# Humpback Whale Tagging in Support of Marine Mammal Monitoring Across Multiple Navy Training Areas in the Pacific Ocean: Final Report of Tagging Efforts off the Pacific Northwest in Summer 2018

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***Prepared by*:**
Daniel M. Palacios, Bruce R. Mate, C. Scott Baker, Barbara A. Lagerquist, Ladd M. Irvine, Tomas M. Follett, Martha H. Winsor, Craig E. Hayslip, and Debbie Steel

Oregon State University, Marine Mammal Institute
Hatfield Marine Science Center
2030 SE Marine Science Drive
Newport, OR 97365

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**6. AUTHOR(S)**
Daniel M. Palacios
Bruce R. Mate
C. Scott Baker
Barbara A. Lagerquist
Ladd M. Irvine
Tomas M. Follett
Martha H. Winsor
Craig E. Hayslip
Debbie Steel

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Oregon State University, Marine Mammal Institute
Hatfield Marine Science Center
2030 SE Marine Science Drive
Newport, OR 97365

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**14. ABSTRACT**

Three of the 14 Distinct Population Segments (DPSs) of humpback whales (Megaptera novaeangliae) recently designated by the National Marine Fisheries Service (NMFS) for listing under the Endangered Species Act (ESA) based on their winter breeding grounds ("Hawaii", "Mexico", and "Central America"), can be found along the western coast of North America during the feeding season. The mixing of whales from 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 throughout their range, as well as on 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 2018, 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 northern Washington and central Oregon in summer 2018, as well as results from previous OSU studies of humpback whales in Oregon in 2016 and 2017. 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. Comparisons are made to tracking results from humpback whales tagged by OSU in California in 2004, 2005, and 2017 (presented in Mate et al. 2018a). For the 2018 data, this report also presents detailed dive behavior analyses and ecological relationships between whale locations and oceanographic conditions.

Four types of non-recoverable, fully implantable tags were used in this study, all providing long-term tracking information via the Argos satellite system: Wildlife Computers SPOT6 Location-Only (LO) tags, Telonics Duration Monitoring (DUR) tags, providing locations and dive duration information, Telonics Duration Monitoring Plus (DUR+) tags, providing locations, dive duration, and number of feeding lunges, and Telonics Dive Monitoring (DM) tags, providing locations, dive duration, number of feeding lunges, and depth. Additionally, one Wildlife Computers MK-10 Advanced Dive Behavior (ADB) tag, a partially implantable, recoverable tag, was used in 2018, providing tracking over multiple weeks while recording high-resolution dive profile information (dive duration, depth, and accelerometer and magnetometer data). Twenty humpback whales (10 DUR+ tags, 9 DM tags, 1 ADB tag) were tagged in Washington in August 2018 and five humpback whales (5 DUR+ tags) were tagged in Oregon in September 2018. Additionally, one fin whale was tagged (1 LO tag) opportunistically in Oregon in September 2018 during humpback whale field efforts. Argos locations were received from all 24 non-recoverable tags on humpback whales, with tracking periods ranging from 6.7 to 110.6 days (d) (mean = 31.0 d, standard deviation [SD] = 24.2 d). The ADB tag transmitted for 12.5 d but was not recovered. The fin whale was tracked for 35.9 d. Seven humpback whales were tagged previously in Oregon; two in 2016 and five in 2017. Locations were received for six of these tags, with tracking periods ranging from 7.3 to 150.4 d (mean = 45.6 d, SD = 52.3 d). Hierarchical switching state-space models (hSSSM) were applied to the Argos locations from the tags for the purpose of generating regularly spaced tracks with annotated movement behavior for use in several analyses including home range, dive behavior, and ecological relationships.

The distribution of tracked humpback whales supported humpback whale affinity for continental shelf and shelf-edge habitat, and also documented extensive use of the western portion of the Salish Sea (Strait of Juan de Fuca, Strait of Georgia, and Puget Sound). The latitudinal range of whales during the feeding season was similar for humpbacks tagged in Washington in 2018 (5 degrees) and those tagged in Oregon from 2016 to 2018 (4 to 7 degrees), as was the total distance traveled by individual whales (1,884 km for Washington whales and 1,610 to 2,944 km for Oregon whales). Locations extended from the north coast of Vancouver Island to the north Oregon coast, for whales tagged in Washington, and from Barkley Sound on the central west coast of Vancouver Island to Point Arena, central California, for whales tagged in Oregon. Feeding-area home ranges and core areas did not differ significantly in size between whales tagged in Washington and those tagged in Oregon. Areas of highest use (where core areas overlapped for multiple whales) for whales tagged in Washington occurred at the western end of the Strait of Juan de Fuca out to Swiftsure Bank off the northwest corner of Washington, and off the Columbia River mouth and Trinidad Head, northern California, for whales tagged in Oregon. When compared with previous tracking results of humpback whales tagged in California, both the overall latitudinal ranges in feeding areas and the home ranges showed overlap in the distribution of whales tagged in Oregon and Washington, and between whales tagged in Oregon and California, but not between whales tagged in Washington and California. The Navy areas considered in this report 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 (W237) within the NWTT, and the Gulf of Alaska Temporary Maritime Activities Area (GOA). Sixty-one percent of all humpback whales tagged by OSU in Washington and Oregon from 2016 to 2018 (19 of 31) were instrumented within the NWTT training range, and all 31 tagged whales had locations within NWTT, with a maximum residency of 86.5 d. Ninety-five percent (19 of 20) of whales tagged in Washington in 2018 had locations within area W237 of the NWTT (maximum residency of 16.8 d), compared to 17 percent (1 of 6) of whales tagged in Oregon in 2016 and 2017 (residency in W237 of 14.3 d). No whales tagged in Oregon in 2018 had locations in area W237. Humpback whale locations occurred in the NWTT and area W237 from August through December. With the exception of one migrating whale (tagged in Oregon in 2017) transiting through SOCAL in January, no whales from Oregon or Washington spent time in southern California training ranges. It is worth noting here that no other whales tagged in the Pacific Northwest began their southbound migrations during their tracking periods. Presumably, humpback whales migrating to and from breeding areas in Mexico or Central America would pass briefly through SOCAL in winter and spring, as the range extends approximately 1,200 km offshore, but otherwise we have no evidence of Oregon or Washington whales spending extended periods of time in the southern ranges. No tagged humpback whales were located in the GOA training range in any of the years covered in this report (2016 to 2018).

The occupancy of US West Coast feeding BIAs also suggests spatial separation of humpback whales throughout feeding areas, as no humpbacks tagged in Washington spent time in BIAs south of Washington, and only one whale tagged in California was found in a BIA north of California, spending less than one day in the Stonewall BIA in Oregon. As noted above, none of the whales tagged in Washington were tracked on their southbound migration, however, and all tagging took place in midlate summer. Longer tracking durations and deployments at other times of year may yield different results in terms of BIA use by Washington whales. Spatial separation was not as clear for whales tagged in Oregon, with one Oregon whale spending time in the Northern Washington (NWA) BIA and the Olympic Coast National Marine Sanctuary (OCNMS) in northern Washington, and others spending time in the Point St. George, Fort Bragg to Point Arena, and the Gulf of the Farallones-Monterey Bay BIAs in California. The extensive use of the NWA BIA and the OCNMS by whales tagged in Washington reflects not only the location of tag deployments in Washington, within or very close to the BIA and/or sanctuary, but also speaks to the whales' affinity for the regions, as evidenced by the substantial residency (average 18.3 d in NWA and 23.1 d in OCNMS) and the seasonal extent (August through October) of locations there. Large proportions of humpback locations occurred east of the western boundary of the NWA BIA and north of the US/Canada maritime border, suggesting Canadian waters at the southwestern tip of Vancouver Island also represent important habitat such as those used to designate BIAs in the US.

The fin whale tagged off Oregon in 2018 was tracked for 35.9 d between the central coasts of Oregon and British Columbia. The areas of highest use for this whale were between Newport and Cascade Head on the central Oregon coast, out to 120 km offshore, and over deep oceanic waters approximately 150 to 300 km west of Queen Charlotte Sound, British Columbia. This whale spent an estimated 14.4 d within the NWTT training range and 3.9 d within area W237 within the NWTT. The time spent in area W237 was estimated from interpolated locations during a 10-d gap in transmissions for the tag. The fin whale was not tracked within any other Navy training area.

Humpback whale dives reported through Argos summarized a mean of 72.7 percent of the tracking durations. Dive behavior was similar for tagged whales off Washington and Oregon with dive durations primarily ranging from 2-7 min and dive depths generally less than 100 m for DM-tagged whales off Washington. Feeding effort was evenly distributed across the areas occupied by tagged whales. Longer duration and deeper daytime dives suggest whales were feeding on krill throughout the study area, although dive depths occurring on Swiftsure Bank off Washington were limited by shallow bottom topography. Tagged whales spent a mean of 53.0 percent of their reported time at ≤ 30 m depth, which is within the zone of possible impact for deep-drafted vessels that transit the Strait of Juan de Fuca. Thus, the high occupancy by tagged whales of the Strait of Juan de Fuca, and the shallower waters of Swiftsure Bank immediately west of the Strait likely place them at an elevated risk for vessel collision.

The output of the state-space models applied to 56 humpback whale Argos tracks, representing a combination of the 2016-2018 data collected under CESU agreements together with earlier data collected by OSU off the US West Coast during tagging efforts in 2004 and 2005, produced a total of 1,893 daily locations with annotated behavioral mode available for ecological characterization. Of these, 82.0 percent were classified as area-restricted searching (ARS; an indication of foraging behavior), 12.0 percent as uncertain, and 6.0 percent as transiting. These locations occurred across 16.6 degrees of latitude, spanning much of US West Coast from the Strait of Juan de Fuca, Washington, in the north to Point Conception, California, in the south. Ecological characterization of these data indicated that tracked humpback whales moved at speeds ranging from a median of 0.61 km/h while engaging in ARS to 2.74 km/h while transiting. While in ARS, whales occurred at a median depth of 146.0 m, over southwest-facing seafloor with median slope of 0.55°, and at median distances of 4.6 km from the shelf break and 21.8 km from shore. In contrast, while in transiting activities, whales were found at a median depth of 376.0 m, over seafloor slopes that faced west-southwest with a steeper median slope of 0.74°, and at median distances of 13.5 km from the shelf break and 39.2 km from shore. There were no apparent behavioral mode differences with respect to sea surface temperature or sea surface temperature gradient (a measure of frontal activity), although tracked whales occurred in waters with higher phytoplankton chlorophyll-a content while engaged in ARS compared to transiting (median = 1.42 versus 0.93 mg/m3). Thus, while occupying waters off the US West Coast during the feeding season, tracked humpback whales spent the majority of their time foraging over relatively shallow continental shelf waters, and spent a small proportion of their time in deeper, more offshore waters beyond the shelf break during transiting.

Analysis of the data by latitudinal 2-degree blocks revealed an apparent pattern in the proportion of locations in ARS behavior across blocks, being lowest (below 62 percent) off the northern Oregon, southern Oregon, and northern California blocks, implying that whales spent less time foraging there compared to the other blocks where the proportion of ARS locations was higher (above 75 percent). Locations occurring in the northernmost block, encompassing locations in the Strait of Juan de Fuca and adjacent waters, were characterized by a more southerly (or even easterly) aspect of the seafloor slope and by smaller median distances to the shelf break and to shore than for the other blocks, reflecting the semi-enclosed and distinct physiographic conditions imposed by the Strait of Juan de Fuca. For the other blocks, median distance to shore gradually decreased from north to south while median distance to the shelf break remained relatively constant, reflecting the narrowing width of the continental shelf along the US West Coast, and the preference for humpbacks to forage over the continental shelf. Other than a strong trend in sea surface temperature across blocks, being lowest in the north and highest in the south and reflecting the well-known global latitudinal temperature gradient, there were no other apparent latitudinal trends in the environmental variables examined. From this analysis we conclude that while other results in this study suggest spatial separation (or at least limited exchange) between BIAs and areas of whale aggregation along the US West Coast, the movement characteristics and environmental conditions associated with the tracking data do not suggest that these areas, or the humpback whale DPSs they support, have different habitat requirements.

