not finished the matching process so no results are available.

3.5 2017 Oregon Tagging

3.5.1 Tracked Movements

Five DUR tags were deployed on humpback whales off Oregon between 14 September and 16 October 2017; two off Newport on the central Oregon coast, two off Cape Blanco on the southern Oregon coast, and one off Clatsop Spit, at the mouth of the Columbia River in northern Oregon. One tag (DUR Tag #23043, a female), deployed off Newport, provided only three transmissions and no locations, and is not considered further in this report. The other four tags had tracking durations ranging from 31.7 to 150.4 d (mean = 61.8 d, SD = 32.6 d; **Table 17**).

Humpback whale locations ranged over 27 degrees of latitude, from just north of Puerto Vallarta on the west coast of Mexico to west of Barkley Sound on the west coast of Vancouver Island, British Columbia (**Figure 5**). One whale (DUR Tag #1387, a male) was responsible for this range, with a distance between northern- and southern-most locations of more than 3,500 km. During the first 3 mo of its tracking period, this whale, tagged off Newport, Oregon, spent most of its time off the Columbia River mouth, in northern Oregon and southern Washington, with shorter periods of time spent off southern Vancouver Island, Cape Blanco, and Point St. George. Most of its locations were over continental shelf waters. On 24 December 2017, this whale began migrating south from Point St. George, on an offshore route over deep oceanic water (maximum distance to shore of ~ 600 km, off central Baja California), until the latitude of the southern tip of the Baja Peninsula in Mexico. On 12 January 2018, the whale turned east and headed for the tip of the peninsula and then continued toward the mainland Mexico coast. This whale reached the coast near Mazatlán on 21 January and stayed there for 3 d before continuing south toward Puerto Vallarta. It was last located on 5 February, ~ 70 km north of Puerto Vallarta.

One of the humpback whales tagged off Cape Blanco (DUR Tag #4174, a female) moved south after 2 d to an area off Eureka, northern California, and remained there for its entire 32-d tracking period. Another whale tagged off Cape Blanco (DUR Tag #10838, of unknown sex) moved more extensively in its 33-d tracking period, traveling south to Trinidad Head in northern California, then north to Cape Blanco, south to Point Arena, in central California, and finally north to Crescent City, northern California. The whale tagged off the Columbia River mouth (DUR Tag #23034, or unknown sex) remained off southern Washington and northern Oregon for its entire 32-d tracking period. Most of the locations for these three whales were over continental shelf and slope waters, with some excursions offshore over deep abyssal plain waters (up to approximately 120 km offshore for both Tags # 10838 and 23034).

3.5.2 Use of Navy Training Areas

The most heavily used Navy training area for humpback whales tagged off Oregon in 2017 was the NWTT, with all four tracked whales having from 8 to 96 percent of their total locations there (**Table 18, Figure 7**). This represented from 4 to 98 percent of their total tracking periods or 1 to 86 d in the NWTT. Distances to shore in the NWTT averaged 49 km (SD = 16.6 km, maximum = 183 km; **Table 19**). One of these humpback whales (Tag #1387) also had 9 percent of its total locations in Area W237 of the NWTT. This represented 10 percent of its total tracking period, or 14 d (**Table 18, Figure 26**). Distance to shore in Area W237 averaged 73 km (SD = 40.3 km, maximum = 175 km; **Table 19**) for Tag #1387. During migration south, whale with Tag #1387 crossed SOCAL, which resulted in 1 percent of its total locations and 1 percent of its total tracking period (2 d) in that area (**Figure 27**). Humpback whale locations occurred in the NWTT during 4 mo (September, October, November, and December), during 2 mo in Area W237 (November and December), and during 1 mo in SOCAL (January). None of the humpback whales tagged off Oregon in 2017 were tracked within the SOAR or the GOA areas.

3.5.3 Use of West Coast BIAs

Humpback whales tagged in Oregon in 2017 had locations in four BIAs along the US West Coast, as well as the OCNMS (**Table 20**). The most heavily used BIA for these whales was PSG, with three of the four tracked whales having locations there (**Figure 28**). This represented 3 to 15 percent of their total locations and 3 to 13 percent of their total tracking periods (2 to 4 d) (**Table 20**). Locations occurred in the PSG BIA in October and December. Two humpback whales had < 1 to 28 percent of their total locations in the Stonewall BIA, representing 1 to 30 percent of their total tracking periods, or 1 to 10 d (**Figure 10**). These locations occurred in October and November. In addition to having locations in the former two BIAs, Tag #1387 also had locations in the NWA BIA and the OCNMS; 5 and 7 percent of total locations, and 5 and 6 percent of total tracking periods in the two areas, respectively (**Figures 29 and 30**). This represented 7 d in the Northern Washington BIA (in November) and 9 d in the OCNMS (in November and December) (**Table 20**). One of the other whales with locations in the PSG BIA (Tag #10838) also had 6 percent of its locations in the Fort Bragg BIA (**Figure 9**). This represented 7 percent of its total tracking period, or 2 d, in October (**Table 20**).

3.5.4 Home Ranges and Core Areas

All four of the tracked humpback whales tagged in Oregon in 2017 provided enough locations to calculate feeding area HRs and CAs (**Table 8, Figures 31 and 32**). HR sizes ranged from 1,620 to 40,858 km^2 (mean = 17,215.6 km^2; SD = 16,861.1 km^2) and extended from Point Arena, central California, to the southwest corner of Vancouver Island, British Columbia. The densest location of HRs occurred at the California/Oregon border, where HRs overlapped for three of the four whales. CAs ranged in size from 156 to 4,428 km^2 (mean = 1,929.0 km^2, SD = 1,802.7 km^2), extending from Trinidad Head, northern California, to Cape Flattery on the northern Washington coast. The areas of highest use, with overlapping CAs for two humpback whales, were off Trinidad Head and the Columbia River mouth, extending out to 20 km offshore at Trinidad Head and to 65 km offshore at the Columbia River. There was no relationship between the number of days used in the analysis and the size of either HRs or CAs (linear regression of log-transformed variables, p-value $\geq$ 0.30).

3.5.5 Dive Behavior

The four operational DUR tags transmitted dive duration summaries for a mean of 3,367 dives (range = 1,808-6,156; **Table 9**) representing a mean of 44.4 percent of the tracking duration. Tag #1387 (a male) migrated to a breeding area in Mexico. Pre-migration dives only occurred prior to 24 December 2018 and are presented and discussed here. Dive durations were similar across all tagged whales, with the majority of dives lasting 3-8 min and occasional dives lasting over 20 min (**Figure 33**). Across all tags, only four anomalous dives were recorded (dives > 60 min) and were removed, leaving the next longest dive as 26.4 min.

A slight diel trend in dive durations was observed, with longer-duration dives occurring during the day (**Figure 34**). Dive durations were generally equal across hSSSM-identified behavioral modes. However, dives occurring during ARS behavior were slightly shorter in duration for the pre-migratory movements of Tag #1387, which traveled the furthest of all tags (**Figure 35**). Dive durations varied spatially with the longest dives occurring in offshore waters, particularly near Newport, Oregon (**Figure 36**).

3.5.6 Ecological Relationships

The hSSSMs generated regularized locations for four humpback whales tagged in Oregon in 2017, resulting in 242 daily estimated locations with annotated behavioral mode and environmental values (**Table 10**). Of this total, 63.2 percent were classified as ARS, 22.3 percent as transiting, and 14.5 percent as uncertain (**Table 10**). The behavioral classification for each location is shown in the map in **Figure 24**.

Details of the environmental variables examined are provided in **Table 1**. Summary statistics for these variables obtained for the hSSSM locations are reported in **Tables 11 and 12**. For the four humpback whales tagged in Oregon in 2017, average SST was 14.05°C (SD = 3.86°C), and average CHL was 3.27 mg m^{-3} (SD = 4.07 mg m^{-3}) (**Table 11**). In terms of seafloor characteristics, in 2017 humpback whales occurred in areas with an average DEPTH of 738 m (SD = 1102.69 m), average DISTSHELF of 27.82 km (SD = 56.18 km), and average DISTSHORE of 54.81 km (SD = 59.69 km). The average SLOPE in these areas was 1.49 deg (SD = 2.09 deg) and faced toward the west-southwest (average ASPECT = 244.92 deg, SD = 64.52 deg) (**Table 12**).

3.5.7 Genetics

Biopsy samples were collected from three of the tagged whales and three untagged whales in 2017. All samples provided DNA profiles sufficient for subsequent analyses.

The mtDNA sequences of the six samples resolved three haplotypes for the consensus region of 500 bp (**Table 13**). Based on submission to *DNA-surveillance* and a BLAST search of GenBank®, all of the mtDNA haplotypes were consistent with field identification of the species as humpback whales. All of the haplotypes have been previously described for North Pacific humpback whales (Baker et al. 2013) and so are in the public domain (**see Table 13**).

The six samples were represented by a unique multi-locus genotype of at least 15 loci with an average of 15.83 loci across the dataset. The probability of identity for any given set of 15 loci ranged from a P_{ID} = 1.7×10^{-12} to 8.2×10^{-14}, providing confidence that the six unique multi-locus genotypes represent six unique individuals. These six individuals included three females and three males.

The DNA profiles of the six individuals were compared to a reference database of 1,805 individuals sampled previously in the North Pacific by the program SPLASH as reported in Baker et al. (2013) and to genotypes from three individuals sampled off the Oregon coast in 2016 (two tagged and one untagged whale) (Mate et al. 2017). No recaptures were detected with either dataset. For population analyses, data from the six individuals sampled during 2017 were combined with data from the three individuals sampled during tagging off the Oregon coast in 2016 (Mate et al. 2017), for a total of nine individuals representing the Oregon feeding area (five of which were also tagged), so we refer to them as the "Oregon tagging samples".

A comparison of the mtDNA haplotype frequencies of the Oregon and California tagging samples indicated a highly significant difference despite the relatively modest samples sizes (F_{ST} = 0.1266, *p*-value = 0.0077; **Figures 37 and 38**). Consequently, the haplotype frequencies of the Oregon tagging samples were compared separately to the SPLASH reference dataset. Pairwise tests of differentiation between the Oregon tagging samples and the SPLASH areas showed significant differences (F_{ST} *p*-values ranging from 0.0006 to 0.0264) for five of the 10 feeding areas described in Baker et al. (2013) (**Table 14**). Notably, and in contrast to the California tagging data set, the Oregon tagging samples were significantly different to the SPLASH California/Oregon feeding area but not to the Southern British Columbia/Washington area. It was also significantly different to the feeding areas of Northern British Columbia, Southeast Alaska and Northern Gulf of Alaska to the north, but not different to the feeding areas off the western Gulf of Alaska, the eastern Aleutians and the Bering Sea to the northwest. When comparing to the eight SPLASH breeding grounds, the Oregon tagging samples were significantly different (F_{ST} *p*-values ranging from 0.0055 to 0.0433) to the three Western North Pacific populations, the Hawaii population and the Central America population, but not to any of the three Mexican breeding grounds (**Table 14**).

The individual assignment likelihoods using the program GeneClass2 showed a stronger contribution of Hawaii and Western North Pacific, in comparison to the analysis of the California tagging samples: two individuals showed the highest likelihood of assignment to the Central America DPS, two to the Mexico DPS, four to the Hawaii DPS, and one to the Western North Pacific DPS (**Table 15, Figure 25**).

3.5.8 Photo-identification

A total of 4,694 photographs were taken of humpback whales during the field effort in Oregon in 2017. A total of 45 individuals were identified from these photographs and added to the photo-ID catalog (**Table 16**). All five of the tagged whales had good fluke photos that could be used for ID purposes. None of the tagged whales were matched to any existing whales in the HappyWhale database, but two tagged individuals (DUR Tag #1387, a male, and DUR Tag #4174, a female) were resighted by researchers working off Nayarit, near Puerto Vallarta, Mexico, during February of 2018 and photographs sent to us allowed for their identification and assessment of the tag site (see **Section 3.3**). The 40 untagged whales that were assigned IDs have not yet been processed by HappyWhale.

3.6 Historical Comparisons

3.6.1 Tracked Movements

A total of 69 humpback whales were tagged by OSU in Eastern North Pacific feeding areas prior to 2017 (covering the period 1997 to 2016), providing tracking data for 67 whales (two tags provided no locations; **Tables 21-27, Figures 39 and 40**). Tracking durations for these whales ranged from 0.2 to 143.9 d. Tracking durations were not significantly different between the seven field seasons (five historical groupings and two seasons in 2017; ANOVA, *p*-value = 0.07; **Table 28**). The average tracking duration for all implantable tags on humpback whales from 1997 through 2017 was 36.8 d (SD = 29.7 d, median = 28.5 d, maximum = 150.4 d, n = 79). Tracking durations from the 2017 California season were significantly different between DUR tags and the DM tags for which the O-rings failed (n = 6; see **Section 3.2.1**), so the latter set of failed tags was not included in the above comparisons of tracking duration.

There was a positive relationship between tracking duration and total distance traveled by individual humpback whales (linear regression using log-transformed variables, *p*-value < 0.0001). After accounting for this relationship, distance traveled was found to be significantly different between humpback whales tagged in Southeast Alaska in 2014 and 2015 and those whales tagged in either Southeast Alaska in 1997 or the Aleutian Islands in 2008 (general linear model of log-transformed variables, p-value = 0.04), with 2014-2015 whales having longer distances than those in 1997 and 2008 (**Table 28**). Total distances traveled by humpback whales tagged in California or Oregon did not differ significantly between years or from any of the Alaska field seasons mentioned above.

Six of the 88 humpback whales tagged by OSU in Eastern North Pacific feeding areas were tracked for their full migration to a winter breeding ground, and 20 more were tracked for part of their southbound migration (**Figures 39 and 40**). Of the 47 humpbacks tagged in Southeast Alaska, 23 began their winter migration, with start dates ranging from 16 November to 5 January. Two of these whales were tracked to winter destinations in Hawaii, with 18 more headed in that direction. One Southeast Alaska whale migrated to Mexico in 2015, and one more traveled down the US West Coast in 2014 along a similar route (presumably to Mexico) before its tag stopped transmitting off Point Arena, California. A third Southeast Alaska whale was tracked on a westerly trajectory into the Gulf of Alaska before its tag stopped transmitting.

Of the 29 humpbacks tagged during California field seasons, two whales began migrating and reached winter destinations; one (actually tagged in southern Oregon) departing from the Gulf of the Farallones and traveling to Mexico, and one departing from Point Conception and traveling to Guatemala, with migration start dates of 27 October 2005 and 13 November 2005, respectively. Of the seven humpbacks tagged in Oregon (2016 and 2017), one whale began migrating and reached a winter destination in Mexico (as described above in **Section 3.2.1**), departing from Point St. George, California, on 24 December 2017.

The latitudinal range, or the difference between the latitudes of the northern-most and southern-most locations for all humpback whales in a given season, was the longest for humpbacks tagged in Southeast Alaska in 2014 and 2015 (when migrations were included) at 40 degrees. Humpbacks tagged in California and Oregon had very similar latitudinal ranges to one another, but they were quite a bit smaller than the range of Southeast Alaska humpbacks (30 degrees for California whales from 2004 and 2005 [not including the whale tagged in southern Oregon in 2005], and 28 degrees for Oregon whales). When migratory locations were not included (i.e., only considering the tracked locations during the feeding season), latitudinal ranges were longest for humpbacks tagged in California and virtually the same between California seasons (11 degrees for California 2017 and 10 degrees for California 2004-2005), extending from the Southern California Bight to central Oregon. The next longest, non-migration, latitudinal range was for humpbacks tagged in Southeast Alaska in the fall of 2014 and 2015 (8 degrees), extending from just north of Vancouver Island to Lynn Canal, north of Juneau. In comparison, the range for whales tagged in Southeast Alaska during summer 1997 was much smaller (3 degrees), extending from the southern end of Chatham Strait to Lynn Canal. Humpback whales tagged in Oregon had intermediate length latitudinal ranges, extending from Point Arena, California, to Vancouver Island in 2017 (7 degrees), and from Cape Mendocino, California, to Depoe Bay, Oregon, in 2016 (4 degrees). The latitudinal range for humpbacks tagged out of Dutch Harbor, in the Aleutian Islands of Alaska, in 2008 was 4 degrees.

3.6.2 Use of Navy Training Areas

The NWTT was the most heavily used Navy training range for all tagged humpback whales, with 14 percent of tracked whales having locations there (**Table 29, Figure 41**), followed by the PT MUGU range (7 percent of tracked whales; **Figure 42)**. The mean number of days spent in the NWTT ranged from a low of 5.7 d (for humpback whales tagged off Oregon in 2016) to 31.1 d (for humpback whales tagged off Oregon in 2017), with a maximum residency in this area of 86.5 d (for a whale tagged off Oregon in 2017). The mean number of days spent in PT MUGU ranged from a low of 1.8 d (for a humpback whale tagged in Southeast Alaska in 2015) to 22.8 d (for humpback whales tagged off California in 2017), with a maximum residency in this area of 33.8 d (for a whale tagged off California in 2005). Four percent or less of the whales tracked had locations in SOCAL, Area W237, or SOAR (**Figures 43-45**). No whales had locations in the GOA training area. Maximum residency in these three Navy areas was 2.8 d, 14.3 d, and 0.4 d, respectively. Sample sizes were not large enough to permit meaningful statistical comparisons of residency between field seasons in any of the Navy training areas.

Humpback whale locations in the NWTT occurred predominantly in the summer and fall (August through November for whales tagged in California, and September through December for whales tagged in Oregon/southern Washington). Two whales tagged in Southeast Alaska had locations in the NWTT in December and January, as they migrated south through the range. Humpback locations occurred in Area W237 during November and December (whales tagged in Oregon) and in December only for whales tagged in Southeast Alaska. Locations in PT MUGU took place during July through December for whales tagged in California and in December only for a whale tagged in Southeast Alaska. Humpback whales were located in SOCAL in November (whales tagged in California), December (a whale tagged in Southeast Alaska), and January (a whale tagged in Oregon). The one humpback trackline that crossed SOAR (a whale tagged in southern Oregon during the 2005 California field effort) occurred there in November.

Mean distances to shore for tagged humpback whales in Navy areas ranged from 34 km in PT MUGU (for a whale tagged off southern California in 2017) to 317 km in SOCAL (for a whale tagged off Oregon in 2017; **Table 30**). As with residency time, sample sizes were not large enough to permit meaningful statistical comparisons of distance to shore between field seasons in any of the Navy training areas. The whales with the greatest distances to shore in Navy areas were those individuals that were migrating south to breeding areas.

3.6.3 Use of BIAs off the US West Coast, Gulf of Alaska, Aleutian Islands, and Bering Sea

Humpback whales tagged off California and Oregon (US West Coast) spent no time in Alaska BIAs, and vice versa, so BIA use for the two regions (West Coast and Alaska) are presented separately (**Tables 31 and 32, Figures 46-52**). Some West Coast BIAs were used almost exclusively by humpback whales tagged in California, and some were used exclusively by whales tagged in Oregon. Of the former, the most heavily used BIA for humpbacks tagged in California was the Farallones-Monterey BIA, with 26 of 28 tagged whales having locations there, and a mean residency of 22.1 d (maximum residency of 71.6 d; **Figures 8 and 46**). Four humpback whales tagged in California used the Morro Bay BIA (mean residency of 6.8 d, maximum residency of 11.7 d; **Figures 12 and 47**), and one whale used the Santa Barbara BIA (residency of 3.3 d; **Figure 11**). The NWA BIA and the OCNMS were used by only one whale, tagged in

Oregon, with residencies of 7.4 d and 8.6 d in each area, respectively (**Figures 29 and 30**). Three West Coast BIAs were used by whales tagged in both California and Oregon; Fort Bragg (**Figures 9 and 48**), PSG (**Figures 28 and 49**), and Stonewall (**Figures 10 and 50**). Six of 28 whales tagged in California had locations in the Fort Bragg BIA (mean residency of 2.4 d, maximum residency of 4.5 d) and 17 percent of whales tagged in Oregon had locations there (one whale with residency of 2.2 d). The PSG BIA was used by a larger proportion of whales tagged in Oregon (four of six tagged whales, mean residency of 3 d, maximum 4.4 d) than whales tagged in California (four of 28 tagged whales, mean residency of 5.4 d, maximum 11.3 d). One humpback whale tagged in California spent 0.7 d in the Stonewall BIA in Oregon, whereas fourhumpbacks tagged in Oregon spent time there (mean residency of 3.9 d, maximum 9.9 d).

Seasonal use was longest for the Farallones-Monterey BIA, with humpback locations there during 5 mo (July through November). This did not differ remarkably between the 2004-2005 and the 2017 California seasons. Humpback whale locations occurred in the Fort Bragg BIA and the Stonewall BIA during 4 mo (August through November). Locations also occurred during 4 mo in the PSG BIA (September through December). Humpback whale locations occurred in the Morro Bay BIA during 3 mo (August, October, and November) and during 3 mo in the Santa Barbara BIA (July, August, and December). One humpback whale (tagged in Oregon) was located in the NWA BIA during November, and in the OCNMS during November and December.

All humpback whales tagged in Southeast Alaska had locations in the SEAK BIAs (summer and fall combined), with residencies ranging from a mean of 12 d for whales tagged in the fall of 2014 and 2015 to a mean of 34.2 d for whales tagged in the summer of 1997 (**Table 32, Figure 51**). Median residency in the SEAK BIAs was not significantly different between whales tagged in the summer and those tagged in the fall (Kruskal-Wallis *p*-value = 0.39). Humpback whale locations occurred in the SEAK BIAs during 3 mo for whales tagged in the fall of 2014 and 2015 (November through January), and during 5 mo for whales tagged in the summer of 1997 (July through November). All five humpback whales tagged out of Dutch Harbor (Aleutian Islands) in 2008 had locations in the Aleutian BIA, with mean residency of 0.9 d (maximum residency of 1 d; **Figure 52**). These locations occurred during September, October, and November. One of these latter whales also spent 1.7 d in October in the Bristol Bay BIA (**Figure 52**).

3.6.4 Home Ranges and Core Areas

HRs (90 percent kernel isopleths) for feeding-area humpback whales differed significantly between the 2014-2015 Southeast Alaska season and the Oregon and California seasons (ANOVA of log-transformed HR, *p*-value = 0.01; **Table 28; Figures 53, 55, 57, and 59**), with HR sizes being smaller for 2014-2015 Alaska whales than whales tagged elsewhere. CAs (50 percent kernel isopleths) also differed significantly between seasons, with those from 2014-2015 Southeast Alaska being smaller than all other seasons and those from 2017 California being smaller than 2004-2005 California (ANOVA of log-transformed CA, *p*-value = 0.006). CAs from 1997 Southeast Alaska and 2017 Oregon were not significantly different from those of either California season.

Areas of highest use (where CAs overlapped for the most number of whales) for humpback whales tagged off California were centered off of Half Moon Bay in 2004-2005 (overlap of four whales; **Figure 54**) and Point Reyesin 2017 (overlap of four whales; **Figure 11**). Humpback whales tagged in Oregon in

2016 did not provide long enough tracks for HR and CA analysis, but those tagged in 2017 off Oregon had areas of highest use off the Columbia River mouth and off Trinidad Head, northern California (**Figure 32**). For humpback whales tagged in the summer of 1997 in Southeast Alaska, areas of highest use were at the southern tip of Admiralty Island, and also along the west coast of Admiralty Island in the northern half of Chatham Strait (overlap of two whales; **Figure 56**). For those whales tagged in the fall of 2014 and 2015, areas of highest use were in Seymour Canal, on the east side of Admiralty Island, and in the southern part of Stephens Passage (overlap of three whales; **Figure 58**). CAs for one humpback tagged in the Aleutians were located just north of Unimak Pass, and at the northeast corners of Unalaska and Umnak Islands (**Figure 59**).

3.6.5 Ecological Relationships

The number of SSSM tracks in the historical data set ranged from two (for Oregon in 2016) to 20 (for Southeast Alaska in 2014), with a corresponding number of regularized locations ranging from 25 to 291 (**Table 10**). The behavioral classification for these locations is shown in the maps in **Figure 24**. The proportion of locations classified as ARS ranged from 0 to 87.2 percent across tagging seasons/years. (All locations for the two Oregon tracks in 2016 were classified as uncertain by the SSSM, likely because these tracks were too short for meaningful behavioral classification). Most notable was the very low percentage of locations classified as ARS for whales tagged in Southeast Alaska in 2014 and 2015 (6.9 and 23.7 percent, respectively), especially when compared to the 1997 season in Southeast Alaska, which yielded the highest proportion of ARS locations among the historical tracks (86.6 percent, **Table 10**). The proportion of locations classified as uncertain and transiting in 2014 and 2015 was correspondingly very high (**Table 10**). Similarly, there was a relatively low percentage of ARS locations for whales tagged in California in 2005 (56.3 percent), especially when compared to 2004 and 2017 (85.0 and 87.2 percent, respectively; **Table 10**).

Details of the environmental variables examined are provided in **Table 1**. Summary statistics for these variables obtained for the SSSM locations are reported in **Tables 11 and 12**. Average SST values at these feeding areas ranged from a low of 7.27°C to a high of 16.18°C, with SST being highest for animals tracked off California and Oregon and lowest for animals tracked in Southeast Alaska and the Aleutian Islands. Average CHL values ranged from a low of 0.39 mg m^{-3} to a high of 4.35 mg m^{-3}, being highest for animals tracked off California and Oregon and lowest for animals tracked in Southeast Alaska and the Aleutian Islands (**Table 11**). (Note that no remotely sensed oceanographic observations were available for the 1997 season in Southeast Alaska, and that very few CHL observations were available at this location for the 2014 and 2015 seasons due to the persistently cloudy conditions and to the enclosed nature of these waters relative to the coarse 4.63-km resolution of the CHL product).

Average seafloor DEPTH in the historical data set ranged from 131.97 m for the animals tracked off the Aleutian Islands in 2008 to 738 m for the animals tagged in Oregon in 2017 (**Table 12**). Average DISTSHELF ranged from 4.29 km for Southeast Alaska in 1997 to 31.6 km for Southeast Alaska in 2015. Consequently, average DISTCOAST had a similar trend, with a low of 6.31 km for animals tagged in Southeast Alaska in 1997, although the highest distances to shore (54.81 km) occurred for animals tagged in Oregon in 2017. Average seafloor SLOPE was lowest for animals tagged in Oregon in 2016 (0.59 deg) and highest for animals tagged in Southeast Alaska in 1997 (2.48 deg). Finally, average

ASPECT of the slope faced toward the southeast for animals tagged in Southeast Alaska in 2014 and 2015 (149.26 and 142.33 deg, respectively), toward the south for animals tagged in Southeast Alaska in 1997 and the Aleutians in 2008 (174.57 and 191.77 deg, respectively), toward the southwest for animals tagged in California in 2004, 2005, and 2017 (234.53, 229.73, and 233.21 deg), and toward the west-southwest for animals tagged in Oregon in 2016 and 2017 (241.9 and 244.92) (**Table 12**).

3.6.6 Genetics

Biopsy samples from several of the historical tagging seasons were collected and are currently archived at OSU (see **Tables 22-27**), but their analysis and interpretation will require additional funding.

3.6.7 Photo-identification

OSU is in the process of submitting photo-IDs to HappyWhale from the historical tagging seasons (see **Table 16**). We also plan to share our catalog with other researchers working in the Eastern North Pacific. However, the matching as well as the integration with the tracking and genetics data streams will require additional funding.

4 Discussion

4.1 Tracked Movements

A total of 88 humpback whales were tagged by OSU in feeding areas of the Eastern North Pacific from 1997 to 2017, providing tracks of 46 whales tagged in Southeast Alaska, 27 whales tagged in California, seven whales tagged in Oregon, and five whales tagged in the Aleutian Islands. The tracking data obtained from humpback whales tagged off California and Oregon in 2017 through this CESU agreement expand our understanding of their localized and long-distance movements in the California Current System and provide valuable insight into feeding group structure in California, Oregon, and Washington. Generally, the locations obtained during 2017 align well with sightings of humpback whales recorded during NOAA ship surveys (summer and fall 1991-2008) and Cascadia Research Collective small-boat surveys (1986-2011) along the US West Coast (Calambokidis et al. 2015), and further support reported humpback whale affinity for continental shelf and shelf edge habitat (Calambokidis et al. 2015).

For whales tagged in California in 2017, the concentration of tracks around San Francisco partly reflects the location of tag deployments in that area and the short tracking durations of six tags that experienced leakages. These caveats notwithstanding, the area is undoubtedly an important feeding habitat for humpbacks, as evidenced by four tagged whales that remained there for periods of 27 to 82 d. The track of the humpback whale tagged in the Santa Barbara Channel on 21 July (DUR Tag #830, a male with genetic assignment to the Central America DPS; **Tables 4 and 15**) did not intersect with the whales tagged off central California, despite a 44-d tracking period for this whale, which would have been ample time to travel to the latter area. This may signify a separation of humpback whales from southern and central California during the feeding season or the more southern whale simply finding adequate forage in the area, but a larger sample size of whales from both regions would be required to fully address this.

Humpback whales tagged off California in 2004 and 2005 had very similar overall distribution to those tagged in 2017, with an almost identical latitudinal range in their locations. CA sizes, however, were significantly larger for whales in 2004-2005 than whales in 2017, and encompassed more of the coastline. Becker et al. (2012) reported humpback whales to be widely spread throughout the California Current System in 2005, compared to more concentrated distributions in other years toward areas where persistent krill hotspots were identified. Fleming et al. (2015) noted a delay in upwelling and low population abundances of krill in the California Current System from 2004 to 2006, with warmer stable conditions allowing sardine and anchovy populations to increase, and range further north, especially in the case of sardine. Isotopic signatures in biopsy samples from humpback whales at that time reflect a diet dominated by schooling fish (Fleming et al. 2015). Perhaps a switch from a diet of krill to fish may have contributed to the larger CA sizes in 2004-2005.

In addition to concentration of locations off central Oregon, southern Oregon, and northern California, the Columbia River mouth was also an area of importance for humpback whales tagged in Oregon in 2017. Calambokidis et al. (2017) documented changes to humpback whale distribution in a number of areas along the US West Coast in recent years, including sightings part way up the Columbia River and around the town of Chinook, Washington, in 2015 and 2016; areas in which locals had previously not seen humpback whales. This contrasts with past studies (Calambokidis et al. 2008), which reported a gap in sightings of humpback whales between central Oregon and central Washington. Humpback whales have been shown to switch their dominant prey type (from euphausiids to fish and vice versa) in response to changing oceanographic conditions and prey availability (Fleming et al. 2016), and Calambokidis et al. (2017) report that shifts in prey, especially when targeting nearshore concentrations of fish like anchovies, has sometimes brought whales closer to shore and into new areas. The humpback whales documented in the Columbia River by Calambokidis et al. (2017) appeared to have been feeding on anchovies. It is unclear whether the use of the Columbia River mouth by humpback whales is a temporary occurrence, or whether this area will continue to be important for feeding humpbacks. Although the anchovy season is reasonably short and the numbers of whales there presently is apparently low, their location in the river mouth (with a busy up-river port) could represent an increased risk to humpback whales from potential collisions with vessels if their numbers continue to grow in the future.

Humpback whales feeding in northern Washington and southern British Columbia are considered a separate feeding aggregation to humpbacks feeding in California and Oregon. This distinction results from the little interchange reported between the two groups (Calambokidis et al. 2008, 2015, Wade et al. 2016), an apparent genetic differentiation between them (Baker et al. 2013), as well as the gap in sightings between central Oregon and central Washington mentioned above. Recently, Schorr et al. (2013) reported the movement of a tagged humpback whale between La Push, on the north coast of Washington, to Willapa Bay, on the south coast. One of the whales tagged off the Columbia River mouth in our study also spent time off Cape Flattery, northern Washington, and the southwest coast of Vancouver Island, as well as off Point St. George, northern California. These findings blur the distinction between Oregon whales and those thought to represent a separate feeding group off northern Washington and southern British Columbia. The genetic differentiation between the northern

Washington/southern British Columbia and the California/Oregon feeding aggregations reported by Baker et al. (2013) was mostly driven by California biopsy samples, with only three samples available from Oregon at the time. The genetic analysis of the biopsy samples obtained by OSU in 2016 and 2017 indicate that Oregon whales are differentiated from central and southern California whales and are more similar to northern Washington and southern British Columbia whales (see **Section 3.5.7** in this report). Additional tagging and genetic sampling in both Oregon and northern Washington would further improve our ability to determine if these feeding aggregations are truly separate.

Two humpback whales tagged off central Oregon in 2016 had a much smaller latitudinal range than those tagged off Oregon in 2017, with extended periods of time spent at various locations between Newport, Oregon, and Cape Mendocino, northern California. This difference is likely due to the much shorter tracking durations in 2016 than 2017, rather than a true range difference between years. The movements of whales tagged off Oregon in 2016 and 2017 provide further evidence for a connection between northern California and central Oregon.

The distribution of feeding humpback whales tagged in Southeast Alaska and the Aleutians during our study aligns well with sighting data published by Dahlheim et al. (2009) as well as unpublished information from opportunistic and line-transect boat-based surveys (Ferguson et al. 2015a). Humpback whales tagged in Southeast Alaska in the fall had smaller HRs than whales tagged in California and Oregon, and smaller CAs than all other regions/seasons, including whales tagged in Southeast Alaska in the summer. Smaller HRs and CAs in Southeast Alaska in the fall may denote shifts in distributions and types of prey at the approach of winter, confining whales to smaller areas to feed (Straley et al. 2018).

Nearly 60 percent of all whales tagged in Southeast Alaska in 2014 and 2015 began their migration out of their feeding area (22 of 37 whales), compared to only 25 percent of all whales tagged in Oregon, 11 percent of whales tagged in Southeast Alaska in 1997, and only 4 percent of whales tagged in California. This is simply the result of tagging late in the feeding season (November) in Southeast Alaska (2014 and 2015), compared to the September and October tagging off Oregon, July tagging in Southeast Alaska in 1997, and July through October tagging in California. To document more migrations to breeding destinations for Oregon and California whales, tagging should occur later in the feeding season unless average tag attachment durations can be greatly increased for this species (which is unlikely in the near future). Tagging late in the feeding season is easier to conduct in the protected inland waters of Southeast Alaska, however, than along the open waters of the West Coast. Late fall and early winter along the California and Oregon coast experience notoriously rough ocean conditions due to storms in the North Pacific, resulting in very few tagging opportunities at that time of year.

4.2 Use of Navy Training Areas

The tracking data obtained from humpback whales through this CESU agreement also contribute to our understanding of whale use of Navy training and testing areas on the US West Coast. Because West Coast Navy training ranges overlap with feeding areas for humpback whales in Oregon and California, tagged humpbacks had extended residencies in the ranges, with a maximum of 86 d in the NWTT for Oregon whales, and a maximum of 34 d in PT MUGU for California whales. With the exception of two migrating whales transiting through southern ranges, no whales from Oregon spent time in PT MUGU or

SOCAL, and no whales from California spent time in Area W237. This latter finding supports the distinction of whales from northern Washington/southern British Columbia and whales from California (Calambokidis et al. 2015). Humpback whales tagged in both Oregon and California spent time in the NWTT area; however, the proportion of whales and their spatial and temporal occupancy in the area differed between the two groups. Fourteen percent of humpback whales tracked from California traveled to the NWTT, predominantly using only the southern half of the range and spending less time there than whales tagged in Oregon, of which 100 percent spent time in the NWTT, with locations throughout the range.

With the exception of two Southeast Alaska whales that migrated down the West Coast, no whales from Southeast Alaska or the Aleutians spent time in Gulf of Alaska or West Coast Navy training ranges. Residency in Navy training ranges for the migrating whales reflected the north-south extent of ranges, with neither whale stopping to spend extended periods of time in any of the training areas (maximums of 10 d in NWTT, 3 d in Area W237, 2 d in PT MUGU, 3 d in SOCAL). Tagging location, timing, and sample size likely play roles in our documentation of foraging humpback whales in Navy training areas. Future tagging earlier in the year, as well as more deployments in the Pacific Northwest and southern California (or south of the US) would improve our understanding of seasonality as well as use of the more southern Navy ranges during the foraging season, while later taggings would produce more southern migration tracks to breeding areas.

4.3 Use of BIAs

The occupancy of US West Coast feeding BIAs may also suggest spatial separation of humpback whales throughout feeding areas, as no humpbacks tagged in Oregon were found in BIAs south of Fort Bragg, California, and only one whale tagged in California was found in BIAs north of PSG. The extensive use of the Farallones-Monterey Bay BIA by whales tagged in California reflects the predominance of tagging locations in or near that BIA, but also speaks to the whales' affinity for the region, as evidenced by substantial residency (average 22 d) and the seasonal extent (July through November) of locations there. The southernmost BIA (Santa Barbara) saw very little use by humpback whales, but this is likely also attributed to tagging location, as only one whale was tagged in southern California. The fact that no humpback whales tagged in California spent time in the NWA BIA or the OCNMS supports the distinction between feeding groups mentioned above. But what complicates that distinction, however, is the humpback whale tagged off central Oregon that had locations in the NWA BIA and the OCNMS, as well as in the PSG BIA in northern California. As with Navy training range use, more tag deployments on humpback whales in the Pacific Northwest and southern California will help us understand potential differences in BIA use among these feeding aggregations. The cluster of locations off the Columbia River mouth shown in this study (**Figures 31 and 32**) as well as in Calambokidis et al. (2017) highlights this is as an area of current importance for humpback whales off the West Coast.

There was substantial overlap between the tracked distribution of humpback whales tagged in Southeast Alaska and the BIAs derived for this species in Southeast Alaska (Ferguson et al. 2015a). None of the humpback whales tagged in Southeast Alaska or the Aleutians had locations in the West Coast BIAs, nor did any of the whales tagged in Oregon and California had locations in the Alaska BIAs. Southeast Alaska's BIAs are generally small, restricted to coastal waters, and used seasonally. Therefore, it is not surprising that migrating whales from Alaska would not occur in West Coast BIAs (and if they did, their movement behavior, as inferred from SSSMs, would likely indicate they are transiting through the BIAs).

4.4 Dive Behavior

DUR and DM tags allowed for an examination of humpback whale diving behavior over extended periods of time (up to 149.8 and 51.4 d, respectively). DM tags generally transmitted data for a larger percentage of the overall tracking period compared to DUR tags. This was likely primarily due to DM tags transmitting for six 1-h periods each day compared to five for the DUR tags. Tags with shorter attachment durations also summarized a larger percentage of the tracking duration as fewer dives were made, meaning messages stayed in the transmit buffer longer, allowing for more repetition of dive messages. This indicates that a larger percentage of the tracking period may be summarized by increasing the number of transmit periods per day. However, increases in the number of transmit periods come with a corresponding reduction in the maximum functional life of the tag's battery, so research priorities should be carefully considered when deciding on the desired level of data recovery.

DM tags documented spatially explicit feeding behavior, with the area of highest relative feeding effort occurring offshore of the tagging area. However, those results are likely biased by the data from Tag #4175 (a female tagged on 4 August 2017, with genetic assignment to the Central America DPS; **Tables 4 and 15**). This tag recorded deeper dive depths and more lunges per dive than other DM tagged whales, suggesting a possible behavioral difference. Humpback whales are flexible foragers, capable of feeding on both fish and krill off the US West Coast (Clapham et al. 1997, Fleming et al. 2016). The data recorded by Tag #4175 were characteristic of rorqual krill-feeding behavior, with multiple lunges per dive made to deeper depths during the day (Calambokidis et al. 2007, Goldbogen et al. 2008, Mate et al. 2017). This whale also spent most of the tracking period further offshore over the continental slope, where krill aggregations are higher (Santora et al. 2011), compared to the other tagged whales. Finally, this tag recorded high numbers of lunges per dive on multiple consecutive dives to the same depth range, indicating feeding bouts (Mate et al 2017).

The generally shallow dive depth and consistent low levels of lunges per feeding dive recorded by other DM-tagged whales suggests they were feeding on fish. Lunges were recorded more sporadically for these whales, with singular lunges occurring intermittently during multiple consecutive dives to a specific depth. It is possible that these whales were feeding at a lower rate, although humpback whales are known to display much more kinematic variability when feeding on fish compared to krill (Cade et al. 2016), so the tags may not have detected all lunge feeding events made on fish. Whatever the case, the spatial distribution of feeding effort (**Figure 23**) over-represented effort from Tag #4175 (possibly feeding on krill) while probably under-represented effort for the other DM-tagged whales (which may have been feeding on fish).