The wide-ranging movements of the single tracked fin whale in this study were in contrast with the more coastal habits of the tracked humpback whales. This track had a high proportion of locations classified as ARS (80.8 percent) and no locations were classified as transiting (although the 10-d gap occurred during this whale's movement between the coastal and oceanic environment, when transiting behavior would likely have been recorded). The overall speed between location pairs was higher for this fin whale's track than for the humpbacks (0.80 km/h versus 0.72 km/h). Although the sample size was very small, this result is supported by previous results from 28 fin whales tagged in the Eastern North Pacific (see Mate et al. 2018b) that point at inter-species differences in movement speed. Similarly, deeper depths (median = 2378.0 m versus 153.0 m) and larger distances to the shelf break (median = 74.9 km versus 5.1 km) and to shore (median = 94.3 km versus 23.7 km) for the fin whale locations compared to the humpbacks' reflect the more oceanic habits of the species.

Biopsy samples were collected from 18 of the 20 tagged humpback whales in Washington in 2018 (plus seven untagged whales) and from all five of the tagged humpback whales in Oregon in 2018 (plus one untagged whale). A biopsy sample was also collected from the fin whale tagged off Oregon. Mitochondrial deoxyribonucleic acid (mtDNA) sequences of the 31 humpback whale samples resolved eight control region haplotypes for a consensus sequence of 500 bp for the Washington samples and four haplotypes for the Oregon samples. All mtDNA haplotypes have been described previously for North Pacific humpback whales and confirmed species identity of the field observations. The mtDNA sequence of the single fin whale sample has also been described previously for North Pacific fin whales. All humpback whale samples were represented by a unique multi-locus genotype of at least 14 loci, confirming individual identity and documenting one genotype recapture between two samples collected from an untagged whale in Washington. Sex-specific molecular markers showed that the 24 Washington individuals represented six females and 18 males, while the six Oregon individuals were all males. The mtDNA haplotypes, multi-locus genotypes, and sex markers together provided a standard "DNA profile" for each of the 30 individual humpback whales sampled in 2018. These profiles were compared to a reference database of 1,805 individuals sampled previously in the North Pacific by the ocean-wide survey referred to as the "Structure of Populations, Levels of Abundance, and Status of Humpbacks" program (SPLASH), and to the 23 individuals sampled during previous tagging off the California and Oregon coasts in 2016 and 2017 under previous CESU agreements (Mate et al. 2018a). This comparison detected one recapture of an individual sampled in Washington during the 2018 tagging effort and sampled previously in Washington during SPLASH in 2005. For population analyses, data from the six individuals sampled during 2018 off Oregon were combined with data from the nine individuals collected in 2016 and 2017, for a total of 15 individuals representing the Oregon feeding area. The fin whale sample was represented by a unique multi-locus genotype of 17 loci. A comparison to a reference dataset of 20 previously tagged fin whales (Mate et al. 2018b) found no recaptures.

Differences in mtDNA haplotype frequencies were used to investigate the influence of maternal fidelity to both feeding aggregations and breeding grounds, including tagging samples collected previously and the SPLASH reference database. A comparison of haplotype frequencies from the California and Oregon samples suggested some degree of differentiation between these feeding aggregations, with Oregon whales appearing more similar to the Southern British Columbia/Washington aggregation. This differentiation between California and Oregon feeding aggregations had not been recognized previously in the limited sampling of the Oregon coast during SPLASH, but was noted in the results of previous tagging efforts, based on smaller sample sizes, under previous CESU agreements in 2016 and 2017 (Mate et al. 2018a). Further, comparisons to the breeding areas defined by SPLASH indicated that the haplotype frequencies of California whales were most similar to Central America, while the haplotype frequencies of Oregon whales were most similar to those found off Mexico. The haplotype frequencies of the Washington sample did not differ significantly from the Southern British Columbia/Washington stratum in SPLASH and showed the greatest affinity with the Hawaii DPS.

The DNA profiles of humpback whale sampled on the feeding grounds were used to calculate the relative likelihood of individual membership in each of the four recognized DPSs in the North Pacific, based on a Bayesian assignment procedure and the SPLASH reference database. The 24 individuals sampled in Washington showed the highest likelihood of assignment to the Hawaii DPS for 13 individuals, to the Mexico DPS for five individuals, to the Central America DPS for four individuals, and to the Western North Pacific DPS for one individual. Two individuals were assigned with nearly equal likelihood to both Mexico and Hawaii. For the six Oregon samples, the individual assignment

showed the highest likelihood of assignment to the Hawaii DPS for two individuals, to the Mexico DPS for two individuals, and to the Central America DPS for one individual. One individual was assigned with similar likelihood to Hawaii and Mexico. Assignments to the Hawaii or the Western North Pacific DPS could suggest changes in the migratory destinations, since some of these whales were tracked and/or photographed in Mexico. In interpreting the results of genetic assignment, however, it is important to keep in mind that accuracy is dependent on the quality of the reference dataset (which is limited to a relatively small sample size for the Central America DPS), and that assignments reflect genetic ancestry, including recent reproductive exchange between breeding areas.

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# Executive Summary

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The fin whale tagged off Oregon in 2018 was tracked for 35.9 d between the central coasts of Oregon and British Columbia. The areas of highest use for this whale were between Newport and Cascade Head on the central Oregon coast, out to 120 km offshore, and over deep oceanic waters approximately 150 to 300 km west of Queen Charlotte Sound, British Columbia. This whale spent an estimated 14.4 d within the NWTT training range and 3.9 d within area W237 within the NWTT. The time spent in area W237 was estimated from interpolated locations during a 10-d gap in transmissions for the tag. The fin whale was not tracked within any other Navy training area.

Humpback whale dives reported through Argos summarized a mean of 72.7 percent of the tracking durations. Dive behavior was similar for tagged whales off Washington and Oregon with dive durations primarily ranging from 2-7 min and dive depths generally less than 100 m for DM-tagged whales off Washington. Feeding effort was evenly distributed across the areas occupied by tagged whales. Longer duration and deeper daytime dives suggest whales were feeding on krill throughout the study area, although dive depths occurring on Swiftsure Bank off Washington were limited by shallow bottom topography. Tagged whales spent a mean of 53.0 percent of their reported time at ≤ 30 m depth, which is within the zone of possible impact for deep-drafted vessels that transit the Strait of Juan de Fuca. Thus, the high occupancy by tagged whales of the Strait of Juan de Fuca, and the shallower waters of Swiftsure Bank immediately west of the Strait likely place them at an elevated risk for vessel collision.

The output of the state-space models applied to 56 humpback whale Argos tracks, representing a combination of the 2016-2018 data collected under CESU agreements together with earlier data collected by OSU off the US West Coast during tagging efforts in 2004 and 2005, produced a total of 1,893 daily locations with annotated behavioral mode available for ecological characterization. Of these, 82.0 percent were classified as area-restricted searching (ARS; an indication of foraging behavior), 12.0 percent as uncertain, and 6.0 percent as transiting. These locations occurred across 16.6 degrees of latitude, spanning much of US West Coast from the Strait of Juan de Fuca, Washington, in the north to Point Conception, California, in the south. Ecological characterization of these data indicated that tracked humpback whales moved at speeds ranging from a median of 0.61 km/h while engaging in ARS to 2.74 km/h while transiting. While in ARS, whales occurred at a median depth of 146.0 m, over southwest-facing seafloor with median slope of 0.55°, and at median distances of 4.6 km from the shelf break and 21.8 km from shore. In contrast, while in transiting activities, whales were found at a median depth of 376.0 m, over seafloor slopes that faced west-southwest with a steeper median slope of 0.74°, and at median distances of 13.5 km from the shelf break and 39.2 km from shore. There were no apparent behavioral mode differences with respect to sea surface temperature or sea surface temperature gradient (a measure of frontal activity), although tracked whales occurred in waters with higher phytoplankton chlorophyll-*a* content while engaged in ARS compared to transiting (median = 1.42 versus 0.93 $mg/m^3$). Thus, while occupying waters off the US West Coast during the feeding season, tracked humpback whales spent the majority of their time foraging over relatively shallow continental shelf waters, and spent a small proportion of their time in deeper, more offshore waters beyond the shelf break during transiting.

Analysis of the data by latitudinal 2-degree blocks revealed an apparent pattern in the proportion of locations in ARS behavior across blocks, being lowest (below 62 percent) off the northern Oregon, southern Oregon, and northern California blocks, implying that whales spent less time foraging there compared to the other blocks where the proportion of ARS locations was higher (above 75 percent). Locations occurring in the northernmost block, encompassing locations in the Strait of Juan de Fuca and adjacent waters, were characterized by a more southerly (or even easterly) aspect of the seafloor slope and by smaller median distances to the shelf break and to shore than for the other blocks, reflecting the semi-enclosed and distinct physiographic conditions imposed by the Strait of Juan de Fuca. For the other blocks, median distance to shore gradually decreased from north to south while median distance to the shelf break remained relatively constant, reflecting the narrowing width of the continental shelf along the US West Coast, and the preference for humpbacks to forage over the continental shelf. Other than a strong trend in sea surface temperature across blocks, being lowest in the north and highest in the south and reflecting the well-known global latitudinal temperature gradient, there were no other apparent latitudinal trends in the environmental variables examined. From this analysis we conclude that while other results in this study suggest spatial separation (or at least limited exchange) between BIAs and areas of whale aggregation along the US West Coast, the movement characteristics and environmental conditions associated with the tracking data do not suggest that these areas, or the humpback whale DPSs they support, have different habitat requirements.

The wide-ranging movements of the single tracked fin whale in this study were in contrast with the more coastal habits of the tracked humpback whales. This track had a high proportion of locations classified as ARS (80.8 percent) and no locations were classified as transiting (although the 10-d gap occurred during this whale's movement between the coastal and oceanic environment, when transiting behavior would likely have been recorded). The overall speed between location pairs was higher for this fin whale's track than for the humpbacks (0.80 km/h versus 0.72 km/h). Although the sample size was very small, this result is supported by previous results from 28 fin whales tagged in the Eastern North Pacific (see Mate et al. 2018b) that point at inter-species differences in movement speed. Similarly, deeper depths (median = 2378.0 m versus 153.0 m) and larger distances to the shelf break (median = 74.9 km versus 5.1 km) and to shore (median = 94.3 km versus 23.7 km) for the fin whale locations compared to the humpbacks' reflect the more oceanic habits of the species.

Biopsy samples were collected from 18 of the 20 tagged humpback whales in Washington in 2018 (plus seven untagged whales) and from all five of the tagged humpback whales in Oregon in 2018 (plus one untagged whale). A biopsy sample was also collected from the fin whale tagged off Oregon. Mitochondrial deoxyribonucleic acid (mtDNA) sequences of the 31 humpback whale samples resolved eight control region haplotypes for a consensus sequence of 500 bp for the Washington samples and four haplotypes for the Oregon samples. All mtDNA haplotypes have been described previously for North Pacific humpback whales and confirmed species identity of the field observations. The mtDNA sequence of the single fin whale sample has also been described previously for North Pacific fin whales. All humpback whale samples were represented by a unique multi-locus genotype of at least 14 loci, confirming individual identity and documenting one genotype recapture between two samples collected from an untagged whale in Washington. Sex-specific molecular markers showed that the 24 Washington individuals represented six females and 18 males, while the six Oregon individuals were all males. The mtDNA haplotypes, multi-locus genotypes, and sex markers together provided a standard "DNA profile" for each of the 30 individual humpback whales sampled in 2018. These profiles were compared to a reference database of 1,805 individuals sampled previously in the North Pacific by the ocean-wide survey referred to as the "Structure of Populations, Levels of Abundance, and Status of Humpbacks" program (SPLASH), and to the 23 individuals sampled during previous tagging off the California and Oregon coasts in 2016 and 2017 under previous CESU agreements (Mate et al. 2018a). This comparison detected one recapture of an individual sampled in Washington during the 2018 tagging effort and sampled previously in Washington during SPLASH in 2005. For population analyses, data from the six individuals sampled during 2018 off Oregon were combined with data from the nine individuals collected in 2016 and 2017, for a total of 15 individuals representing the Oregon feeding area. The fin whale sample was represented by a unique multi-locus genotype of 17 loci. A comparison to a reference dataset of 20 previously tagged fin whales (Mate et al. 2018b) found no recaptures.

Differences in mtDNA haplotype frequencies were used to investigate the influence of maternal fidelity to both feeding aggregations and breeding grounds, including tagging samples collected previously and the SPLASH reference database. A comparison of haplotype frequencies from the California and Oregon samples suggested some degree of differentiation between these feeding aggregations, with Oregon whales appearing more similar to the Southern British Columbia/Washington aggregation. This differentiation between California and Oregon feeding aggregations had not been recognized previously in the limited sampling of the Oregon coast during SPLASH, but was noted in the results of previous tagging efforts, based on smaller sample sizes, under previous CESU agreements in 2016 and 2017 (Mate et al. 2018a). Further, comparisons to the breeding areas defined by SPLASH indicated that the haplotype frequencies of California whales were most similar to Central America, while the haplotype frequencies of Oregon whales were most similar to those found off Mexico. The haplotype frequencies of the Washington sample did not differ significantly from the Southern British Columbia/Washington stratum in SPLASH and showed the greatest affinity with the Hawaii DPS.

The DNA profiles of humpback whale sampled on the feeding grounds were used to calculate the relative likelihood of individual membership in each of the four recognized DPSs in the North Pacific, based on a Bayesian assignment procedure and the SPLASH reference database. The 24 individuals sampled in Washington showed the highest likelihood of assignment to the Hawaii DPS for 13 individuals, to the Mexico DPS for five individuals, to the Central America DPS for four individuals, and to the Western North Pacific DPS for one individual. Two individuals were assigned with nearly equal likelihood to both Mexico and Hawaii. For the six Oregon samples, the individual assignment showed the highest likelihood of assignment to the Hawaii DPS for two individuals, to the Mexico DPS for two individuals, and to the Central America DPS for one individual. One individual was assigned with similar likelihood to Hawaii and Mexico. Assignments to the Hawaii or the Western North Pacific DPS could suggest changes in the migratory destinations, since some of these whales were tracked and/or photographed in Mexico. In interpreting the results of genetic assignment, however, it is important to keep in mind that accuracy is dependent on the quality of the reference dataset (which is limited to a relatively small sample size for the Central America DPS), and that assignments reflect genetic ancestry, including recent reproductive exchange between breeding areas.

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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 |
| ERD | Environmental Research Division |
| 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 SPOT5 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 | Southeast Alaska Biologically Important Area (summer and fall) |

| | |
|---|---|
| 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 |
| SWFCS | Southwest Fisheries Science Center |
| SWS | Saltwater conductivity switch |
| US | United States |
| V | Volt |

# 1 Introduction

The purpose of this Cooperative 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 National Marine Fisheries Service (NMFS) to the Navy for activities in all Pacific Ocean testing and training range complexes. With regard to humpback whales, in 2016 NMFS divided the global population into fourteen Distinct Population Segments (DPS) for purposes of listing under the Endangered Species Act[1] (ESA). Four DPS 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 DPS (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).

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 a 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.

Through the use of satellite telemetry, genetic analyses, and photo-identification (photo-ID), this study sought to provide greater detail on which humpback whale DPSs (as delineated under the ESA; Federal Register 2016a, b) use the Navy activity areas in the North Pacific Ocean. Information was also sought on humpback whale use of other areas of special interest to NMFS, such as the Olympic Coast National Marine Sanctuary (OCNMS) 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). Satellite tag deployments occurred in the Strait of Juan de Fuca as well as off the outer Washington and Oregon coasts in the summer of 2018 to track the movements of humpback whales off the US West Coast for multiple weeks to multiple months after deployment. This Final Report provides

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

detail on humpback whale use of Navy ranges, BIAs, and the OCNMS, as well as their feeding-season home range, habitat use, and ecological characteristics. In addition, this Final Report includes details on dive duration, feeding activity, and behavioral characteristics from tagged whales. The results are discussed in the context of previous tagging efforts by OSU off California and Oregon.

## 1.1 Study Goals

With this project, OSU sought to track humpback whale movement between or through Pacific Navy range complexes, and to collect photo-IDs and genetic samples (taken during tag placement) to further help delineate the DPS, as well as to describe their feeding-season home range, migration to breeding areas, habitat use, and ecological characteristics. In addition, data from tagged whales provided detail on dive duration, feeding activity, and behavioral characteristics over periods spanning multiple weeks to multiple months. Specifically, the goals of the summer 2018 field efforts in the Pacific Northwest were to:

- Attach Telonics RDW-665 Dive Monitoring (DM) satellite tags (equipped with depth sensors, accelerometers, and rapid orientation-change detection software) to nine humpback whales to monitor diving behavior and activity levels.
- Attach Telonics RDW-665 Dive Duration Plus (DUR+) satellite tags (equipped with accelerometers and rapid orientation-change detection software, but not depth sensors) to 15 humpback whales to monitor dive duration and activity levels.
- Attach a Wildlife Computers Advanced Dive Behavior (ADB) tag (equipped with accelerometers, magnetometers, depth, and temperature sensors) to one humpback whale to collect high-resolution archival dive and behavior data for a better understanding of the whale's fine-scale feeding behavior.
- Attach a Wildlife Computers SPOT6 Location-Only satellite tag to either a blue or fin whale encountered during humpback tagging operations to monitor long-term movements.

Additionally, through the collection of biopsy samples and genetic analyses of tagged whales, this study sought to provide:

- Sex determination
- Individual identification using mitochondrial haplotype sequencing and nuclear microsatellite loci, including matching with individually identifying photographs and tissue samples from whales previously sampled
- Assignment of individuals to DPS using mitochondrial haplotype sequencing and nuclear microsatellite loci, with population structure analysis including comparison to existing published databases for humpback whales in the Pacific Ocean.

# 2 Methods

## 2.1 Field Efforts

### 2.1.1 Tag Deployments

All tagging efforts were conducted from a small, 6.7-m rigid-hulled inflatable boat. The tagging crew consisted of a tagger, biopsy darter, photographer, and boat driver/data recorder. 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 4 meters (m) with 93- to 120-pound force per square inch in the applicator's pressure chamber.

### 2.1.2 2018 Tagging

Humpback whale tagging efforts off Washington took place as day trips from Neah Bay, just east of Cape Flattery on the Olympic Peninsula, from 1 to 20 August, 2018. Tagging efforts off Oregon took place as day trips out of Newport, on three days from 6 to 8 September 2018.

### 2.1.3 2016 and 2017 Tagging

Humpback whale tagging efforts in 2016 and 2017 were conducted as day trips from ports along the Oregon coast. Two days of tagging took place out of Newport, in central Oregon in 2016. In 2017, tagging trips took place during 7 days (d), as follows: 2 d out of Newport; 1 d each out of Charleston, Brookings, and Gold Beach, in southern Oregon; and 2 d out of Clatsop Spit, in northern Oregon. 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.

## 2.2 Satellite Tags

Four types of fully implantable, non-recoverable, Argos-based tags were used from 2016 to 2018: Telonics RDW-640 tags (hereafter referred to as Duration-Only or DUR tags); Telonics RDW-665 Duration-Plus tags (hereafter referred to as DUR+ tags); Telonics RDW-665 Dive-Monitoring tags (hereafter referred to as DM tags); and Wildlife Computers SPOT6 tags (hereafter referred to as Location-Only or LO tags). All tag types were composed of a main body, a penetrating tip, and an anchoring system (**Figure 1**). The main body consisted of a stainless steel cylinder (1.9 centimeter [cm] in diameter × 15.9 cm in length for the DUR tag, 1.9 cm in diameter × 20.7 cm in length for the DUR+ and DM tag, and 2.0 cm in diameter x 20.7 cm in length for the LO tag) that houses a certified Argos transmitter and a 6 volt (V) lithium battery pack. A flexible whip antenna and a saltwater conductivity switch (SWS) were mounted on the distal endcap of this cylinder, while a penetrating tip was screwed onto the other end. On the DUR, DUR+, and DM tags, the antenna consisted of a 15.8 cm long x 1.3 millimeter (mm) diameter nitinol cable and the SWS, also made of nitinol, measured 2.2 cm long x 1.3 mm diameter. On the LO tag, the nitinol antenna measured 15.0 cm long x 1.3 mm diameter and the stainless steel SWS measured 3.5 cm long x 1.3 mm diameter. The polycarbonate endcap of the DUR, DUR+, and DM tags 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 stainless steel endcap on the LO tag also had perpendicular stops, made of stainless steel, measuring 1.4 cm long x 0.6 cm wide x 0.83 cm thick. 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. Maximum tag weight was 300 grams (g) for all tag types.

Two of the DUR tags and the LO tag also had eight stainless steel wires (3.5 cm long, 0.9 mm gauge) mounted behind the blades on the penetrating tip. These wires provided initial anchorage prior to deployment of the curved metal strip anchors, which were held flush to the tag body with wraps of water-soluble starch fabric (Solvy®), and deployed to their curved position after the Solvy® dissolved. To minimize tissue damage at the tag site, we eliminated the wires from remaining tags. Instead, Solvy® was rolled into ropes and tied around the metal strip anchors to hold them flush for tag deployment. Upon deployment the Solvy® ropes were pushed up the tag body, allowing the anchors to deploy immediately, eliminating the need for additional wire anchors.

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 33 d [standard deviation (SD) = 35.4 d, median = 23.9 d, n = 245], with a maximum duration of 220 d (OSU, unpublished data).

One partially implantable, recoverable tag was also used in 2018, which will hereafter be referred to as the Advanced Dive Behavior (ADB) tag (**Figure 2**). The ADB tag consisted of a certified Argos transmitter and a Wildlife Computers Time-Depth Recorder, with a three-axis accelerometer and magnetometer, cast in an epoxy tube (2.0 cm in diameter and 11.5 cm long). A FastLoc® geographic positioning system (GPS) receiver, encased in syntactic foam (10.0-cm diameter dome with a maximum height of 4.0 cm), was attached to one end of the epoxy tube. Three light-emitting diode lights were mounted on top of the syntactic foam to facilitate relocation of the tag. The tubular portion of the tag was slid into a cylindrical stainless steel tag housing (2.6 cm in diameter and 14.5 cm long) for deployment. A circular stainless steel plate, or collar, was welded onto the distal end of the housing to protect the syntactic foam during deployment. A penetrating tip and anchoring system, similar to that of the implantable tags, was mounted onto the cylindrical end of the tag housing. The cylindrical portion of the tag housing was designed for implantation beneath the whale's skin while the plate and syntactic foam GPS receiver sat atop the whale's back. The ADB tag and housing weighed approximately 470 g (approximately 240 g for the tag and approximately 230 g for the housing). A plastic "D-ring" was mounted on the bottom of the syntactic foam with a corrodible wire. This D-ring passed through a slot in the stainless steel plate and was secured on the backside of the plate with a screw. After a pre-determined time, an electrical current was activated within the tag, oxidizing the corrodible wire, whereupon the tag was ejected from the housing and floated to the surface for recovery (Mate et al. 2017). For this study, the electro-mechanical connection between the tag and its housing was programmed to release the tag on 15 August 2018, allowing time for tag recovery during our three-week field effort.