Dive durations for both California- and Oregon-tagged whales were remarkably consistent throughout the day, although Oregon whales showed a slight trend for longer daytime dives. The spatial pattern of dive durations for Oregon whales was also more variable compared to California whales. While these results may be due to the more limited sample size of Oregon whales, there is reason to suspect it may be related to behavior differences. The data recorded for California Tag #4175 are very similar to two DM-tagged humpback whales tagged off Oregon in 2016 (Mate et al. 2017). Both 2016 Oregon whales recorded multiple lunges per dive and one showed a strong diel trend in its dive behavior (the other tagged whale did not have a strong diel trend, although it may have had more limited feeding opportunities as it traveled the furthest during the tracking period). The similarities to Tag #4175 suggest the whales were feeding on krill off of Oregon. High concentrations of krill are also most often found in highly localized upwelling regions (Santora et al. 2011), while schools of fish are more mobile so the spatial variability in dive behavior may be indicative of krill feeding. Future deployment of additional DM tags off Oregon would help to resolve this question, as would direct documentation of prey type being targeted.

While there was not an overall trend of dive durations across the different hSSSM-derived behavioral modes, there were indications that durations were longer for locations classified as transiting and uncertain for tracks with substantial directed travel (e.g., DUR Tag #10822 that traveled to Oregon, a male with genetic assignment to the Central America DPS; **Tables 4 and 15**). Other rorquals have been shown to dive for shorter duration than expected when feeding due to the high energetic costs of lunge feeding (Acevedo-Gutierrez et al. 2002), so the shorter dive durations during ARS mode may represent an increased energetic cost while the whales were feeding. Unfortunately, there are several confounding factors limiting our ability to interpret behavior from dive duration data. Dive depth is positively correlated to dive duration due to the increased travel time, which may offset any reduction in duration due to increased energetic cost of feeding. Also, while an assumption might be made of an optimal dive duration while traveling, other considerations like poor weather or large waves may lead to energetic benefits for the whales staying underwater longer.

These results provide interesting trends for humpback whale behavior and underscore the need for additional DM tag deployments. The addition of dive depth and lunge-feeding events to the dive duration information has the possibility of revealing significant aspects of humpback whale behavior. The ability to potentially distinguish between whales feeding on fish versus krill allows for the exploration of many important questions. Perhaps most important to the Navy is whether the movement of whales differs when they are feeding on fish versus krill, as this could determine how long a whale might stay within a training area and thus be exposed to potential anthropogenic impacts. Also of interest is whether individual whales feed on multiple prey types or if they specialize, which would suggest the possibility of additional structure within the population.

4.5 Ecological Relationships

The proportion of hSSSM locations classified as ARS was higher for animals tagged off California than off Oregon in 2017 (87.2 versus 63.2 percent), with a corresponding difference in proportion of locations classified as transiting (6.5 versus 22.3 percent). As discussed for the observed differences in dive behavior between these two regions (see **Section 4.4**), this result could be an indication of prey types being targeted (fish or krill), with the associated energetic demands of lunge feeding, but it may also be driven by the small number of animals tracked off Oregon.

The proportion of SSSM locations classified as ARS was generally high across feeding grounds, with a couple of notable exceptions. As discussed for the tracked movements during these years (see **Section 4.1**), whales were reported to be widely spread throughout the California Current System in 2005, presumably in response to oceanographic anomalies and dispersed prey resources (Becker et al. 2012, Fleming et al. 2015).

The notably low percentage of ARS locations for whales tagged in Southeast Alaska in fall of 2014 and 2015, compared to the high proportion recorded in summer 1997, is likely a reflection of seasonal differences in foraging behavior, prey types, and habitat occupation. As discussed for the tracked movements (see **Section 4.1**), whale distribution in Southeast Alaska was more confined in the fall, probably affecting the behavioral classification by the SSSMs.

The average SST values at the different feeding areas, ranging from a low of 7.27°C to a high of 16.18°, followed the well-known global latitudinal temperature gradient. In contrast, the high average CHL values for animals tracked off California and Oregon reflected the elevated phytoplankton biomass characteristic of the upwelling-driven California Current Ecosystem, while the low average CHL values for animals tracked in Southeast Alaska and the Aleutian Islands reflected the low phytoplankton biomass characteristic of the downwelling-driven coastal Gulf of Alaska (Stabeno et al. 2004, Saldivar-Lucio et al. 2016). Average SST values in California provided additional support for the observed behavioral differences between 2004 and 2005 discussed above. In 2005, SST was, on average, 1.65°C warmer than in 2004 and it was spatially more variable (SD = 5.21°C), confirming that in 2005 whales off California were foraging in a warmer (i.e., with reduced upwelling) and more heterogeneous environment.

Average seafloor DEPTH was shallowest for animals that did not move much during the tracking period, such as off the Aleutians in 2008 and Oregon in 2016 (131.97 and 133.16 m, respectively), indicating the strong preference for humpback whales for forage over continental shelf habitats (Calambokidis et al. 2015). Animals tagged in other feeding areas occupied somewhat deeper depths (246.57 to 738 m) suggesting that foraging over the continental slope was also important, but these averages were also likely affected by movements over deep waters, especially for whales that migrated toward breeding destinations. In any case, these depth ranges contrast with the significantly deeper depths occupied by tagged blue and fin whales in similar habitats in the Eastern North Pacific (see Mate et al. 2017). Average distance to the shelf break in all feeding areas was relatively small (maximum = 31.6 km), similarly highlighting the association with the shelf and shelf break for humpback whales. Except for the very low average slope recorded for animals tracked off Oregon in 2016 (0.59 deg), which was likely biased by the small sample size and short duration of these tracks, average slope was fairly similar (1.30-2.48 deg) across foraging sites. However, the aspect of the slope varied from a predominantly southwest direction for animals tracked off California, to west-southwest for animals tagged in Oregon, to south for animals tagged in Southeast Alaska and the Aleutians, predictably following the large-scale geometry of the basin, but otherwise did not appear indicative of an ecological relationship.

4.6 Genetics

4.6.1 Population Structure of Feeding Areas

The analysis of mtDNA haplotypes showed significant differences between the tagging samples from California and the tagging samples from Oregon, despite the relatively small sample size for the latter. This indicates a degree of differentiation between feeding areas not previously accounted for the SPLASH program (Baker et al. 2013). Previously, whales feeding off of Oregon were considered to be more closely affiliated with California, referred to in SPLASH as CA/OR (see **Figure 38**). With the inclusion of the tagging samples, Oregon now shows a closer affinity with the Southern British Columbia/Washington feeding area (SBC/WA in **Figure 38**). A larger samples size for Oregon and finer-scale analyses are needed to delineate the most appropriate boundary for feeding areas along the US West Coast.

4.6.2 Individual Assignment to DPS

The individual assignment procedures provided evidence of the genetic affinity of each individual to each of the four DPSs. The relative likelihood scores of these assignments for the whales tagged in California were generally consistent with the expectation of mixing between individuals from the Mexico and Central America DPSs, as reported previously from photo-identification (Calambokidis et al. 2008, 2017) and from the comparisons of mtDNA haplotype frequencies (Baker et al. 2013). The relative likelihood scores of assignments for the whales tagged in Oregon showed a greater diversity of affinities for the DPSs, including a greater proportion of ancestry from Hawaii and the Western North Pacific. This is consistent with the test of differentiation showing a significant difference in mtDNA haplotypes for the California and Oregon tagging samples (i.e., the haplotype characteristics of the Central America DPS are less frequent off the coast of Oregon). This is presumably due to differences in migratory connections and habitat use (see Calambokidis et al. 2017). Evidence of presence of the Western North Pacific DPS off the western coast of North America was previously known from photographic matches (e.g., between Japan and Vancouver Island in 1990, 1991, and 1993; Darling et al. 1996), and the close affinity of the Oregon tissue samples to the Southern British Columbia/Washington feeding area found in this study reflects this composition.

Although the results of the assignment procedure are encouraging and provide a useful covariate for analysis of the tagging results, it is important to note that the accuracy of the assignments is dependent on the quality of the reference data set, in this case, as described from samples collected during the SPLASH program (Baker et al. 2013). These samples were collected more than a decade ago, and more importantly, were limited in number of microsatellite loci and in population sampling for the two DPSs of greatest concern, Central America and Mexico (see **Table 14**). The confidence in individual assignments of whales on the feeding grounds could be improved by increasing the number of loci in the reference data set using genomic methods (e.g., RADseq or similar, Andrews et al. 2016) and by increasing the population sampling using available samples collected in Mexico during SPLASH (Calambokidis et al. 2008). For Central America, however, there is a need to collect new samples, preferably from throughout the breeding range of this DPS.

4.7 Photo-identification

Although the focus of the photo-ID results presented in this report is only on the tagged whales, the number of IDs collected from untagged whales during the field efforts was substantially higher (see **Table 16**). We are in the process of submitting these IDs to HappyWhale. Once the analysis and matching is complete, these additional IDs will greatly increase the number of migratory connections and potential DPS assignments for whales seen in the vicinity of tagged whales, which will expand the overall interpretation and significance of our tagging and genetic results.

Photo-ID is a powerful tool for identifying whales over time and distance, but is limited by the amount of cooperation between researchers in sharing their catalogs and the amount of time needed to review IDs for matches, compile, and exchange the results. By using HappyWhale, which automates much of the work and brings together many sources, we hope to overcome some of these limitations to make more connections between areas. Our humpback whale work in Oregon has already nearly tripled the number of individual IDs from that area that are in HappyWhale. However, since not all researchers submit their photo-IDs to HappyWhale, more detailed work will also have to involve direct collaboration with those researchers to get a more complete picture of where the tagged whales go after the tags have stopped transmitting and where they have been seen historically.

4.8 Assignment to DPS from Multiple Lines of Evidence

Tagging has long been a useful tool in marine animal population management and conservation, and methods have been developed for incorporating movement data and other data streams from electronic tags (Kurota et al. 2006, Greene et al. 2009, Taylor et al. 2011, Sippel et al. 2014). For humpback whales, the shorter average tag attachment duration relative to other whale species (Mate et al. 2007) represents a limitation. Further, the mixing of DPSs that occurs in the feeding areas (Bettridge et al. 2015) poses additional challenges that are best addressed using complementary approaches like genetics and photo-ID (Witteveen et al. 2011). Nevertheless, through the first year of this CESU agreement, we have begun to compile a data set that offers great potential for addressing current management questions for humpback whale DPSs at the scale of the Eastern North Pacific.

A relatively small proportion of the tags deployed in feeding areas in this study lasted until the animals arrived in a breeding area. Nevertheless, these tracks were extremely valuable for directly documenting the diversity of migration routes and, in some cases, the DPS to which these whales belong. In this way, we documented one whale tagged in California in 2005 that migrated to Guatemala, revealing its association with the Central America DPS; two whales tagged in Oregon in 2005 and 2017 that were tracked to Mexico, indicating an association with either the Mexico or the Central America DPSs; and one whale tagged in Southeast Alaska in 2015 that migrated to Mexico (plus one other whale tagged in Southeast Alaska in 2014 that was last located off central California with a trajectory toward Mexico), similarly indicating an association with the Mexico (or the Central America) DPS.

For whales whose tags stopped transmitting in Mexico (or earlier), we cannot confirm that they did not travel further south to breeding areas along the coast of Central America, so the DPS assignment is less certain in these cases. However, for whales migrating out of Southeast Alaska the divergence toward the different breeding destinations is more apparent. For this region, 87 percent of the tracks (20 out of 23) had trajectories toward Hawaii (with two reaching the islands before their tags stopped transmitting, confirming their association with the Hawaii DPS), while 9 percent (2 out of 23) were tracked migrating toward Mexico, as mentioned above (although we cannot know if this was their final destination).

Inference from hSSSM/SSSM analysis of movement behavior of the tracking data can reveal additional information, however. For example, the two whales tagged in Oregon in 2005 and 2017 that were tracked to the mainland Mexico breeding ground engaged in ARS behavior on arrival (likely associated with reproductive activities) until the tags stopped transmitting shortly thereafter (see **Figure 24**), providing additional support for assignment to the Mexico DPS for these two whales. In contrast, the 2005 California whale that migrated to Guatemala passed through the same area in transiting mode and without clear evidence of a behavioral switch to ARS mode. Thus, behavioral annotation of tracking data using SSSMs/hSSSMs can potentially be helpful in distinguishing DPSs that use the same area for different purposes (e.g., as a migratory corridor versus as a feeding or breeding destination; see also **Section 4.3**), especially when no tissue samples or photo-IDs are available (as was the case for the 2005 California whale that migrated to Guatemala).

Through photo-ID we obtained additional information about the sighting histories of several of the tagged whales, both within the feeding areas and in the breeding areas, long after their tags had stopped transmitting. Notably, we were able to establish a migratory connection to Mexico for four whales tagged in California (DM Tag #833, a male; DUR Tag #10822, a male; DUR Tag #1389, a female; and DUR Tag #834, a female) and one whale tagged in Oregon (DUR Tag #4174, a female).

In terms of genetics, the composition of mtDNA haplotype frequencies indicated a significant level of differentiation between the California and Oregon feeding aggregations that was not previously realized, with Oregon animals appearing more similar to the NWA/SBC aggregation previously identified during SPLASH. Further, comparisons to the breeding areas defined by SPLASH indicated that the haplotypic composition of California whales was most similar to Central America, while the Oregon whales were most similar in haplotypic composition to those found off Mexico.

Finally, the tests of individual genetic assignment to DPS were generally successful, with assignment likelihoods in all but one case being above 65 percent, and in many cases surpassing 93 percent (see **Table 15**). As a whole, the majority of these assignments indicated a strong affinity by California animals to the Central America DPS (with a few assignments to Mexico and Hawaii), but Oregon animals were variously assigned to the Hawaii, Mexico, and Central America DPSs (and in one case the Western North Pacific DPS). In one case these results were consistent with other lines of evidence (Oregon DUR Tag #4174 stopped early but this animal was photographed in Mexico and had highest likelihood of being from the Mexico DPS), but in other cases they were at apparent odds with the tracking or photo-ID data. For example, Oregon DUR Tag #1387 was tracked to (and photographed in) Mexico, but had the highest likelihood of being from the Hawaii DPS. Four other whales tagged in California were recaptured photographically in Mexico, but their highest assignment likelihoods variously corresponded to the Central America, Mexico, and Hawaii DPSs. (In the latter cases we cannot know if Mexico was their final migratory destination or if they were in transit to Central America). These discrepancies could suggest changes in the migratory destinations of these animals (as is known to occur occasionally; Forestell and

Urbán-R 2007, Stevick et al. 2010, 2016, Clapham and Zerbini 2015). In interpreting these assignment results, however, it is important to keep in mind that their accuracy is dependent on the quality of the reference data set (which is limited to a relatively small sample size for the Central America DPS), and that assignments are also reflecting the genetic ancestry of these animals, including recent historical exchange between breeding areas.

A number of tissue samples and photo-IDs collected by OSU during the historical tagging seasons are available, and their analysis, interpretation, and integration with the tracking data would further improve our sample sizes and understanding of the occurrence of DPSs throughout the Eastern North Pacific. However, these efforts would require additional funding not currently covered by this CESU agreement.

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Table 1. List of environmental data products and variables on the ERDDAP server accessed through the R package xtractomatic v. 3.4.1. Columns include variable name (and abbreviation), measurement unit, data set or parameter (dtypename) required by xtractomatic, satellite sensor or product, and temporal and spatial resolution.

Variable	Unit	dtypename	Sensor/Product	Temporal resolution	Spatial resolution
Sea surface temperature (SST)	°C	jplMURSST41SST*	Multi-scale Ultra-high Resolution (MUR) SST Analysis fv04.1	1 d	0.01 deg (1.11 km)
Chlorophyll-*a* concentration (CHL)	mg m^{-3}	mhchla8day**	Moderate Resolution Imaging Spectroradiometer (MODIS) on Aqua satellite	8 d†	0.0417 deg (4.63 km)
Depth (DEPTH)	m	ETOPO180	ETOPO1 global relief model of Earth's surface	NA	0.0167 deg (1.85 km)
Slope (SLOPE)‡	degrees	ETOPO180	ETOPO1	NA	0.0167 deg (1.85 km)
Aspect (ASPECT)‡	degrees	ETOPO180	ETOPO1	NA	0.0167 deg (1.85 km)
Distance to 200-m isobath (DISTSHELF)‡	km	ETOPO180	ETOPO1	NA	0.0167 deg (1.85 km)
Distance to shore (DISTSHORE)§	km	cntry_06.shp	ESRI World Countries 2006	NA	50 m

*jplMURSST41SST is available from 1 June 2002 to present

**mbchla8day is available from 5 January 2003 to present

†Although this variable covers 8-d periods, it is computed as a running composite, such that it provides a value for every day.

‡The variables SLOPE, ASPECT, and DISTSHELF were not available on ERDDAP. They were derived from a DEPTH extract covering the entire study area.

§The variable DISTSHORE was not obtained from ERDDAP. It was computed from the World Countries 2006 shoreline available in ArcGIS.

Table 2. Table 2. Approach details for humpback whale tagging efforts in California and Oregon during 2017.

Season	# Days of Tagging Effort	# Whales Approached	# Whales Tagged	# Whales Tagged per Day	Average Time in Tagging Vessel (h/d)
California 2017	7	173	14	2.0	9.2
Oregon 2017	7	105	5	0.7	8.9

Table 3. Responses to tagging and/or biopsy darting by humpback whales tagged in California and Oregon in 2017.

Number of Humpback whales - California	Response to tagging/biopsy darting
6	Moderate tail flick
3	Mild tail flick
4	Tail lift
1	Moderate tail flick and tail slap
Number of Humpback whales – California	**Response to biopsy darting alone**
1	Mild tail flick
1	Tail lift
Number of Humpback whales - Oregon	**Response to tagging/biopsy darting**
1	No response
3	Mild tail flick
1	Moderate tail flick

Table 4. Deployment and performance data by tag type for satellite-monitored radio tags deployed on humpback whales off California during summer 2017. See Section 2.3.1 for location filtering method. Also included is the genetic assignment to DPS using the highest relative likelihood reported in Table 15 and shown in Figure 29. Migratory connections are indicated with symbols next to each tag number where known through tracking or from photographic recaptures (see Section 3.4.8).

Tag #	Sex	Lab ID	Deployment Locality	Deployment Date	Tag Type	Biopsy	ID Photo Collected	# Days Tracked	# Filtered Locations	Total Distance (km)	DPS Assignment
830	Male	Mno17CA001	SB Channel, CA	21-Jul-17	DUR	Yes	Yes	44.4	166	1,972	CentAm
834‡	Female	Mno17CA003	Half Moon Bay, CA	30-Jul-17	DUR	Yes	Yes	81.9	275	3,178	Mexico
1389†‡	Female	Mno17CA009	Half Moon Bay, CA	3-Aug-17	DUR	Yes	Yes	50.9	149	1,620	Hawaii
1390	Female	Mno17CA011	Half Moon Bay, CA	3-Aug-17	DUR	Yes	Yes	68.7	211	2,181	CentAm
10822†	Male	Mno17CA005	Half Moon Bay, CA	30-Jul-17	DUR	Yes	Yes	84.7	219	3,282	CentAm
10842	Female	Mno17CA007	Half Moon Bay, CA	31-Jul-17	DUR	Yes	Yes	40.2	147	1,232	CentAm
23038	Female	Mno17CA013	Half Moon Bay, CA	4-Aug-17	DUR	Yes	Yes	27.0	112	1,023	CentAm
Mean **Median**								**56.8** **50.9**	**183** **166**	**2,070** **1,972**	
833†	Male	Mno17CA002	Half Moon Bay, CA	30-Jul-17	DM	Yes	Yes	16.4	84	642	CentAm
838	Male	Mno17CA004	Half Moon Bay, CA	30-Jul-17	DM	Yes	Yes	3.9	33	273	Mexico
840	Male	Mno17CA006	Half Moon Bay, CA	30-Jul-17	DM	Yes	Yes	3.8	34	196	CentAm
848	Male	Mno17CA008	Half Moon Bay, CA	31-Jul-17	DM	Yes	Yes	4.2	33	216	Hawaii
2083	Male	Mno17CA010	Half Moon Bay, CA	3-Aug-17	DM	Yes	Yes	0.3	3	32	Mexico
4173	Female	Mno17CA012	Half Moon Bay, CA	3-Aug-17	DM	Yes	Yes	8.9	44	548	CentAm
4175	Female	Mno17CA014	Half Moon Bay, CA	4-Aug-17	DM	Yes	Yes	51.6	126	1,535	CentAm
Mean **Median**								**12.7** **4.2**	**51** **34**	**492** **273**	

KEY: DM = Telonics RDW-665 Dive-Monitoring tag; DUR = Telonics RDW-640 Duration-only tag; km = kilometer(s); # = number; CentAm = Central America; † previously seen in Mexico (HappyWhale photographic recapture), ‡ resighted in Mexico after tagging (HappyWhale photographic recapture).

Table 5. Percentage of filtered locations and time spent inside the SOCAL, PT MUGU, NWTT, W237, and SOAR areas for humpback whales tagged off southern and central California, 2017. See Section 2.3.1 for location filtering method.

Filtered Locations

Tag #	Tag Type	Total		SOCAL			PT MUGU			NWTT			W237			SOAR		
		# Locs	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days
830	DUR	167	44.4	0	0	0	50	51	22.8	0	0	0	0	0	0	0	0	0
834	DUR	276	81.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1389	DUR	150	50.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1390	DUR	212	68.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10822	DUR	220	84.7	0	0	0	0	0	0	46	33	28.2	0	0	0	0	0	0
10842	DUR	148	40.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23038	DUR	113	27.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
833	DM	85	16.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
838	DM	34	3.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
840	DM	35	3.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
848	DM	34	4.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2083	DM	4	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4173	DM	45	10.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4175	DM	127	51.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean+		**118**	**34.9**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Median+		**120**	**33.6**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

KEY: DM = Telonics RDW-665 Dive-Monitoring tag; DUR = Telonics RDW-640 Duration-only tag; Locs = Locations; # = number; % = percentage; +Summary statistics do not include zero values in their calculation.

Table 6. Geodesic distances (km) to nearest point on shore in Navy training ranges for humpback whales tagged off California in 2017 (including mean, median, and maximum distance to shore). The number of locations includes filtered locations (see Section 2.3.1 for filtering method) plus deployment location (when the deployment location occurred in a Navy range).

Tag #	Tag Type	SOCAL				PT MUGU				NWTT				W237			
		n	Mean	Median	Max	n	Mean	Median	Max	n	Mean	Median	Max	n	Mean	Median	Max
830	DUR	0	-	-	-	84	34	23	98	0	-	-	-	0	-	-	-
10822	DUR	0	-	-	-	0	-	-	-	102	88	64	201	0	-	-	-
Mean			-	-	-		-	-	-		-	-	-		-	-	-
Median			-	-	-		-	-	-		-	-	-		-	-	-

KEY: DUR= Telonics RDW-640 Duration-only tag; n = number of locations.

Table 7. Percentage of filtered locations and time spent inside BIAs for humpback whales tagged off southern and central California, 2017. See Section 2.3.1 for location filtering method.

Filtered Locations

Tag #	Tag Type	Total		Santa Barbara - San Miguel			Morro Bay to Point Sal			Gulf of the Farallones			Fort Bragg			Point St. George			Stonewall to Heceta Bank			Northern Washington			Olympic Coast NMS		
		# Locs	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days
830	DUR	167	44.4	10	8	3.3	15	15	6.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
834	DUR	276	81.9	0	0	0	0	0	0	87	87	71.6	4	3	2.5	0	0	0	0	0	0	0	0	0	0	0	0
1389	DUR	150	50.9	0	0	0	0	0	0	57	57	28.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1390	DUR	212	68.7	0	0	0	0	0	0	84	87	59.6	9	7	4.5	0	0	0	0	0	0	0	0	0	0	0	0
10822	DUR	220	84.7	0	0	0	0	0	0	33	36	30.5	<1	1	1.1	0	0	0	2	<1	<1	0	0	0	0	0	0
10842	DUR	148	40.2	0	0	0	0	0	0	97	99	40.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23038	DUR	113	27.0	0	0	0	0	0	0	95	98	26.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
833	DM	85	16.4	0	0	0	0	0	0	76	80	13.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
838	DM	34	3.9	0	0	0	0	0	0	68	71	2.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
840	DM	35	3.8	0	0	0	0	0	0	71	69	2.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
848	DM	34	4.2	0	0	0	0	0	0	100	100	4.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2083	DM	4	0.3	0	0	0	0	0	0	100	99	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4173	DM	45	10.2	0	0	0	0	0	0	67	65	6.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4175	DM	127	51.6	0	0	0	0	0	0	92	99	51.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean+		**118**	**34.9**	-	-	-	-	-	-	**79**	**81**	**26.0**	**4**	**4**	**2.7**	-	-	-	-	-	-	-	-	-	-	-	-
Median+		**120**	**33.6**	-	-	-	-	-	-	**84**	**87**	**26.4**	**4**	**3**	**2.5**	-	-	-	-	-	-	-	-	-	-	-	-

KEY: DM = Telonics RDW-665 Dive-Monitoring tag; DUR = Telonics RDW-640 Duration-only tag; Locs = Locations; # = number; % = percentage; + Summary statistics do not include zero values in their calculation.

Table 8. Sizes of HRs and CAs of use calculated from hierarchical state-space modeled (hSSSM) locations for humpback whales tagged off southern and central California, 2017 and Oregon, 2017. In the Sex column, Unknown sex whales are cases where no biopsy sample was collected. hSSSM locations were calculated at three per day.

Tag #	# hSSSM Locations	Sex	HR Size (km^2)	CA Size (km^2)
Humpback Whales California				
830	134	Male	5,991	958
834	246	Female	3,984	277
1389	153	Female	4,969	616
1390	207	Female	3,279	599
4175	155	Female	1,720	156
10822	213	Male	101,188	6,033
10842	121	Female	2,660	435
Humpback Whales Oregon				
1387	305	Male	40,858	4,428
4174	95	Female	1,620	156
10838	98	Unknown	16,219	1,344
23034	98	Unknown	10,166	1,789
		Mean	**17,514**	**1,526**

Key: km^2 = square kilometers.

Table 9. Summary of Duration-only (DUR) and Dive-Monitoring (DM) tag deployments on humpback whales off southern and central California during July-August 2017, and off Oregon during September-October 2017. Note this table does not include Tag #840, as no dive information was received from that tag.

Tag ID	Tag Style	Location	Summary Period (d)	# Dives	% Track Summarized	Median Dives Per Day	Min Dives Per Day	Max Dives Per Day
830	DUR	CA	33.0	2019	35.3	60	7	100
834	DUR	CA	78.8	4914	38.4	59	4	181
1389	DUR	CA	50.4	2454	25.1	47	8	117
1390	DUR	CA	68.5	3283	27.6	41.5	7	96
10822	DUR	CA	76.8	1003	6.7	20	9	86
10842	DUR	CA	38.6	2855	44.0	72	26	155
23038	DUR	CA	26.9	2205	53.4	89	9	168
	mean		53.3	2676.1	32.9	55.5	10.0	129.0
833	DM	CA	14.2	1482	59.1	103	19	188
838	DM	CA	1.9	195	69.2	36	20	139
848	DM	CA	2.9	369	88.7	104	19	142
2083	DM	CA	0.2	33	91.7	16.5	9	24
4173	DM	CA	8.9	997	56.7	118	56	146
4175	DM	CA	51.4	2985	40.3	67	1	160
	mean		13.2	1010.2	67.6	74.1	20.7	133.2
1387	DUR	OR	149.8	6156	23.62	40	9	137
4174	DUR	OR	31.3	2173	61.57	62	3	131
10838	DUR	OR	32.3	3331	55.16	96.5	19	191
23034	DUR	OR	32.6	1808	37.30	49.5	20	108
	mean		61.5	3367.0	44.4	62.0	12.8	141.8

Table 10. Number of SSSM/hSSSM locations with their behavioral classification (including percentage of the total, %) for each tagging year/season (AK = Southeast Alaska, ALE = Aleutian Islands, CA = California, OR = Oregon). Unclassified locations correspond to the end-of-track locations, which do not receive a behavioral mode annotation. This number can be lower than the number of tracks because of the exclusion of locations on land and those with high estimation uncertainty.

Season	No. Tags	No. Locs	Transiting	%	Uncertain	%	ARS	%	Unclassified	%
1997AK	9	246	3	1.2	24	9.8	213	86.6	6	2.4
2004CA	6	253	1	0.4	32	12.6	215	85.0	5	2.0
2005CA	6	295	64	21.7	61	20.7	166	56.3	4	1.4
2008ALE	5	154	7	4.5	18	11.7	125	81.2	4	2.6
2014AK	20	291	93	32.0	171	58.8	20	6.9	7	2.4
2015AK	17	287	99	34.5	113	39.4	68	23.7	7	2.4
2016OR	2	25	0	0	25	100.0	0	0	NA	NA
2017CA	13	476	31	6.5	30	6.3	415	87.2	NA	NA
2017OR	4	242	54	22.3	35	14.5	153	63.2	NA	NA

Table 11. Summary statistics (average [Mean] and standard deviation [SD]) for the remotely sensed oceanographic variables obtained for each SSSM/hSSSM location in each tagging year/season (AK = Southeast Alaska, ALE = Aleutian Islands, CA = California, OR = Oregon). The total number of SSSM/hSSSM locations (No. Locs) and the number of locations that received an annotated value for the different variables (n) are given for each year/season. SSSM/hSSSM locations falling on land and those with high estimation uncertainty have been excluded.

Season	No. Locs	SST (°C)			CHL (mg m^{-3})		
		n	Mean	SD	n	Mean	SD
1997AK*	246	0	NA	NA	0	NA	NA
2004CA	253	253	14.53	1.07	224	4.11	3.28
2005CA	295	295	16.18	5.21	279	4.30	4.70
2008ALE	154	154	7.27	0.92	80	1.52	1.52
2014AK	291	291	8.18	1.36	7	1.23	0.40
2015AK	287	287	8.53	3.56	23	0.39	0.19
2016OR	25	25	13.24	0.87	24	4.35	2.32
2017CA	476	476	15.59	1.40	353	3.40	4.70
2017OR	242	242	14.05	3.86	227	3.27	4.07

* Remotely sensed observations are unavailable prior to 2002.

Table 12. Summary statistics (average [Mean] and standard deviation [SD]) for the bathymetric variables obtained for each SSSM/hSSSM location in each tagging year/season (AK = Southeast Alaska, ALE = Aleutian Islands, CA = California, OR = Oregon). The total number of SSSM/hSSSM locations (No. Locs) and the number of locations that received an annotated value for the different variables (n) are given for each year/season. SSSM/hSSSM locations falling on land and those with high estimation uncertainty have been excluded.

Season	No. Locs	Depth (m)			DISTSHELF (km)			DISTCOAST (km)			SLOPE (deg)			ASPECT (deg)		
		n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD
1997AK	246	246	246.57	288.54	246	4.29	10.61	246	6.31	10.91	246	2.48	2.04	246	174.57	106.16
2004CA	253	253	333.93	535.72	253	11.12	9.26	253	29.03	12.82	253	1.68	2.63	253	234.53	48.70
2005CA	295	295	590.51	749.76	295	17.43	20.27	295	31.48	24.88	295	2.20	2.73	295	229.73	66.96
2008ALE	154	154	131.97	133.79	154	16.38	43.55	154	22.54	28.77	154	1.21	1.66	154	191.77	117.67
2014AK	291	291	530.57	982.81	291	20.98	42.05	291	30.68	70.16	291	2.06	1.97	291	149.26	90.33
2015AK	287	287	694.41	1184.43	287	31.60	44.10	287	38.15	73.06	287	1.54	1.97	287	142.33	105.27
2016OR	25	25	133.16	88.76	25	11.10	7.53	25	28.59	13.70	25	0.59	0.84	25	241.90	60.92
2017CA	476	476	301.55	582.08	476	13.67	19.15	476	30.32	22.80	476	1.30	2.12	476	233.21	60.99
2017OR	242	242	738.00	1102.69	242	27.82	56.18	242	54.81	59.69	242	1.49	2.09	242	244.92	64.52

Table 13. Frequency and identity of nine mtDNA haplotypes, including GenBank codes, for the 23 whales sampled off California and Oregon during 2016-2017. Numbers in parentheses refer to the three individuals sampled off Oregon during 2016.

Haplotype	GenBank code	California tagging	Oregon tagging
A+	KF477244		2+(2)
E1	KF477249	1	2
E2	KF477256		(1)
E4	KF477258	2	2
E13	KF477253	1	
E15	KF477255	1	
F2	KF477266	3	
F3	KF477271	4	
F6	KF477267	2	
Total		14	9

Table 14. Results of pairwise tests of differentiation of mtDNA haplotype frequencies between the California (n = 14; 2017) and Oregon (n = 9; 2016 and 2017) tagging populations and the 18 regional strata (feeding areas and breeding grounds) defined in SPLASH (Baker et al. 2013). The regional abbreviations and associated sample sizes are consistent with Figure 42. The sample sizes refer to the number of individuals with associated haplotypes. Rows in italics indicate low sample numbers for comparisons with Western Aleutians and the Philippines.

		California tagging		**Oregon tagging**	
Population	**n**	**F_{ST}**	**p-value**	**F_{ST}**	**p-value**
Feeding Areas					
Russia (RUS)	70	0.1159	0.0004	0.0802	0.0256
Western Aleutians (WAL)	*8*	*0.0385*	*0.1334*	*0.0291*	*0.2918*
Bering (BER)	114	0.1298	0.0002	0.0246	0.1950
Eastern Aleutians (EAL)	36	0.0929	0.0021	0.0415	0.1293
Western Gulf of Alaska (WGOA)	96	0.1065	0.0005	0.0364	0.1327
Northern Gulf of Alaska (NGOA)	233	0.1540	0.0002	0.0901	0.0264
Southeast Alaska (SEA)	183	0.3964	0.0001	0.3437	0.0006
Northern British Columbia (NBC)	104	0.3321	0.0000	0.2488	0.0026
Southern British Columbia/Washington (SBC/WA)	51	0.1144	0.0008	0.0072	0.3443
California/Oregon (CA/OR)	123	0.0378	0.0589	0.1130	0.0066
Breeding Grounds					
Philippines (PHI)	*13*	*0.1961*	*0.0007*	*0.1576*	*0.0257*
Okinawa (OK)	72	0.2290	<0.0001	0.1538	0.0055
Ogasawara (OG)	159	0.1068	0.0002	0.0563	0.0433
Hawaii (HI)	227	0.1979	0.0001	0.1195	0.0166
Mexico-Archipelago Revillagigedo (MX-AR)	106	0.0998	0.0009	0.0290	0.1543
Mexico-Baja California (MX-BC)	110	0.0740	0.0017	0.0413	0.0723
Mexico-Mainland (MX-ML)	62	0.0678	0.0037	0.0161	0.2399
Central America (CENTAM)	36	0.0559	0.0560	0.1541	0.0059

Table 15. The relative likelihood of assignment for each biopsy-sampled whale in 2016 and 2017 to the four DPSs based on the program GeneClass2 and using the published SPLASH dataset as reference samples (Baker et al. 2013). The highest likelihood for each individual is indicated in bold.

Tag #	Tag Type	Lab ID	Sex	Assignment Likelihood to DPS			
				Western Pacific	Hawaii	Mexico-ML/AR	Central America
California							
830	DUR	/Mno17CA001-California	Male	0.00	0.00	0.00	**100.00**
833	DM	/Mno17CA002-California	Male	0.69	6.93	5.02	**87.37**
834	DUR	/Mno17CA003-California	Female	0.23	0.52	**97.40**	1.88
838	DM	/Mno17CA004-California	Male	6.19	0.44	**93.30**	0.05
10822	DUR	/Mno17CA005-California	Male	0.00	0.01	0.02	**99.96**
840	DM	/Mno17CA006-California	Male	0.00	0.00	1.35	**98.65**
10842	DUR	/Mno17CA007-California	Female	0.00	0.01	1.02	**98.98**
848	DM	/Mno17CA008-California	Male	0.01	**67.79**	23.50	8.66
1389	DUR	/Mno17CA009-California	Female	1.37	**76.28**	16.10	6.26
2083	DM	/Mno17CA010-California	Male	0.00	0.00	**51.90**	48.09
1390	DUR	/Mno17CA011-California	Female	0.00	0.00	20.50	**79.48**
4173	DM	/Mno17CA012-California	Female	0.00	1.66	2.86	**95.49**
23038	DUR	/Mno17CA013-California	Female	0.20	0.00	1.32	**98.48**
4175	DM	/Mno17CA014-California	Female	0.00	0.01	0.01	**99.98**
Oregon							
Untagged	--	/Mno17OR001-Oregon	Male	0.02	**65.69**	34.30	0.00
Untagged	--	/Mno17OR002-Oregon	Female	0.01	0.00	13.00	**87.03**
Untagged	--	/Mno17OR003-Oregon	Male	0.00	0.01	19.20	**80.78**
1387	DUR	/Mno17OR004-Oregon	Male	0.35	**68.07**	31.60	0.00
4174	DUR	/Mno17OR005-Oregon	Female	32.40	0.43	**64.00**	3.20
23043	DUR	/Mno17OR006-Oregon	Female	**75.10**	0.11	17.80	6.95
Untagged	--	/Mno16OR001-Oregon	Male	0.01	**99.71**	0.02	0.27
5923	DM	/Mno16OR002-Oregon	Male	17.60	**79.28**	3.14	0.00
5838	DM	/Mno16OR003-Oregon	Female	3.29	10.16	**86.60**	0.00

Key: Mexico-ML/AR = Mexico mainland and Revillagigedo Archipelago, combined.

Table 16. Summary of ID photographs of humpback whales collected by OSU during tagging efforts in feeding areas of the North Pacific Ocean, including number of IDs in the OSU catalog and progress status on submission and matching to HappyWhale.

Tagging Season	Total IDs	Total IDs Matched in HappyWhale	Tagged Whale IDs		
			Total Tagged	Tagged with IDs	Tagged IDs matched in HappyWhale
Southeast Alaska 1997	10	Not yet submitted	10	10	--
California 2004	50	30	8	5	4
California 2005	59	28	7	4	4
Dutch Harbor, Alaska 2008	40	Not yet analyzed	5	5	--
Southeast Alaska 2014	19*	1	19	16	1
Southeast Alaska 2015	18*	1	18	15	1
Oregon 2016	16	0	3***	0	0
California 2017	142	9**	14	13	9
Oregon 2017	45	10	5	5	0

*IDs of untagged whales have not been extracted for this season yet.
**Only tagged whales have been analyzed at this time.
***One tag bounced off the whale on deployment, so effectively only two whales were tagged

Table 17. Deployment and performance data for satellite-monitored radio tags deployed on humpback whales off Oregon and Washington during summer/fall 2017. See Section 2.3.1 for location filtering method. Also included is the genetic assignment to DPS using the highest relative likelihood reported in Table 15 and shown in Figure 29. Migratory connections are indicated with symbols next to each tag number where known through tracking or from photographic recaptures (see Section 3.5.8).

Tag #	Sex	Lab ID	Deployment Locality	Deployment Date	Tag Type	Biopsy	ID Photo Collected	# Days Tracked	# Filtered Locs	Total Distance (km)	DPS Assignment
1387†‡	Male	Mno17OR004	Newport, OR	14-Sep-17	DUR	Yes	Yes	150.4	736	11,399	Hawaii
4174‡	Female	Mno17OR005	Port Orford, OR	27-Sep-17	DUR	Yes	Yes	31.7	117	729	Mexico
10838	Unknown		Gold Beach, OR	28-Sep-17	DUR	No	Yes	32.6	213	2,029	
23034	Unknown		Clatsop Spit, OR	4-Oct-17	DUR	No	Yes	32.7	189	2,153	
23043*	Female	Mno17OR006	Newport, OR	16-Oct-17	DUR	Yes	Yes	0.1	0	0	WestPac
Mean **Median**								**61.8** **32.6**	**314** **201**	**4,077** **2,091**	

KEY: DUR = Telonics RDW-640 Duration-only tag; km = kilometer(s); # = number; * Tag # 23043 is not included in summary statistics; WestPac = Western Pacific; † satellite-tracked to Mexico, ‡ resighted in Mexico after tagging (photographic recapture by N. Ransome and E. Arroyo-Sánchez).

Table 18. Percentage of filtered locations and time spent inside the SOCAL, PT MUGU, NWTT, W237, and SOAR areas for humpback whales tagged off Oregon, 2017. See Section 2.3.1 for location filtering method.

Filtered Locations																			
Tag #	Tag Type	Total		SOCAL			PT MUGU			NWTT			W237			SOAR			
		# Locs	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	
1387	DUR	737	150.4	1	1	1.8	0	0	0	59	58	86.5	9	10	14.3	0	0	0	
4174	DUR	118	31.7	0	0	0	0	0	0	8	4	1.2	0	0	0	0	0	0	
10838	DUR	214	32.6	0	0	0	0	0	0	15	14	4.7	0	0	0	0	0	0	
23034	DUR	190	32.7	0	0	0	0	0	0	96	98	31.9	0	0	0	0	0	0	
23043	DUR	0	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Mean+		**315**	**61.8**	-	-	-	-	-	-	**45**	**43**	**31.1**	-	-	-	-	-	-	
Median+		**202**	**32.7**	-	-	-	-	-	-	**37**	**36**	**18.3**	-	-	-	-	-	-	

KEY: DUR = Telonics RDW-640 Duration-only tag; Locs = Locations; # = number; % = percentage; +Summary statistics do not include zero values in their calculation.

Table 19. Geodesic distances (km) to nearest point on shore in Navy training ranges for humpback whales tagged off Oregon and Washington in 2017 (including mean, median, and maximum distance to shore). The number of locations includes filtered locations (see Section 2.3.1 for filtering method) plus deployment location (when the deployment location occurred in a Navy range).

Tag #	Tag Type	SOCAL				PT MUGU				NWTT				W237			
		n	Mean	Median	Max	n	Mean	Median	Max	n	Mean	Median	Max	n	Mean	Median	Max
1387	DUR	7	317	308	385	0	-	-	-	438	67	52	183	69	73	56	175
4174	DUR	0	-	-	-	0	-	-	-	10	30	30	36	0	-	-	-
10838	DUR	0	-	-	-	0	-	-	-	32	59	46	122	0	-	-	-
23034	DUR	0	-	-	-	0	-	-	-	183	55	51	118	0	-	-	-
23043	DUR	0	-	-	-	0	-	-	-	1	32	32	32	0	-	-	-
Mean			**-**	**-**	**-**		**-**	**-**	**-**		**49**	**42**	**98**		-	-	-
Median			**-**	**-**	**-**		**-**	**-**	**-**		**55**	**46**	**118**		-	-	-

KEY: DUR= Telonics RDW-640 Duration-only tag; n = number of locations.

Table 20. Percentage of filtered locations and time spent inside BIAs for humpback whales tagged off Oregon 2017. See Section 2.3.1 for location filtering method.

		Filtered Locations																									
Tag #	Tag Type	Total		Santa Barbara - San Miguel			Morro Bay to Point Sal			Gulf of the Farallones			Fort Bragg			Point St. George			Stonewall to Heceta Bank			Northern Washington			Olympic Coast NMS		
		# Locs	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days	% Locs	% of Days	# Days
1387	DUR	737	150.4	0	0	0	0	0	0	0	0	0	0	0	0	3	3	4.4	<1	1	1.0	5	5	7.4	7	6	8.6
4174	DUR	118	31.7	0	0	0	0	0	0	0	0	0	0	0	0	12	6	2.0	0	0	0	0	0	0	0	0	0
10838	DUR	214	32.6	0	0	0	0	0	0	0	0	0	7	7	2.2	15	13	4.4	0	0	0	0	0	0	0	0	0
23034	DUR	190	32.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	30	9.9	0	0	0	0	0	0
23043	DUR	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean+		**315**	**61.8**	-	-	-	-	-	-	-	-	-	-	-	-	**10**	**8**	**3.6**	**14**	**16**	**5.4**	-	-	-	-	-	-
Median+		**202**	**32.7**	-	-	-	-	-	-	-	-	-	-	-	-	**12**	**6**	**4.4**	**14**	**16**	**5.4**	-	-	-	-	-	-

KEY: DUR = Telonics RDW-640 Duration-only tag; Locs = Locations; # = number; % = percentage; + Summary statistics do not include zero values in their calculation.

Table 21. Deployment and performance data for satellite-monitored radio tags deployed on humpback whales in Southeast Alaska during summer 1997. See Section 2.3.1 for location filtering method.

Tag #	Sex	Lab ID	Deployment Locality	Deployment Date	Tag Type	Biopsy	ID Photo Collected	# Days Tracked	# Filtered Locations	Total Distance (km)
843	Unknown	-	Frederick Sound, AK	3-Jul-97	ST15	No	Yes	14.6	31	341
1388	Unknown	-	Frederick Sound, AK	3-Jul-97	ST15	No	Yes	8.8	28	381
2082	Unknown	-	Frederick Sound, AK	4-Jul-97	ST15	No	Yes	76.7	92	1,978
2083	Unknown	-	Frederick Sound, AK	5-Jul-97	ST15	No	Yes	19.2	40	658
4173	Unknown	-	Frederick Sound, AK	11-Jul-97	ST15	No	Yes	6.4	9	272
4176	Unknown	-	Frederick Sound, AK	11-Jul-97	ST15	No	Yes	143.9	90	2,384
4177	Unknown	-	Frederick Sound, AK	13-Jul-97	ST15	No	Yes	3.8	8	187
23030	Unknown	-	Frederick Sound, AK	14-Jul-97	ST15	No	Yes	68.4	75	1,650
23031	Unknown	-	Frederick Sound, AK	14-Jul-97	ST15	No	No	5.5	13	237
Mean **Median**								**38.6** **14.6**	**39** **29**	**899** **381**

KEY: km = kilometer(s); ST15 = Telonics ST15 Location-only tag; # = number.

Table 22. Deployment and performance data for satellite-monitored radio tags deployed on humpback whales off California during summer 2004. See Section 2.3.1 for location filtering method.

Tag #	Sex	Lab ID	Deployment Locality	Deployment Date	Tag Type	Biopsy	ID Photo Collected	# Days Tracked	# Filtered Locations	Total Distance (km)
831	Unknown	Mno04Ca006	Half Moon Bay, CA	20-Aug-04	ST15	Yes	No	64.4	169	2,500
835	Unknown	Mno04Ca008	Half Moon Bay, CA	21-Aug-04	ST15	Yes	No	17.3	27	965
1388	Unknown	Mno04Ca002	Half Moon Bay, CA	28-Jul-04	ST15	Yes	Yes	33.3	38	1,821
2082	Unknown	Mno04Ca007	Half Moon Bay, CA	21-Aug-04	ST15	Yes	Yes	19.4	2	56
10830	Male	Mno04Ca004	Gulf of the Farallones, CA	2-Aug-04	ST15	Yes	Yes	56.8	153	2,576
23037	Unknown	Mno04Ca001	Half Moon Bay, CA	29-Jul-04	ST15	Yes	Yes	28.5	75	1,382
Mean Median								**36.6 30.9**	**77 57**	**1,550 1,602**
10826	Unknown	Mno04Ca005	Monterey Bay, CA	16-Aug-04	ST21	Yes	Yes	0	0	0
10827	Unknown	Mno04Ca003	Gulf of the Farallones, CA	2-Aug-04	ST21	Yes	No	55.3	231	2,669

KEY: km = kilometer(s); ST15 = Telonics ST15 Location-only tag; ST21 = Telonics ST21 Depth-sensing tag; # = number

Table 23. Deployment and performance data for satellite-monitored radio tags deployed on humpback whales off California during summer and fall 2005. See Section 2.3.1 for location filtering method.

Tag #	Sex	Lab ID	Deployment Locality	Deployment Date	Tag Type	Biopsy	ID Photo Collected	# Days Tracked	# Filtered Locations	Total Distance (km)
1387	Unknown	Mno05Ca002	Gulf of the Farallones, CA	4-Aug-05	ST15	Yes	Yes	0.1	2	5
10822	Unknown	Mno05Ca003	Cape Mendocino, CA	28-Aug-05	ST15	Yes	No	29.1	21	552
10832	Unknown	Mno05Ca001	Gulf of the Farallones, CA	4-Aug-05	ST15	Yes	Yes	2.8	11	217
10843*	Unknown	-	Big Sur, CA	11-Aug-05	ST15	No	No	122.1	135	6,708
841**	Unknown	-	Port Orford, OR	5-Oct-05	ST15	No	Yes	94.9	127	5,806
10825	Unknown	-	Point St. George, CA	6-Oct-05	ST15	No	Yes	57.2	106	2,542
10827	Unknown	-	Point St. George, CA	6-Oct-05	ST15	No	No	36.2	88	1,402
Mean								**48.9**	**70**	**2,462**
Median								**36.2**	**88**	**1,402**

KEY: km = kilometer(s); ST15 = Telonics ST15 Location-only tag; # = number; * migrated to Bahía de Banderas, Mexico; ** migrated to Guatemala, Central America.

Table 24. Deployment and performance data for satellite-monitored radio tags deployed on humpback whales off Dutch Harbor in Alaska during summer 2008. See Section 2.3.1 for location filtering method.

Tag #	Sex	Lab ID	Deployment Locality	Deployment Date	Tag Type	Biopsy	ID Photo Collected	# Days Tracked	# Filtered Locations	Total Distance (km)
833	Female	Mno08GOA002	Dutch Harbor, AK	16-Sep-08	ST15	Yes	Yes	73.9	151	2,764
838	Unknown	-	Dutch Harbor, AK	15-Sep-08	ST15	No	Yes	28.4	38	510
4173	Female	Mno08GOA003	Dutch Harbor, AK	16-Sep-08	ST15	Yes	Yes	22.1	31	222
5640	Unknown	-	Dutch Harbor, AK	16-Sep-08	ST15	No	Yes	25.5	41	540
5654	Female	Mno08GOA001	Dutch Harbor, AK	16-Sep-08	ST15	Yes	Yes	21.9	44	790
Mean **Median**								**34.4** **25.5**	**61** **41**	**965** **540**

KEY: km = kilometer(s); ST15 = Telonics ST15 Location-only tag; # = number

Table 25. Deployment and performance data for satellite-monitored radio tags deployed on humpback whales off Southeast Alaska during fall 2014. See Section 2.3.1 for location filtering method.

Tag #	Sex	Lab ID	Deployment Locality	Deployment Date	Tag Type	Biopsy	ID Photo Collected	# Days Tracked	# Filtered Locations	Total Distance (km)
826	Unknown	-	Frederick Sound, AK	14-Nov-14	Spot5	No	Yes	8.1	43	346
835	Unknown	-	Frederick Sound, AK	14-Nov-14	Spot5	No	No	28.5	159	2,268
836	Unknown	-	Frederick Sound, AK	14-Nov-14	Spot5	No	No	6.7	42	410
841	Female	Mno14AK004	Seymour Canal, AK	19-Nov-14	Spot5	Yes	Yes	22.0	67	219
843	Male	Mno14AK002	Frederick Sound, AK	16-Nov-14	Spot5	Yes	Yes	31.3	139	4,283
845	Unknown	-	Seymour Canal, AK	19-Nov-14	Spot5	No	Yes	78.2	478	6,635
2082	Unknown	-	Seymour Canal, AK	20-Nov-14	Spot5	No	Yes	29.2	145	964
4172	Male	Mno14AK008	Seymour Canal, AK	20-Nov-14	Spot5	Yes	Yes	31.1	147	3,334
4173	Female	Mno14AK012	Seymour Canal, AK	20-Nov-14	Spot5	Yes	Yes	44.0	182	2,742
4176	Female	Mno14AK011	Seymour Canal, AK	20-Nov-14	Spot5	Yes	Yes	34.3	163	603
5670	Female	Mno14AK005	Seymour Canal, AK	19-Nov-14	Spot5	Yes	No	27.9	114	1,446
5679	Unknown	-	Frederick Sound, AK	14-Nov-14	Spot5	No	Yes	25.2	116	2,357
5719	Male	Mno14AK001	Frederick Sound, AK	13-Nov-14	Spot5	Yes	Yes	27.4	119	2,764
5843	Male	Mno14AK003	Frederick Sound, AK	17-Nov-14	Spot5	Yes	Yes	8.1	41	202
5878	Male	Mno14AK009	Seymour Canal, AK	20-Nov-14	Spot5	Yes	Yes	3.3	18	51
5882	Unknown	-	Frederick Sound, AK	17-Nov-14	Spot5	No	Yes	39.9	185	2,624
5883	Female	Mno14AK010	Seymour Canal, AK	20-Nov-14	Spot5	Yes	No	6.2	40	134
5910	Unknown	-	Frederick Sound, AK	13-Nov-14	Spot5	No	Yes	30.0	144	4,406
23039	Male	Mno14AK006	Seymour Canal, AK	19-Nov-14	Spot5	Yes	Yes	21.7	106	487
Mean **Median**								**26.5** **27.9**	**129** **119**	**1,909** **1,446**
5743	Female	Mno14AK013	Petersburg, AK	23-Nov-14	ST15	Yes	Yes	43.5	114	2,028

KEY: km = kilometer(s); SPOT5 = Wildlife Computers SPOT5 Location-only tag; ST15 = Telonics ST15 Location-only tag; # = number

Table 26. Deployment and performance data for satellite-monitored radio tags deployed on humpback whales off Southeast Alaska during fall 2015. See Section 2.3.1 for location filtering method.

Tag #	Sex	Lab ID	Deployment Locality	Deployment Date	Tag Type	Biopsy	ID Photo Collected	# Days Tracked	# Filtered Locations	Total Distance (km)
827	Female	Mno15AK004	Seymour Canal, AK	10-Nov-15	DUR	Yes	No	37.4	114	1,658
848	Female	Mno15AK006	Seymour Canal, AK	11-Nov-15	DUR	Yes	Yes	28.3	69	594
1386	Female	Mno15AK016	Frederick Sound, AK	17-Nov-15	DUR	Yes	Yes	28.3	146	3,982
2083	Female	Mno15AK018	Frederick Sound, AK	17-Nov-15	DUR	Yes	Yes	25.1	60	936
4175	Female	Mno15AK017	Frederick Sound, AK	17-Nov-15	DUR	Yes	Yes	55.7	275	2,504
5746	Unknown	-	Seymour Canal, AK	10-Nov-15	DUR	No	Yes	18.6	73	1,658
23030	Female	Mno15AK010	Seymour Canal, AK	11-Nov-15	DUR	Yes	Yes	21.0	111	718
Mean **Median**								**30.6** **28.3**	**121** **111**	**1,721** **1,658**
5641	Unknown	-	Seymour Canal, AK	16-Nov-15	Spot5	No	No	28.0	130	1,731
5655	Male	Mno15AK001	Seymour Canal, AK	10-Nov-15	Spot5	Yes	Yes	19.1	98	2,027
5685	Male	Mno15AK008	Seymour Canal, AK	15-Nov-15	Spot5	Yes	No	21.7	105	3,048
10829	Female	Mno15AK015	Frederick Sound, AK	17-Nov-15	Spot5	Yes	Yes	13.4	51	535
10830	Male	Mno15AK014	Frederick Sound, AK	17-Nov-15	Spot5	Yes	Yes	9.2	45	630
10833	Male	Mno15AK005	Seymour Canal, AK	11-Nov-15	Spot5	Yes	No	70.9	68	5,436
10834	Female	Mno15AK009	Seymour Canal, AK	15-Nov-15	Spot5	Yes	No	43.0	161	5,069
10840	Male	Mno15AK002	Seymour Canal, AK	10-Nov-15	Spot5	Yes	No	19.4	82	430
23029	Unknown	-	Seymour Canal, AK	16-Nov-15	Spot5	No	Yes	29.1	143	3,100
23041	Female	Mno15AK003	Seymour Canal, AK	10-Nov-15	Spot5	Yes	Yes	28.8	137	1,859
Mean **Median**								**28.3** **24.9**	**102** **102**	**2,387** **1,943**

KEY: km = kilometer(s); DUR = Telonics RDW-640 Duration-only tag; SPOT5 = Wildlife Computers SPOT5 Location-only tag; # = number

Table 27. Deployment and performance data for satellite-monitored radio tags deployed on humpback whales off central Oregon, 2016. See Section 2.3.1 for location filtering method. Deployment dates reflect UTC dates.

Tag #	Sex	Lab ID	Deployment Locality	Deployment Date	Tag Type	Biopsy	# Days Tracked	# Filtered Locations	Total Distance (km)
5838	Female	Mno16OR003	Newport, OR	15-Sep-16	DM	yes	7.3	37	409
5923	Male	Mno16OR002	Newport, OR	15-Sep-16	DM	yes	18.9	87	948
Mean				**DM**			**13.1**	**62**	**678**
Median				**DM**			**13.1**	**62**	**678**

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

Table 28. Mean (and SE) tracking duration, total distance traveled, home range, and core area for 78 humpback whales tagged by OSU in feeding areas of the Eastern North Pacific from 1997 to 2017. DM tags deployed in California in 2017 with O-ring failures are not included here.

	Tracking Duration (d)			Total Distance (km)			Home Range (km^2)			Core Area (km^2)		
	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE
2004-2005CA	14	44.1	7.7	14	2085.8	491.7	8	20435.6	7322.8	8	3781.8	906.2
2017CA	7	56.8	10.9	7	2069.8	695.3	7	17684.4	13927.6	7	1296.2	795.5
2016OR	2	13.1	20.3	2	678.4	1300.9	0	-	-	0	-	-
2017OR	4	61.8	14.4	4	4077.4	919.8	4	17215.6	8430.6	4	1029.0	901.3
1997AK	9	38.6	9.6	9	898.6	613.2	3	4904.3	1728.8	3	1791.1	531.7
2014-2015AK	37	28.2	4.7	37	2005.9	302.4	5	2862.7	1834.2	5	477.3	273.2
2008Aleutian	5	34.4	12.8	5	965.3	822.7	1	9367.5	-	1	811.6	-

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

Table 29. Mean and maximum number of days spent inside the SOCAL, MUGU, NWTT, W237, and SOAR areas for 85 humpback whales tagged in feeding areas of the Eastern North Pacific, 1997-2017.

	# Days														
Season (# Whales Tracked)	**SOCAL**			**MUGU**			**NWTT**			**W237**			**SOAR**		
	n	**Mean**	**Max**	**n**	**Mean**	**Max**	**n**	**Mean**	**Max**	**n**	**Mean**	**Max**	**n**	**Mean**	**Max**
2004-2005CA (14)	2	2.3	2.8	4	12.8	33.8	3	13.1	14.5	0	-	-	1	0.4	0.4
2017CA (14)	0	-	-	1	22.8	22.8	1	28.2	28.2	0	-	-	0	-	-
2016OR (2)	0	-	-	0	-	-	2	5.7	6.6	0	-	-	0	-	-
2017OR (4)	1	1.8	1.8	0	-	-	4	31.1	86.5	1	14.3	14.3	0	-	-
1997AK (9)	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-
2014-2015AK (37)	1	2.7	2.7	1	1.8	1.8	2	8.0	9.6	2	2.6	3.2	0	-	-
2008Aleut (5)	0	-	-	0	-	-	0	-	-	0	-	-	0	-	-
All Seasons (85)	**4**	**2.3**	**2.8**	**6**	**12.6**	**33.8**	**12**	**18.2**	**86.5**	**3**	**6.5**	**14.3**	**1**	**0.4**	**0.4**

KEY: n = sample size; # = number.

Table 30. Geodesic distances (km) to nearest point on shore in Navy training ranges for four humpback whales tagged in feeding areas of the Eastern North Pacific, 1997-2017 (including mean, median, and maximum distances to shore). SOAR is not included here because no whales had locations there (one whale's tracked crossed the area, however).

Tag #	SOCAL				PT MUGU				NWTT				W237			
	n	Mean	Median	Max	n	Mean	Median	Max	n	Mean	Median	Max	n	Mean	Median	Max
2004-2005CA	2	71	71	95	4	41	36	70	3	44	45	55	0	-	-	-
2017CA	0	-	-	-	1	34	34	34	1	88	88	88	0	-	-	-
2016OR	0	-	-	-	0	-	-	-	3	36	39	42	0	-	-	-
2017OR	1	317	317	317	0	-	-	-	5	49	55	67	1	73	73	73
1997AK	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-
2014-2015AK	1	168	168	168	1	156	156	156	2	181	181	209	2	241	241	273
2008Aleut	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-
Mean		**185.3**	**185.3**	**193**		**77**	**75.3**	**86.7**		**79.6**	**81.6**	**92.2**		**157**	**157**	**173**
Median		**168**	**168**	**168**		**41**	**36**	**70**		**49**	**55**	**67**		**157**	**157**	**173**

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

Table 31. Mean and maximum number of days spent inside the West Coast BIAs for 34 humpback whales tagged off California, Oregon, and Washington from in 2004, 2005, 2016, and 2017.

	# Days																							
Season (# tracked)	**Santa Barbara – San Miguel**			**Morro Bay to Point Sal**			**Gulf of the Farallones**			**Fort Bragg**			**Point St. George**			**Stonewall to Heceta Bank**			**Northern Washington**			**Olympic Coast NMS**		
	n	**Mean**	**Max**	**n**	**Mean**	**Max**	**n**	**Mean**	**Max**	**n**	**Mean**	**Max**	**n**	**Mean**	**Max**	**n**	**Mean**	**Max**	**n**	**Mean**	**Max**	**n**	**Mean**	**Max**
2004-2005CA (14)	0	-	-	3	6.8	11.7	13	18.3	51.5	3	2.1	4.3	4	5.4	11.3	0	-	-	0	-	-	0	-	-
2017CA (14)	1	3.3	3.3	1	6.8	6.8	13	26.0	71.6	3	2.7	4.5	0	-	-	1	0.7	0.7	0	-	-	0	-	-
2016OR (2)	0	-	-	0	-	-	0	-	-	0	-	-	1	2.5	2.5	2	2.4	3.3	0	-	-	0	-	-
2017 OR (4)	0	-	-	0	-	-	0	-	-	1	2.2	2.2	3	3.6	4.4	2	5.4	9.9	1	7.4	7.4	1	8.6	8.6
All Years (34)	**1**	**3.3**	**3.3**	**4**	**6.8**	**11.7**	**26**	**22.1**	**71.6**	**7**	**2.4**	**4.5**	**8**	**4.4**	**11.3**	**5**	**3.3**	**9.9**	**1**	**7.4**	**7.4**	**1**	**8.6**	**8.6**

KEY: n = sample size; # = number.

Table 32. Mean, median, and maximum number of days spent inside the Alaska BIAs for 51 humpback whales tagged off Southeast Alaska and the Aleutian Islands in 1997, 2008, 2014, and 2015.

	# Days											
Season (# tracked)	Southeast Alaska (summer and fall combined)				Aleutians				Bristol Bay			
	n	Mean	Median	Max	n	Mean	Median	Max	n	Mean	Median	Max
1997AK (9)	9	34.2	14.5	126.8	0	-	-	-	0	-	-	-
2014-2015AK (37)	37	12.0	10.7	31.3	0	-	-	-	0	-	-	-
2008Aleutians (5)	0	-	-	-	5	0.9	0.9	1.0	1	1.7	1.7	1.7
All Years (51)	**46**	**16.3**	**10.75**	**126.8**	**5**	**0.9**	**0.9**	**1.0**	**1**	**1.7**	**1.7**	**1.7**

KEY: n = sample size; # = number.

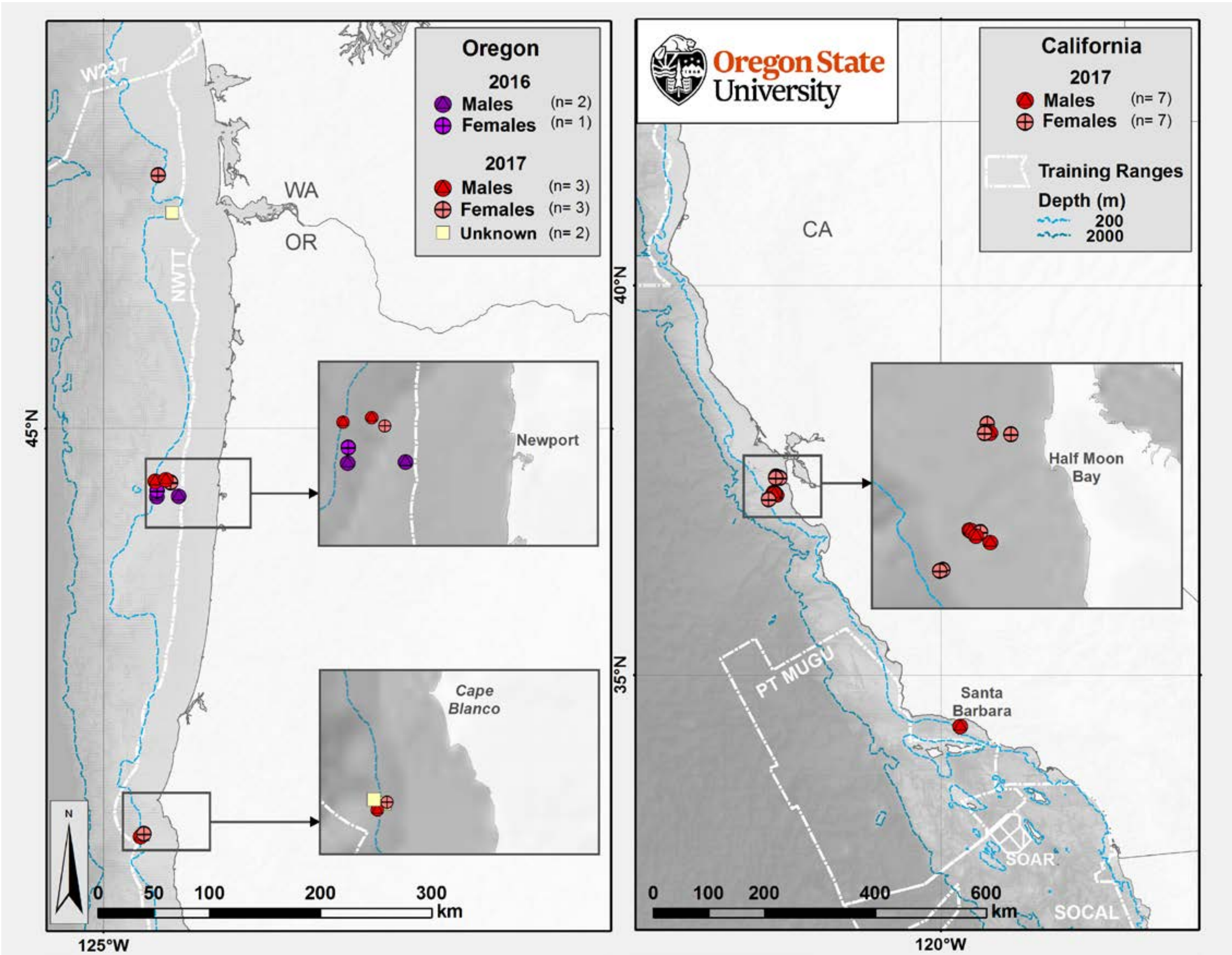


Figure 1. Deployment locations for humpback whales tagged off Oregon in 2016 and 2017 and off California in 2017.

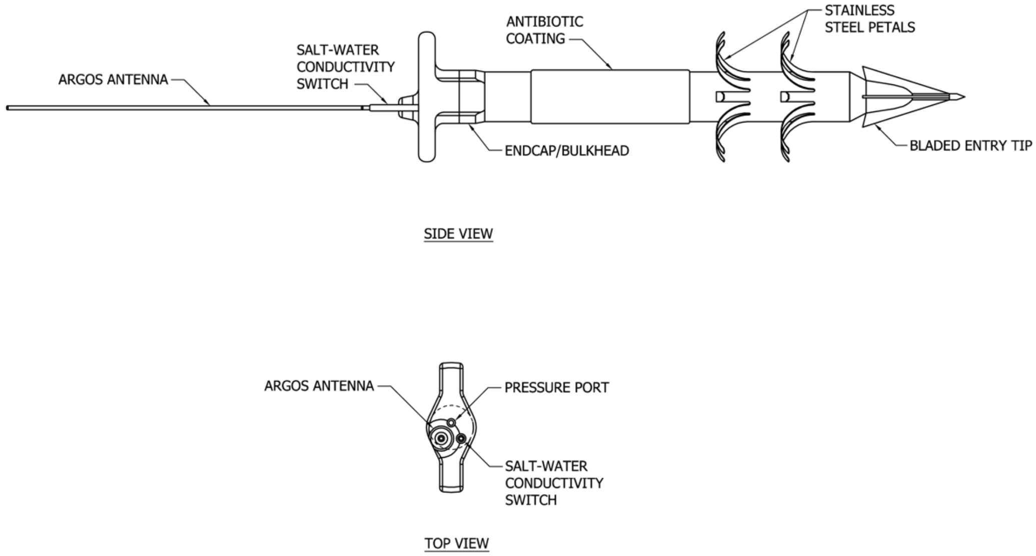


Figure 2. Schematic diagram of the Telonics RDW-665 DM tag showing the main body, the distal endcap with the antenna and saltwater conductivity switch endcap, as well as the penetrating tip and anchoring system.

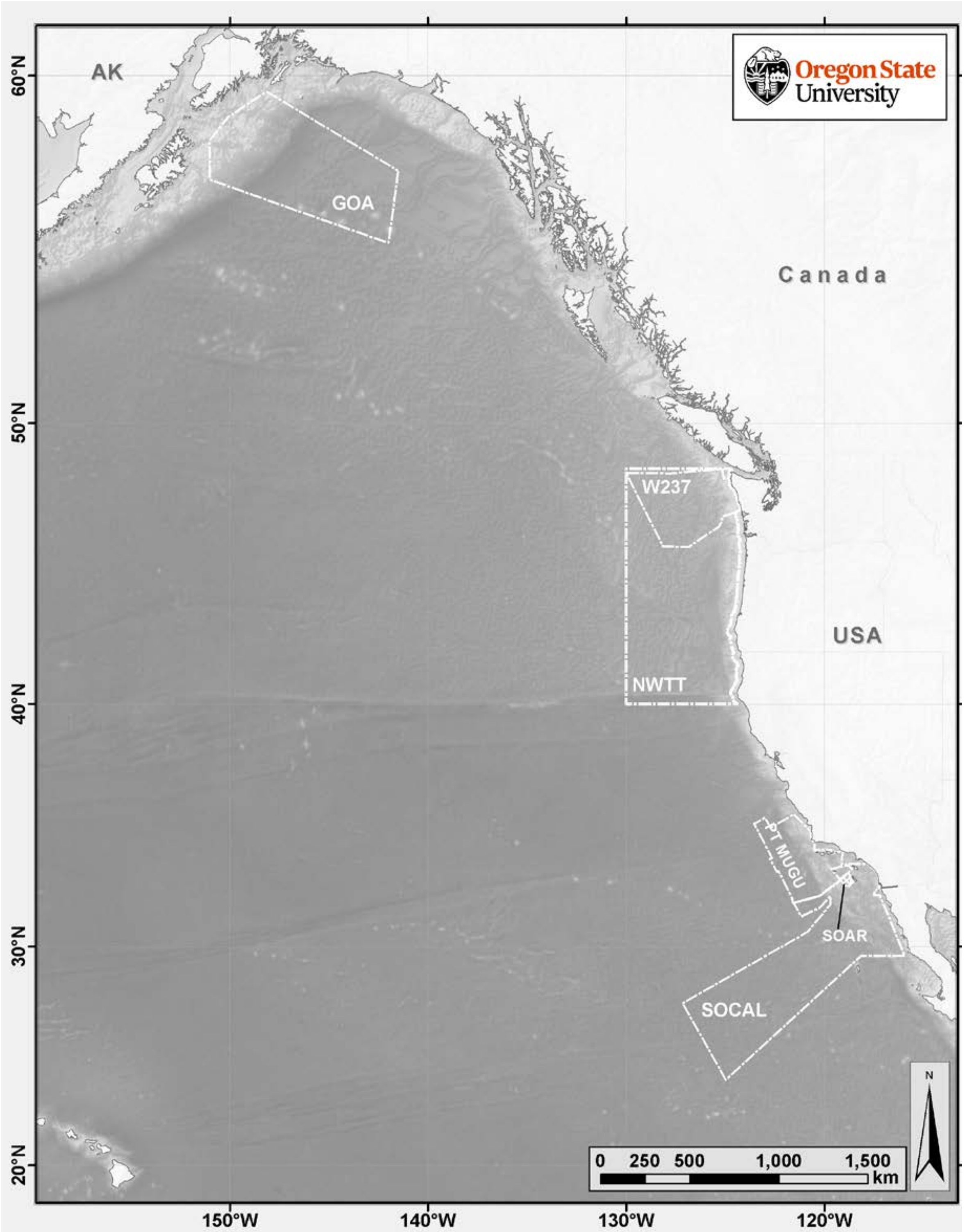


Figure 3. Map showing the six U.S. Navy Training Areas considered in this report.

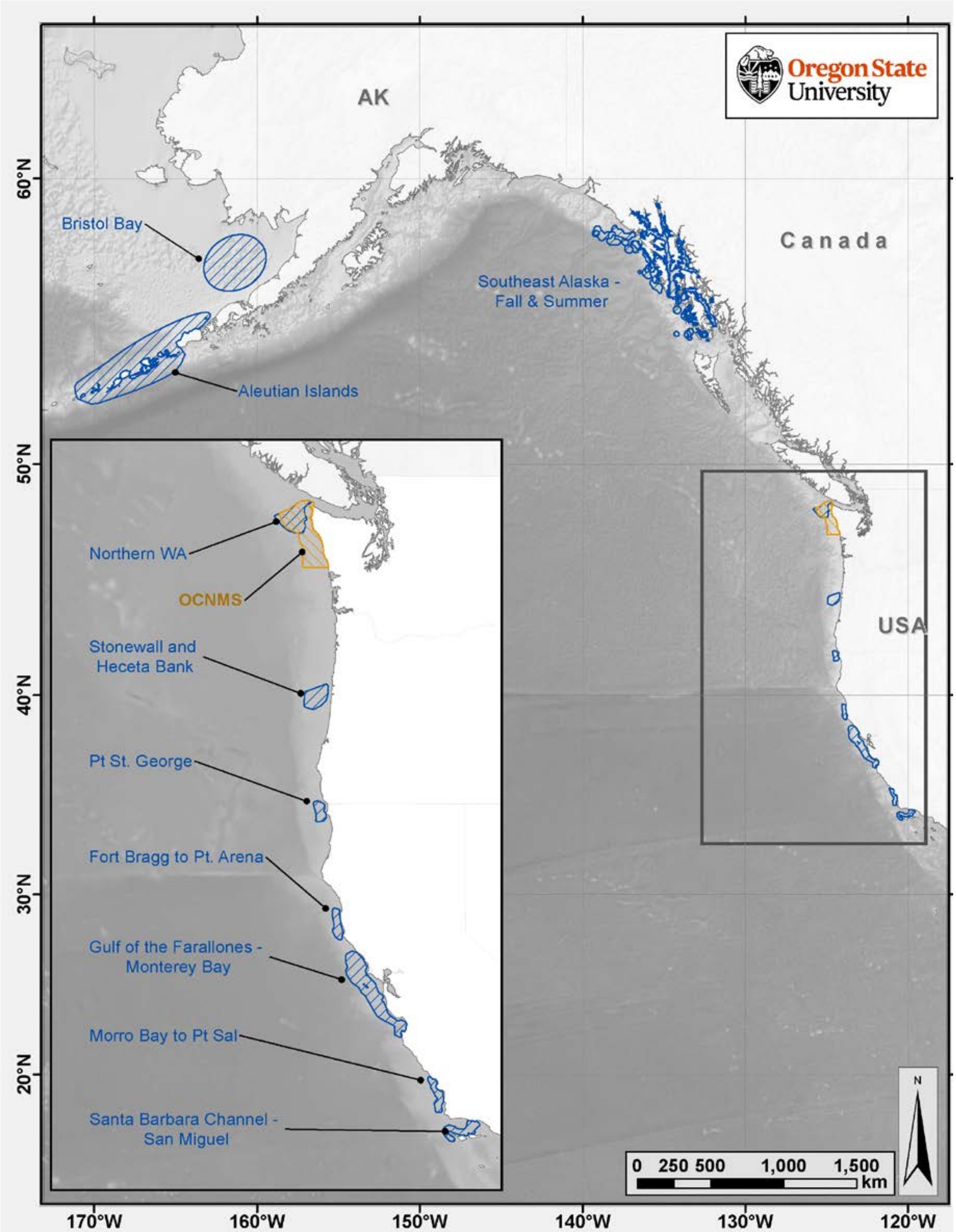


Figure 4. Map showing the Olympic Coast National Marine Sanctuary (OCNMS) and the ten Biologically Important Areas (BIAs) for humpback whales considered in this report.

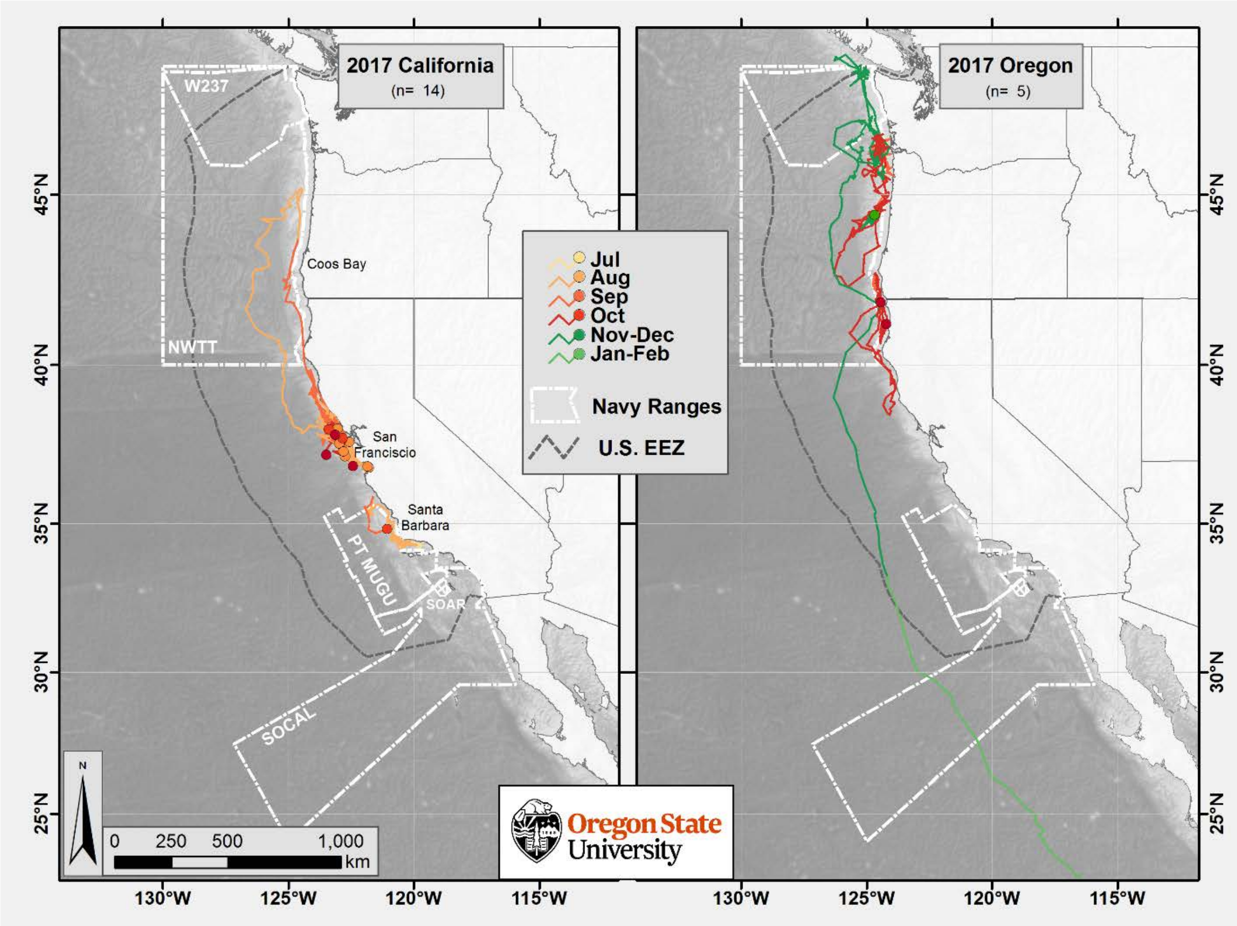


Figure 5. Satellite-monitored tracks for humpback whales tagged off California in July and August 2017 (7 DUR tags, 7 DM tags; left panel) and Oregon in September and October 2017 (5 DUR tags; right panel).