### 2.2.1 DUR Tag Programing

DUR tag programing details as well as dive behavior results can be found in Mate et al. (2018a) and are not presented in this report.

### 2.2.2 DM Tag Programing

DM tags contained a pressure sensor and tri-axial accelerometers, and were able to record dive depth, dive duration, changes in body orientation, and motion while attached to a whale. They used 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 and 10 m in depth. 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. Accelerometer readings were recorded every 0.25 s.

Feeding activity was derived from the motion data for selected dives 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 30 s from the previous lunge.

Argos messages for DM tags consisted 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. The tags maintained an Argos message buffer that held up to 10 messages in the tag's memory. When enough selected dives were recorded to create a new message it was added to the buffer. If there were already 10 messages in the buffer, the oldest message was discarded to make space for the new message. Every time the tag transmitted a dive data message, it randomly selected one of the messages for transmission from the buffer. One diagnostic message was sent for every 24 data messages. The current Jerk mean and SD values were included in the diagnostic message 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 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 90 to 120 d.

### 2.2.3 DUR+ Tag Programing

DUR+ tags lacked a pressure sensor, but were otherwise configured the same way as the DM tag, with a SWS for submergence detection and tri-axial accelerometers, and onboard processing software to detect behavioral events in the motion data. Argos messages for DUR+ tags consisted of the start date and time of each selected dive (dives > 2 min duration), dive duration, and number of lunges for a variable number of consecutive selected dives, typically four to six depending on data compression. The tag maintained an Argos message buffer like that of the DM tag, with similar transmission protocols (described above in **Section 2.2.2**). DUR+ tags were programmed to transmit during six 1-h periods per day coinciding with times when satellites were most likely to be overhead, until 30 September 2018, then transmit during six 1-h periods every other day thereafter. This resulted in an electronic life expectancy of approximately 120 to 180 d.

### 2.2.4 ADB Tag Programming

The ADB tag was programmed to collect a GPS-quality FastLoc® location every 7 min or as soon thereafter as the whale surfaced from a dive. Dive depth was recorded every 1 s with 2-m vertical resolution. Body orientation (from the accelerometer) and magnetic compass heading (from the magnetometer) were also recorded at 1-s intervals. These data were all archived onboard the tag and accessible only when the tag was recovered. Qualifying dives (those greater than 2 min in duration and 10 m in depth) were also summarized for transmission through the Argos system along with GPS locations recorded by the tag. Summary messages (behavior messages) describing individual qualifying dives were generated by recording dive duration, maximum dive depth, dive shape (U-, V-, or square-shaped- and whether the U- or V-shaped dives were skewed right, left or centered) and the subsequent surfacing duration. Up to four consecutive summarized dives were transmitted in each behavior message (Wildlife Computers PAT-MK10 User Guide [30 Nov 2015] http://wildlifecomputers.com/wp-content/uploads/manuals/MK10-User-Guide.pdf). A single Argos message from the tag could send either one GPS location, one histogram summary (not used here), or one behavior message (summarizing four dives). Version 3 of the FastLoc® GPS acquisition program was installed in the ADB tag (Mate et al. 2017).

## 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).

In order to generate a complete track from the Argos location data, OSU implemented a sequential data editing protocol on the received ("raw") locations from each tag to retain the best locations for analysis. 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 2.3.3** and **2.3.4** 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 2.3.5, 2.3.6, 2.4, and 2.5** 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 the 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 20,000 iterations being thinned by retaining every 20th sample to reduce autocorrelation, yielding a final 1,000 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 value from 1 to 2 for each location (Jonsen et al. 2005, Jonsen 2016). As has been the practice in other studies (Jonsen et al. 2005, Bailey et al. 2009, Irvine et al. 2014), we chose behavioral state values greater than 1.75 to represent ARS mode and values lower than 1.25 to represent transiting mode. Locations with behavioral state values in between were considered "uncertain".

### 2.3.3 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.

### 2.3.4 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 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 (W237) within the NWTT, and (6) the Gulf of Alaska Temporary Maritime Activities Area (GOA; **Figure 3**). Area W237 is located within area NWTT, so whale occurrence in W237 is also counted as occurrence in NWTT as the two areas were analyzed separately.

The number of locations and corresponding percentages were also computed for areas of interest to NMFS, such as 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 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), and (7) Northern Washington (NWA BIA; **Figure 4**). The 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.

### 2.3.5 Home Range Analysis

Because the focus of this section was on habitat occupation during the feeding season, we removed the migration portion of the tracks prior to analysis. For this purpose, the migration portion was established as the segment of each hSSSM track where behavioral mode remained as 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 track 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. Spatial hotspots were identified based on the amount of overlap between the individual home ranges.

### 2.3.6 Historical Comparisons

Comparisons between previous tagging in the Pacific Northwest and the 2018 season 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. A Kruskal-Wallis test was used to test for differences in medians when the assumption of homogeneity of variance was not met.

Comparisons between previous OSU tagging of humpback whales in California are addressed in the Discussion section of this report. Detailed results from California tagging are presented in Mate et al. (2018a) and are not duplicated here. Appendix I presents an erratum to the Mate et al. (2018a) report, with an amended table of days spent inside Navy training ranges, as we discovered that locations in the NWTT for two whales tagged in California in 2004 were excluded from the previous report (Mate et al. 2018a). The amended table also separates the humpback whale tagged off southern Oregon in 2005 from the whales tagged in California that year, in which it was included in the previous report.

## 2.4 Dive Behavior Analyses

The goals of the analyses in this section were to use dive data from tags 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.

### 2.4.1 DUR+, DM, and ADB Tag Analysis

The percent of the tracking duration summarized by reported dives[2] from all 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) divided by the tracking duration.

[2] In the past (e.g., Mate et al. 2018a, b), DUR, DUR+, and DM tags have 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). 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), but diagnostic information is limited to conclude this definitively. Whales in this and previous reports were documented regularly diving for 20–25 min, so dives > 25 min in duration were removed as "anomalous" in this report (N = 13).

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 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). In order to examine possible exposure to vessel collision, we also calculated the time spent by a whale near the surface (≤ 30 m depth) as the sum of all PDI's plus the sum of dive durations for dives made to maximum dive depths ≤ 30 m. The overall percentage of time spent near the surface based on the received dive summaries was then calculated for each whale as the time spent near the surface divided by the sum of all dive durations and PDIs for that whale. This results in a conservative estimate as it does not include the portion of deeper dives where whales transited through waters ≤ 30 m deep or the PDI of the last dive in a transmission as described above.

Summary plots showing dive duration and number of feeding lunges versus date and versus time of day were generated for each individual tag and for all DM and DUR+ 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. Similar plots showing maximum dive depth were made for data received from the ADB and DM tags.

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 tagged whales that occupied each grid cell and another showing the number of dives that occurred in each cell. These last two maps indicate where tagged whales spent more time diving. This process was repeated using maximum dive depths recorded by DM and ADB tags. A similar method was used to generate gridded plots of the number of feeding lunges recorded by DM and DUR+ tags however in this case, the sum of the number of lunges made in each cell was calculated, and then divided by the sum of the dive durations for all dives occurring in the cell (i.e., the total time spent diving in that cell) to get the number of lunges per hour reported for each grid cell. 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 and is presented with corresponding maps showing the number of individuals and number of dives made in each cell.

## 2.5 Ecological Relationships

We conducted an ecological characterization of the tracking data by describing the environment used by the tagged whales during the course of their movements. In order to have a sufficient sample size for meaningful analysis and interpretation, in this section we consider the 2016-2018 tracking data collected under CESU agreements together with earlier tracking data collected by OSU off the US West Coast during tagging efforts in 2004 and 2005, as previously documented in last year's report (Mate et al. 2018a).

We considered environmental variables representing static features of the seascape from digital elevation models of seafloor relief, as well as oceanographic variables representing dynamic processes from remotely sensed measurements, and extracted observations that most closely matched the SSSM/hSSSM locations in time and space. Considering that the environmental data products used in this ecological characterization had a temporal resolution of 1 d or coarser (**Table 1**), and to avoid pseudo-replication, the 2016-2018 hSSSM tracks were thinned from three to one location per day (keeping only the first estimated location of each day) prior to extraction. The historical tracking data had been previously modeled at one location per day using the conventional SSSM methodology (as described in Mate et al. 2018a) because those tags were programmed with a different duty cycle (four 1-h transmission periods per day every day for the first 90 d and subsequently going to every second day). We additionally excluded from analysis SSSM/hSSSM locations that were estimated on land, as well as those locations with 95 percent credible limits exceeding 1 degree in longitude and/or in latitude to reduce introducing bias by locations with large estimation uncertainty. Finally, since the focus of this section was on habitat use during the feeding season, we removed the migrating portion of the tracks prior to analysis, as described in **section 2.3.5** (Home Range Analysis).

The static variables describing the seafloor relief were depth (DEPTH), slope (SLOPE, or depth gradient), aspect (ASPECT, the directional facing of the slope), and distance to the 200-m isobath (DISTSHELF, or distance to the shelf break). Distance to the nearest shoreline (DISTSHORE) was also calculated for each SSSM/hSSSM location (**Table 1**). The dynamic oceanographic variables extracted were sea surface temperature (SST), magnitude of the horizontal sea surface temperature gradient (SSTG, a measure of frontal activity), and phytoplankton chlorophyll-*a* concentration (CHL) (**Table 1**).

Several of these data products were available from the Environmental Research Division (ERD) of the NOAA/NMFS/SWFSC through the web service *Environmental Research Division Data Access Program* (ERDDAP, Simons 2019; http://coastwatch.pfeg.noaa.gov/erddap/index.html), as detailed in **Table 1**. For these variables, the extraction process for matching tracking and environmental data was automated using the package *rerddapXtracto* v. 0.4.1 (Mendelssohn 2019), a collection of functions that permit client-side access to the data sets served by ERDDAP from within the software for statistical computing R v. 3.6.1 (R Core Team 2019). These functions additionally allow the use of a box of arbitrary size to extract the underlying data around each location. Thus, 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 1.39 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.

For each track we also computed the distance and speed between pairs of SSSM/hSSSM locations (i.e., pairwise distance [PWDIST] and pairwise speed [PWSPEED], respectively) as metrics of the local scales of movement of the tagged whales across the study area. For these calculations we used the R package *trip* v. 1.6.0 (Sumner et al. 2009, Sumner 2011). In this way, we generated fully annotated SSSM/hSSSM tracks with behavioral mode, pairwise distance and speed, and a suite of environmental variables at each estimated location for ecological characterization.

Considering the large latitudinal extent covered by the compiled humpback whale tracking data set, we partitioned the study area into eight 2-degree latitudinal blocks spanning the range 34-50°N for the purpose of investigating possible regional differences in habitat characteristics that would support the pattern of occupation by the different humpback whale DPSs along the US West Coast during the feeding season. The relationships between the environmental variables and the whale tracking data are presented using descriptive statistics, as well through graphical methods such as spatial maps and box-violin plots. Because in many cases the environmental variables had strongly skewed and/or long-tailed distributions, we report the median and the median absolute deviation (MAD) as more robust metrics compared to the mean and the SD.

## 2.6 Genetics

### 2.6.1 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). These sequences were edited for quality control and trimmed to a 500-bp consensus region in Sequencher v. 4.6. Variations in the control region sequences were used to identify unique haplotypes among the samples collected during each season of the project. The unique haplotypes were then aligned with previously published haplotypes downloaded from the public repository GenBank® to investigate differences in regional haplotype frequencies (Baker et al. 2013). As mtDNA is a maternally inherited genome, unique haplotypes represent maternal lineages and the distribution of haplotypes reflect maternal fidelity to migratory destinations (Baker et al. 2013).

### 2.6.2 Microsatellite Genotypes

Variation in the nuclear DNA of each sample was investigated by multi-locus genotyping of up to 16 microsatellite loci for each humpback whale sample using previously published conditions (Baker et al. 2013). Unlike mtDNA, the allele frequencies of nuclear DNA genotypes reflect patterns of biparental inheritance, including reproductive isolation considered in the delineation of DPSs. 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). All of the above loci were also amplified for the fin whale sample, with the exception of EV1. A further two loci were also amplified for the fin whale sample; GATA98 (Palsbøll et al. 1997) and DlrFCB17 (Buchanan et al. 1996). Microsatellite loci were amplified individually in 10-microliter reactions and co-loaded in four multiplexes 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.

### 2.6.3 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).

### 2.6.4 Individual Identification

Individual whales were identified from the multi-locus genotypes of 16 microsatellite loci using CERVUS v. 3.0.3 (Marshall et al. 1998). Mismatches of up to three loci were allowed in initial comparisons 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).

### 2.6.5 Species and Stock Identification

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

For stock identification of humpback whales, we had access to a large "DNA register" available from the ocean-wide survey referred to as the "Structure of Populations, Levels of Abundance and Status of Humpbacks" program, or SPLASH. This register includes a standard "DNA profile" for each sample, representing 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 humpback whales sampled during this project 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. To increase sample sizes for some analyses, we included DNA profiles from both tagged and untagged whales collected during the specified field effort.

Tests of differentiation in mtDNA haplotype frequencies between the Washington and Oregon datasets and the 18 populations defined during SPLASH (Baker et al. 2013) were conducted using a permutation procedure implemented in the program Arlequin (Excoffier and Lischer 2010). Assignment of individuals from the Washington and Oregon datasets to the four DPSs, as recognized by the ESA (Federal Register 2016a, b), was based on multi-locus genotyping using the Bayesian population assignment procedure implemented in the program GeneClass2 (Piry et al. 2004). This program uses multi-locus genotypes and mtDNA 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. The confidence of any individual assignment, as reflected in the relative likelihood score, is the result of several factors, including the sample size of the reference database, the number of variable loci and the true underlying differentiation of the breeding populations (Manel et al. 2005).

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 dataset 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.

The DNA profile of the single fin whale was compared to the small DNA register (n = 20) available from the previous tagging of this species along the coast of California. This allowed for individual identification but not for any statistical analyses of population differentiation.

## 2.7 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 was completed, our photo-IDs were submitted to the online resource "Happywhale" (http://happywhale.com) to determine if the whales we encountered have been seen previously or subsequently. Photo-IDs were submitted and compared to Happywhale up to 15 November 2019.

Happywhale is a global database of photo-IDs contributed by the public and other researchers that provides automated matching using state-of-the-art algorithms and machine learning.

# 3 Results

Twenty humpback whales were tagged (10 DUR+ tags, 9 DM tags, 1 ADB tag) out of Neah Bay, Washington, between 3 and 18 August 2018, and five humpback whales (5 DUR+ tags) and one fin whale (SPOT6 tag) were tagged out of Newport, Oregon, between 6 and 8 September 2018. Argos satellite locations were received from all 25 tags deployed on humpback whales. Tracking periods for all 15 DUR+ tags (deployed in both Washington and Oregon) ranged from 9.2 to 110.6 days (mean = 35.1 d, SD = 28.3 d). Tracking periods for the nine DM tags ranged from 6.7 to 52.1 d (mean = 24.1 d, SD = 14.0 d). Minimum distance traveled averaged 2,122 km (SD = 1,210 km) for DUR+ tags and 1,335 km (SD = 621 km) for DM tags. The ADB tag transmitted for 12.5 d (one day before it was to release and float to the surface) and 590 km, after which we didn't hear from it. Presumably the tag came off the whale while still attached to its housing and sank to the seafloor. The tag was designed to release from its housing after detecting a constant depth for 24 h, so would ultimately surface again after sinking, but either the release procedure failed or the tag was positioned (or trapped) on the seafloor in such a way that prevented it from separating from its housing and surfacing. Finally, the fin whale tagged off Oregon was tracked for 35.9 d and 1,963 km. Tracking results are presented in further detail in **Section 3.3**.

## 3.1 Tagging Rates

A total of 334 humpback whales were approached during 17 d of tagging efforts in Washington in 2018, and 20 tags were deployed (**Table 2**). Off Oregon, 73 humpback whales were approached in 3 d of tagging and five tags were deployed (**Table 2**). Humpback whale tagging rates were similar between Washington (1.2 tags per day) and Oregon (1.7 tags per day). Seven fin whales were approached on the day the fin whale was tagged off Oregon.

## 3.2 Behavioral Responses to Tagging

Eighteen of the 20 humpback whales tagged in Washington (90 percent) and all five humpbacks tagged in Oregon (100 percent) in 2018 exhibited moderate, short-term startle responses to the tagging/biopsy process. These responses consisted of mild to hard tail flicks, fast dives, rolls, 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. Two of the eight humpback whales that were biopsy-sampled (but not tagged) responded to the biopsy darting process, exhibiting mild or medium tail flicks. The fin whale did not respond to the tagging/biopsy process.

## 3.3 Wound Healing

Five humpback whales tagged in Washington in 2018 were resighted by OSU on subsequent days during the Washington field effort. No whales tagged in Oregon in 2018 were resighted by OSU during the Oregon field effort. One Washington whale (whale #5640, a male) was resighted 2 d after tagging, but the tag site was not seen. The remaining four whales (#s 5654, 5700, 5823, 10839) were resighted from 1 to 10 d after tagging (**Table 4**). No swelling was visible at the tag sites for three of these whales, but each had an area of "rough" skin around the tag, ranging from approximately 4 to 5 cm in diameter (**Table 4**). The whale resighted 10 days after tagging (#10839, a female) had moderate swelling around the tag site, approximately 50 cm in diameter and 10 cm in height (**Table 4**).

After OSU field efforts had ended in Washington, five tagged whales (#s 5654, 5790, 5883, 5923, 23029) were seen and photographed in 2018 by naturalists aboard commercial whale watching boats and by another researcher. Photographs submitted to us from these encounters allowed for an assessment of the tag sites. In these five cases, tags were still present and there was no sign of swelling at the tag sites (**Table 4**). One whale (#5654) was first seen off Clallam Bay 33 d after tagging and 6 d after the tag's last transmission. This whale was later seen near Race Rocks off the southern end of Vancouver Island 68 d and 73 d after tagging. There was no sign of the antenna on the tag, which had stopped transmitting 46 d after tagging. The tag body was present and protruding approximately 8 cm out of the whale. The tag was surrounded by a divot with an approximate diameter of 20 cm and depth of 4 cm. Whale #5790 was resighted approximately 19 km northwest of Port Angeles, 36 d after tagging. The tag was still transmitting, but protruding approximately 2 cm and angled toward the rear of the whale. It was surrounded by a divot approximately 20 cm in diameter and 5 cm in depth. The third whale (#23029) was seen 6 km south of San Juan Island 22 d after tagging. The tag was still transmitting at the time, but stopped 6 d later. Red tissue, approximately 8 cm in diameter, surrounded the tag. The fourth whale (#5923) was resighted off Clallam Bay 27 d after tagging. The tag was still transmitting, but stopped 7 d later. The whale was photographed by a drone and photo quality was poor, but it appeared the tag was protruding approximately 7 cm and leaning forward. A reddish circle of tissue surrounded the tag. There appeared to be no swelling, but this was difficult to determine from above. The fifth whale (#5883) was sighted off Clallam Bay 38 d after it was tagged and 23 d after it last transmitted. The photos of this whale were poor, but appeared to show a small divot around the tag with some white tissue present approximately 4 cm in diameter and 2 cm in depth.

Four whales (#s 4177, 5700, 5801, 23029) tagged in Washington in 2018 were resighted during OSU's 2019 tagging field efforts in Washington from 17 September to 6 October. These whales were resighted from 402 to 417 d after tagging and from 363 to 400 d after their tags' last transmission (**Table 4**), and no tags were present. Tag scars consisted of divots, ranging in size from approximately 5- to 20-cm diameter and 1- to 8-cm depth, with lighter or discolored skin (**Table 4**). There was no visible swelling at any of the tag sites and all four whales were in good body condition. One of the whales (#23029, a female) was accompanied by a calf.

## 3.4 Tracking Results

### 3.4.1 Washington Tagging

Locations for humpback whales tagged off Washington ranged over 26 degrees of latitude, from the northern tip of Vancouver Island, British Columbia, Canada, to just south of Magdalena Bay, on the west coast of Baja California, Mexico (**Figure 5**). Tracking periods for these whales ranged from 6.7 to 110.6 d, and total distances traveled ranged from 288 to 4,808 km (**Table 5**). The individual with the widest range (whale #5790; hereafter whales are referred to by their tag number) was tagged off Neah Bay, and tracked for 37 d in the Strait of Juan de Fuca, after which it moved west to continental shelf waters approximately 50-90 km off Cape Flattery, Washington. There was then a 66-d gap in locations for this whale before one last location was received off Magdalena Bay, Baja California, Mexico, on 3 December.

The vast majority of locations for humpback whales tagged off Washington occurred between Pillar Point, 40 km east of Neah Bay, and approximately 30 km west of Cape Flattery, with the densest area of locations over Swiftsure Bank, approximately 25 km northwest of Cape Flattery (**Figure 5**). Seven whales had locations east of Pillar Point, four of which traveled as far east as Port Angeles, two traveled as far as Victoria, Vancouver Island, and one traveled up into the Strait of Georgia, northwest of Vancouver, British Columbia (**Figure 5**).

#### *3.4.1.1 Use of Navy Training Areas*

All twenty humpback whales tagged in Washington in 2018 spent time in the Navy's NWTT, with percentages of locations in NWTT ranging from 2.1 to 93.0 percent and time spent there ranging from 0.2 to 94.1 percent of their total tracking periods (or 0.01 to 28.9 d; **Table 6, Figure 6**). Nineteen of these whales also had locations in area W237 of the NWTT, with percentages of locations ranging there ranging from 0.5 to 60.0 percent and time spent in W237 ranging from 0.2 to 51.2 percent of their total tracking periods (or 0.03 to 16.8 d; **Table 6, Figure 7**). Distances to shore in NWTT averaged 27 km (SD = 11.6 km, maximum = 105 km; **Table 7**). Distances to shore in W237 averaged 46 km (SD = 13.3 km, maximum = 105 km; **Table 7**). Humpback whale locations occurred in NWTT and W237 during the months of August, September, and October. None of the humpback whales tagged in Washington in 2018 were tracked within the PT MUGU, SOCAL, SOAR, or GOA areas (although it is likely that whale #5790 crossed one or more of the Navy areas in southern California during the 66-d gap with no locations, on its transit to Mexican waters).