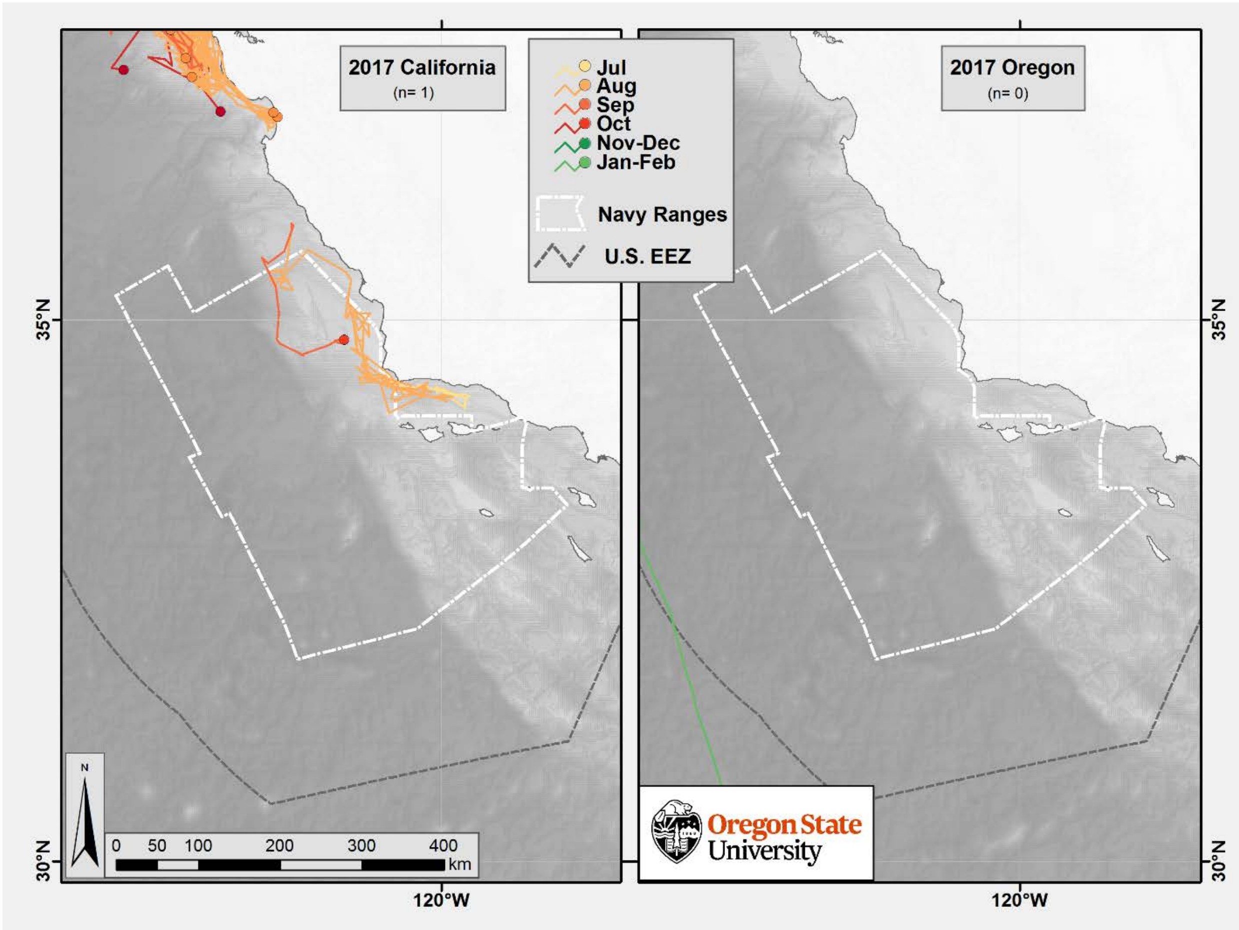


Figure 6. Satellite-monitored tracks in PT MUGU for humpback whales tagged off California in July and August 2017 (1 DUR tag; left panel) and Oregon in September and October 2017 (0 tags; right panel).

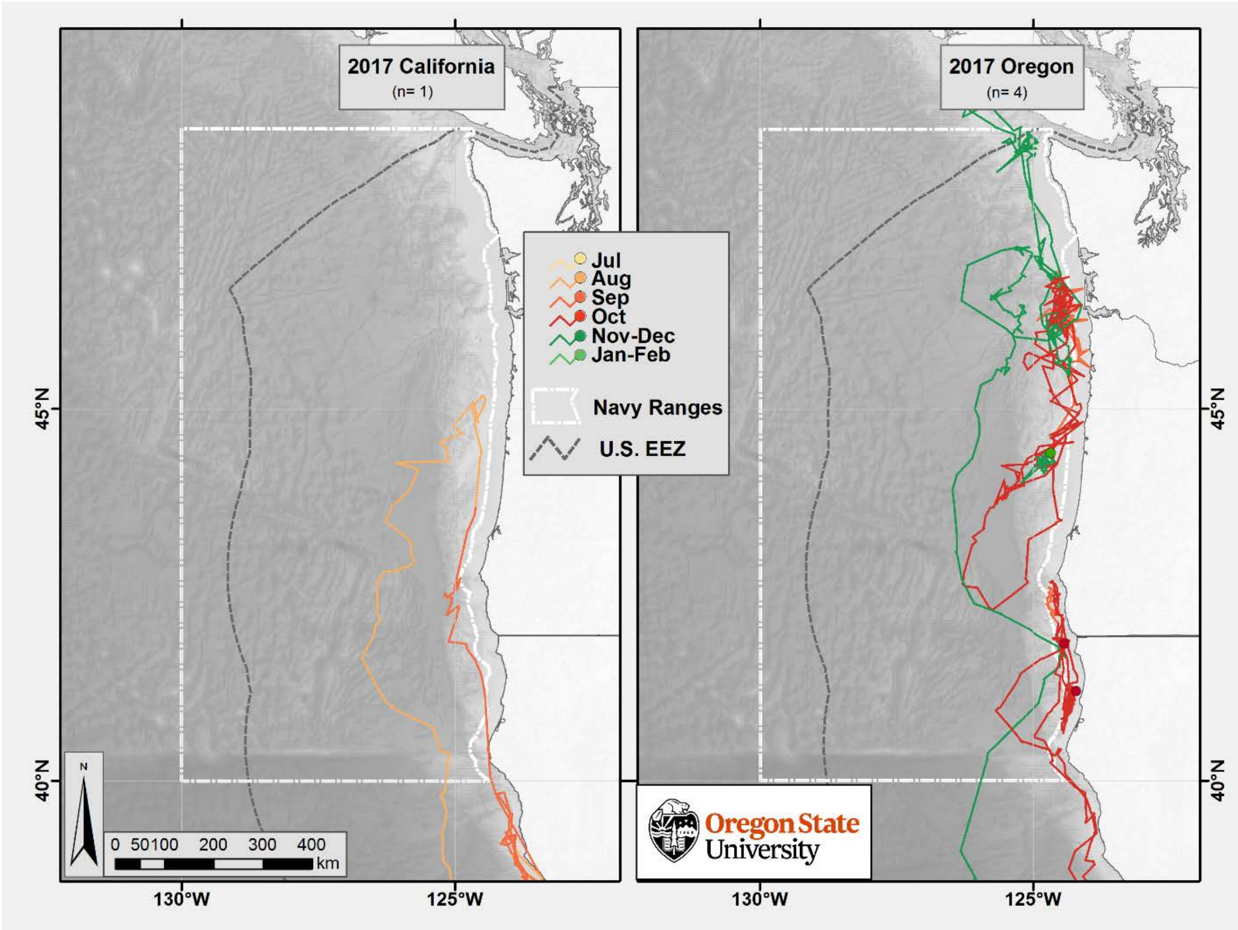


Figure 7. Satellite-monitored tracks in NWTT for humpback whales tagged off California in July and August 2017 (1 DUR tag; left panel) and Oregon in September and October 2017 (4 DUR tags; right panel).

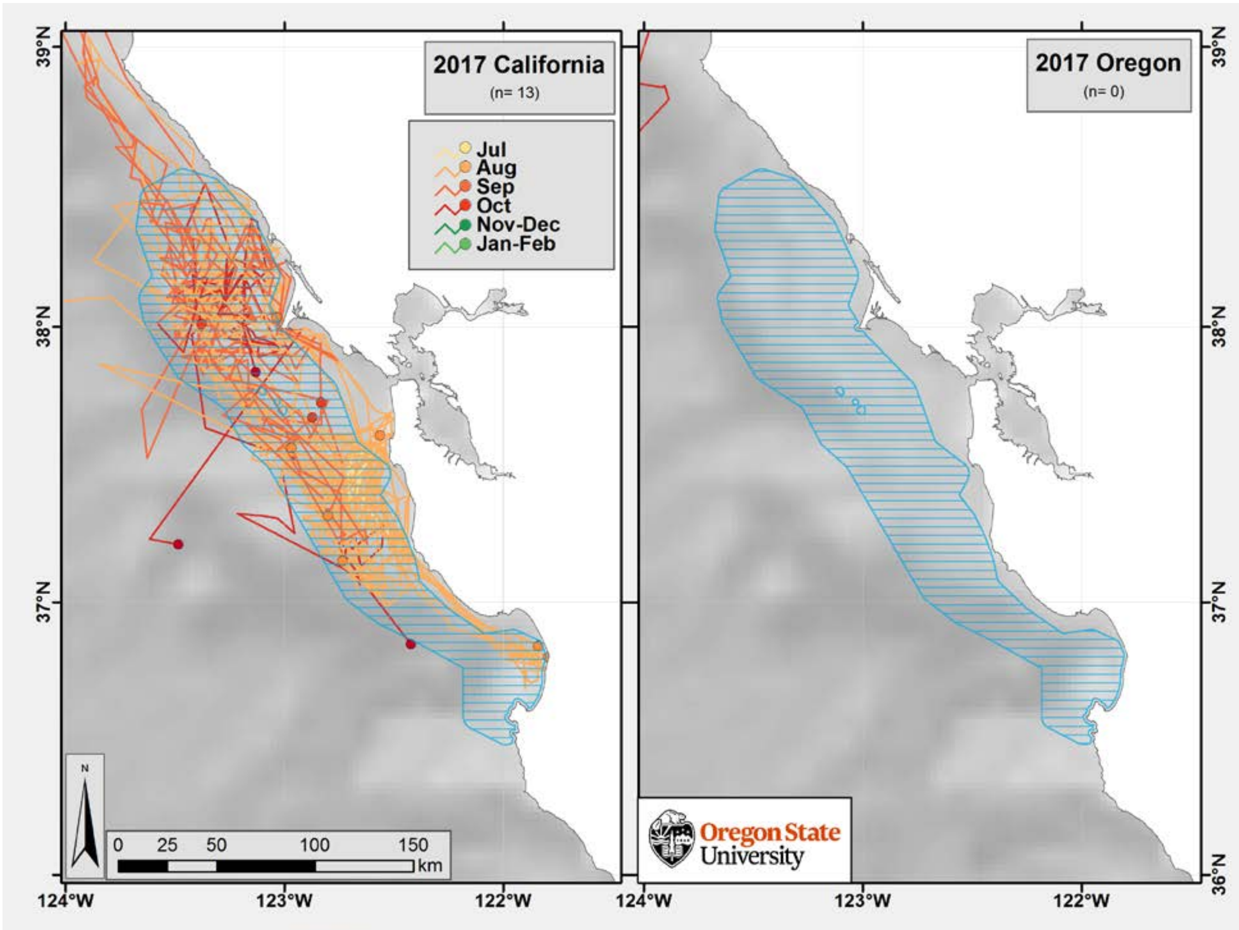


Figure 8. Satellite-monitored tracks in the Gulf of the Farallones to Monterey Bay BIA for humpback whales tagged off California in July and August 2017 (6 DUR tags, 7 DM tags; left panel) and Oregon in September and October 2017 (0 tags; right panel).

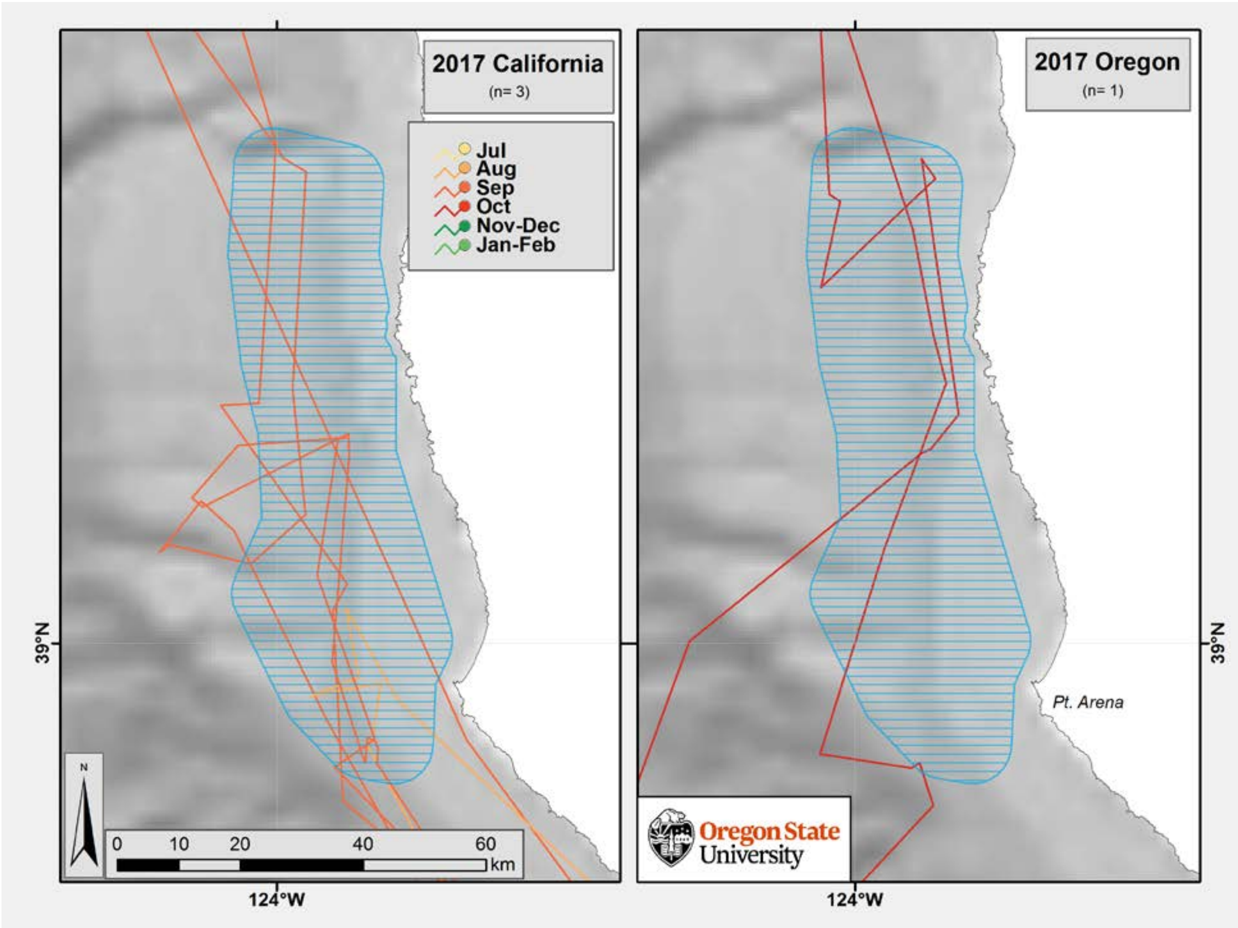


Figure 9. Satellite-monitored tracks in the Fort Bragg to Point Arena BIA for humpback whales tagged off California in July and August 2017 (3 DUR tags; left panel) and Oregon in September and October 2017 (1 DUR tag; right panel).

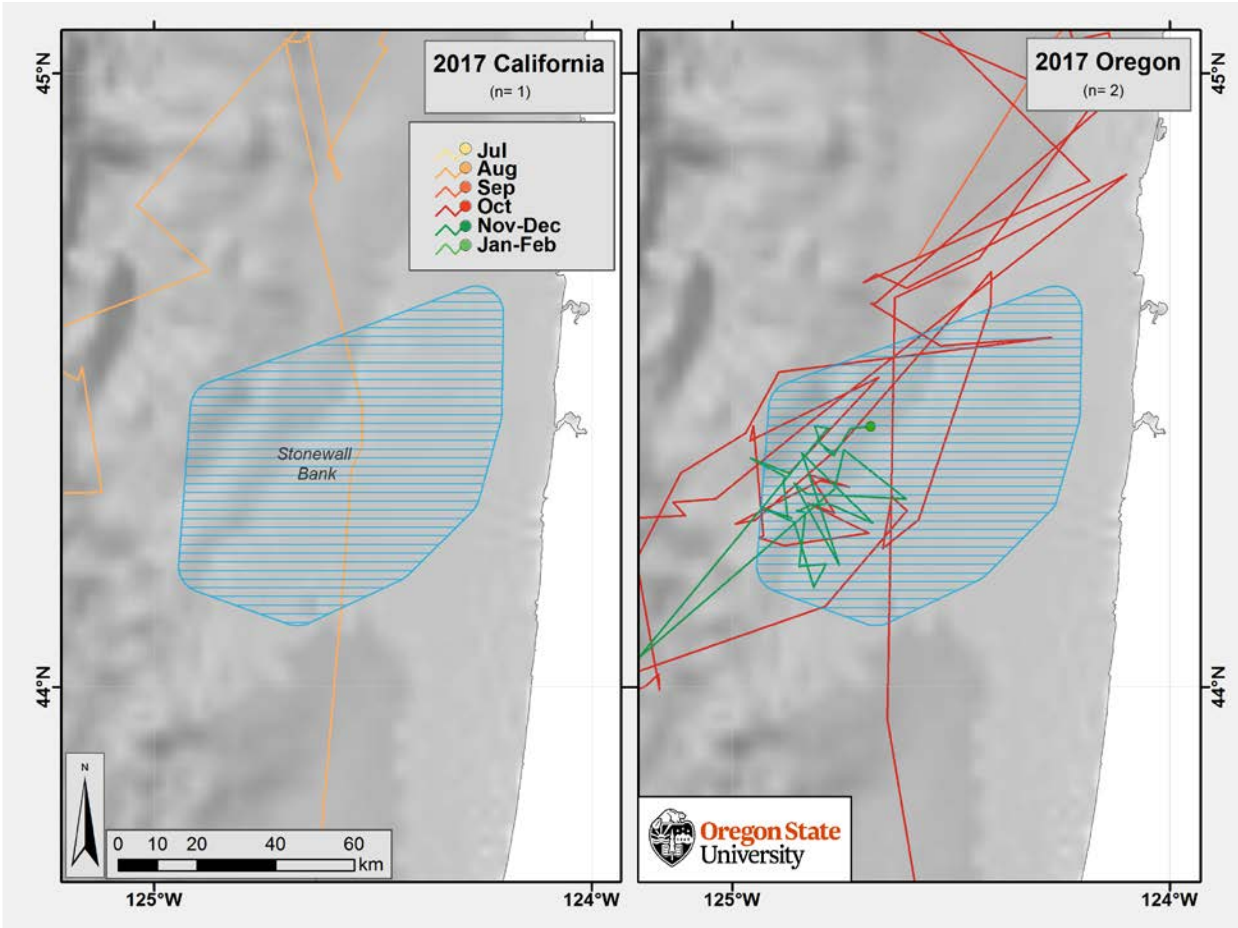


Figure 10. Satellite-monitored tracks in the Stonewall and Heceta Bank BIA for humpback whales tagged off California in July and August 2017 (1 DUR tag; left panel) and Oregon in September and October 2017 (2 DUR tags; right panel).

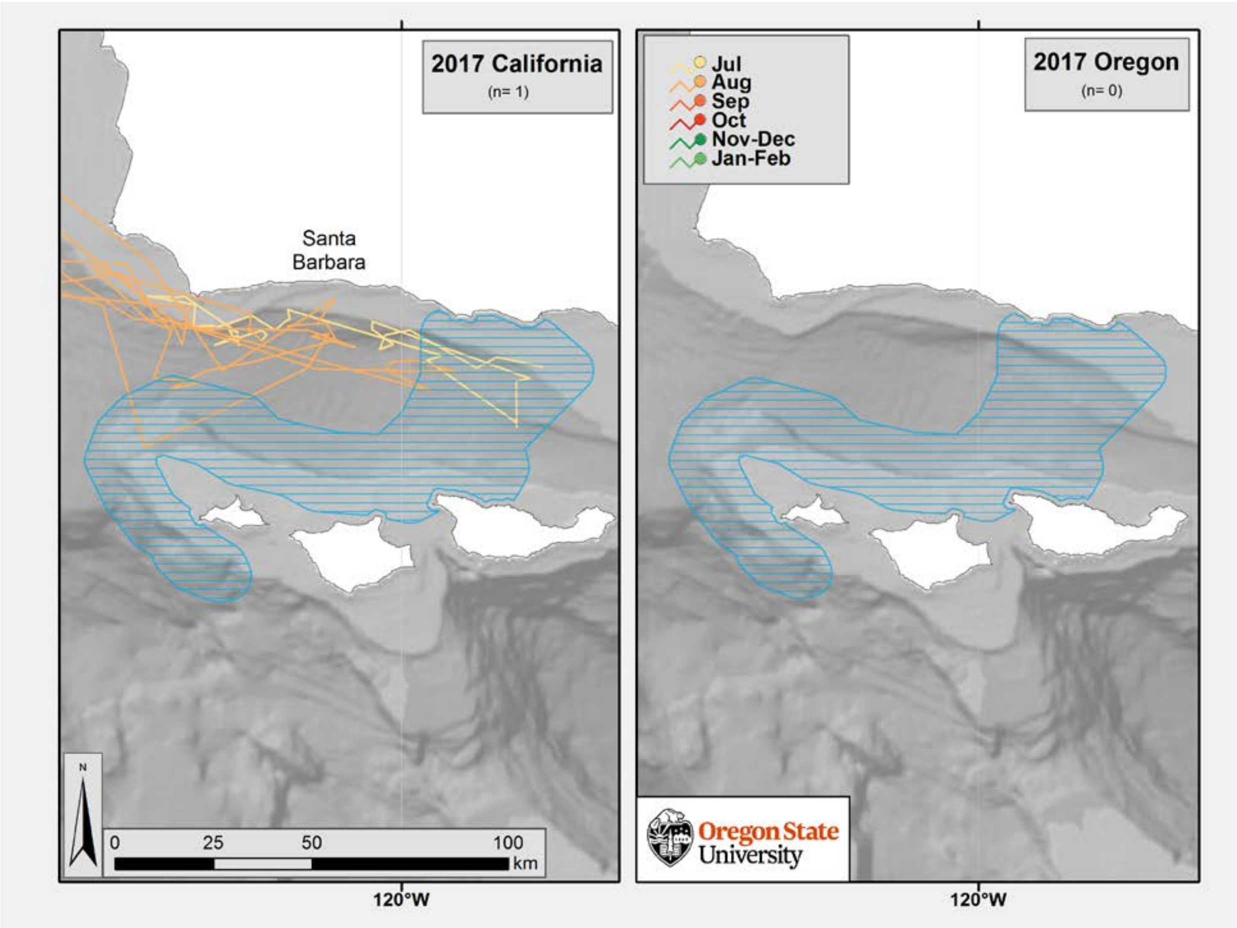


Figure 11. Satellite-monitored tracks in the Santa Barbara Channel – San Miguel BIA for humpback whales tagged off California in July and August 2017 (1 DUR tag; left panel) and Oregon in September and October 2017 (0 tags; right panel).

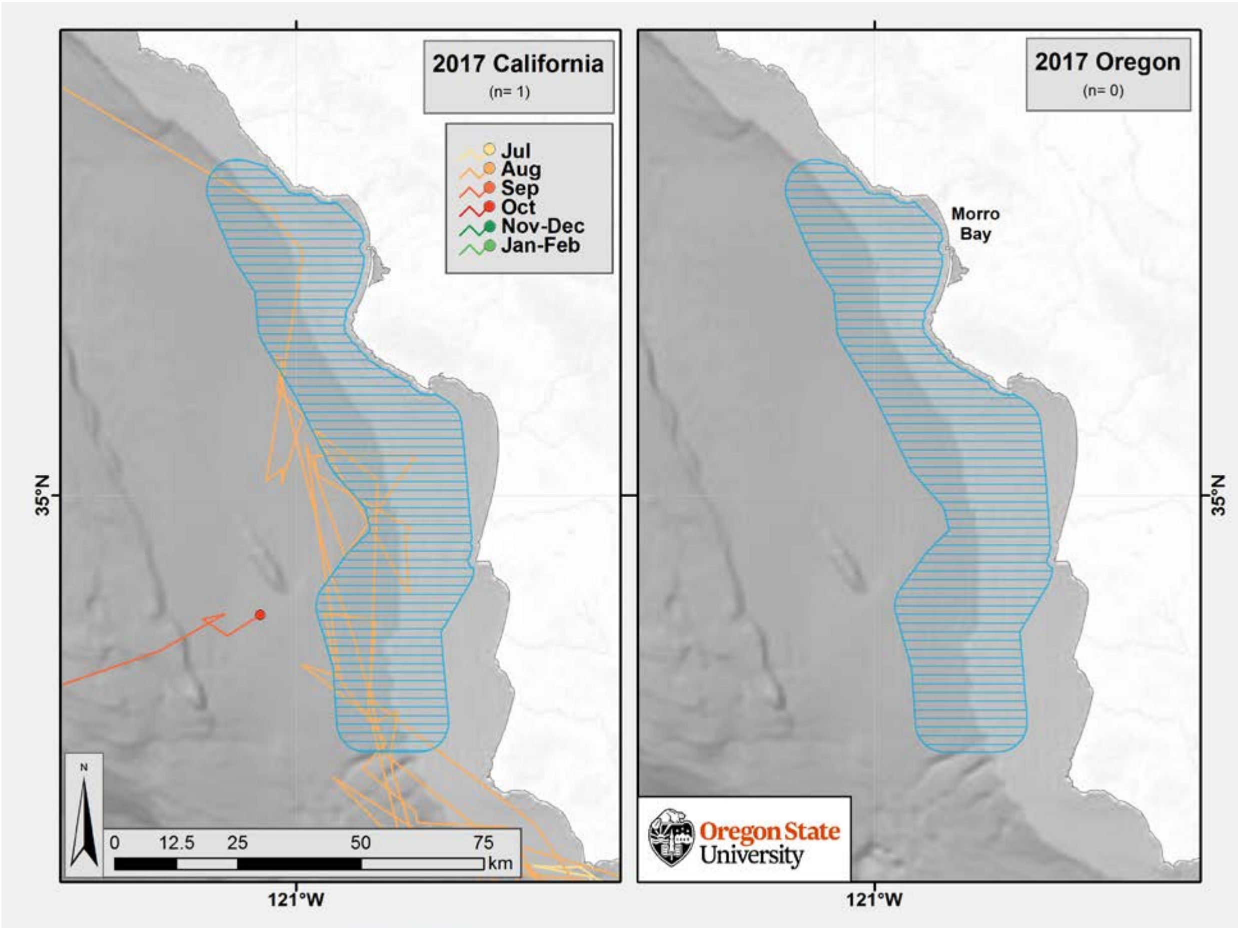


Figure 12. Satellite-monitored tracks in the Morro Bay to Point Sal BIA for humpback whales tagged off California in July and August 2017 (1 DUR tag; left panel) and Oregon in September and October 2017 (0 tags; right panel).

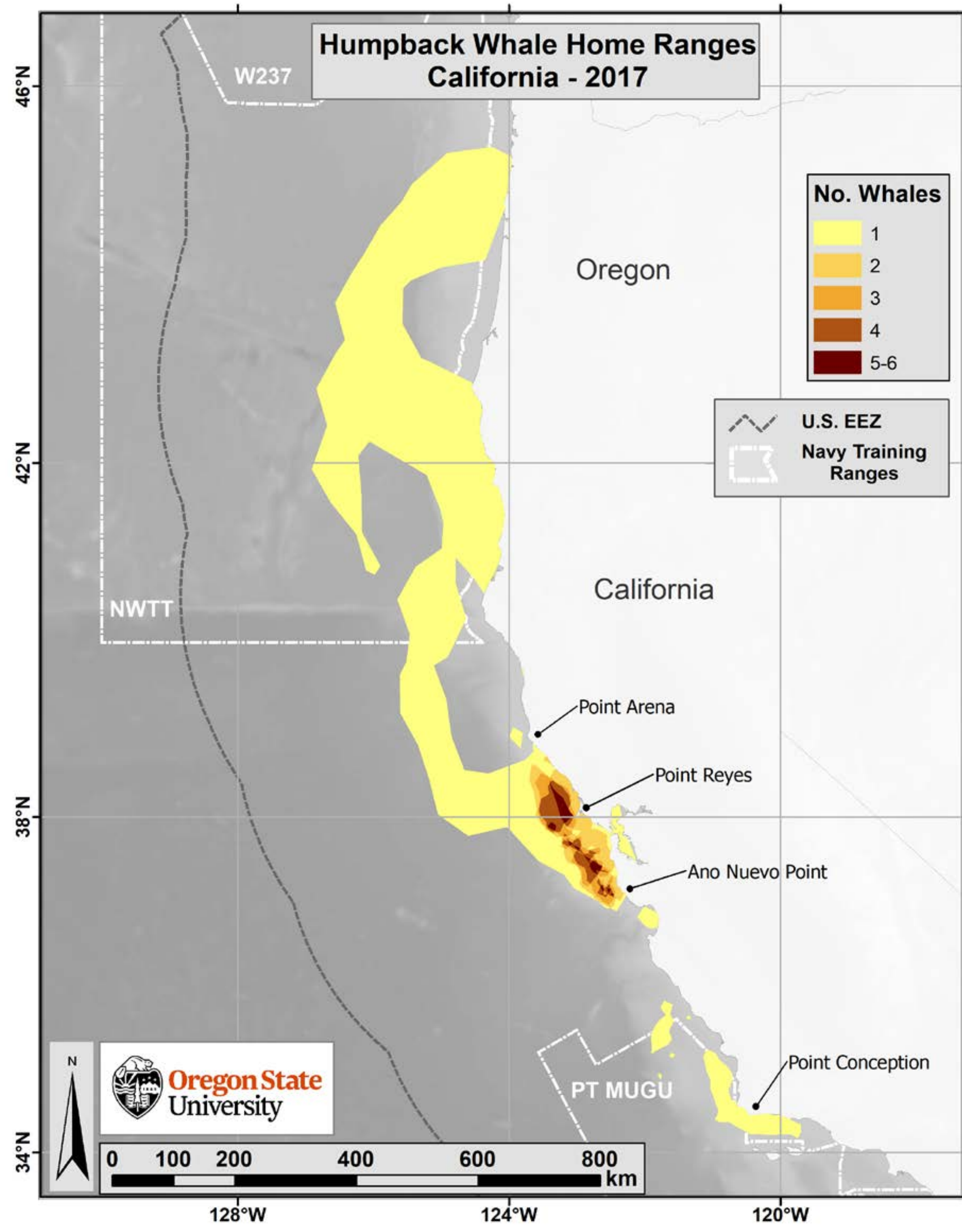


Figure 13. Feeding area HRs for seven humpback whales tagged off California in July and August 2017. Shading represents the number of individual whales with overlapping HRs.

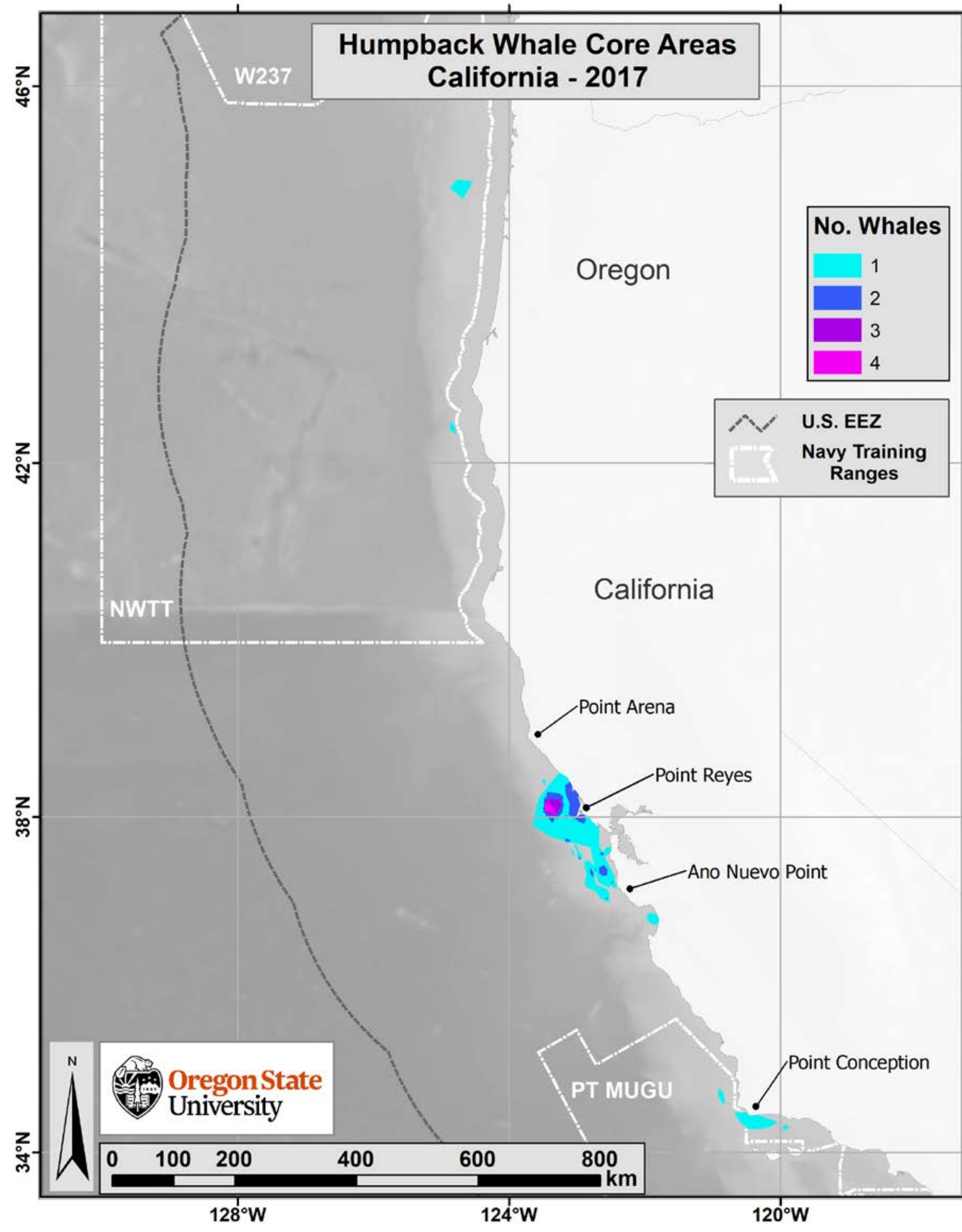


Figure 14. Feeding area CAs for seven humpback whales tagged off California in July and August 2017. Shading represents the number of individual whales with overlapping CAs.

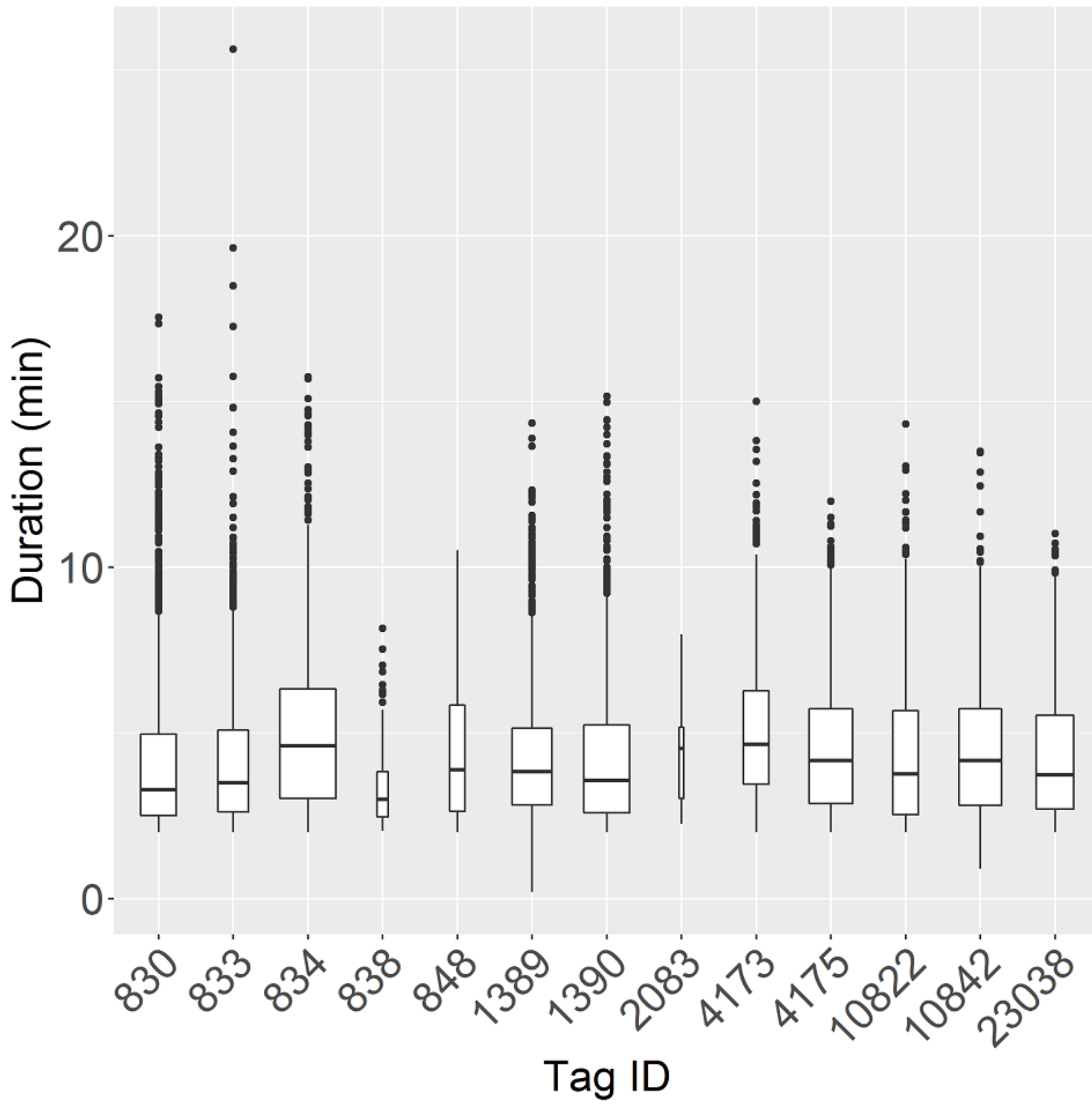


Figure 15. Dive duration of DM and DUR tagged humpback whales tagged off central and southern California during summer 2017. Boxes represent the first and third quartiles of the data while points represent values exceeding 1.5 times the inter-quartile range. Box widths are proportional to the sample size. Note Tag #840 is not included in the figure as it did not provide any dive data.