#### *3.4.1.2 Use of West Coast BIAs*

Nineteen humpback whales tagged in Washington in 2018 had locations in the NWA BIA, with 0.4 to 43.0 percent of their total number of locations there (**Table 8, Figure 8**). This represented 1.3 to 51.1 percent of their total tracking periods, or 0.2 to 18.3 d (**Table 8**). Humpback whale locations occurred in the NWA BIA during August, September, and October. All 20 of the humpback whales tagged in Washington spent time in the OCNMS, having between 1.6 and 53.6 percent of their total number of locations there (**Table 8, Figure 9**). This represented between 0.4 and 59.1 percent of their total tracking periods, or 0.03 to 23.1 d in the sanctuary (**Table 8**). Humpback whale locations occurred in the OCNMS during August, September, and October. None of the humpback whales tagged in Washington had locations in any other West Coast BIA.

#### *3.4.1.3 Home Ranges and Core Areas*

Nine of the humpback whales tagged in Washington in 2018 provided enough locations to calculate feeding area HRs and CAs (**Table 9, Figures 10 and 11**). HR sizes ranged from 1,912 to 4,316 $km^2$ (mean = 2,884 $km^2$; SD = 931.3 $km^2$) and extended from Tofino on the west coast of Vancouver Island to Cannon Beach, northern Oregon. The densest location of HRs occurred at the northwest corner of Washington, where HRs overlapped for all nine of the whales. CAs ranged in size from 245 to 1,095

$km^2$ (mean = 494 $km^2$, SD = 270.2 $km^2$), extending throughout the western end of the Strait of Juan de Fuca, between Washington and Vancouver Island, to approximately 60 km offshore. One additional core area (for whale #5838) was located approximately 55 km off the central Washington coast, near Taholah. The areas of highest use, with overlapping CAs for six to seven whales, were in the central Strait, from approximately 15 km east of Neah Bay, Washington, to approximately 20 km west-northwest of Cape Flattery, Washington, over Swiftsure Bank. There was no relationship between the number of locations used in the analysis and the size of either HRs or CAs (linear regression of log-transformed variables, $p$-values > 0.21).

### 3.4.2 Oregon Tagging

Locations for humpback whales tagged off Oregon ranged over 5 degrees of latitude, from the Columbia River mouth at the border of Oregon and Washington to just north of Cape Mendocino in northern California (**Figure 12**). Tracking periods for these whales ranged from 9.2 to 60.2 d, and total distances traveled ranged from 698 to 3,815 km (**Table 10**). The densest concentration of locations was over the continental shelf edge west of Stonewall Bank, between Newport and Waldport on the central Oregon coast, with a secondary concentration along the shelf edge south of Heceta Bank, between Waldport and Coos Bay.

The fin whale (whale #5882) was tracked for 35.9 d and a minimum distance of 1,963 km (**Table 10**, **Figure 13**). It remained off the central Oregon coast mainly over shelf edge and slope waters for the first 12 d of its tracking period, after which there was a 10-d gap in locations. Whale #5882 was then located approximately 250 km west of Queen Charlotte Sound, between Vancouver Island and Haida Gwaii, British Columbia, over deep oceanic waters. It spent 10 d in this area before heading southwest, with its last location (on 12 October) approximately 90 km west of the Hesquiat Peninsula, on the central west coast of Vancouver Island (**Figure 13**).

#### *3.4.2.1 Use of Navy Training Areas*

All five humpback whales tagged in Oregon in 2018 spent time in the Navy's NWTT, with percentages of locations in NWTT ranging from 37.3 to 89.8 percent and time spent there ranging from 39.9 to 95.0 percent of their total tracking periods (or 4.9 to 44.5 d; **Table 11, Figure 14**). Distances to shore in NWTT averaged 39 km (SD = 1.4 km, maximum = 73 km; **Table 12**). Humpback whale locations occurred in NWTT during the months of September, October, and November. None of the humpback whales tagged in Oregon in 2018 were tracked within area W237 of the NWTT, or PT MUGU, SOCAL, SOAR, or GOA areas.

Fifteen percent of the tagged fin whale's locations occurred within NWTT (in September), representing 40 percent of this whale's tracking period (14.4 d; **Table 11**, **Figure 13**). Distance to shore in NWTT averaged 55 km (SD = 26.7 km, maximum = 91 km; **Table 12**). The amount of time spent within NWTT included time along an interpolated track for this whale during the 10-d gap in locations, mentioned above in Section 3.4. The fin whale's interpolated track also crossed area W237 within NWTT, providing an estimated 11 percent of the whale's tracking period, or 3.9 d, in September (**Table 11, Figure 13**). This whale was not tracked within the PT MUGU, SOCAL, SOAR, or GOA areas.

#### *3.4.2.2 Use of West Coast BIAs*

Four of the five humpback whales tagged in Oregon in 2018 had locations in the Stonewall-Heceta Bank BIA, with 8.0 to 55.9 percent of their total number of locations there (**Table 13, Figure 15**). This represented 7.6 to 49.6 percent of their total tracking periods, or 1.4 to 7.4 d (**Table 13**). Humpback whale locations occurred in the Stonewall-Heceta Bank BIA during September and October. Two of the five humpback whales tagged in Oregon spent time in the PSG BIA, having between 2.7 and 3.8 percent of their total number of locations there (**Table 13, Figure 16**). This represented between 2.0 and 3.2 percent of their total tracking periods, or 0.4 to 0.5 d (**Table 13**). Humpback whale locations occurred in the PSG BIA during September. None of the humpback whales tagged in Oregon had locations in any other West Coast BIA or the OCNMS.

#### *3.4.2.3 Home Ranges and Core Areas*

Only one of the five humpback whales tagged in Oregon in 2018 provided enough locations to

calculate feeding area HR and CA (**Table 9, Figure 17**). This whale's HR was 3,721 $km^2$ and extended from Newport to Charleston on the central Oregon coast. CAs for this whale totaled 425 $km^2$ and were centered off Newport, Florence, and Reedsport, Oregon.

The fin whale also provided a long enough track to calculate feeding area HR and CA, with sizes of 122,816 $km^2$ and 15,951 $km^2$, respectively (**Figure 18**). The home range extended from the central Oregon coast northwest to approximately 350 km off Queen Charlotte Sound, British Columbia. CAs were centered between Newport and Cascade Head, on the central Oregon coast, extending up to 120 km offshore, and in an area west of Queen Charlotte Sound, ranging from approximately 150 to 260 km off the Sound.

### 3.4.3 Historical Comparisons

#### *3.4.3.1 Tracked Movements*

Seven humpback whales were tagged by OSU in the Pacific Northwest prior to 2018, two off Oregon in 2016 and five off Oregon in 2017, providing tracking data for six whales (one tag deployed in 2017 provided only three transmissions and no locations, and is not considered further in this report), as previously reported in Mate et al. (2018a). Tags deployed in 2016 were DM style and tags deployed in 2017 were DUR style (similar to DUR+ but without lunge detection; see Mate et al. 2018a for description of the DUR tag). Tracking durations for these whales ranged from 7.3 to 150.4 d. Because of the small sample size for 2016 (two tags) tracking results for 2016 and 2017 were combined in further comparisons. Tracking durations were not significantly different between whales tagged in Washington in 2018, whales tagged in Oregon in 2018, and whales tagged in Oregon prior to 2018 (ANOVA, $p$-value = 0.50; **Table 14**). The latter analysis did not include the tracking duration of the ADB tag deployed in Washington in 2018, because this tag had a planned two-week release for recovery. The average tracking duration for all implantable tags deployed on humpback whales in Oregon and Washington from 2016 to 2018 was 33.9 d (SD = 31.2 d, median = 26.8 d, maximum = 150.4 d, n = 30). 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 not significantly different between humpback whales tagged with implantable tags in Washington in 2018, in Oregon in 2018, or in Oregon prior to 2018 (general linear model of log-transformed variables, *p*-value = 0.25; **Table 14**).

Only two whales were tracked south of their feeding areas. One of these, tagged off Newport, Oregon, in 2017, began its southbound migration on 24 December 2017 and was last located approximately 70 km north of Puerto Vallarta, Mexico, on 5 February 2018, as previously reported in Mate et al. (2018a). The other whale, tagged off Neah Bay, Washington in 2018 was last located after a 66-d gap in locations, off Magdalena Bay, Baja California, Mexico, on 3 December 2018.

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 identical for humpbacks tagged in Oregon in 2017 and those tagged in Washington in 2018 (when migration was included) at 27 degrees. When migratory locations were not included (i.e., only considering the tracked locations during the feeding season), latitudinal ranges were also similar between humpback whales tagged in Washington (5 degrees) and those tagged in Oregon (6 degrees in 2018, 7 degrees in 2017, and 4 degrees in 2016). Locations of humpback whales tagged in Washington ranged from the north coast of Vancouver Island to the northern Oregon coast, off Manzanita. Locations of whales tagged in Oregon ranged from Barkley Sound on the central west coast of Vancouver Island to Point Arena, on the central coast of California.

#### *3.4.3.2 Use of Navy Training Areas*

Sixty-one percent of all humpback whales tagged by OSU in Washington and Oregon from 2016 to 2018 (19 of 31) were tagged within the NWTT training range, and all 31 tagged whales had locations within NWTT (**Table 15, Figure 19**). The mean number of days spent in the NWTT ranged from a low of 10.8 d (for humpback whales tagged in Washington in 2018) to 22.6 d (for humpback whales tagged in Oregon in 2016 and 2017), with a maximum residency in this area of 86.5 d (for a whale tagged off Oregon in 2017). Mean number of days spent in NWTT was not significantly different between whales tagged in Washington in 2018, in Oregon in 2018, or in Oregon in 2016 and 2017 (ANOVA, *p*-value = 0.33). Ninety-five percent (19 of 20) of whales tagged in Washington in 2018 had locations within area W237 of the NWTT, compared to 17 percent (1 of 6) of whales tagged in Oregon in 2016 and 2017, and no whales tagged in Oregon in 2018 had locations in W237 (**Table 15**, **Figure 20**). The mean number of days spent in W237 for Washington whales was 4.3 d (maximum of 16.8 d), and the one whale tagged in Oregon in 2017 (#1387) spent 14.3 d there. During its migration south, whale #1387 crossed SOCAL, spending a total of 1.8 d there (**Table 15**), as previously reported in Mate et al. (2018a). None of the humpback whales tagged off Washington or Oregon in 2016 to 2018 were tracked within the PT MUGU, SOAR, or GOA training areas.

Humpback whale locations in the NWTT occurred predominantly in the summer and fall, with whales tagged in Washington in 2018 having locations there from August through October, whales tagged in Oregon in 2018 having locations there from September through November, and whales tagged in Oregon in 2016 and 2017 having locations there from September through December. Humpback locations in W237 of the NWTT occurred from August through October for whales tagged in Washington in 2018 and in November and December for the whale tagged in Oregon in 2017 (#1387). The southbound migration of whale #1387 went through SOCAL in January (Mate et al. 2018a).

Distances to shore for tagged humpback whales in Navy areas ranged from a mean of 27 km in NWTT (for whales tagged in Washington in 2018) to 317 km in SOCAL (for a whale tagged off Oregon in 2017; **Table 16**). Distance to shore in NWTT was significantly different for whales tagged in Washington in 2018 (mean = 27 km, SD = 11.6 km) than whales tagged in Oregon in 2018 (mean = 40 km, SD = 1.4 km) or 2016 and 2017 (mean = 49 km, SD = 14.0 km; ANOVA of log-transformed distance, *p*-value = 0.003; **Table 16**). Sample sizes were not large enough to permit meaningful statistical comparisons of distance to shore between field seasons in any other Navy training areas. The whale with the greatest distance to shore in Navy areas was the individual that migrated south.