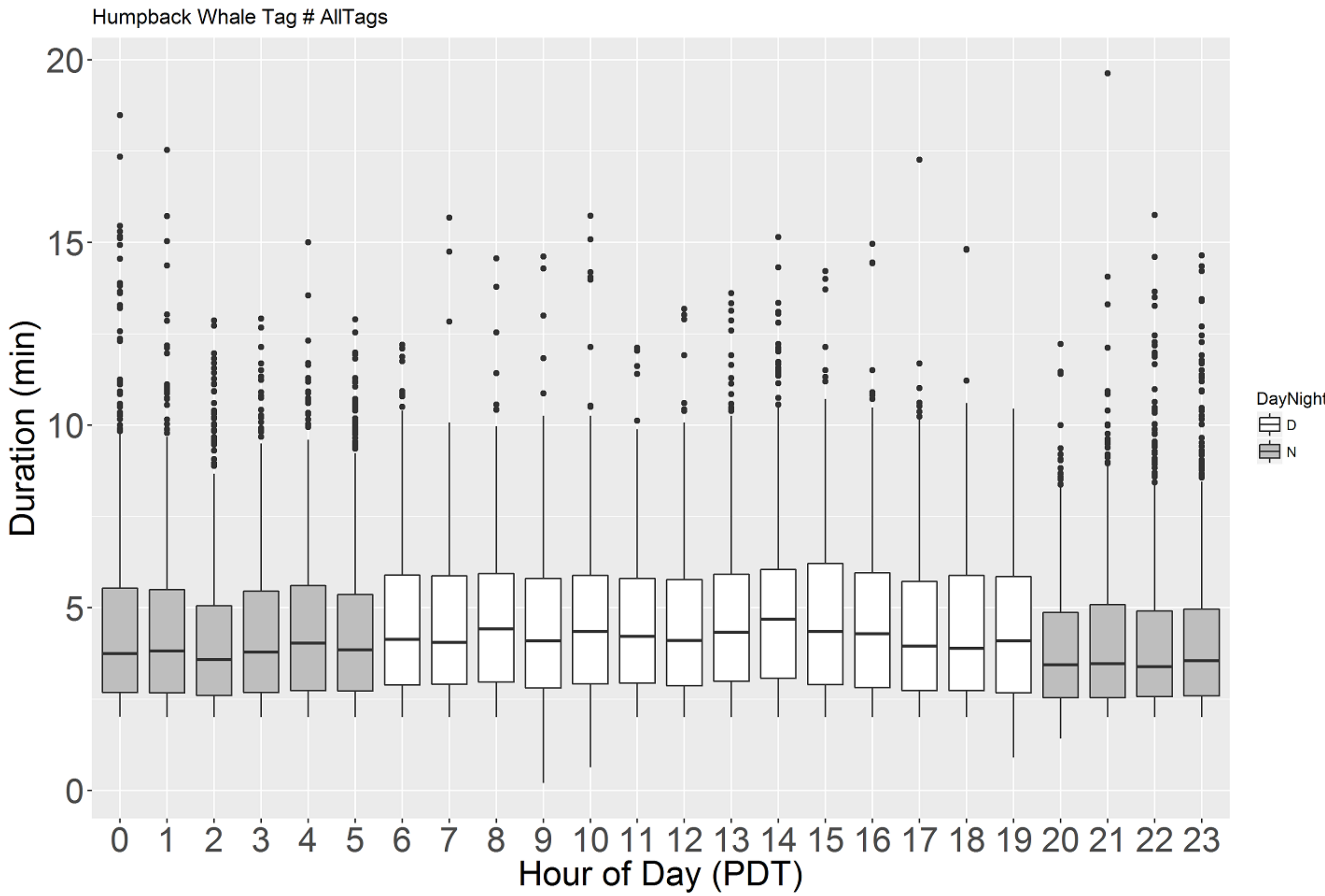


Figure 16. Dive duration of DM and DUR tagged humpback whales tagged off California during summer 2017 (n = 13). Data are presented by hour of day to better visualize diel variability. Note Tag #840 is not included in the figure as it did not provide any dive data.

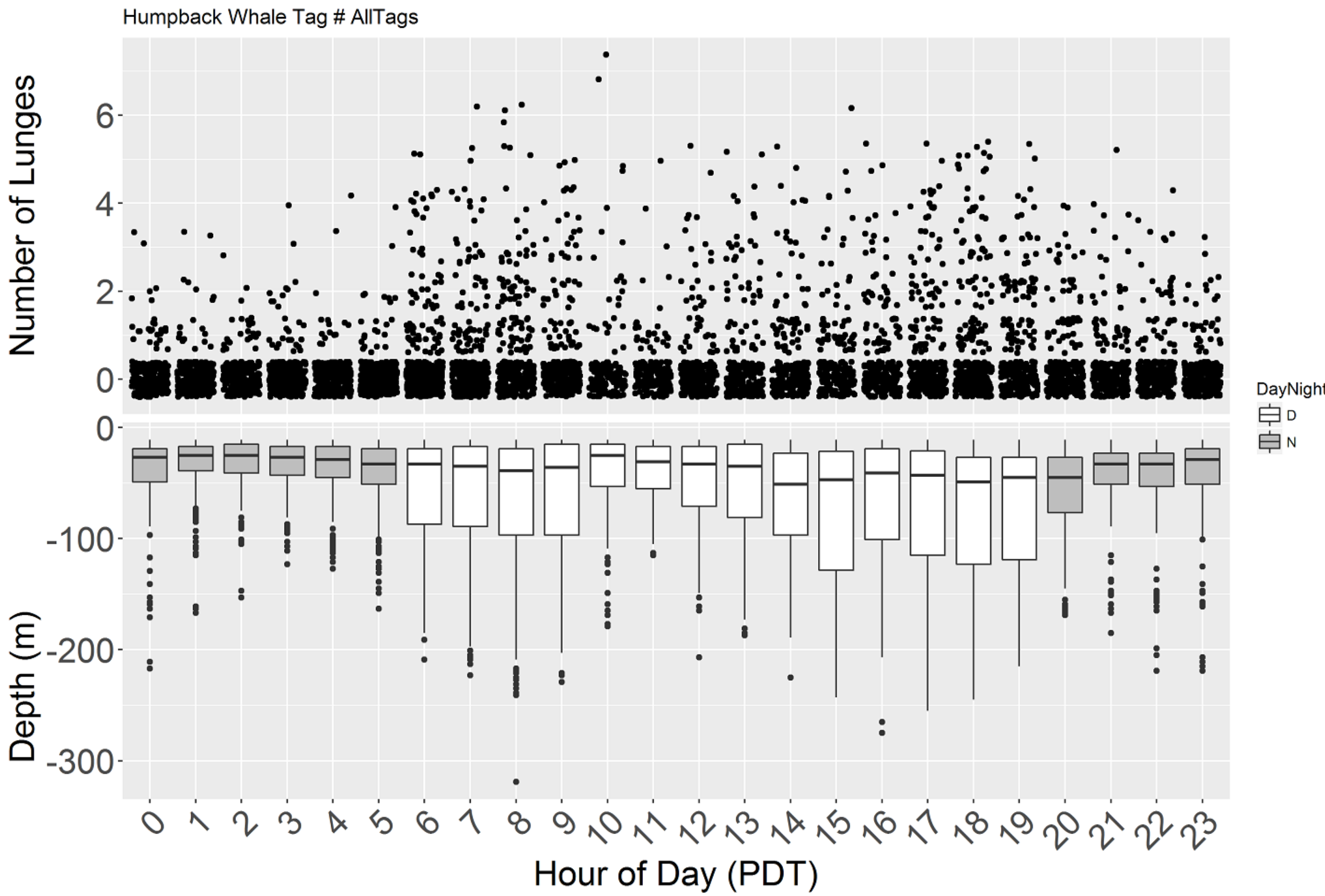


Figure 17. Number of lunges per dive (upper panel) and maximum dive depth (lower panel) of DM-tagged humpback whales tracked off central California during summer/fall 2017 (n = 6). Data are presented by hour of day to better visualize diel variability and the data in the top panel are jittered to avoid overplotting. Note Tag #840 is not included in the figure as it did not provide any dive data.

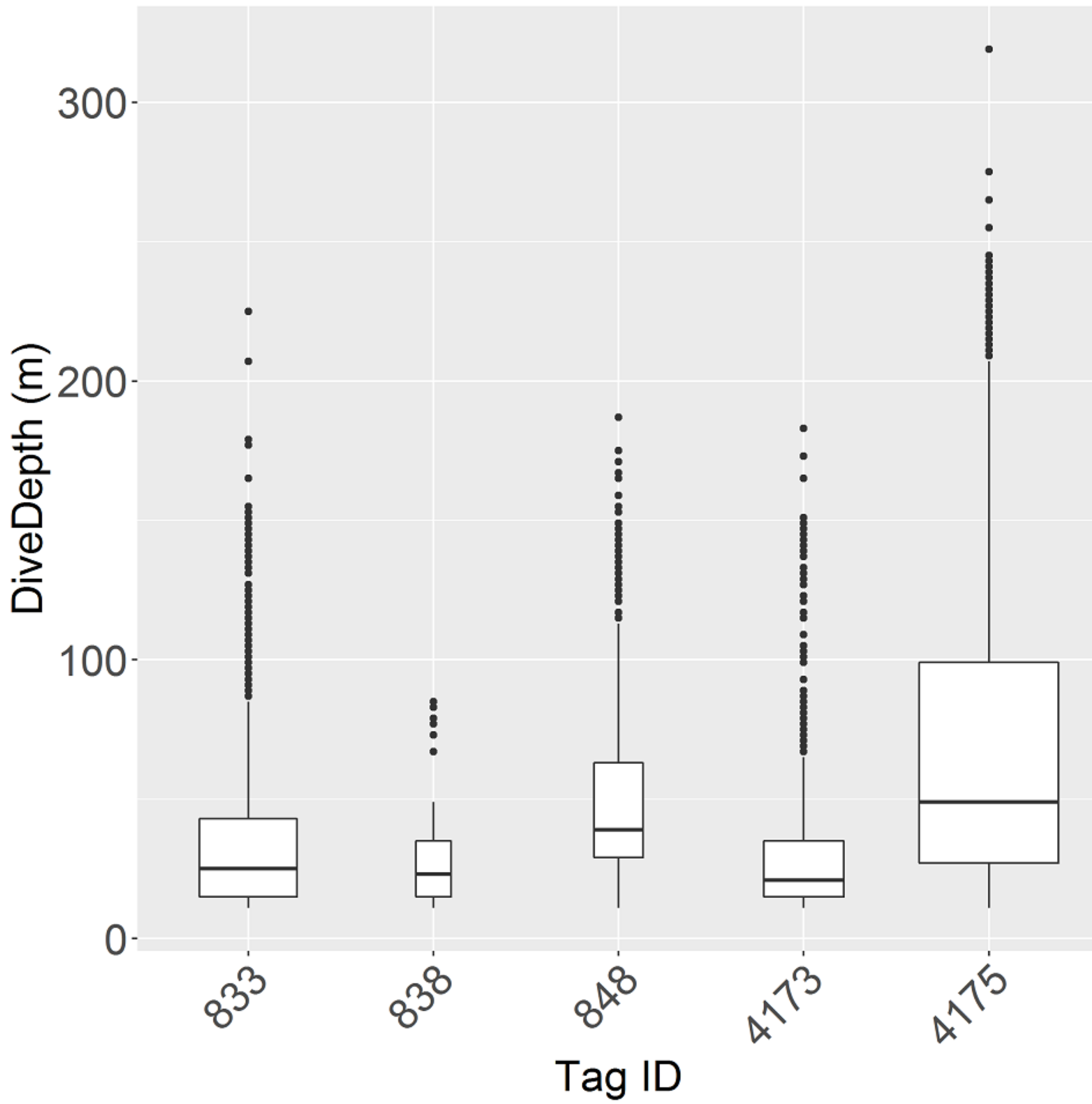


Figure 18. Dive depth of DM-tagged humpback whales tagged off central California during summer 2017. Boxes represent the first and third quartiles of the data while points represent values exceeding 1.5 times the inter-quartile range. Box widths are proportional to the sample size. Note Tag #840 is not included in the figure as it did not provide any dive data.

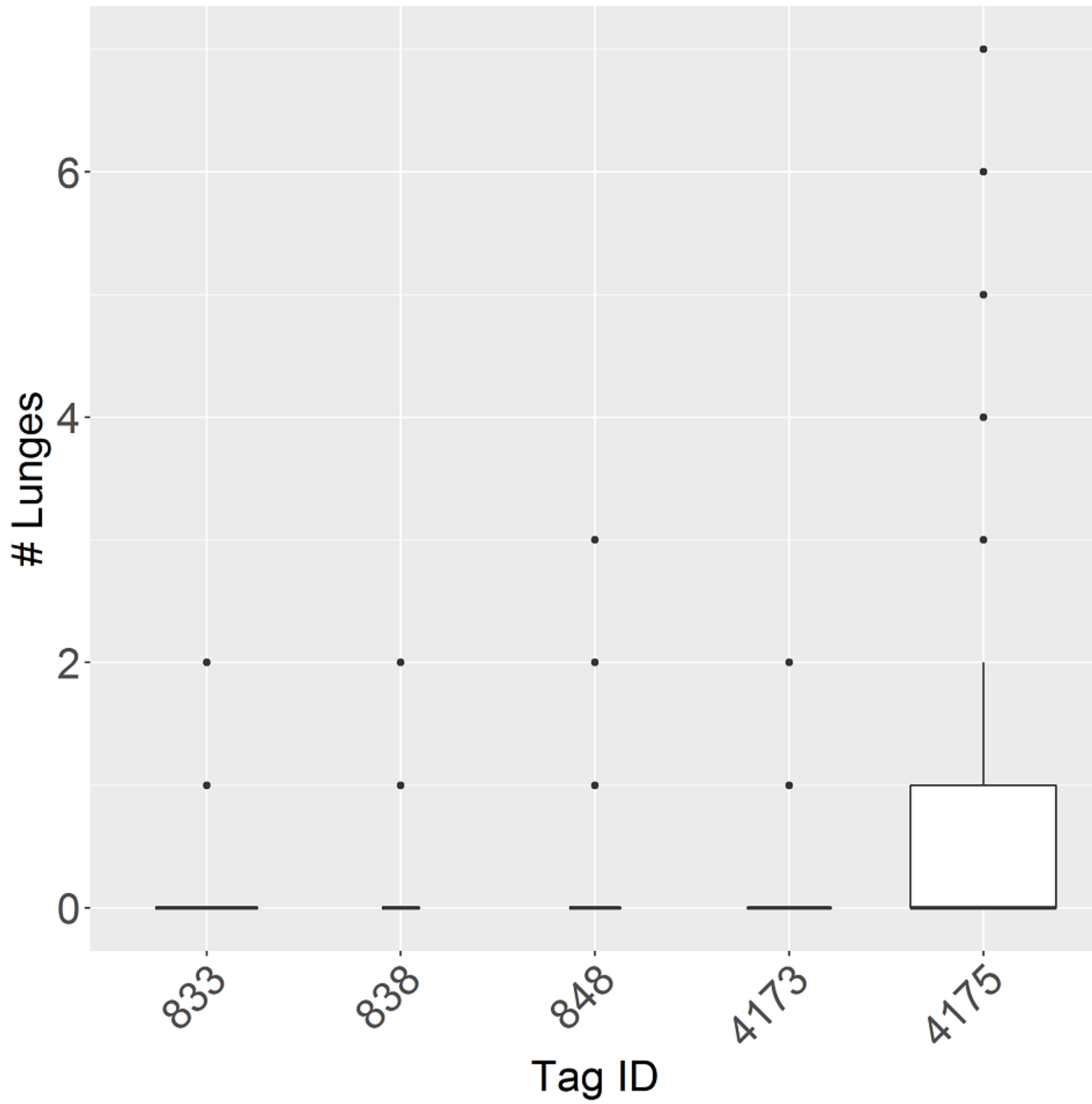


Figure 19. Number of feeding lunges per dive recorded by DM-tagged humpback whales off central California in summer/fall 2017. Note Tag #840 is not included in the figure as it did not provide any dive data.

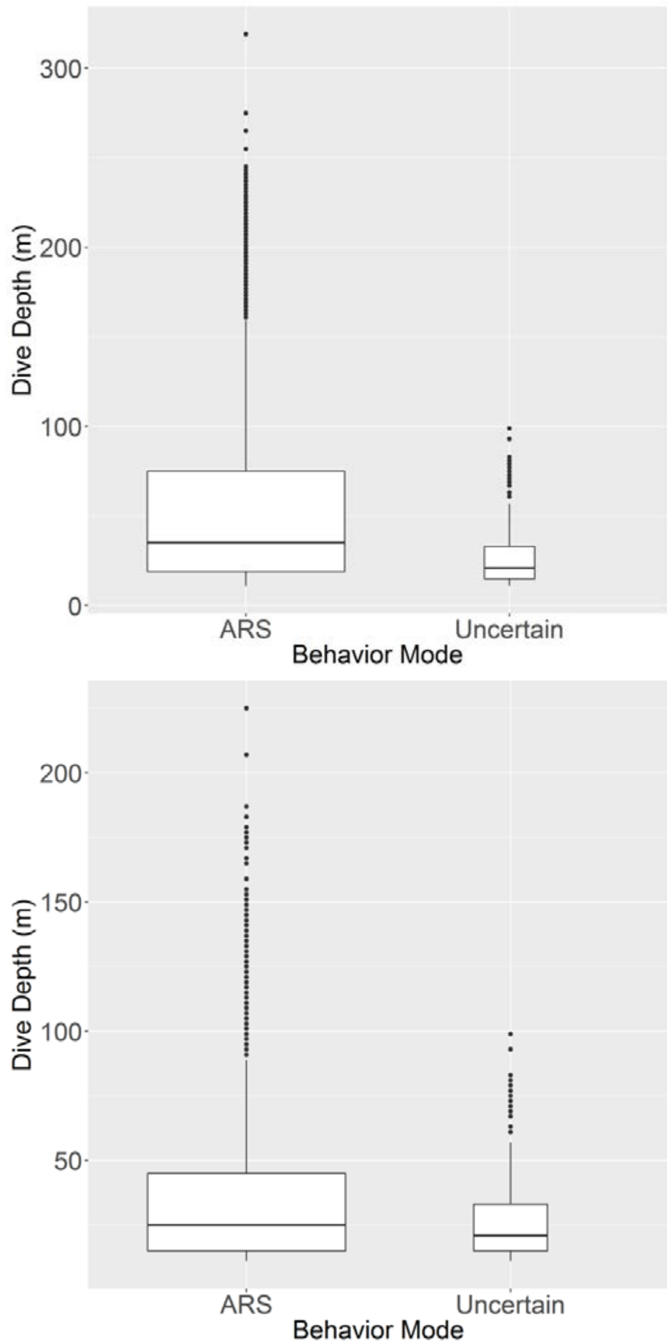


Figure 20. Maximum dive depth of DM-tagged humpback whales tagged off central California during summer 2017 presented by hSSSM-derived behavior state for all DM tagged whales (top panel) and all DM tagged whales except Tag #4175 (bottom panel). Width of the boxes is proportional to the number of data points each box represents. Note no DM tagged positions were classified as "transit" so it is not shown. Also note that Tag #840 is not included in the figure as it did not provide any dive data.

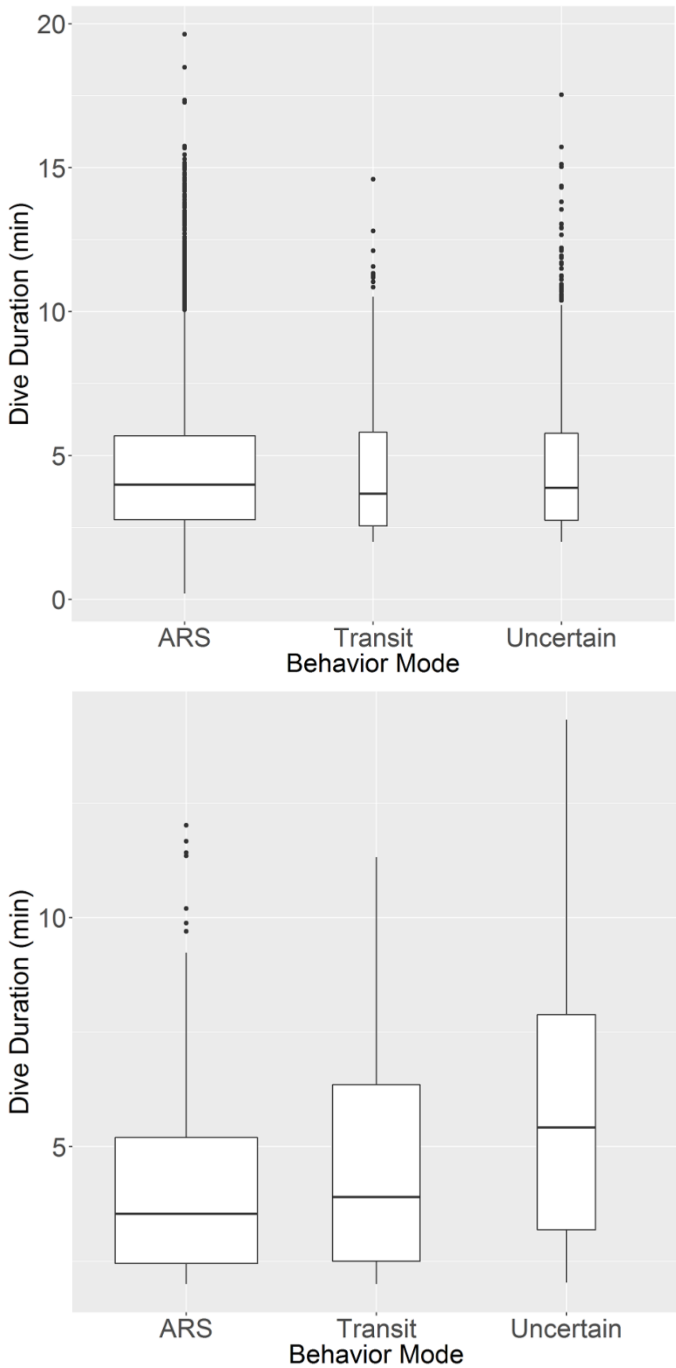
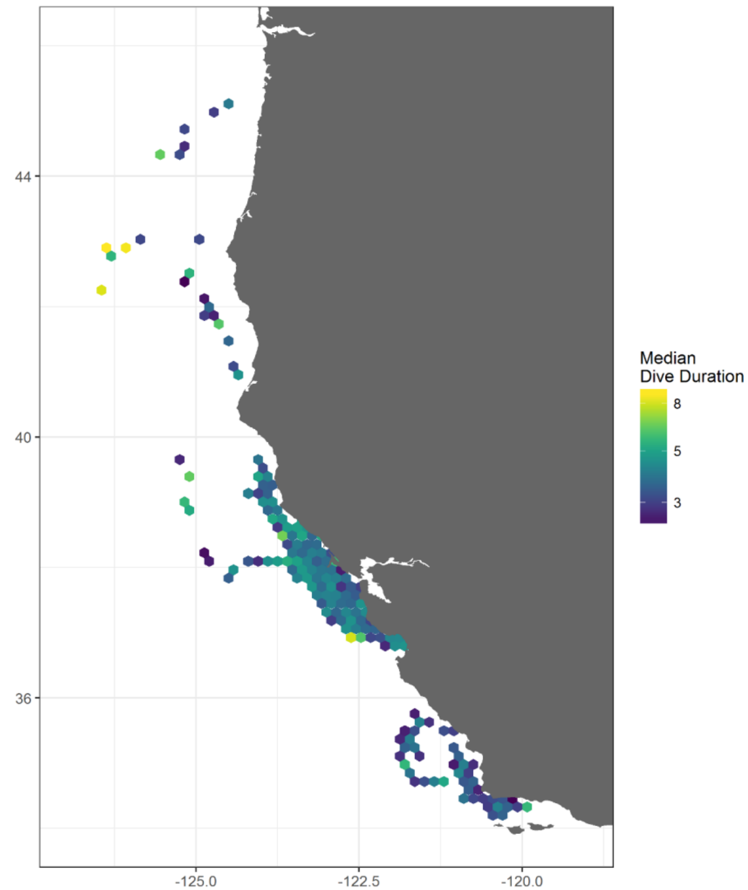


Figure 21. Dive duration of DM and DUR-tagged humpback whales tagged off central California during summer 2017 presented by hSSSM-derived behavior state for all tagged whales (top panel) and Tag #10822 (bottom panel). Width of the boxes is proportional to the number of data points each box represents. Note Tag #840 is not included in the figure as it did not provide any dive data.



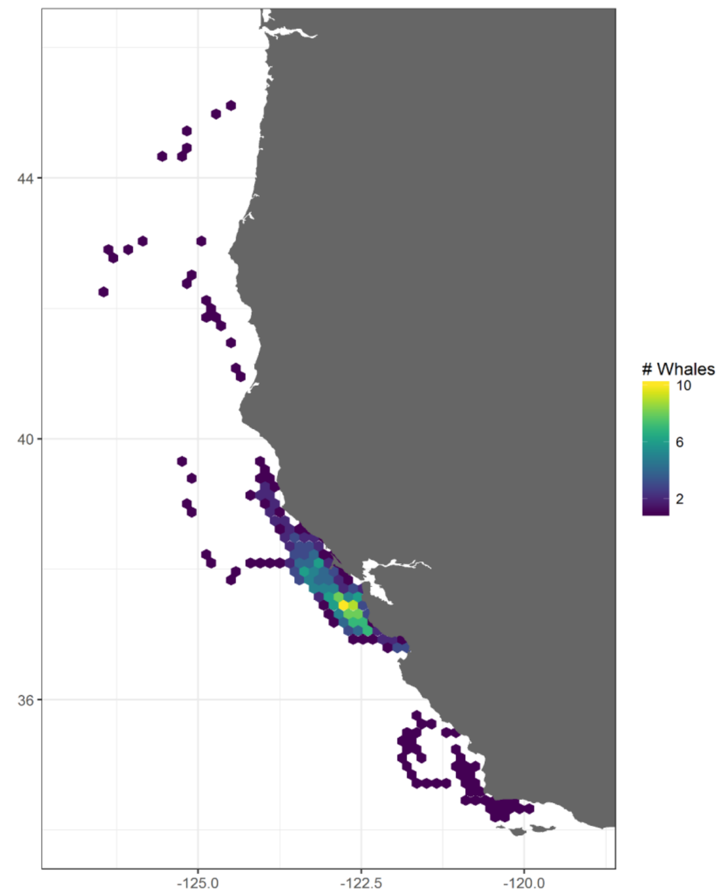


Figure 22. Left) A 0.15-degree hexagonal grid showing the median dive duration reported by DM and DUR-tagged humpback whales tagged off California in summer 2017. Right) A 0.15-degree hexagonal grid showing the number of DM and DUR-tagged humpback whales occupying each grid cell. Note that this figure does not include Tag #2083 as the track was too short to run through the hSSSM model, or Tag #840 as it did not provide any dive data.

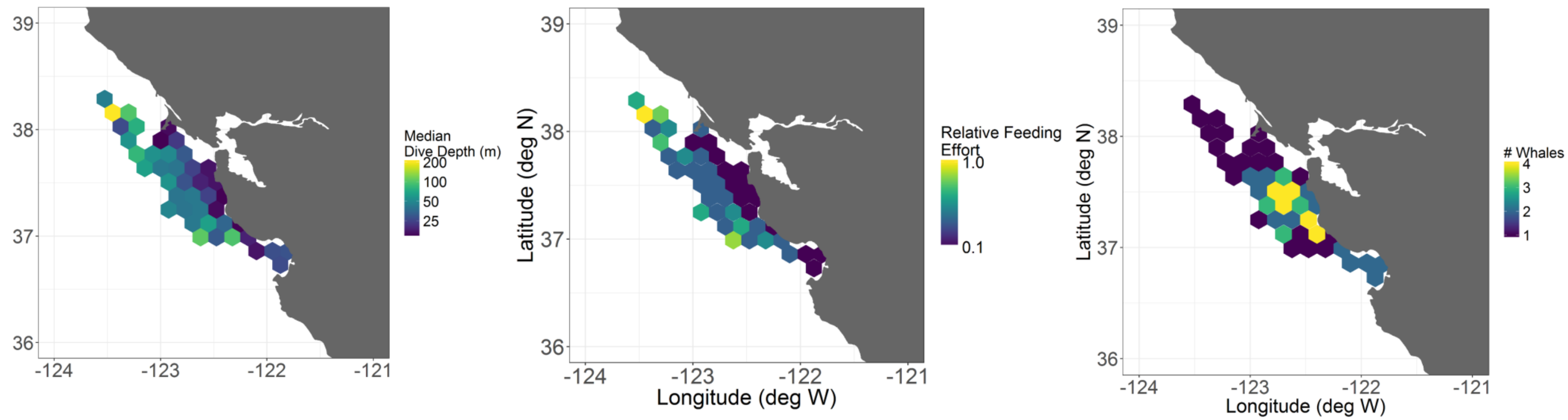


Figure 23. Left) A 0.15-degree hexagonal grid showing the median maximum dive depth reported by DM-tagged humpback whales tagged off California in summer 2017. Center) A representation of the amount of feeding that occurred in each grid cell based on the number of lunges recorded by DM-tagged humpback whales. Right) A 0.15-degree hexagonal grid showing the number of DM and DUR-tagged humpback whales occupying each grid cell. Note that this figure does not include Tag #2083 as the track was too short to run through the hSSSM model, or Tag #840 as it did not provide any dive data.

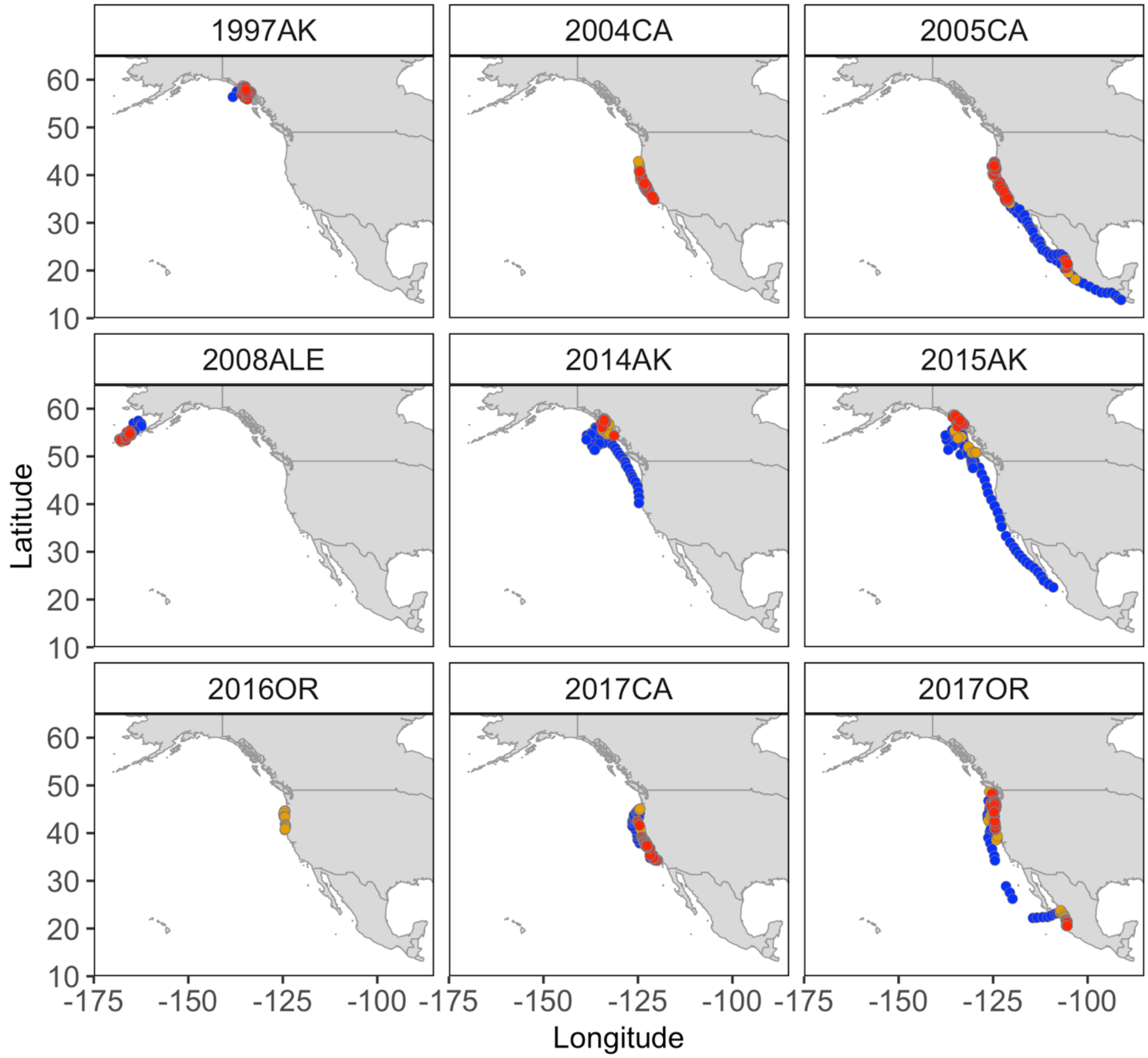
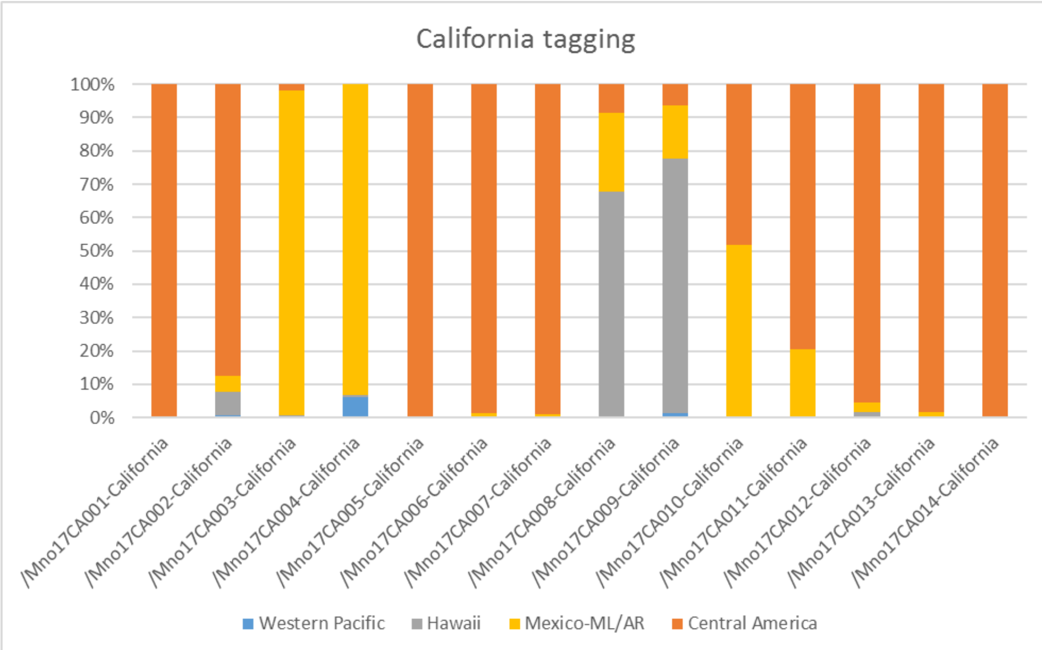


Figure 24. The geographic distribution of SSSM/hSSSM locations colored by behavioral mode (blue = transiting, orange = uncertain, red = ARS) for each tagging year/season for humpback whales tagged by OSU in feeding areas of the Eastern North Pacific from 1997 to 2017 (AK = Southeast Alaska, ALE = Aleutian Islands, CA = California, OR = Oregon).



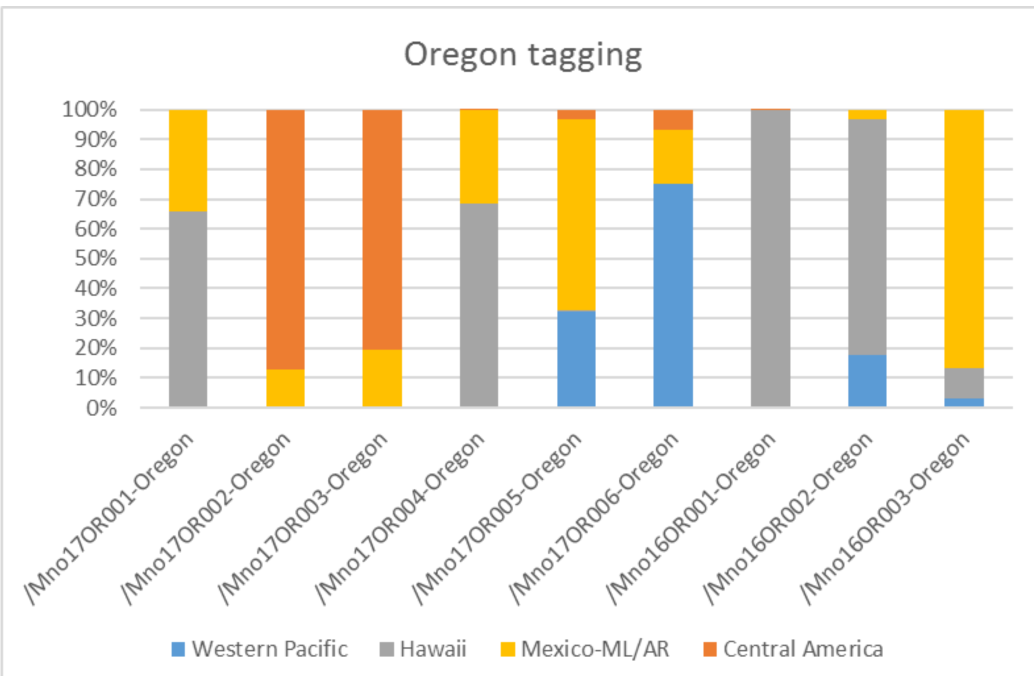


Figure 25. Individual assignment of the California (top) and Oregon (bottom) tagging samples to the four Distinct Population Segments (DPSs) recognized by the US Endangered Species Act. The stacked bars represent the relative likelihood of assignment for each whale to the four DPSs based on the program GeneClass2 and using the published SPLASH dataset as reference samples (Baker et al. 2013).

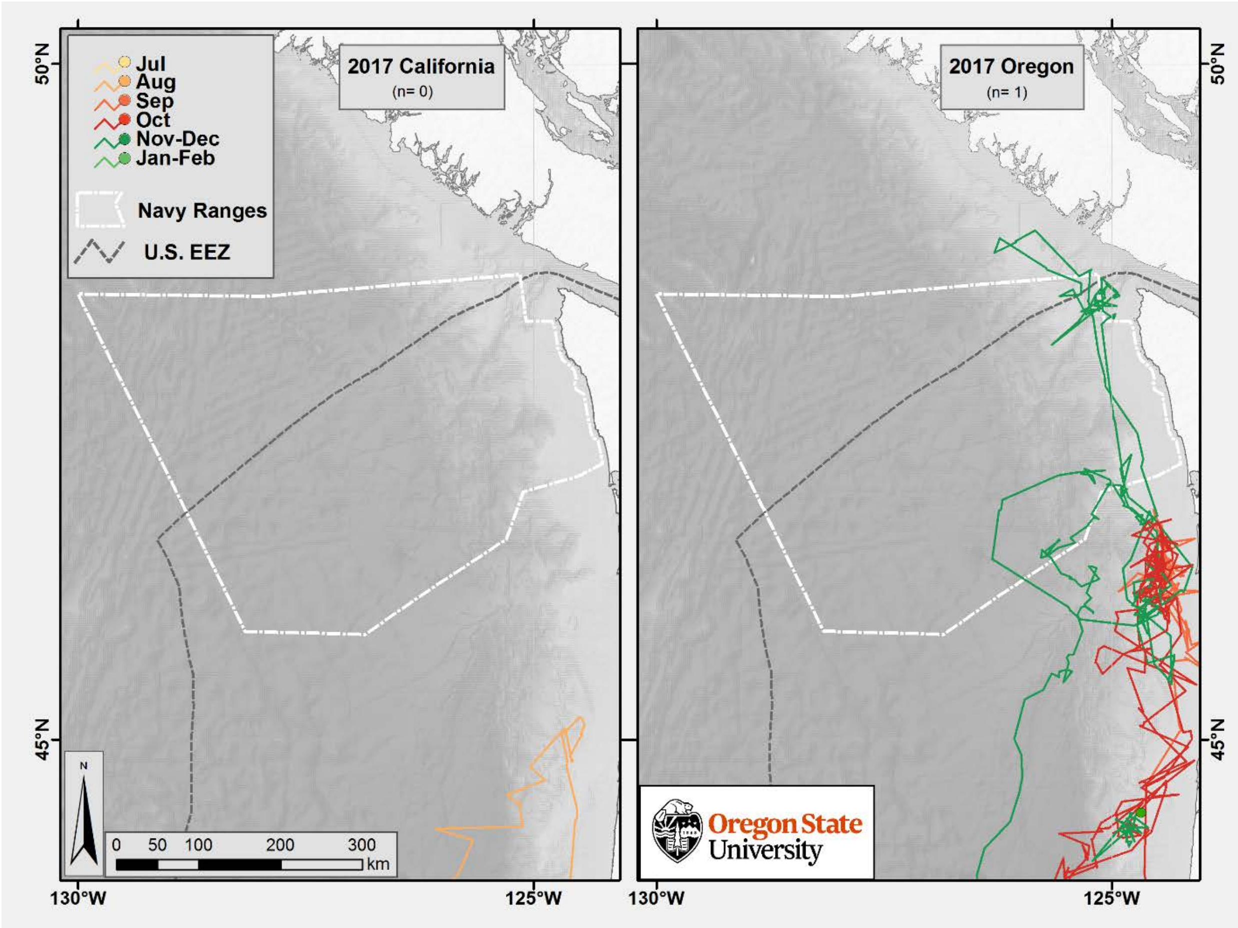


Figure 26. Satellite-monitored tracks in Area W237 of the NWTT range for humpback whales tagged off California in July and August 2017 (0 tags; left panel) and Oregon in September and October 2017 (1 DUR tag; right panel).

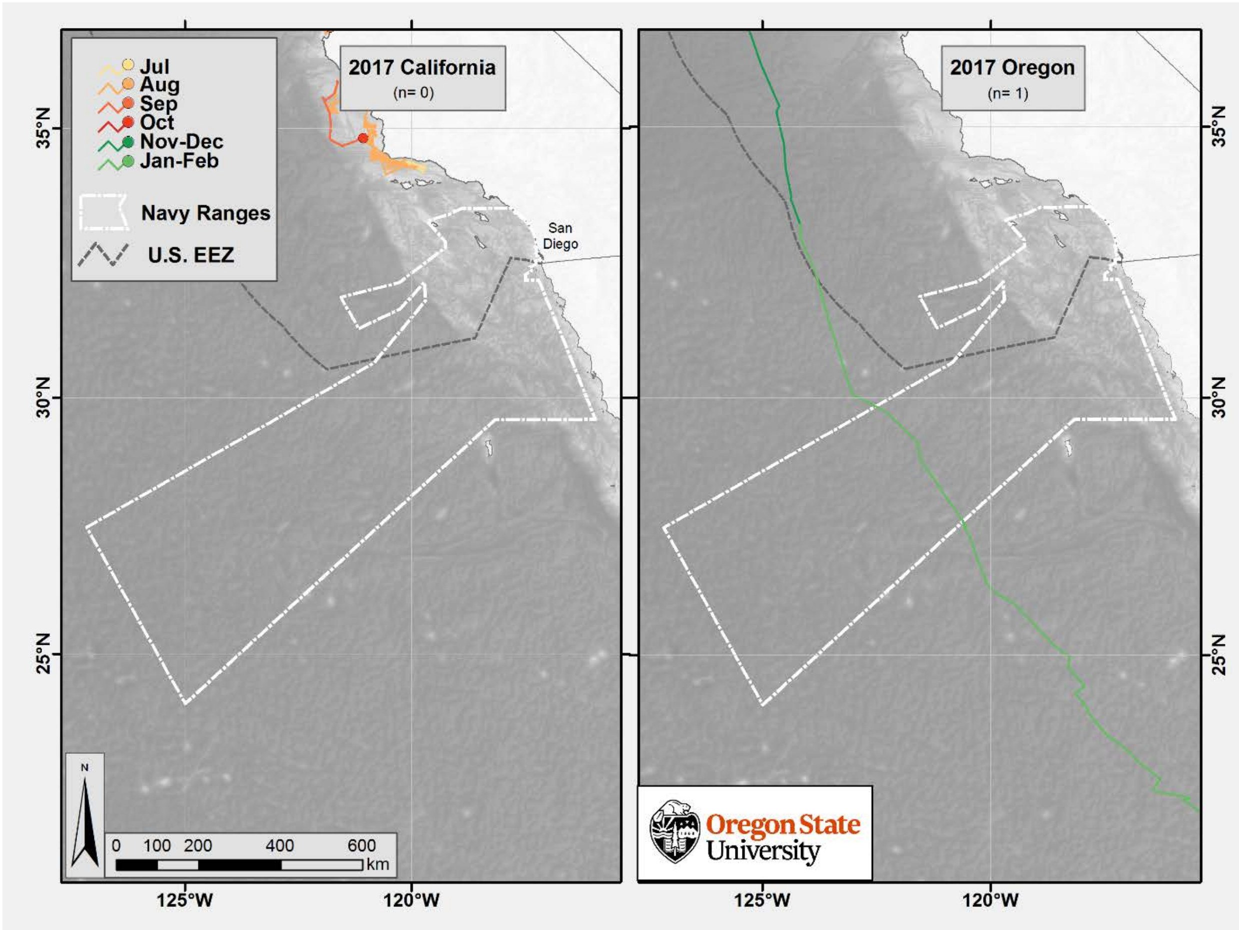


Figure 27. Satellite-monitored tracks in SOCAL for humpback whales tagged off California in July and August 2017 (0 tags; left panel) and Oregon in September and October 2017 (1 DUR tag; right panel).

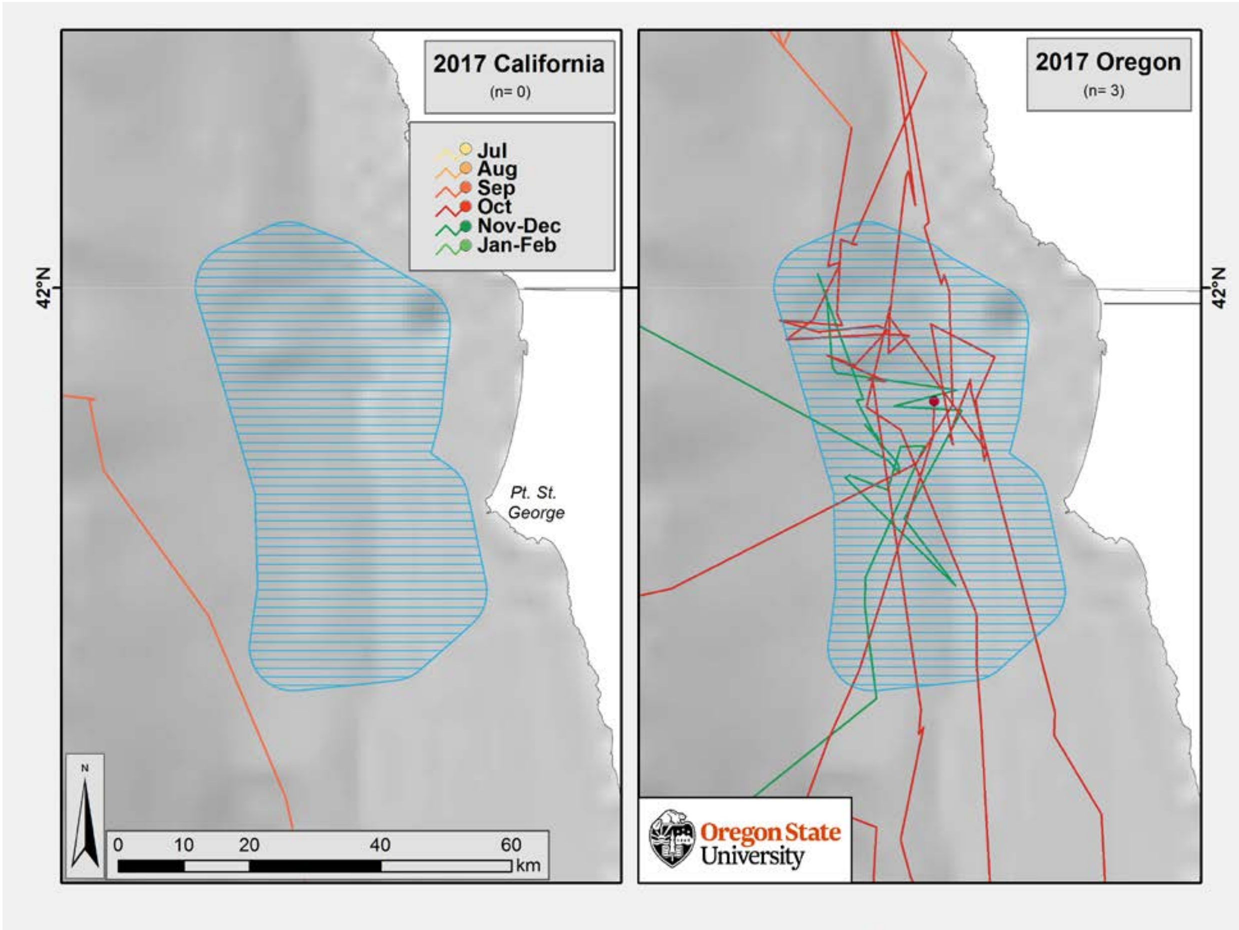


Figure 28. Satellite-monitored tracks in the Point St. George BIA for humpback whales tagged off California in July and August 2017 (0 tags; left panel) and Oregon in September and October 2017 (3 DUR tags; right panel).

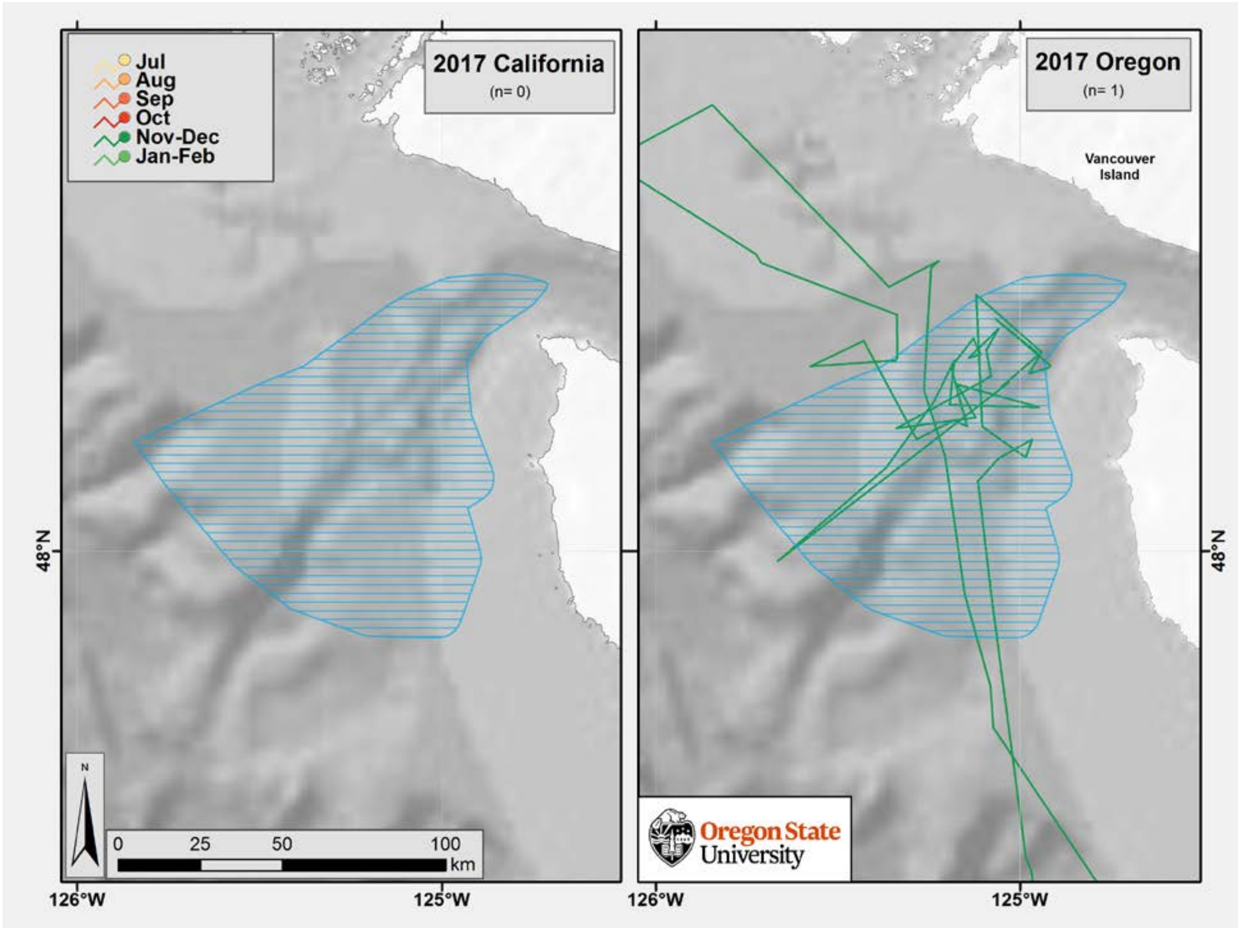


Figure 29. Satellite-monitored tracks in the Northern Washington BIA for humpback whales tagged off California in July and August 2017 (0 tags; left panel) and Oregon in September and October 2017 (1 DUR tag; right panel).

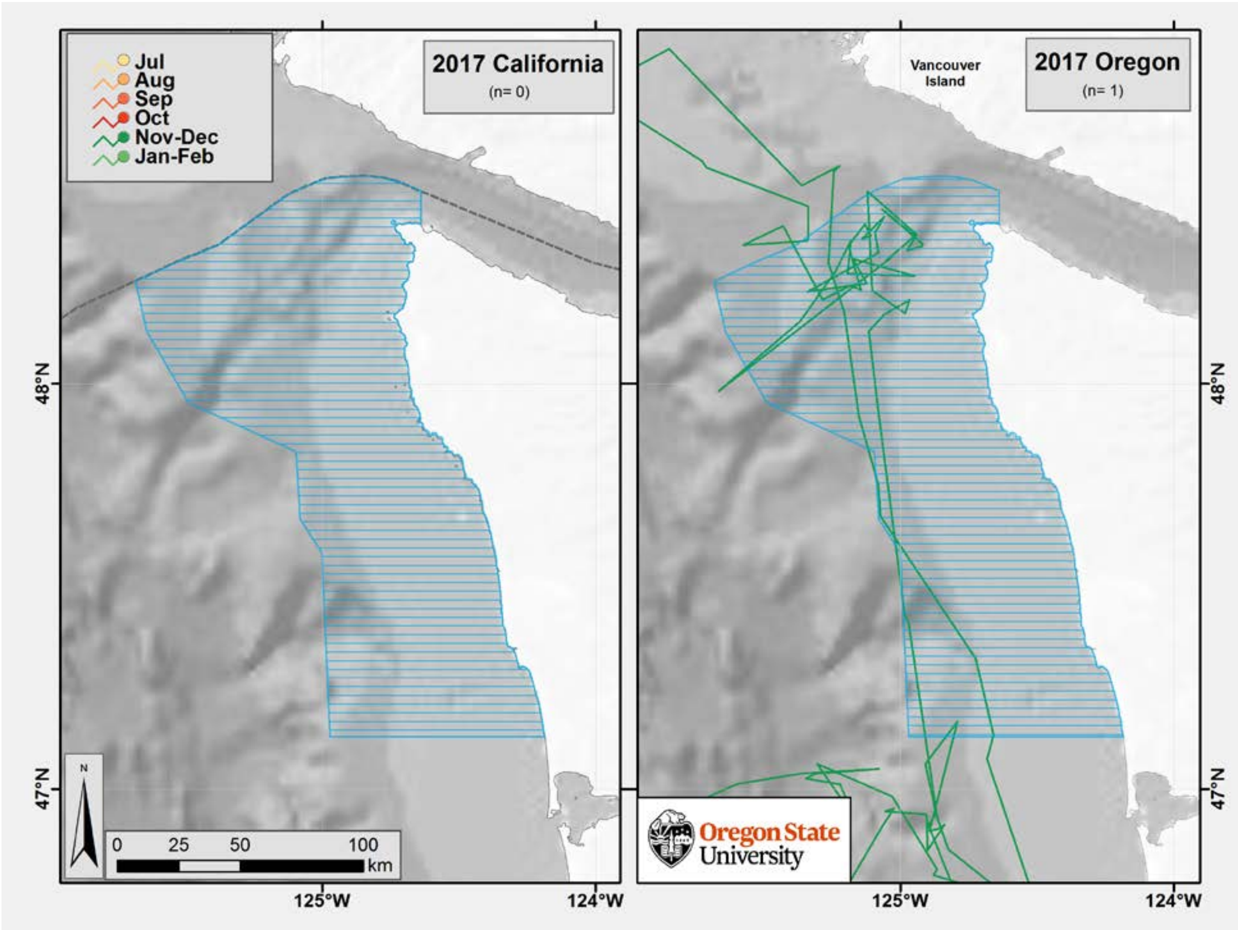


Figure 30. Satellite-monitored tracks in the Olympic Coast National Marine Sanctuary BIA for humpback whales tagged off California in July and August 2017 (0 tags; left panel) and Oregon in September and October 2017 (1 DUR tag; right panel).

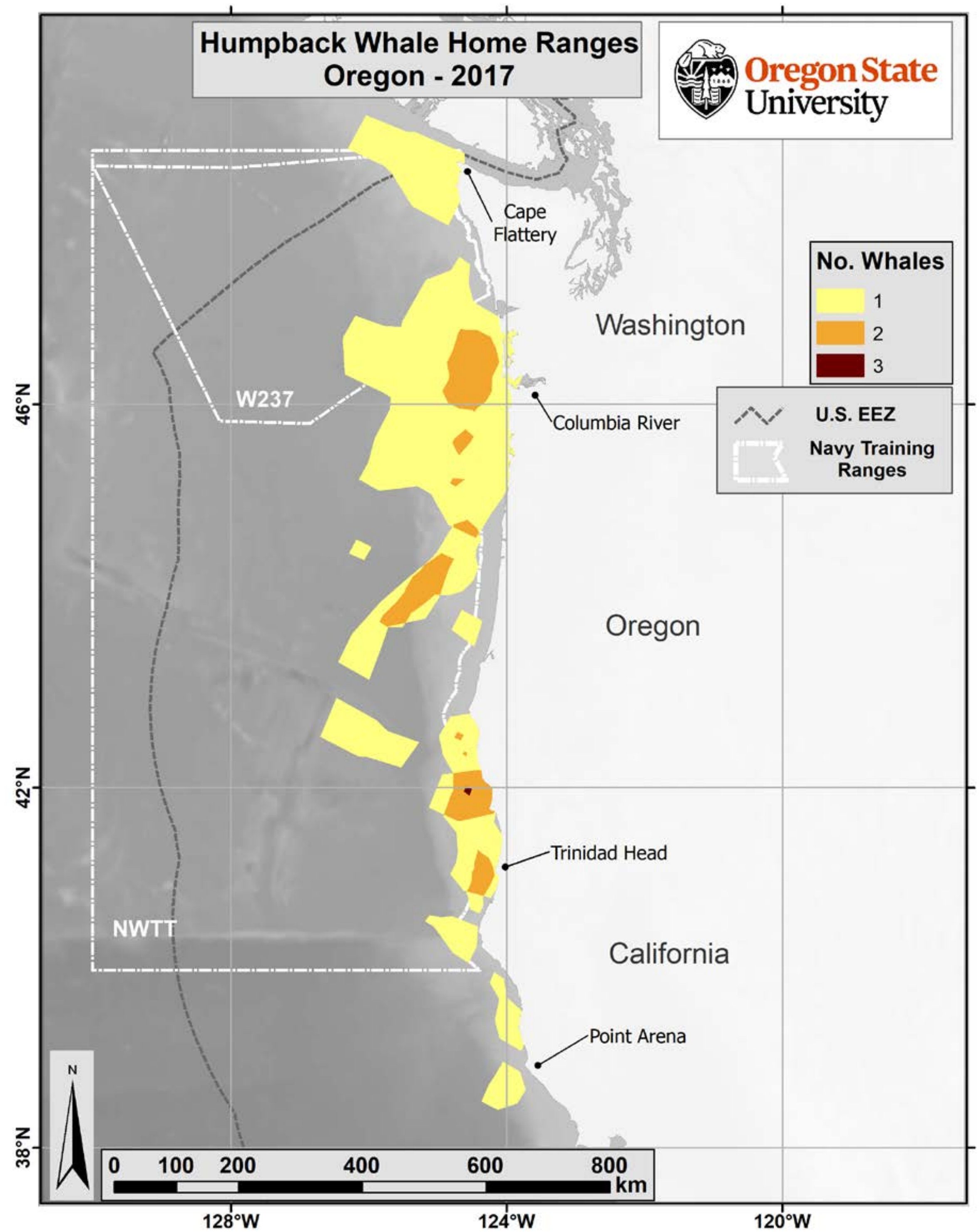


Figure 31. Feeding area HRs for four humpback whales tagged off Oregon in September and October 2017. Shading represents the number of individual whales with overlapping HRs.

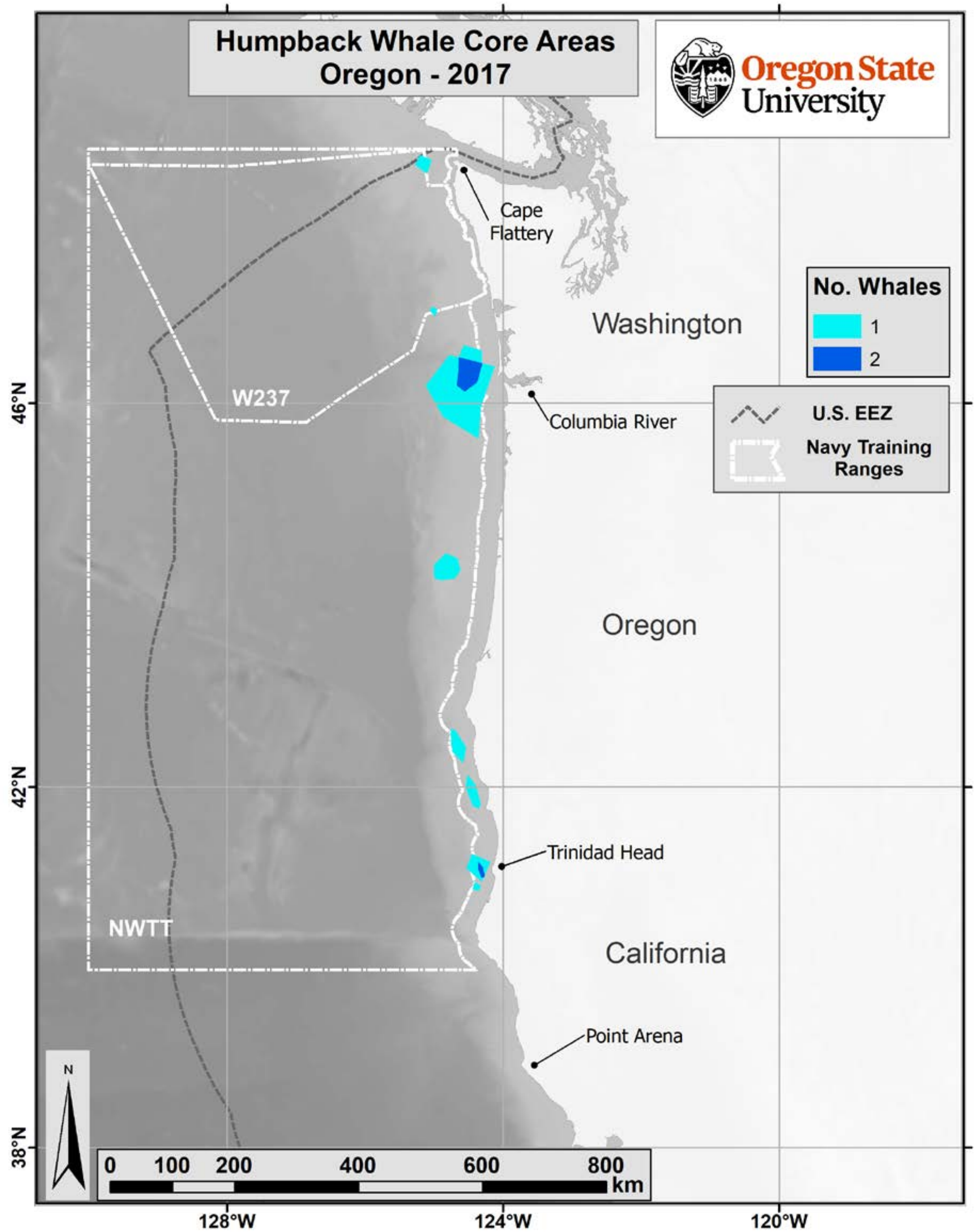


Figure 32. Feeding area CAs for four humpback whales tagged off Oregon in September and October 2017. Shading represents the number of individual whales with overlapping CAs.

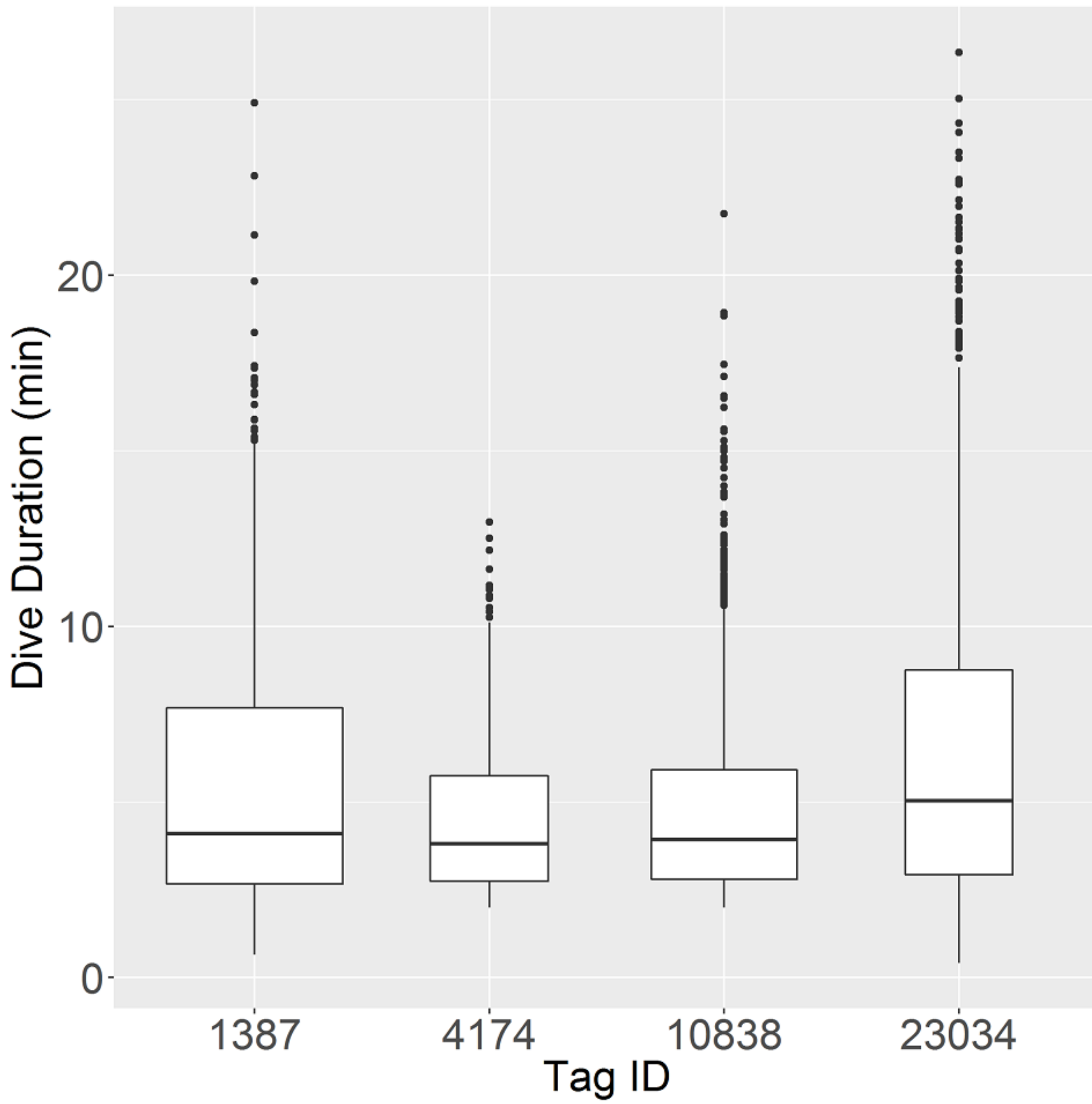


Figure 33. Dive duration of DUR tagged humpback whales tagged off Oregon during fall 2017. Boxes represent the first and third quartiles of the data while points represent values exceeding 1.5 times the inter-quartile range. Box widths are proportional to the sample size.

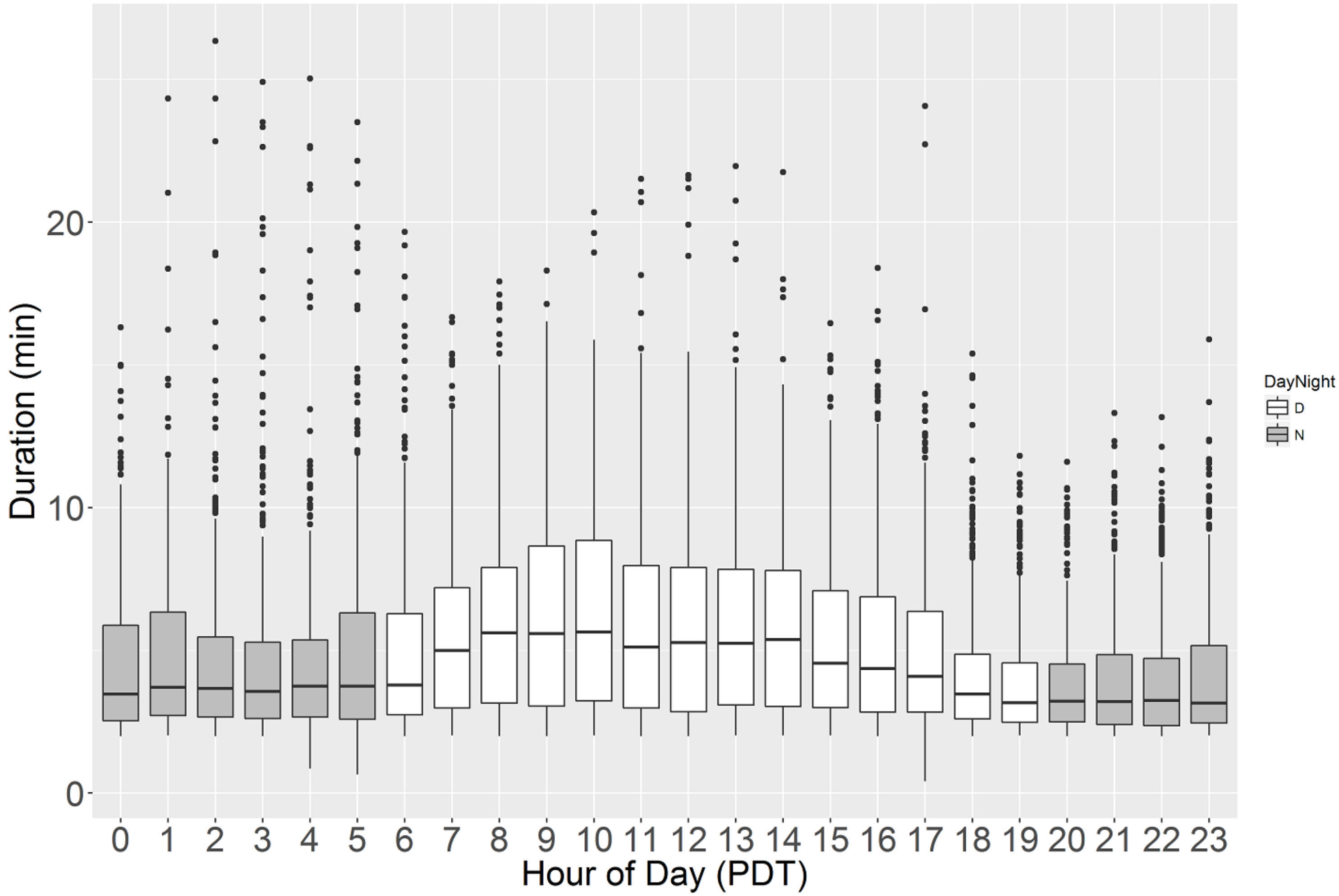


Figure 34. Dive duration of DUR tagged humpback whales tagged off Oregon during fall 2017 (n = 4). Data are presented by hour of day to better visualize diel variability.

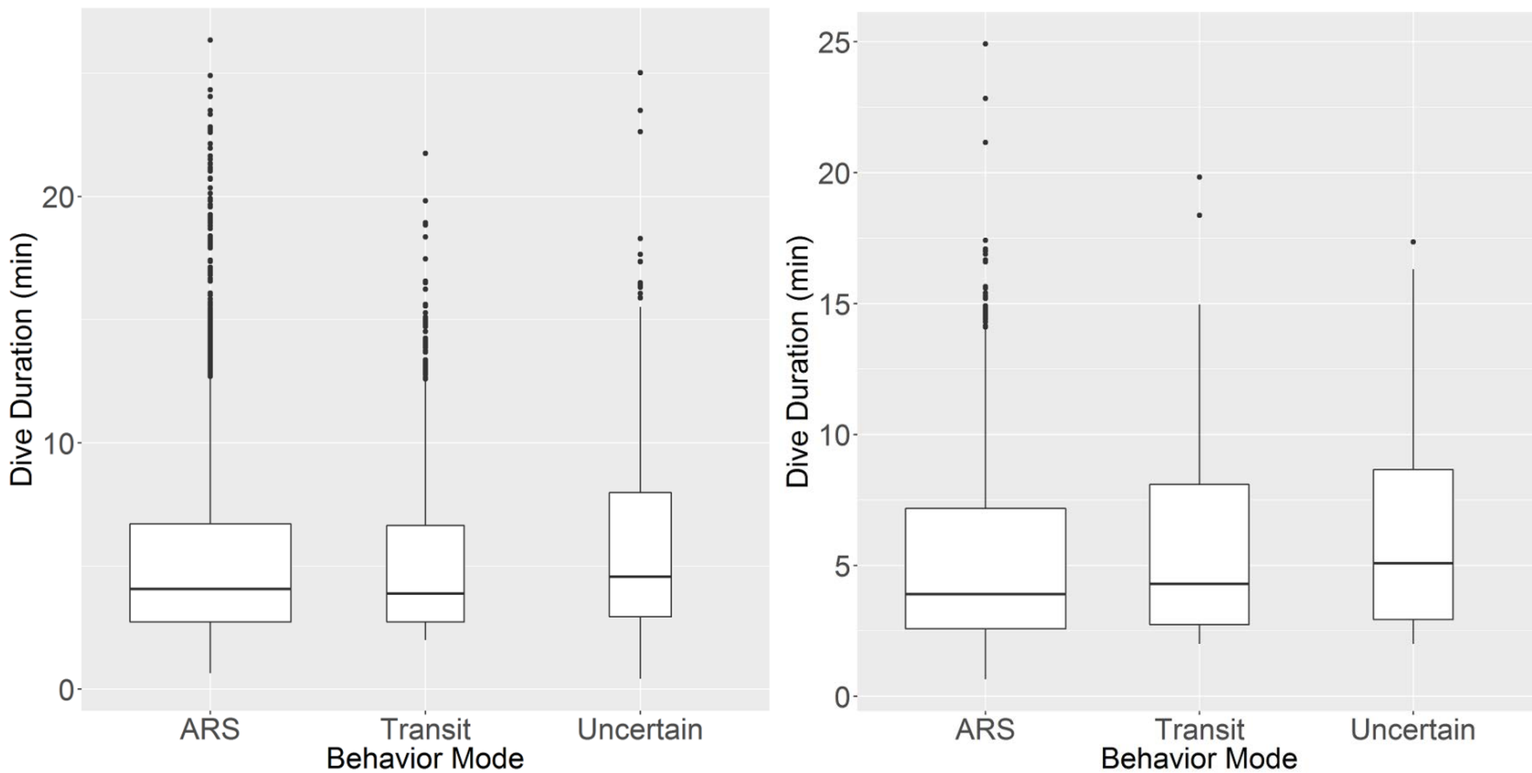


Figure 35. Dive duration of DUR-tagged humpback whales tagged off Oregon during Fall 2017 presented by hSSSM-derived behavior state for all tagged whales (left panel, n = 12,147) and pre-migration Tag #1387 (right panel, n = 4,839). Width of the boxes is proportional to the number of data points each box represents.

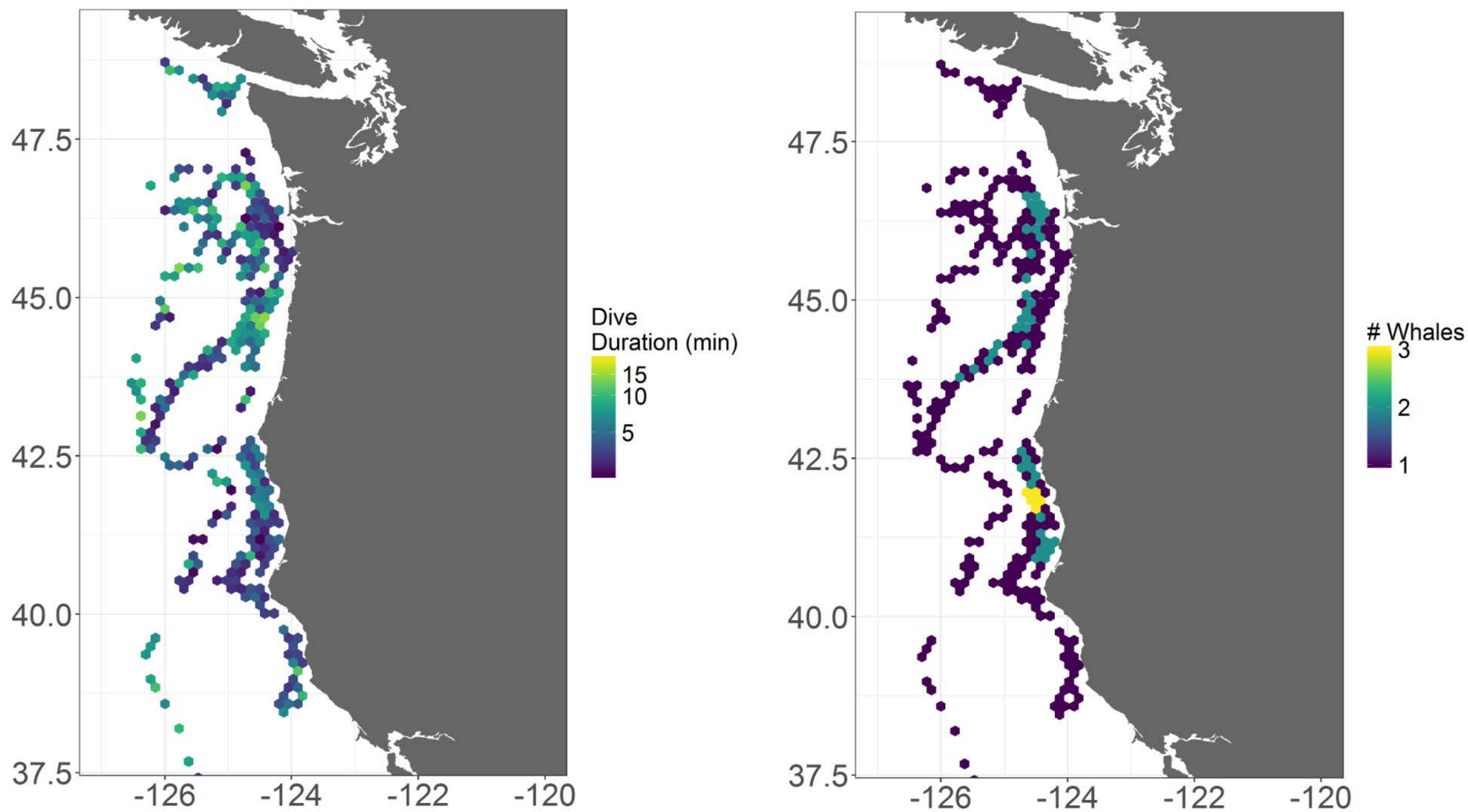


Figure 36. Left) A 0.15-degree hexagonal grid showing the average dive duration reported by DUR-tagged humpback whales tagged off Oregon in fall 2017. Right) A 0.15-degree hexagonal grid showing the number of DUR-tagged humpback whales occupying each grid cell. Both panels focus on pre-migratory movements from northern California to Vancouver Island, British Columbia.

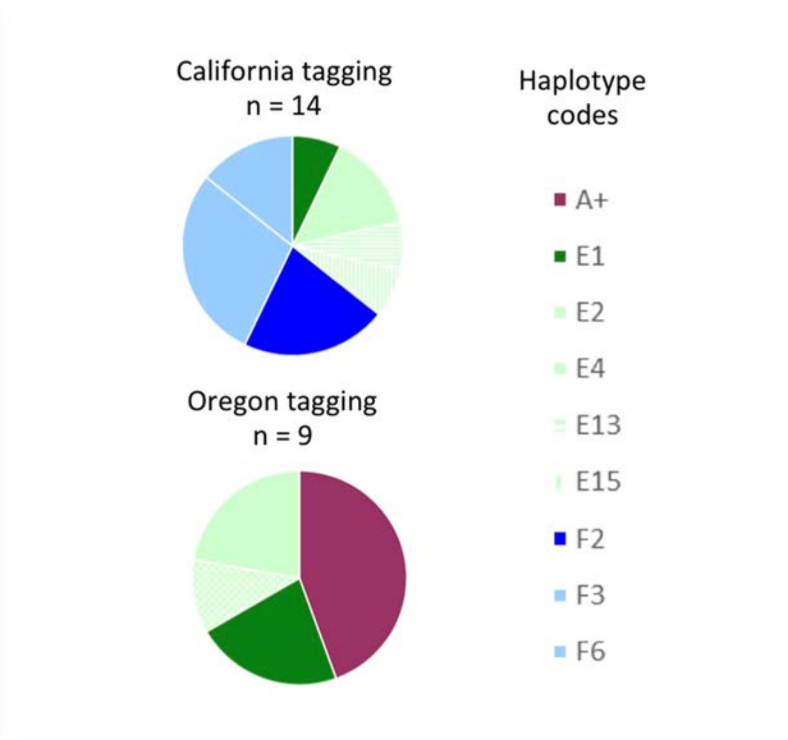


Figure 37. Pie charts of mtDNA haplotype frequencies for the California and Oregon tagging samples. The size of the slice reflects the relative frequency of each haplotype for each data set. The differentiation in haplotype frequencies between the two data sets was significant (F_{ST} = 0.1266, p = 0.0077).