#### *3.4.3.3 Use of West Coast BIAs*

With the exception of one humpback whale tagged in Oregon in 2017, only whales tagged in Washington had locations in the NWA BIA and the OCNMS (**Table 17**, **Figures 21 and 22**). Nineteen of 20 whales tagged in Washington in 2018 had locations in the NWA BIA, with a mean residency of 6.8 d (maximum residency of 18.3 d). All 20 whales tagged in Washington in 2018 had locations in OCNMS, with a mean residency of 8.3 d (maximum residency of 23.1 d). Humpback whales tagged in Washington were not found in any other West Coast BIA during their tracking periods. Similar proportions of whales tagged in Oregon in 2016-2017 (4 of 6) and in Oregon in 2018 (4 of 5) had locations in the Stonewall BIA, with a mean residency of 3.9 d and maximum residency of 9.9 d (**Table 17, Figure 23**). Four of six humpback whales tagged in Oregon in 2016-2017 had locations in the PSG BIA (mean residency of 3.3 d, maximum residency of 4.4 d), compared to only two of five whales tagged in Oregon in 2018 (mean residency of 0.4 d, maximum residency of 0.5 d; **Table 17**, **Figure 24**). One whale tagged in Oregon in 2017 spent 2.2 d in the Fort Bragg BIA (**Table 17**, **Figure 25**). No other West Coast BIAs were used by humpback whales tagged in Oregon from 2016 to 2018.

Humpback whale locations in the NWA BIA occurred in August through October for whales tagged in Washington (2018) and in November for the Oregon whale (2017). The latter Oregon whale also spent time in the OCNMS in November and December. Humpback locations occurred in the Stonewall BIA in September (2016, 2018), October (2017, 2018), and November (2017), in the PSG BIA in September (2016, 2018), October (2017), and December (2017), and in the Fort Bragg BIA in October (2017).

#### *3.4.3.4 Home Ranges and Core Areas*

Feeding-area HRs (90 percent kernel isopleths) for humpback whales did not differ significantly in size between whales tagged in Oregon and those tagged in Washington (Kruskal-Wallis test of medians, *p*-value = 0.05; **Table 14, Figure 26**). Only one whale tagged in Oregon in 2018 provided enough locations for HR calculation, so all Oregon seasons were combined for HR and CA statistical comparisons. Feeding-area CAs (50 percent kernel isopleths) also did not differ significantly in size between whales tagged in Oregon and those tagged in Washington (ANOVA of log-transformed CA, *p*-value = 0.17; **Table 14, Figure 27**).

HRs overlapped for whales tagged in Washington in 2018 and one whale tagged in Oregon in 2017, but not for other whales tagged in Oregon, in 2016, 2017, or 2018 (**Figure 26**). Areas of highest use (where CAs overlapped for the most number of whales) for humpback whales tagged in Washington were located at the western end of the Strait of Juan de Fuca extending out to Swiftsure Bank off the northwest corner of Washington (**Figure 27**). Areas of highest use for whales tagged in Oregon occurred off the Columbia River mouth and Trinidad Head, northern California (**Figure 27**).

## 3.5 Dive Behavior

The ADB tag was not recovered, however it reported dive summaries for 320 dives through Argos (**Table 18**) which included dive duration, maximum dive depth, and PDI (but not number of feeding lunges). These data are reported jointly with corresponding DUR+ and DM tag data as appropriate. The 25 DM-, DUR+- and ADB-tagged whales in 2018 provided a mean of 2,977 dive summaries (range = 320 -7,135; **Table 18**). Reported dives summarized a mean of 72.7 percent of the tracking durations (range = 22.6 to 95.5 percent). Dive depths were generally less than 100 m, however, dives to 329 m were also recorded (**Figure 28**). Dive durations were very consistent across all tags primarily ranging from 2 – 7 min (**Figure 29**). Dive durations were generally longer during the day; however, the trend was more pronounced with whales tagged off Oregon (**Figure 30**) compared to those tagged off Washington (**Figure 31**). Dive depths were only available for whales tagged off Washington, and were deeper during the day, though generally remained shallower than 125 m (**Figure 32**). A mean of 53.0 % of reported time was spent within 30 m of the surface (**Table 18**). Lunges occurred across all hours of the day, but were more common during daylight hours and occurred in larger numbers per dive at those times (**Figures 30 through 32)**. Closer examination of data from Washington tags indicates the observed diel trends were driven primarily by dives occurring within the Strait of Juan de Fuca (**Figures 33 through 36**). Dives of Washington-tagged whales were predominantly recorded near the mouth of the Strait of Juan de Fuca (**Figures 35 and 36**). Shallower, shorter-duration, daytime dives occurred in the area of Swiftsure Bank, west of the Strait of Juan de Fuca compared to the rest of the area used by Washington tagged whales (**Figures 35 and 36**). Feeding effort was uniformly distributed across the tracking area for both Washington and Oregon whales. The highest number of dives from Oregon-tagged whales were recorded near the tagging area west of Newport, but were more evenly distributed throughout the rest of the area (**Figure 37**). Spatial distribution of dive durations for Oregon-tagged whales was relatively uniform, with longer median dive durations occurring in areas with a lower total number of dives recorded (**Figure 37**). No patterns were evident between sexes in dive behavior or the spatial distribution of dives between sexes.

## 3.6 Ecological Relationships

### 3.6.1 Humpback whales

A total of 56 tracks from humpback whales tagged in waters of California, Oregon, and Washington over the period 2004-2018 was available for SSSM/hSSSM modeling. For the feeding season off the US West Coast this analysis generated a total of 1,893 SSSM/hSSSM daily locations with annotated behavioral mode and environmental values, covering an extent of 9 degrees of longitude and 16.6 degrees of latitude (**Table 19, Figure 38**). Apparent concentrations of SSSM/hSSSM locations occurred in six "hotspots" along the US West Coast: at the mouth of the Strait of Juan de Fuca in northern Washington, at the mouth of the Columbia River on the Washington/Oregon border, off central Oregon, off southern Oregon/northern California, off central California, and around Point Conception in southern California (**Figure 39b**).

A map of the behavioral classification of the locations in each tagging year/season is shown in **Figure 38**. Of the total 1,893 locations analyzed for the study area, 63.0 percent were classified as ARS mode by the SSSM/hSSSM, 12.0 percent as uncertain, and 5.5 percent as transiting (**Table 20**). For a given tagging year/season, behavioral classification as ARS mode ranged from as low as 50.0 percent (season: 2005CA2) to as high as 90.1 percent (2005CA); uncertain classification ranged from 6.5 percent (2018WA) to 100 percent (2016OR); and transiting mode ranged from 0.4 percent (2004CA) to 17.8 percent (2017OR) (**Table 20, Figure 38**). Within the eight latitudinal 2-degree blocks defined for the study area, behavioral classification as ARS mode ranged from a low of around 60 percent of the locations (blocks #4-6) to more than 90 percent (blocks #2 and 8), while the proportion of transiting locations ranged from less than 3 percent (blocks #2 and 8) to more than 15 percent (blocks #5-7) (**Figure 39a**).

The overall median distance and speed between SSSM/hSSSM location pairs were 17.3 km (MAD = 15.7 km) and 0.7 km/h (MAD = 0.7 km/h), respectively (**Table 21**). For a given tagging year/season, median PWDIST ranged from as low as 13.9 km (2018WA) to as high as 33.8 km (2005CA2), while median PWSPEED ranged from as low as 0.58 km/h (2018WA) to as high as 1.41 km/h (2005CA2) (**Table 21**). When considered with respect to behavioral mode classification, PWDIST was lowest while engaging in ARS behavior (median = 14.6 km, MAD = 12.3 km) and highest while transiting (median = 65.8 km, MAD = 32.1 km). Since SSSM/hSSSM locations were sampled at one per day (i.e., with a regular spacing of 24 h), PWSPEED was consequently lowest while engaging in ARS behavior (median = 0.61 km/h, MAD = 0.51 km/h) and highest while transiting (median = 2.74 km/h, MAD = 1.34 km/h) (**Table 22**). Within the eight latitudinal 2-degree blocks defined for the study area, median PWDIST (the notch in the box-and-whisker plot in **Figure 40a**) appeared to be slightly lower for block #8, encompassing locations in the Strait of Juan de Fuca and adjacent waters at the northern end of the study area, than for the other seven blocks along the US West Coast. Consequently, PWSPEED reflected the same pattern (**Figure 41a**).

Over the study area, descriptive statistics indicated that tracked humpback whales were found in a median depth of 153.0 m (MAD = 93.4 m), a median seafloor slope of 0.57° (MAD = 0.61°), a median seafloor aspect of 230.8° (MAD = 52.2°), a median distance from the shelf break of 5.1 km (MAD = 5.8 km), and a median distance from shore of 23.7 km (MAD = 19.6 km) (**Table 23**). When analyzed with respect to behavioral mode classification, tracked humpback whales were found in shallowest depth while in ARS (median = 146.0 m, MAD = 84.5 m) and deepest while transiting (median = 376.0 m, MAD = 413.7 m). Whales occurred seafloor slopes that were flatter while in ARS (median = 0.55°, MAD = 0.58°) and steeper while transiting (median = 0.74°, MAD = 0.83°), while the aspect of the seafloor faced in a southwest direction while in ARS (median = 227.4°, MAD = 52.6°) and a more west-southwest direction while transiting (median = 245.6°, MAD = 64.6°). Whales were found closest to the shelf break while in ARS behavior (median = 4.6 km, MAD = 5.0 km) and farthest while transiting (median = 13.5 km, MAD = 14.8 km). Similarly, whales were closest to shore while in ARS (median = 21.8 km, MAD = 18.9 km) and farthest while transiting (median = 39.2 km, MAD = 31.3 km) (**Table 24**).

Within the eight latitudinal 2-degree blocks defined for the study area, and despite substantial spread, median depth was in the 100-200 m range for all blocks except #1, 4, and 5, for which median depth was in the 200-400 m range (**Figure 42a**). The was no evident latitudinal pattern across the blocks in regard to slope of the seafloor (**Figure 43a**), but the median aspect of the seafloor for block #8 faced in a more southerly direction, with a substantial number of observations in this block even facing in the easterly direction (**Figure 44a**). Median distance to the shelf break was closest for block #8 at about 2.5 km, while it occurred at 5-10 km for the other seven blocks along the US West Coast (**Figure 45a**). Similarly, median distance to shore was just under 10 km for block #8, while it was in the 20-40 km range for the other seven blocks along the US West Coast, being farthest away for block #7 and closest for block #1 (**Figure 46a**).

During the feeding season off the US West Coast, tracked humpback whales occurred in waters with a median SST of 13.6°C (MAD = 1.9°C), a median SSTG of 0.17°C/deg (MAD = 0.10°C/deg), and a median CHL of 1.39 mg/m$^3$ (MAD = 1.09 mg/m$^3$) (**Table 25**). When analyzed with respect to behavioral mode classification, tracked humpback whales occurred in waters that were not appreciably different with respect to SST (median = 13.7 and 13.4°C for ARS and transiting, respectively) or to SSTG (median = 0.17°C/deg for both ARS and transiting), but they did occur in waters that had higher CHL content while in ARS (median = 1.42 mg/m$^3$, MAD = 1.09 mg/m$^3$) and lower while transiting (median = 0.93 mg/m$^3$, MAD = 0.62 mg/m$^3$) (**Table 26**).

Within the eight blocks defined for the study area, there was a clear latitudinal trend in SST, being lowest for block #8 in the north (median = 12.5°C) and highest for block #1 in the south (median = 15.8°C) (**Figure 47a**). Median SSTG was lowest for blocks #7 and 8 in the north (just under 0.13°C/deg), while for the remaining blocks there was an apparent latitudinal trend with SSTG being highest for block #6 (median = 0.30°C/deg) and lowest for block #1 in the south (median = 0.17°C/deg) (**Figure 48a**). The was no evident latitudinal pattern across the blocks in regard to CHL, with median CHL generally in the range 0.8-2.5 mg/m$^{-3}$ (**Figure 49a**).