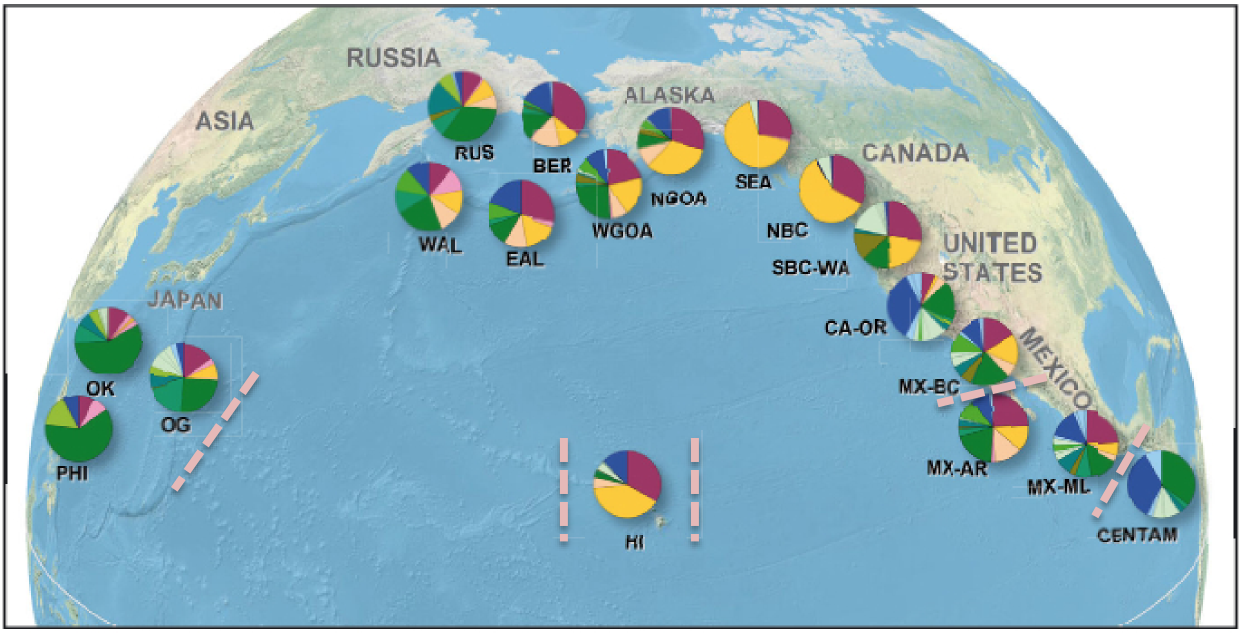


Figure 38. Pie charts of mtDNA frequency for the 10 feeding areas and eight breeding grounds sampled during the SPLASH program, as modified from Figure 2 in Baker et al. (2013). The dashed lines indicate the stratification used to represent the reference database of the four DPSs: Central America, Mexico (MX-ML and MX-AR), Hawaii and the Western Pacific (OK, OG, and PHI). See text for details.

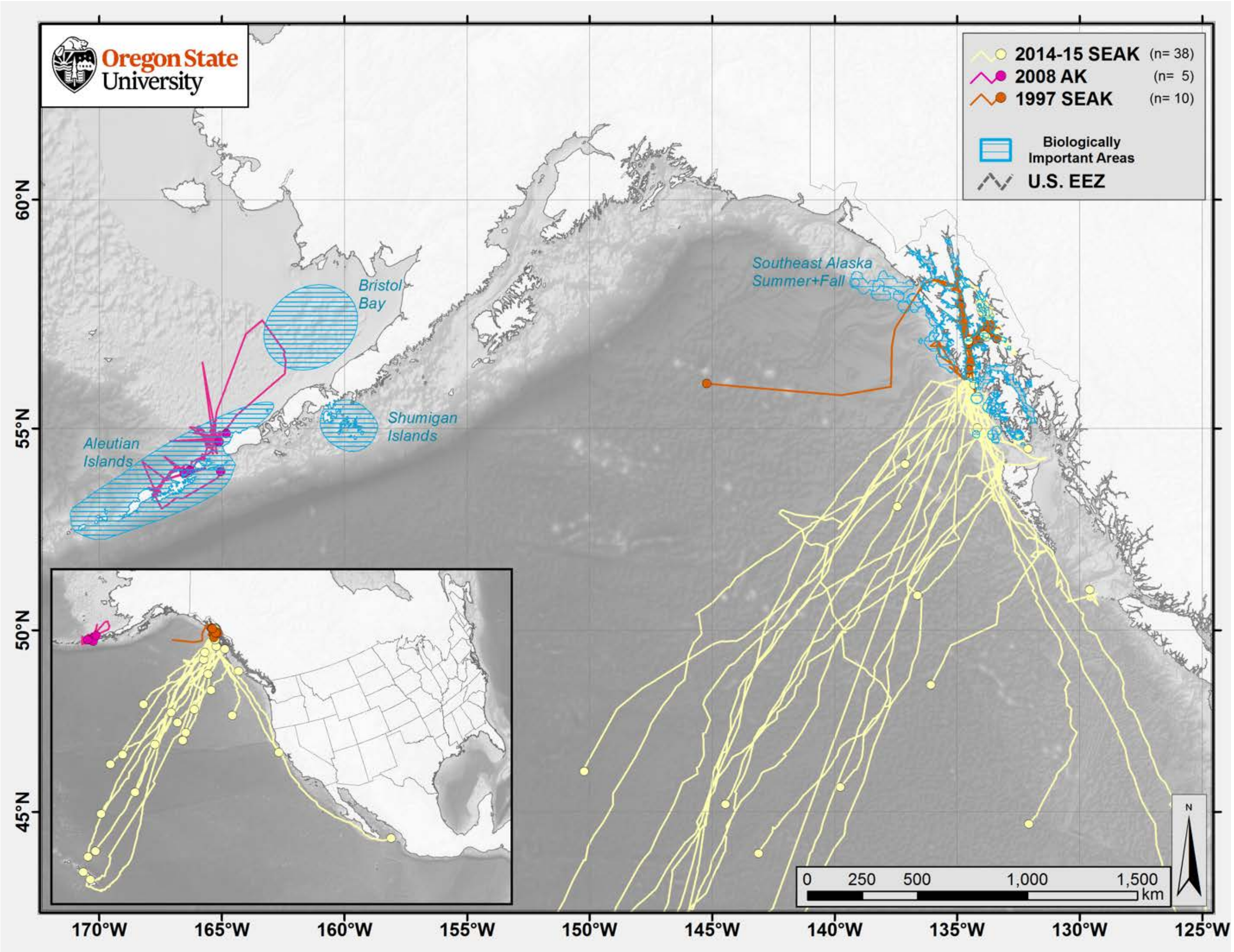


Figure 39. Satellite-monitored tracks for humpback whales tagged by OSU off Southeast Alaska in 1997 and 2014-2015, and off Dutch Harbor, Alaska in 2008. Inset shows full migration tracks.

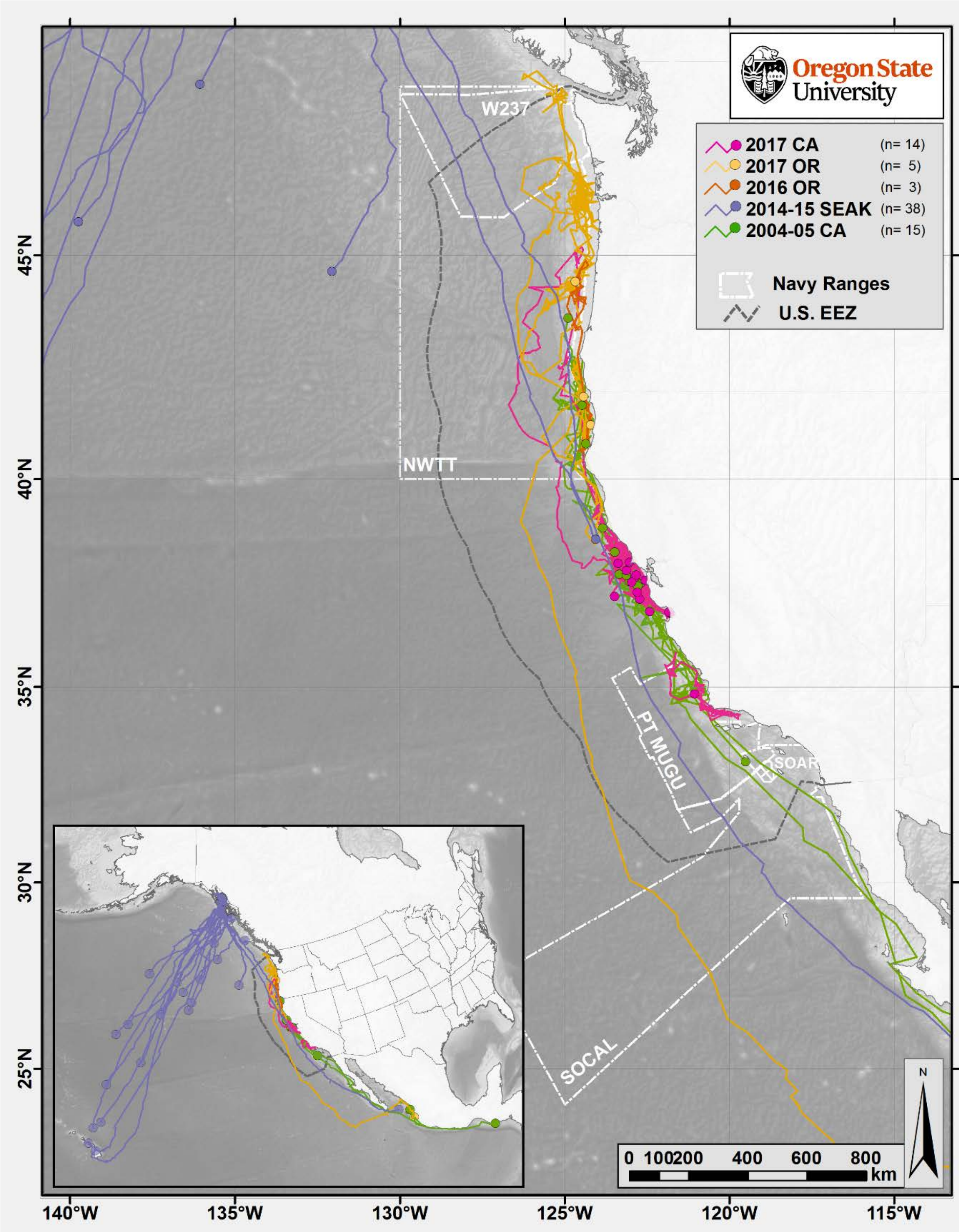


Figure 40. Satellite-monitored tracks for humpback whales tagged by OSU off California in 2004-2005 and 2017, Oregon in 2016 and 2017, and Southeast Alaska in 2014-2015. Inset shows full migration tracks.

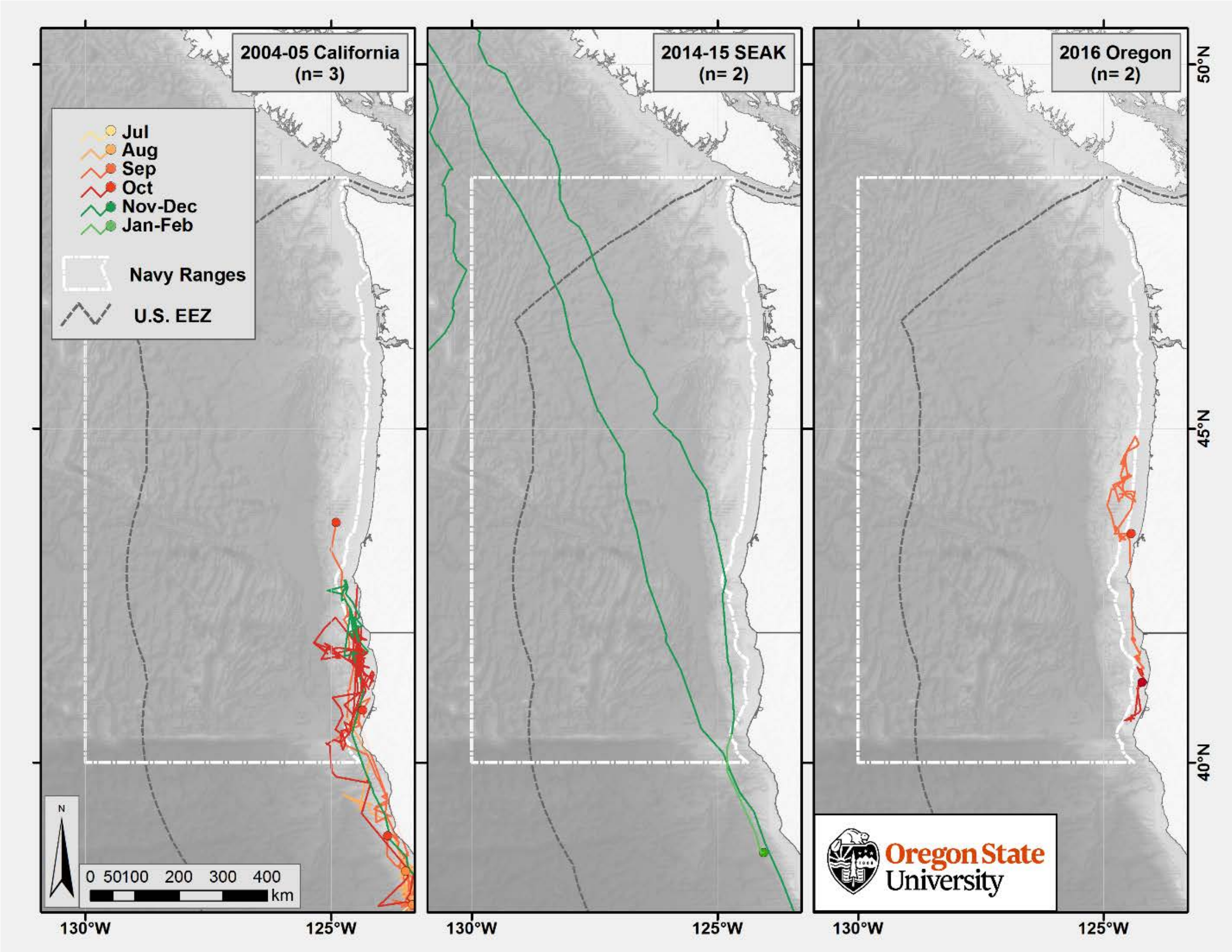


Figure 41. Satellite-monitored tracks in NWTT for humpback whales tagged off California in 2004-2005 (3 tags; left panel), Southeast Alaska in 2014-2015 (2 tags; middle panel), and in Oregon in 2016 (2 tags; right panel).

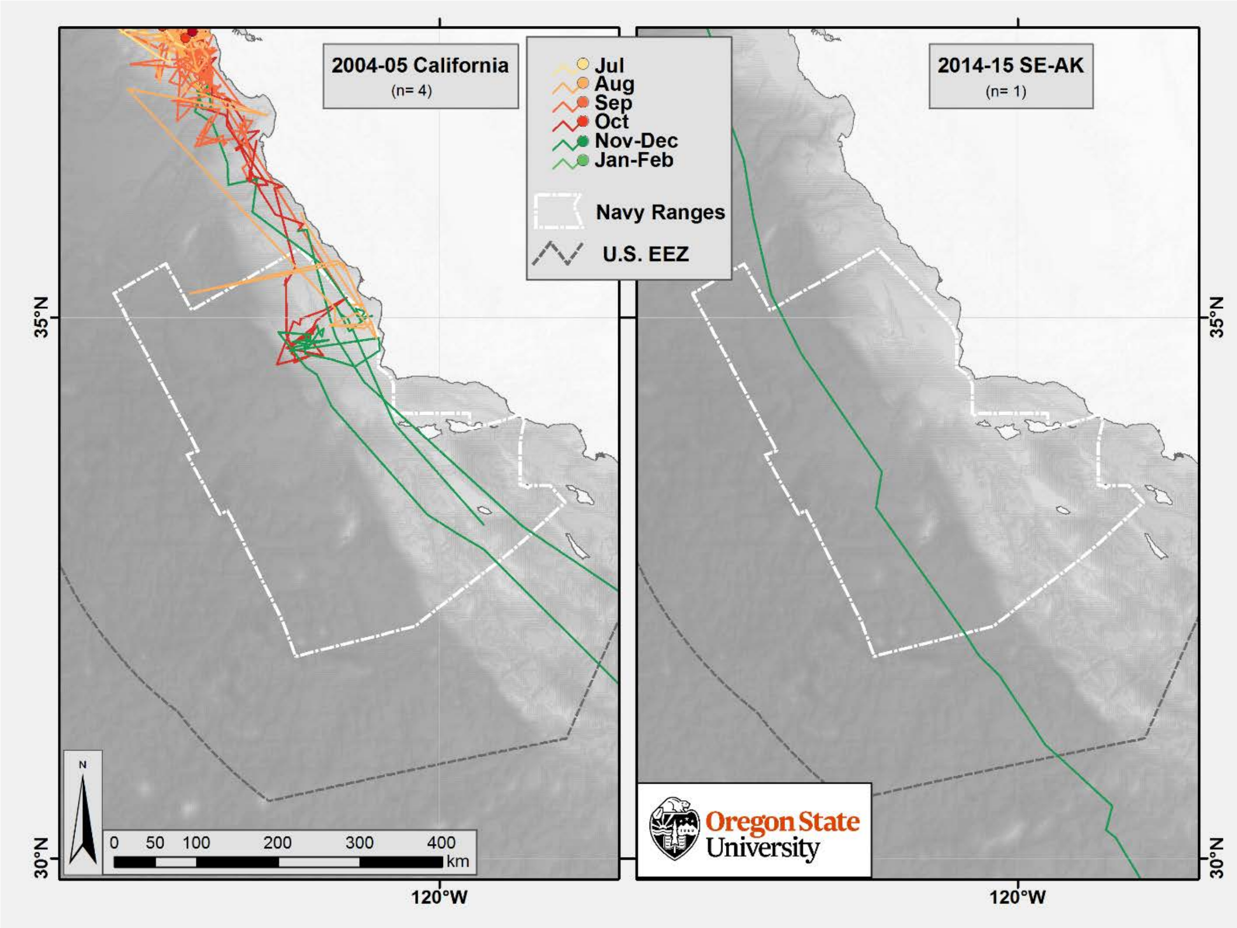


Figure 42. Satellite-monitored tracks in PT MUGU for humpback whales tagged off California in 2004-2005 (4 tags; left panel) and Southeast Alaska in 2014-2015 (1 tag; right panel).

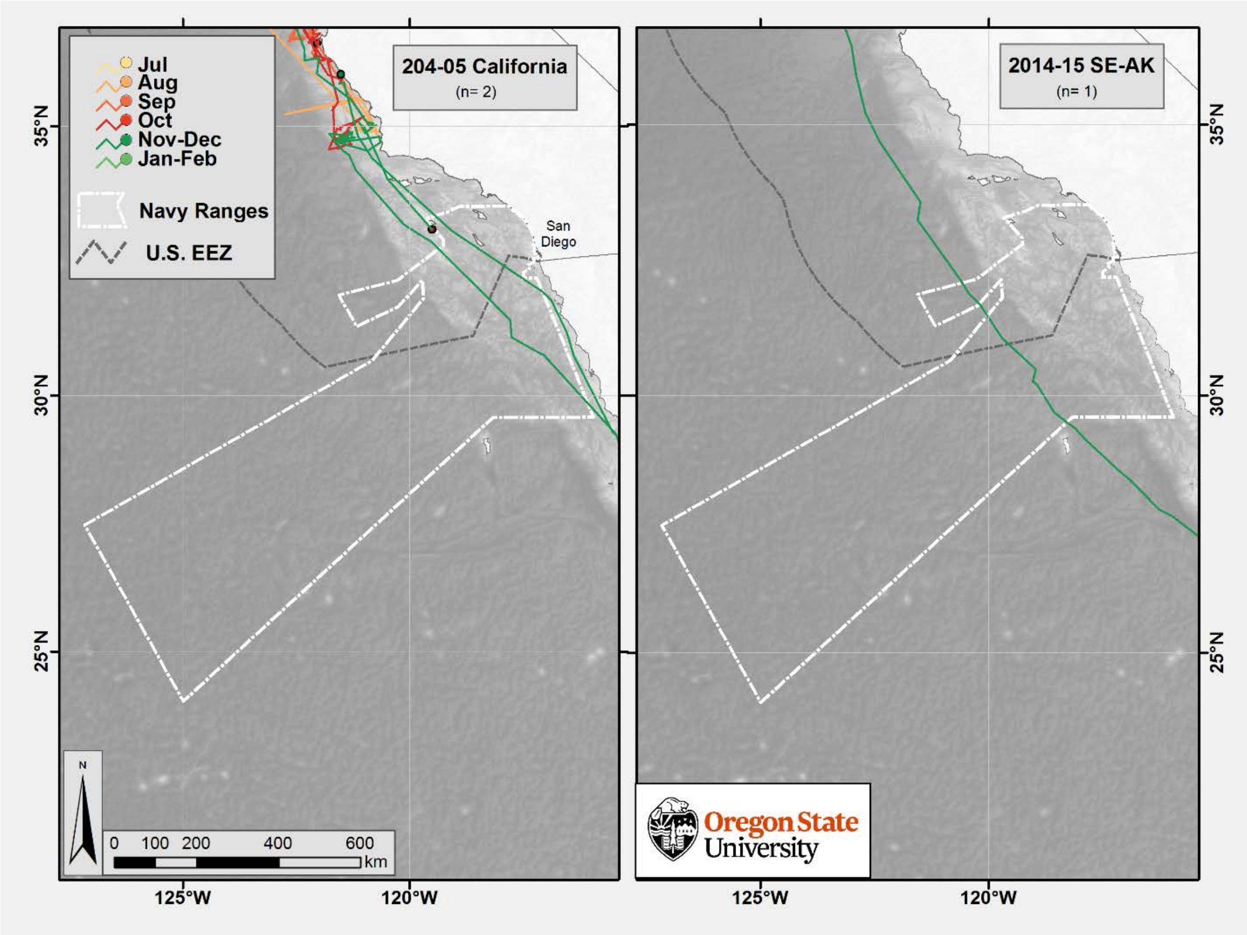


Figure 43. Satellite-monitored tracks in SOCAL for humpback whales tagged off California in 2004-2005 (2 tags; left panel) and Southeast Alaska in 2014-2015 (1 tag; right panel).

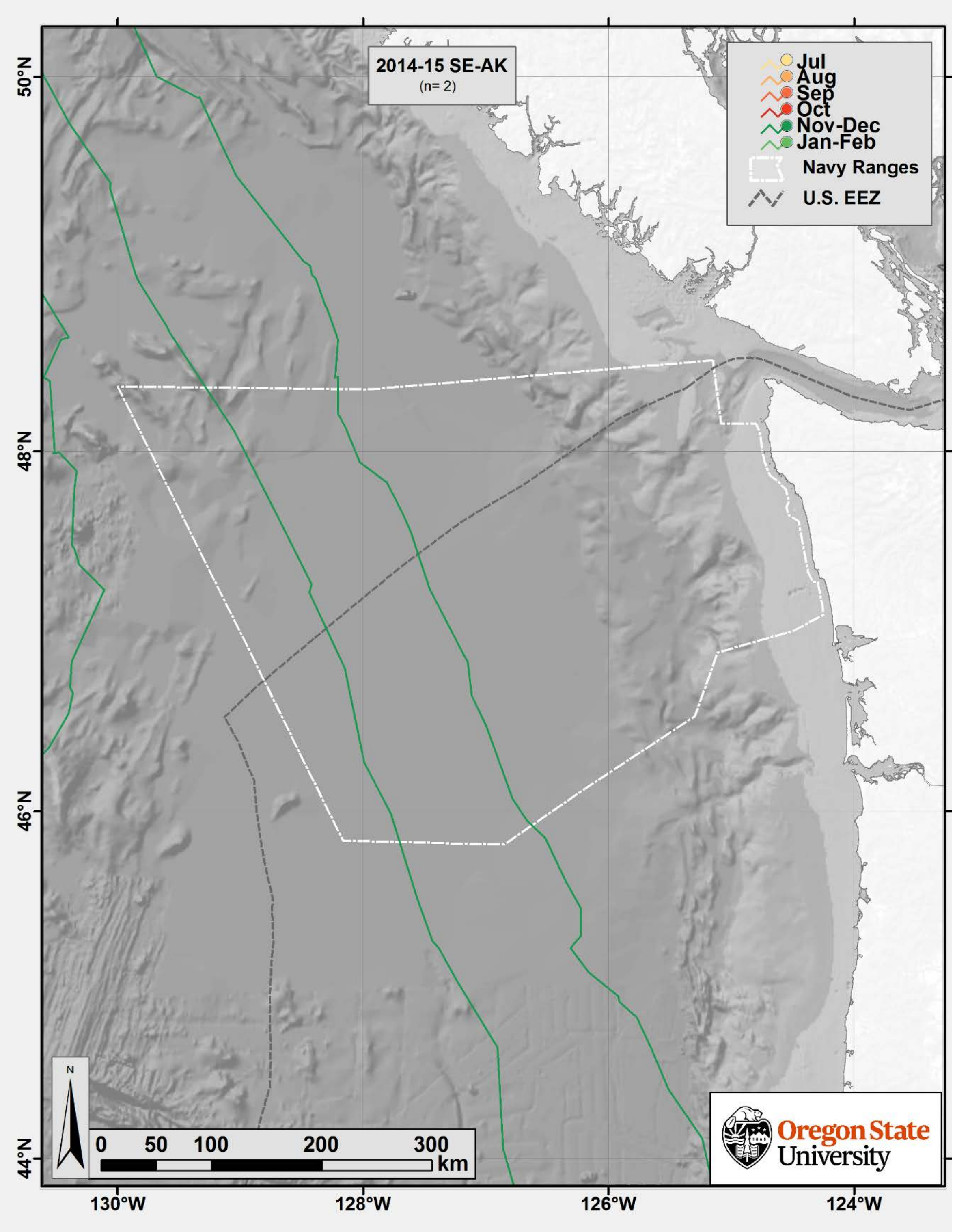


Figure 44. Satellite-monitored tracks in Area W237 of the NWTT range for humpback whales tagged off Southeast Alaska in 2014-2015 (2 tags).

Figure 45. Satellite-monitored tracks in SOAR for humpback whales tagged off California in 2004-2005 (1 tag).

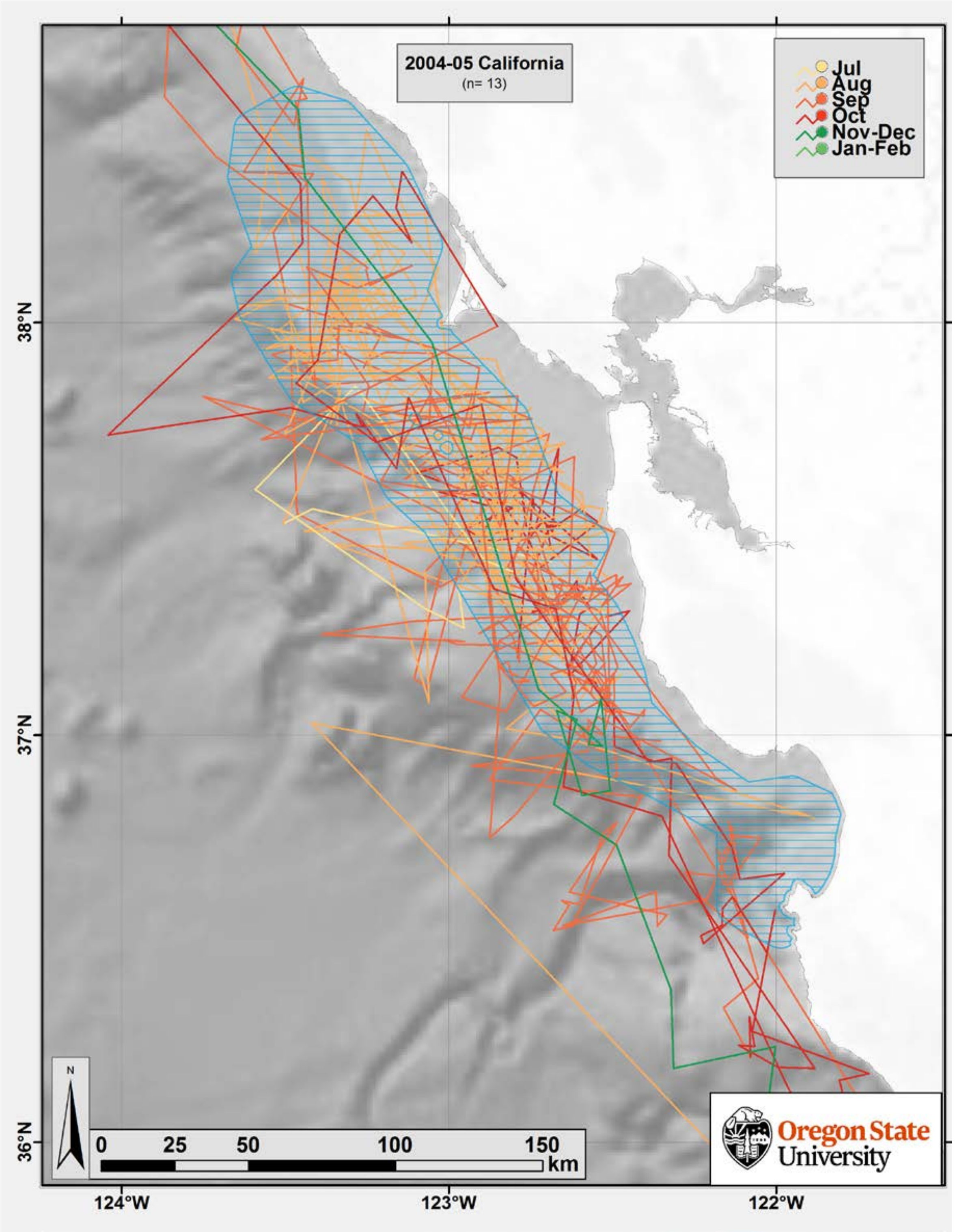


Figure 46. Satellite-monitored tracks in the Gulf of the Farallones to Monterey Bay BIA for humpback whales tagged off California in 2004-2005 (13 tags).

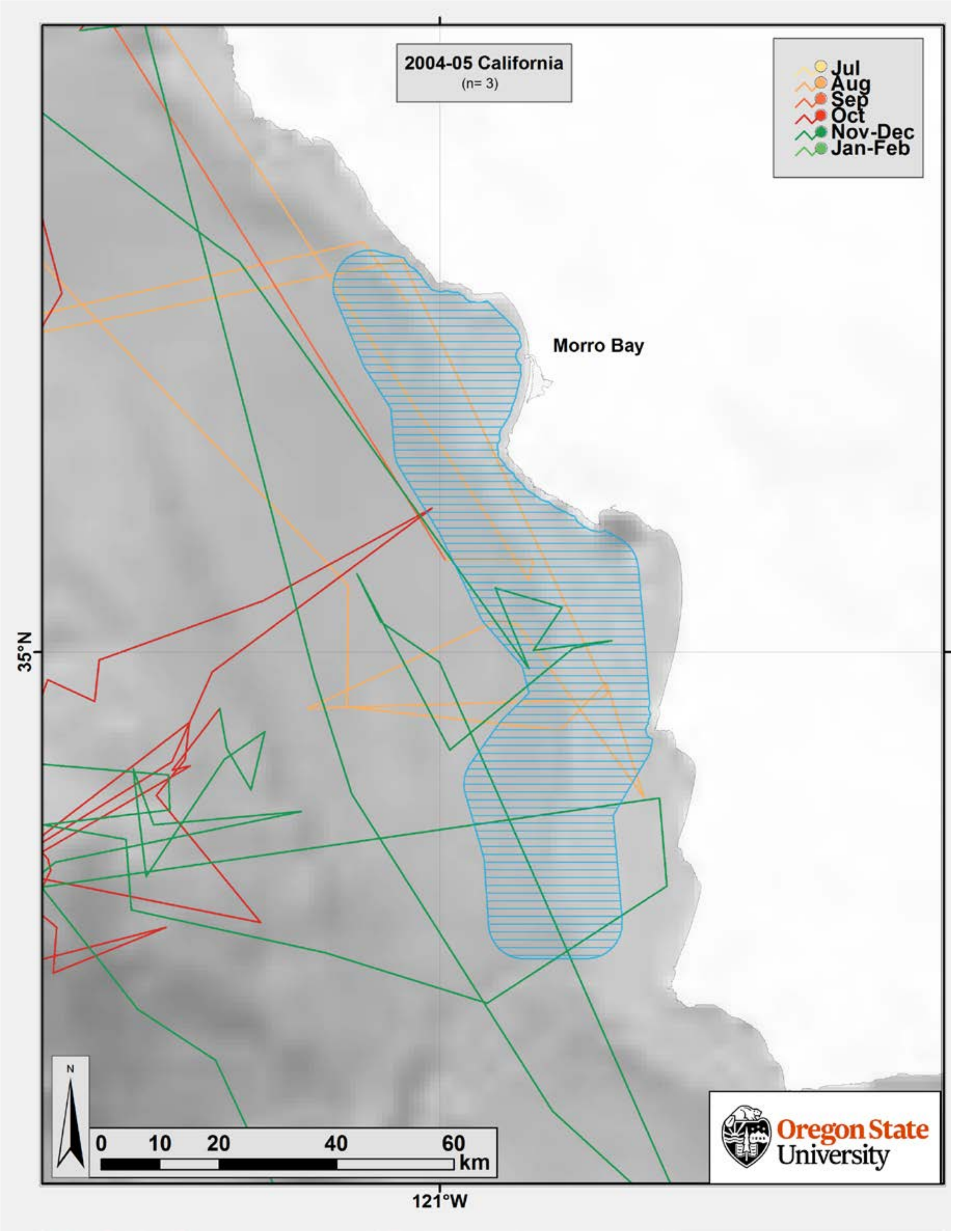


Figure 47. Satellite-monitored tracks in the Morro Bay to Point Sal BIA for humpback whales tagged off California in 2004-2005 (3 tags).

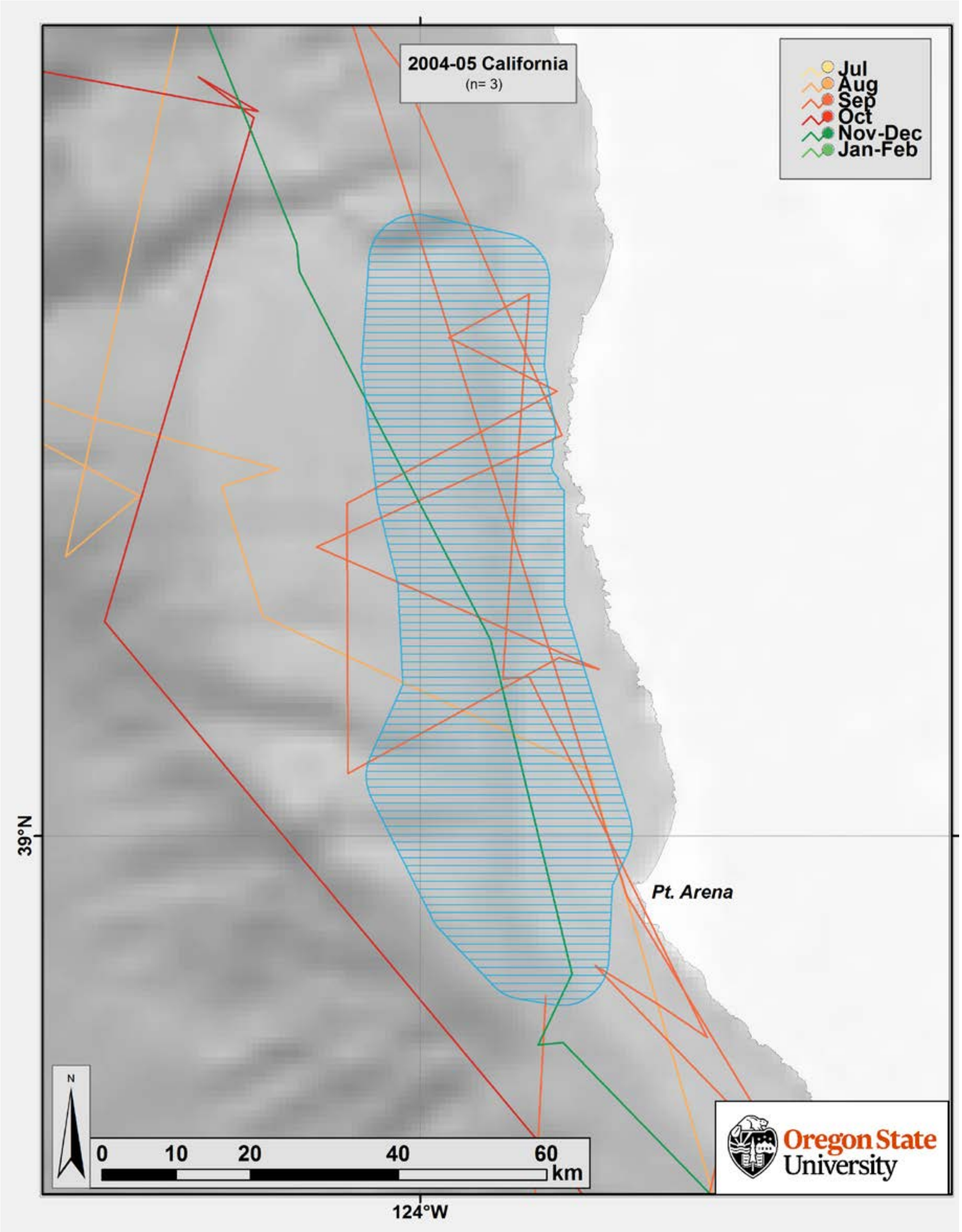


Figure 48. Satellite-monitored tracks in the Fort Bragg to Point Arena BIA for humpback whales tagged off California in 2004-2005 (3 tags).

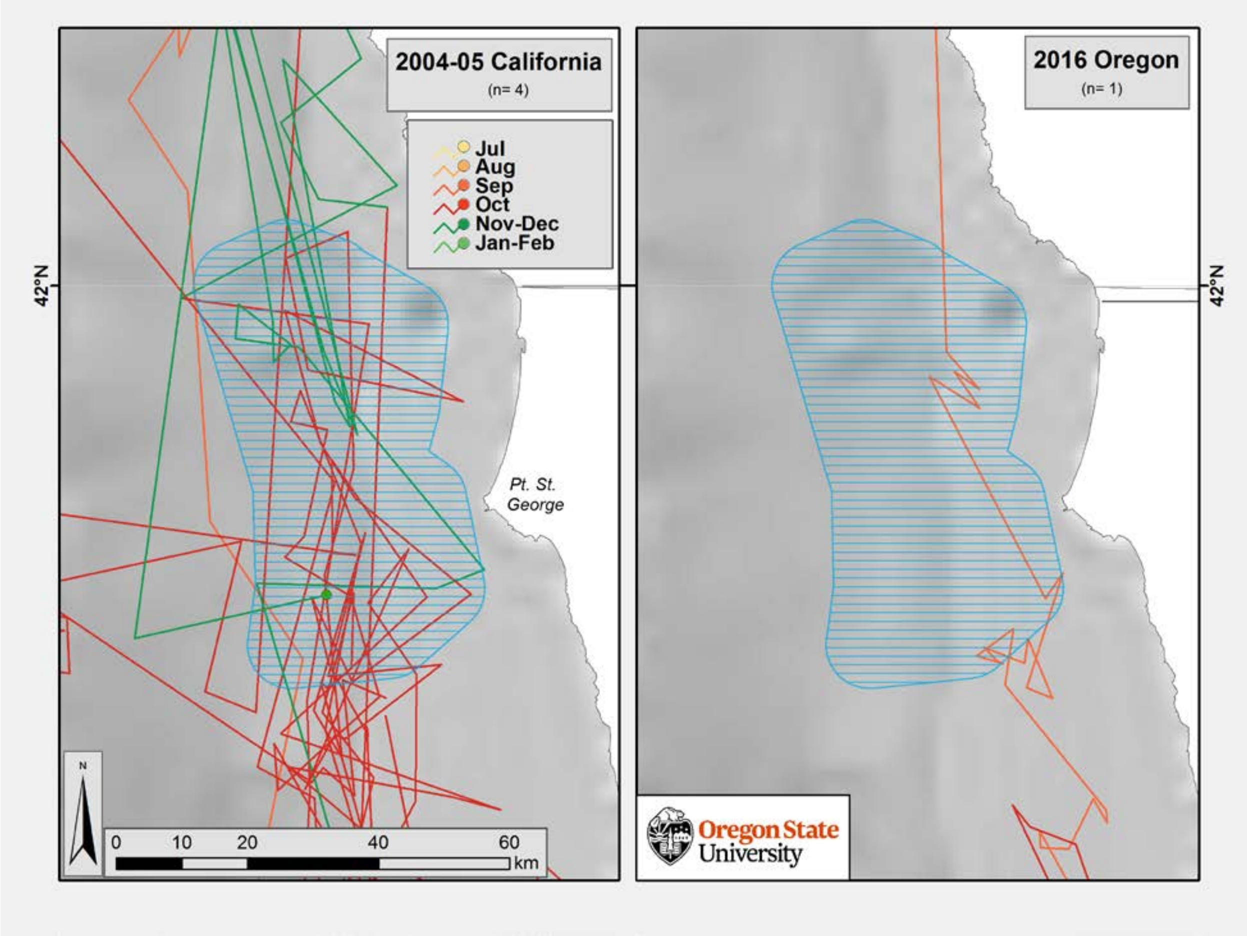


Figure 49. Satellite-monitored tracks in the Point St. George BIA for humpback whales tagged off California in 2004-2005 (4 tags; left panel) and Oregon in 2016 (1 tag; right panel).

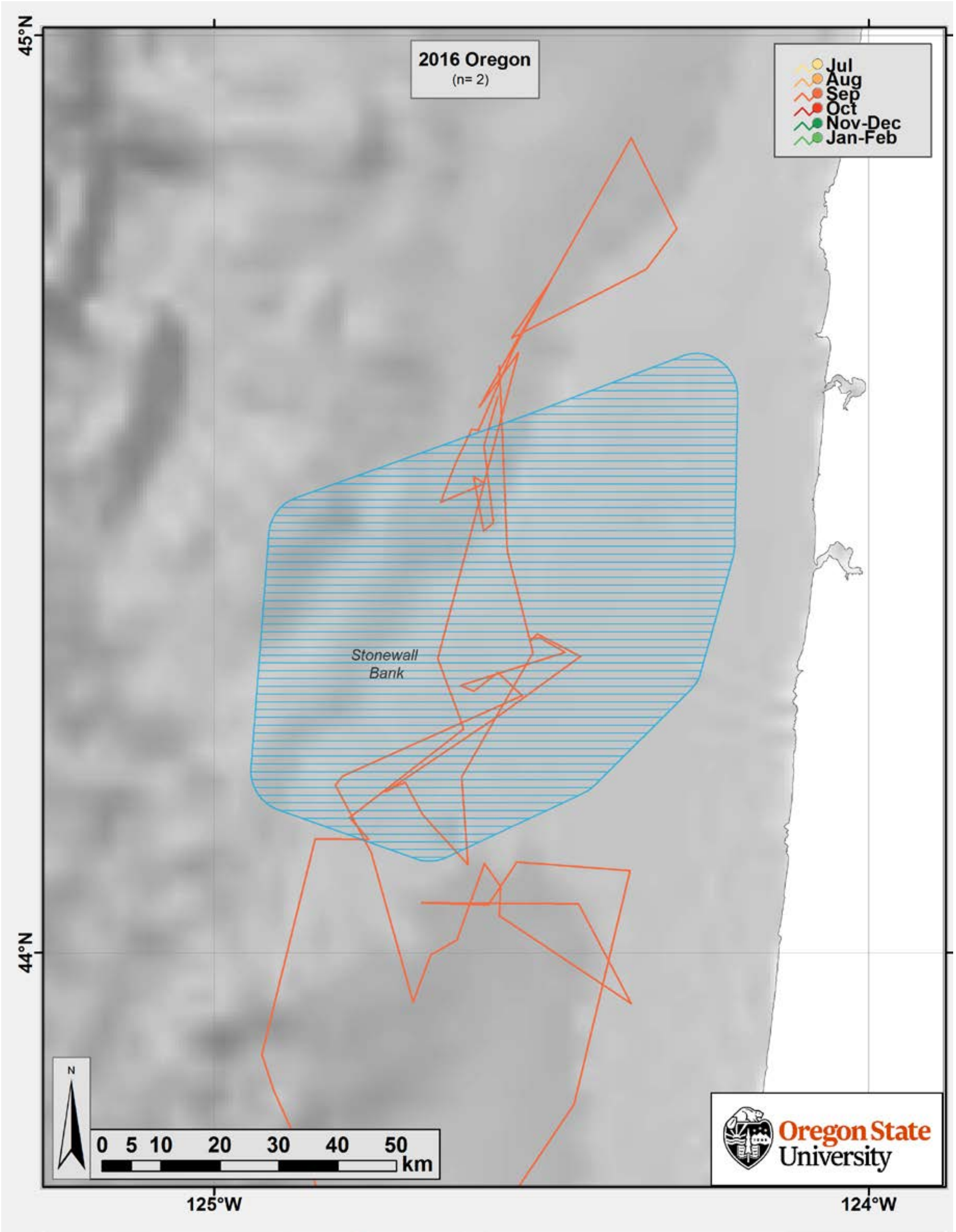


Figure 50. Satellite-monitored tracks in the Stonewall and Heceta Bank BIA for humpback whales tagged off Oregon in 2016 (2 tags).

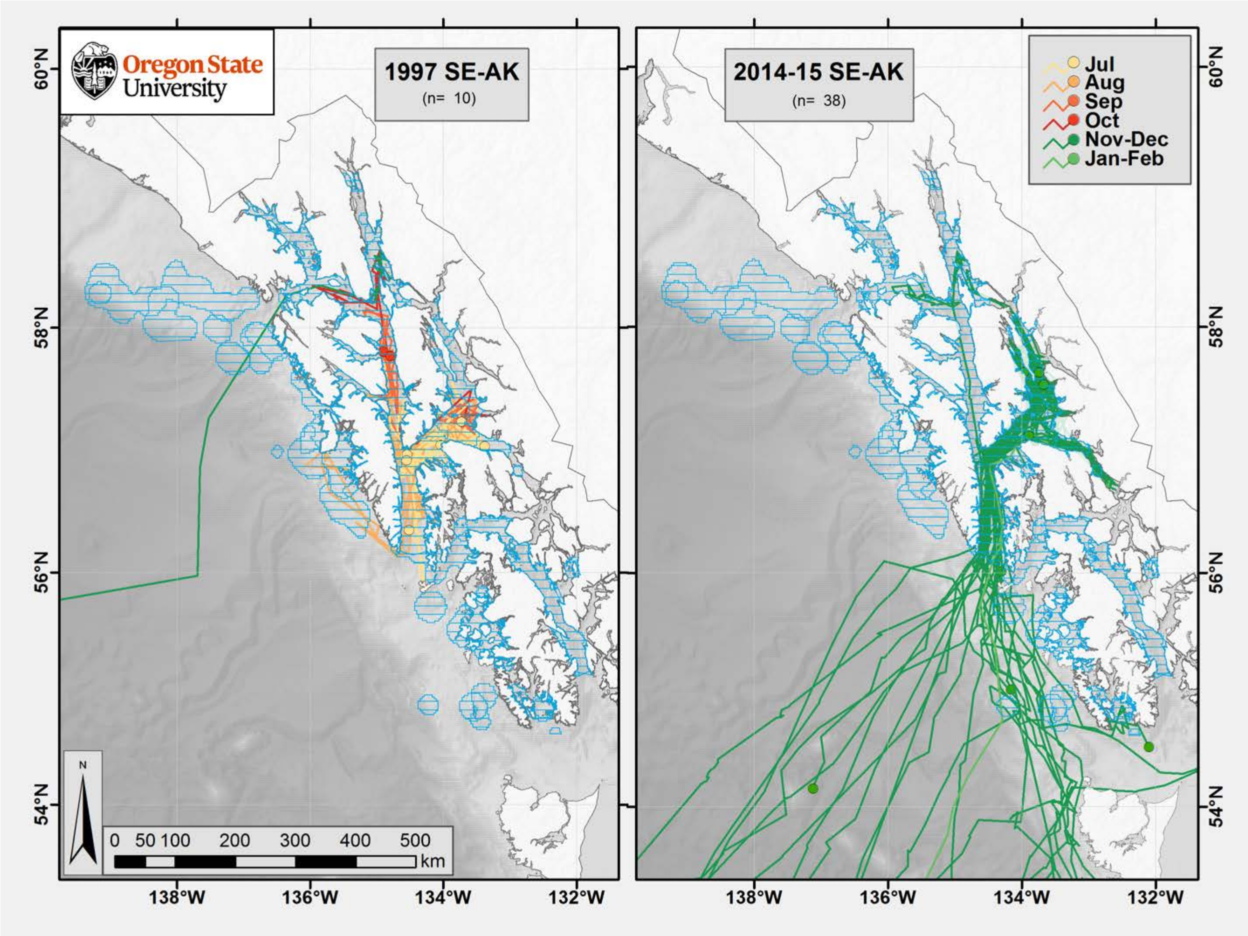


Figure 51. Satellite-monitored tracks in the summer and fall Southeast Alaska BIAs for humpback whales tagged in Southeast Alaska in summer 1997 (10 tags; left panel) and in fall 2014-2015 (37 tags; right panel).

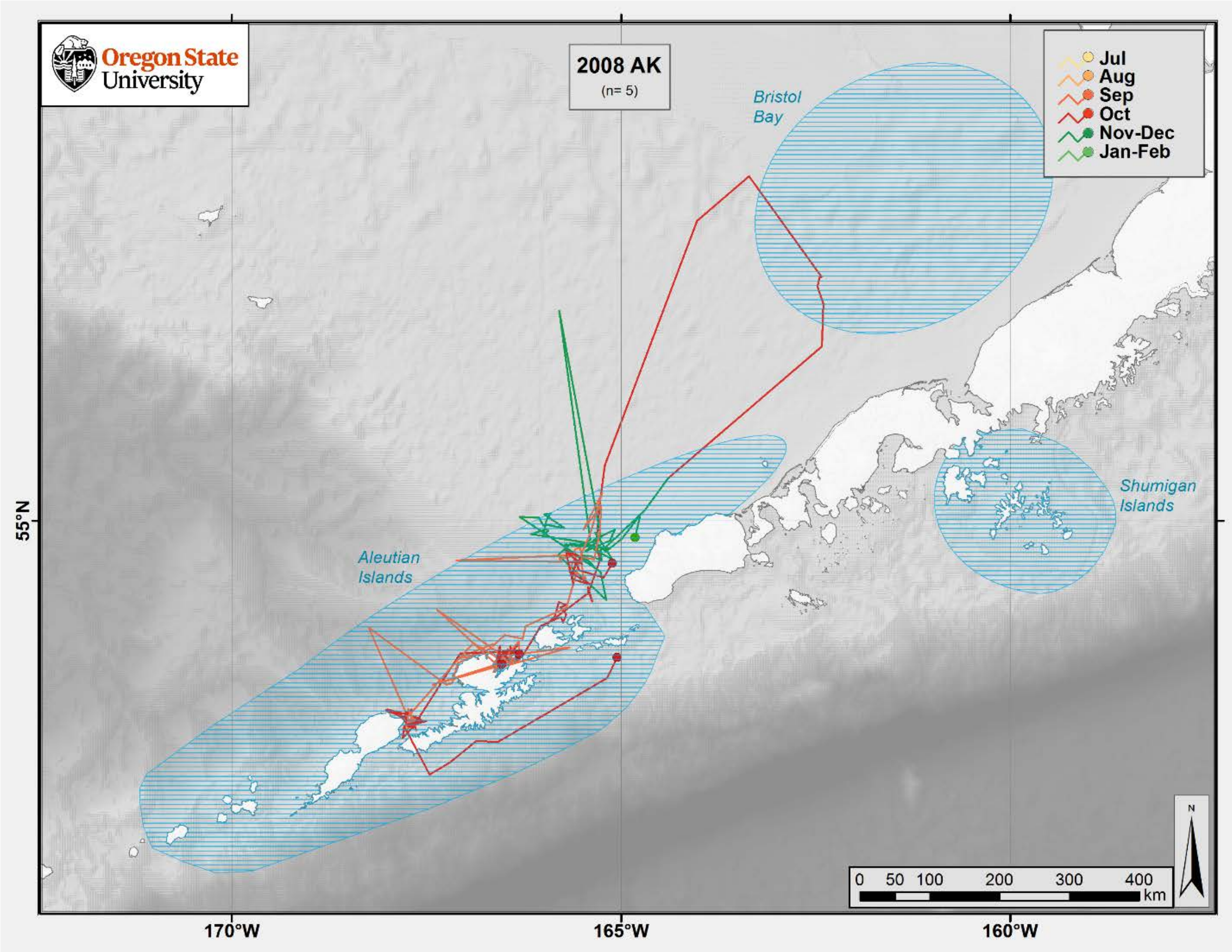


Figure 52. Satellite-monitored tracks in the Aleutian Islands BIA and the Bristol Bay BIA for humpback whales tagged off Dutch Harbor, Alaska, in September 2008 (5 tags).

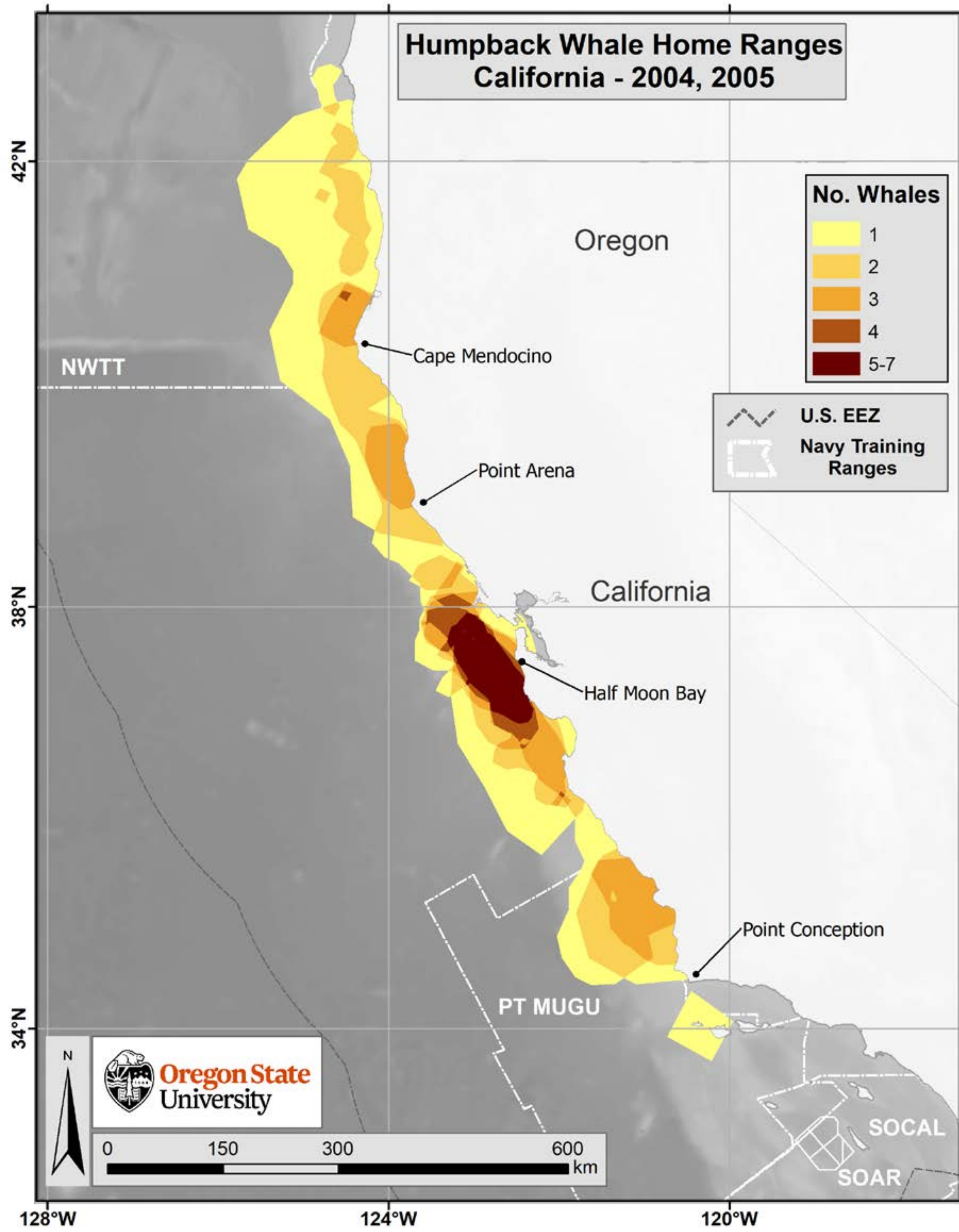


Figure 53. Feeding area HRs for eight humpback whales tagged off California in 2004-2005. Shading represents the number of individual whales with overlapping HRs.

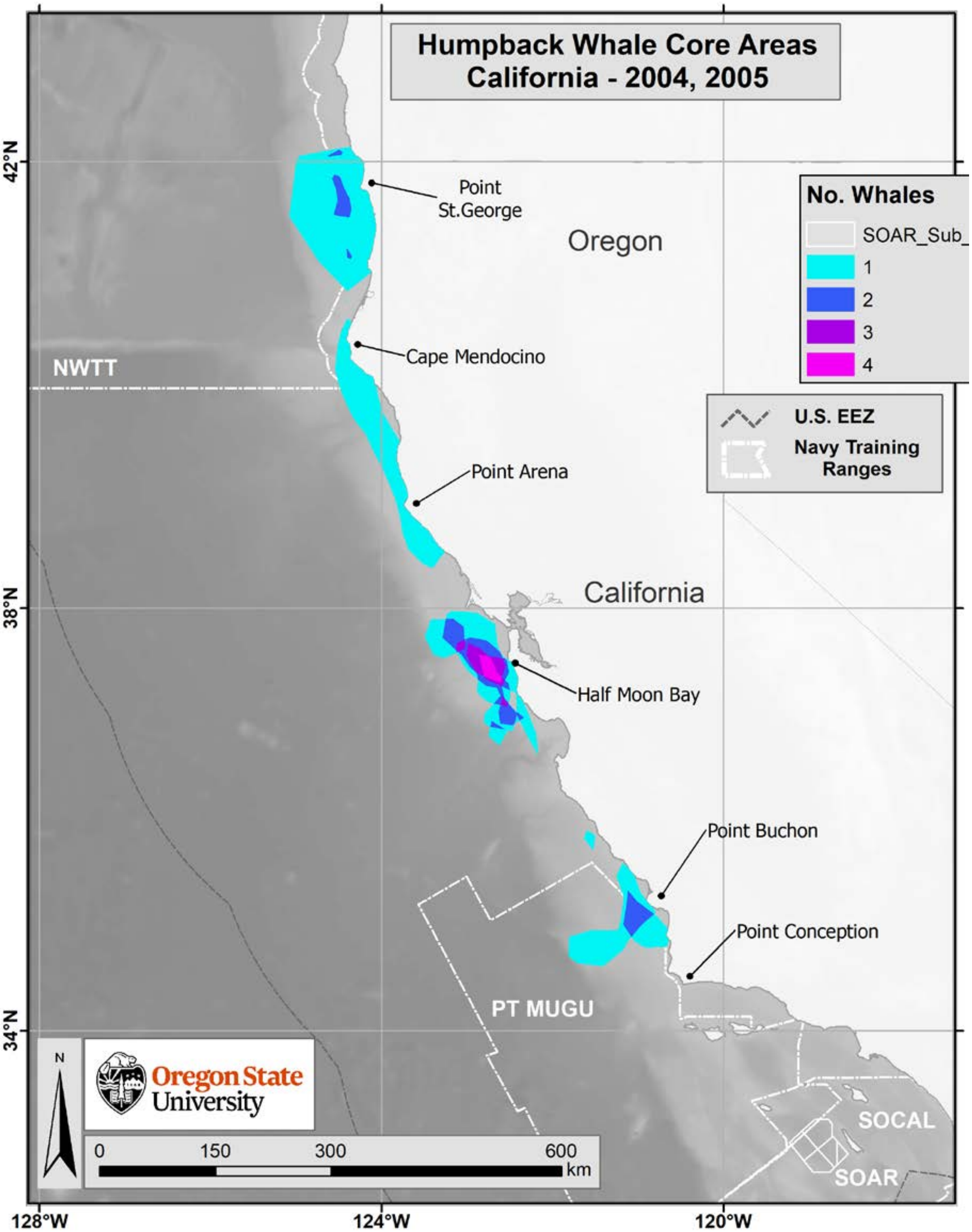


Figure 54. Feeding area CAs for eight humpback whales tagged off California in 2004-2005. Shading represents the number of individual whales with overlapping CAs.

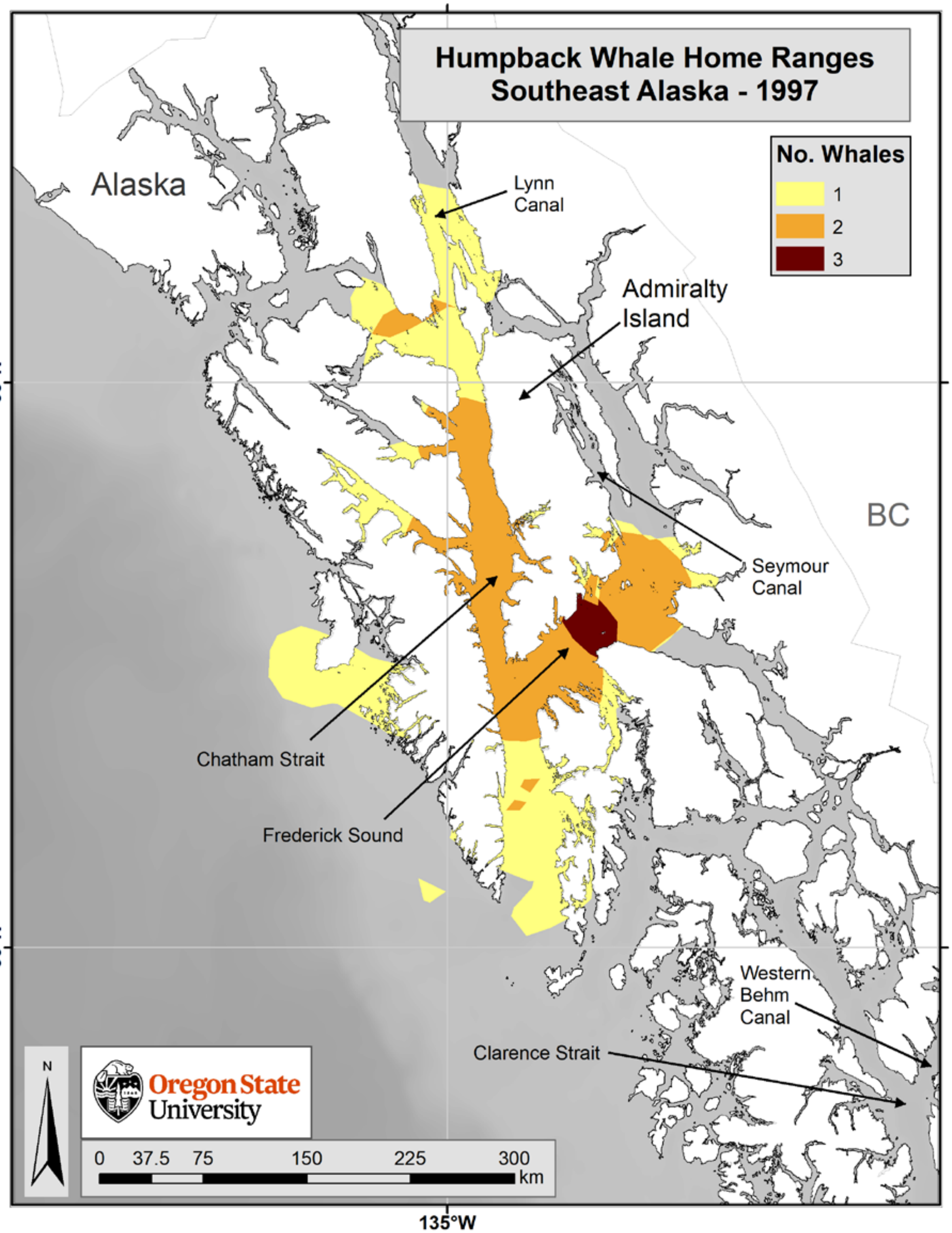


Figure 55. Feeding area HRs for three humpback whales tagged in Southeast Alaska in summer 1997. Shading represents the number of individual whales with overlapping HRs.

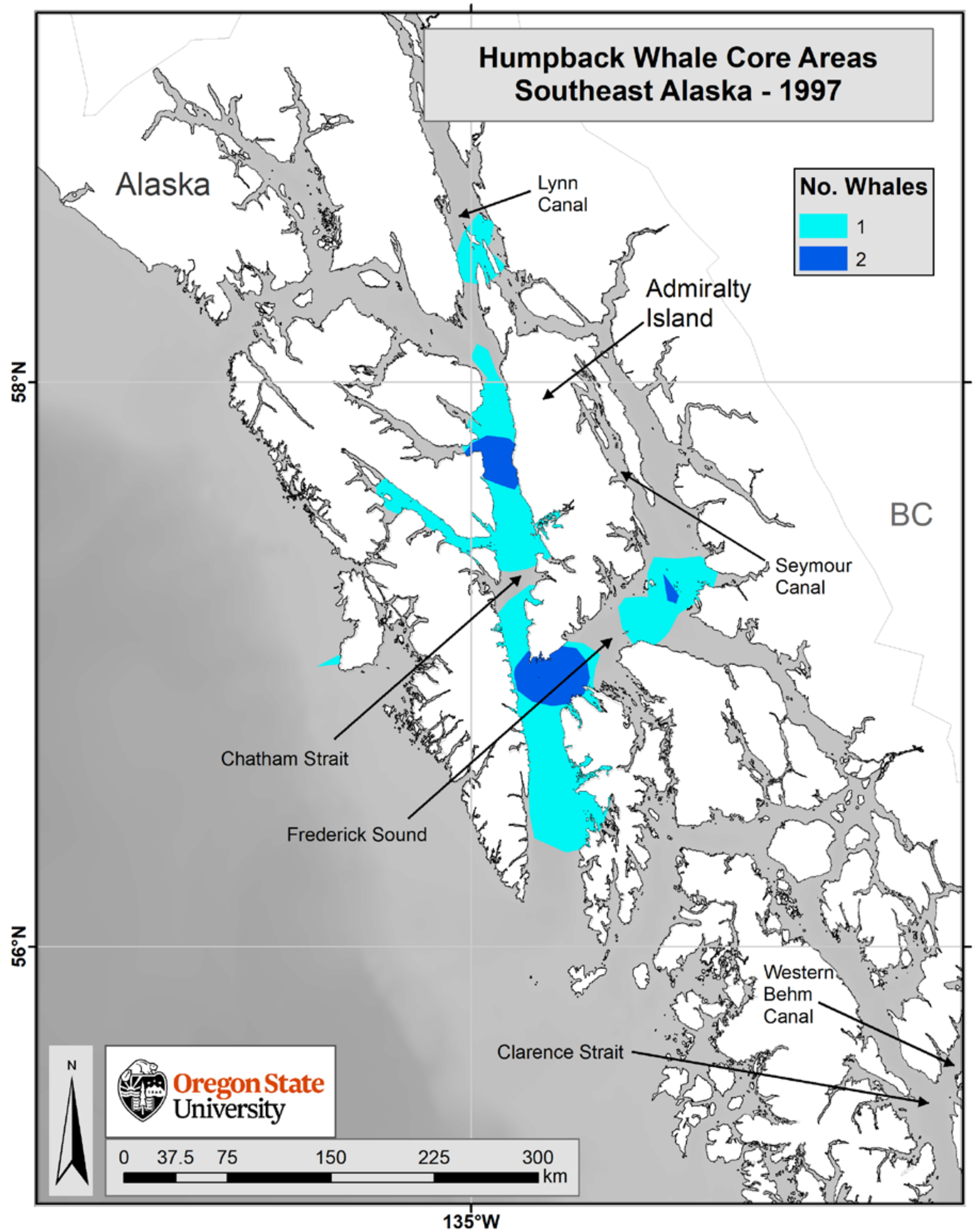


Figure 56. Feeding area CAs for three humpback whales tagged in Southeast Alaska in summer 1997. Shading represents the number of individual whales with overlapping CAs.

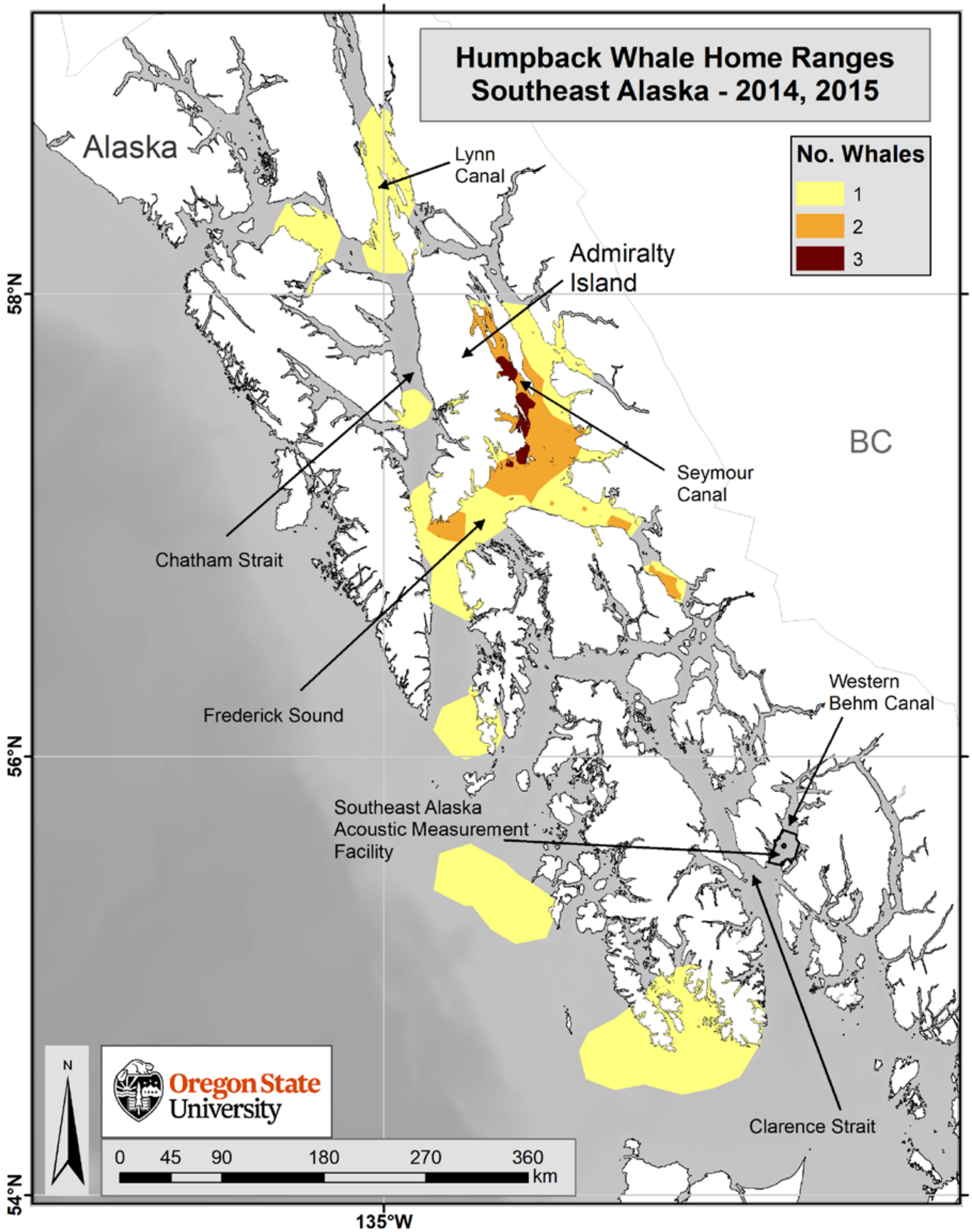


Figure 57. Feeding area HRs for five humpback whales tagged in Southeast Alaska in fall 2014-2015. Shading represents the number of individual whales with overlapping HRs.

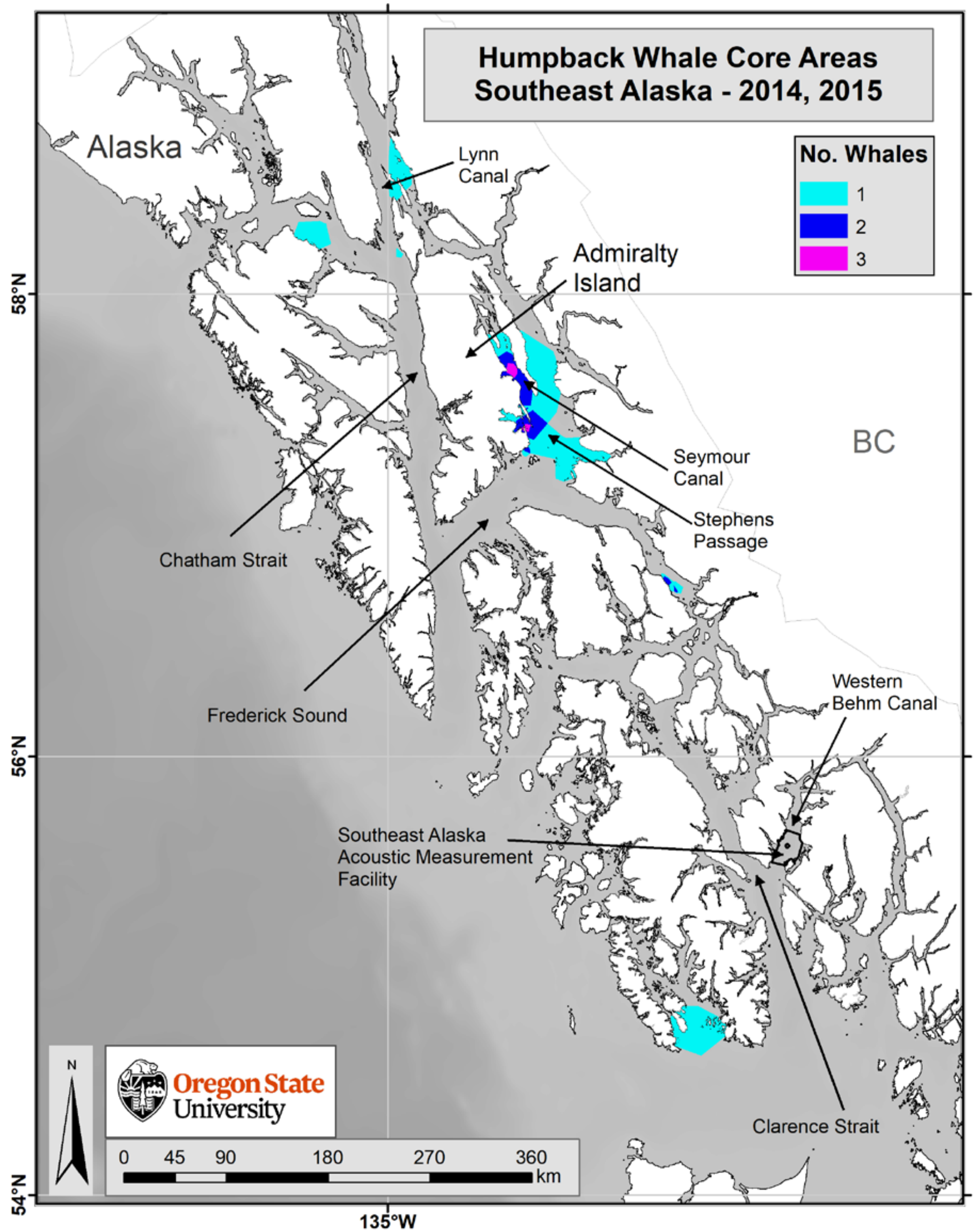


Figure 58. Feeding area CAs for five humpback whales tagged in Southeast Alaska in fall 2014-2015. Shading represents the number of individual whales with overlapping CAs.

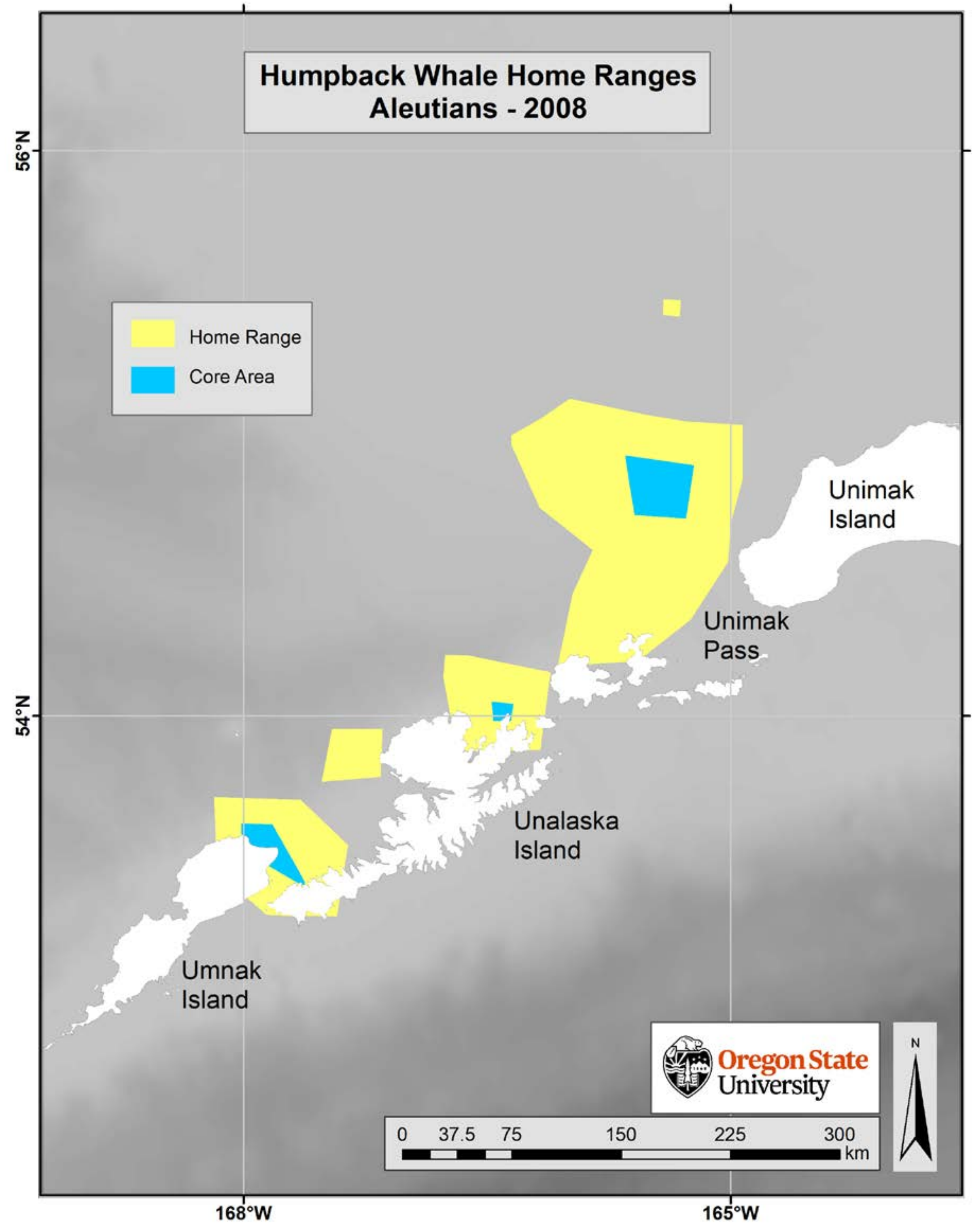


Figure 59. Feeding area HR (yellow) and CA (blue) for one humpback whale tagged off Dutch Harbor, Alaska in late summer 2008.