### 3.6.2 Fin whale

The single fin whale tagged off Oregon in 2018 (whale #5882) generated a track with 37 daily SSSM locations. Although the SSSM generated interpolated locations over the 10-d gap in Argos transmissions described for this track in **section 3.4.2** (Oregon Tagging), their 95 percent credible limits exceeded 1 degree in longitude and/or latitude, and so were excluded. Thus, only 26 SSSM locations were usable for analysis of ecological relationships. These locations covered an extent of 9.6 degrees of longitude and 6.4 degrees of latitude (**Table 19**, **Figure 50**). Apparent concentrations of SSSM locations occurred off the central Oregon coast and, after the 10-d gap, in deep oceanic waters west of Queen Charlotte Sound, between Vancouver Island and Haida Gwaii (**Figure 50**).

Of the 26 locations analyzed for this fin whale, 21 (80.8 percent) were classified as ARS mode and 5 (19.2 percent) as uncertain by the SSSM; no locations were classified as transiting (**Table 20**). Due to these small sample sizes, for this ecological characterization we only report descriptive statistics for the overall set of locations that passed the screening criteria and do not discuss separate values for the different behavioral modes (although for reference they are included in **Tables 22, 24, and 26**).

The overall median distance and speed between SSSM location pairs for this track were 19.3 km (MAD = 12.7 km) and 0.80 km/h (MAD = 0.53 km/h), respectively (**Table 21**). These locations occurred in a median depth of 2378.0 m (MAD = 1112.7 m), a median seafloor slope of 0.57° (MAD = 0.43°), a median seafloor aspect of 239.2° (MAD = 66.9°), a median distance from the shelf break of 74.9 km (MAD = 102.7 km), and a median distance from the coastline of 94.3 km (MAD = 94.2 km) (**Table 23**). This tracked fin whale occurred in waters with a median SST of 14.7°C (MAD = 1.6°C), a median SSTG of 0.20°C/deg (MAD = 0.09°C/deg), and a median CHL of 1.08 mg/m$^3$ (MAD = 0.56 mg/m$^3$) (**Table 25**).

## 3.7 Genetics

### 3.7.1 Washington Genetic Results

Biopsy samples were collected from 18 tagged whales and from seven untagged humpback whales. For convenience, we refer to these 25 samples as the "Washington tagging samples". All samples provided DNA profiles sufficient for subsequent analyses. The mtDNA sequences of the 25 samples resolved eight haplotypes for the consensus region of 500 bp (**Table 27, Figure 53**). 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 27**).

The 25 samples were represented by a unique multi-locus genotype of at least 14 loci with an average of 15 loci across the dataset. The probability of identity for any given set of 14 loci ranged from $P_{ID} = 2.3 \times 10^{-12}$ to $9.3 \times 10^{-14}$. One recapture was identified by photo-ID and confirmed by genotype matching. After removing this replicate, the Washington dataset represented 24 individuals. These 24 individuals included six females and eighteen males. The DNA profiles of the 24 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). From this comparison, one recapture was detected; a tagged female (biopsy code Mno18WA016, whale #5700) was a genotype match to an individual biopsy sampled in Washington in 2005 (Genetic ID gWAS05-51398, SPLASH ID 460280). This individual was resighted seven times during the SPLASH effort based on associated photo-ID: six times in the Southern British Columbia/Northern Washington feeding area (four in 2004 and two in 2005) and once in the mainland Mexico breeding area in 2006.

Pairwise comparisons of mtDNA haplotype frequencies showed significant differentiation of the Washington tagging samples with five of the 10 SPLASH feeding areas described in Baker et al. (2013). The Washington tagging samples were not significantly different to the Western Aleutians (likely due to small sample size for the Western Aleutians), Eastern Aleutians, Northern Gulf of Alaska, Northern British Columbia or Southern British Columbia/Washington (**Table 28**). The Washington tagging samples differed significantly from all eight SPLASH breeding grounds described in Baker et al. (2013) with the exception of Hawaii (**Table 28**).

Individual assignment using the program GeneClass2 showed the highest likelihood of assignment to the Hawaii DPS for thirteen individuals, to the Mexico DPS for four individuals, to the Central America DPS for four individuals, and to the Western Pacific DPS for one individual (**Table 29, Figure 51**). Two individuals were assigned with nearly equal likelihood to both Mexico and Hawaii.

### 3.7.2 Oregon Genetic Results

Biopsy samples were collected from five tagged humpback whales, one untagged humpback whale, and one tagged fin whale off the Oregon coast in 2018. All samples provided DNA profiles sufficient for subsequent analyses.

The mtDNA sequences of the six humpback whale samples resolved four haplotypes for the consensus region of 500 bp (**Table 27, Figure 53**). 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 (**Table 27**).

All six humpback samples were represented by a unique multi-locus genotype of 15 loci. The probability of identity for these 15 loci was $P_{ID} = 1.7 \times 10^{-12}$, providing confidence that the six unique multi-locus genotypes represent six individuals. These six individuals were all 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 nine individuals sampled off the Oregon coast in 2016 and 2017 (Mate et al. 2018a). No recaptures were detected with either dataset. For population analyses, data from the six individuals sampled during 2018 were combined with data from the nine individuals sampled during tagging off the Oregon coast in 2016 and 2017 (Mate et al. 2018a), for a total of 15 individuals representing the Oregon feeding area, of which 11 were tagged. For convenience, we refer to these 15 as the "Oregon tagging samples".

Pairwise tests of differentiation between the Oregon tagging samples and SPLASH showed significant differences to three of the 10 feeding areas described in Baker et al. (2013) (**Table 28**); Russia, Southeastern Alaska, and Northern British Columbia. The difference between the Oregon tagging samples and the California/Oregon stratum of SPLASH approached significance ($F_{ST} = 0.0345$, $p = 0.0588$). The Oregon tagging samples were also significantly different to three of the eight SPLASH breeding grounds; the Philippines, Okinawa, and Central America (**Table 28**).

The individual assignment likelihoods showed the highest likelihood of assignment for two individuals to the Hawaii DPS, two to the Mexico DPS, and one to the Central America DPS (**Table 29, Figure 51**). One individual was assigned with similar likelihood to Hawaii and Mexico.

The mtDNA sequence of the fin whale sample was consistent with the field identification of the species as a fin whale based on submission to *DNA-surveillance* and a BLAST search of GenBank®. This mtDNA haplotype matched one of the 52 mtDNA haplotypes described in Archer et al (2013) (haplotype code z6253) and has previously been identified in a fin whale tagged off California in 2015 (Bph15CA003 – whale #5800). The 2018 fin whale was identified as a female and was represented by a unique multilocus genotype of 17 loci. This DNA profile was compared to the DNA profiles from 20 previously tagged individuals (2007, 2015, and 2016; Mate et al. 2018b) and no replicates were found.

## 3.8 Photo-identification

### 3.8.1 Washington

A total of 18,565 photographs were taken of humpback whales in Washington during the 2018 field season. From these photographs 134 individuals were identified and added to OSU's photo-ID catalog. Of the 20 whales tagged, 15 fluke photos were obtained. A fluke photo of one of the five remaining tagged whales from 2018 was subsequently obtained when the animal was resighted during our 2019 field efforts in Washington. Out of these 16 tagged whales, 13 have been identified in the Happywhale photo-ID database. Twelve whales had been seen prior to tagging; six in Washington, two in Hawaii, two in Mexico, and two in both Mexico and Washington. Eleven whales were seen after tagging; seven in Washington, two in Hawaii, and two in Mexico and Washington. Fluke photos were obtained of all six whales that were biopsied without being tagged and two were matched in Happywhale to Washington. The whales seen in Mexico included one in mainland Mexico, two in Baja California, and one in both mainland Mexico and Baja California.

Of the remaining 113 identified whales (untagged or unbiopsied), 82 had matches to Happywhale. In addition to 33 matches to southern British Columbia and Washington, there were 49 matches to other areas; 34 in Mexico, 11 in Hawaii, two in California and Mexico, one in southeastern Alaska, and one in northern British Columbia. The whales seen in Mexico included ten in mainland Mexico, 16 in Baja California, 11 in both mainland Mexico and Baja California, and one in the Revillagigedo Archipelago.

### 3.8.2 Oregon

A total of 5,166 photos of humpbacks were taken in Oregon during the 2018 field season. From these photographs 23 individuals were identified and added to OSU's photo-ID catalog. Fluke photos were obtained of all five tagged humpback whales and four of these have been matched in Happywhale. Three tagged whales had been seen prior to tagging (in previous years); one in Washington, one in Baja Mexico, and one in both mainland Mexico and Baja California. Two tagged whales were seen after tagging; one in California and one in mainland Mexico. A fluke photo was obtained of the humpback whale that was biopsied only (not tagged); this whale was matched in Happywhale to a whale that had been seen in mainland Mexico, both before and after it was sampled in Oregon in 2018.

Of the 17 remaining identified whales (untagged or unbiopsied), 11 were matched in Happywhale; two in California, eight in Mexico, and one in both California and Mexico. The whales seen in Mexico included three in mainland Mexico, three in Baja California, and two seen both in mainland Mexico and Baja California. The Happywhale resightings included one ID photo submitted to Happywhale from our own efforts in California in 2017 (Mate et al. 2018a).

A total of 551 photos were taken of fin whales in Oregon during the 2018 field season, including a right-side dorsal ID photo of the tagged whale. Comparison of the tagged whale ID with fin whales photographed by OSU in Oregon and California (Mate et al. 2018b) resulted in no matches. Resight analysis and a determination of the number of individual IDs obtained from untagged fin whales has not been completed at the time of report submission.

### 3.8.3 Historical Photo-identification Efforts

A total of 5,364 photos were taken of humpback whales during our 2016 and 2017 field seasons in Oregon. From these photos 63 individuals were identified and added to OSUs photo-ID catalog (five tagged whales, 3 biopsied-only whales, and 55 untagged whales). No ID photographs were obtained from whales tagged in 2016 because they did not raise their flukes at any time during our encounters with them. Fluke photos were obtained of all five humpback whales tagged in 2017, and two of these whales were matched in Happywhale to Baja California in 2019. Fluke photos were obtained for the three biopsied-only whales in 2017 and all were matched in Happywhale; one in Baja California, one in mainland Mexico, and one in Hawaii. The latter whale was resighted by us during our 2018 field season in Hawaii.

Of the 55 untagged whales, 36 have been matched in Happywhale. In addition to two matches to Oregon only, there were 34 matches to other areas; five in Washington, two in Washington and Mexico, two in California, two in California and Mexico, one in Hawaii, and 22 in Mexico. The whales seen in Mexico included eight seen in mainland Mexico, 13 in Baja California, and 5 seen in both mainland Mexico and Baja California. The Happywhale resightings included ID photos submitted to Happywhale from our own efforts in California in 2017 (Mate et al. 2018a), Oregon in 2018, and Hawaii in 2018.

# 4 Discussion

## 4.1 Tracked Movements

A total of 25 humpback whales were tagged by OSU in feeding areas of the Pacific Northwest (Washington and Oregon) in the summer of 2018, providing tracks of five whales tagged in Oregon and 20 whales tagged in Washington. This tracking data expands our understanding of the localized and long-distance movements of humpback whales in the Pacific Northwest, and when combined with tracking data obtained from our previous tag deployments in Oregon and California, provides valuable insight into feeding group structure in California, Oregon, and Washington. Generally, the locations obtained from Pacific Northwest tag deployments align well with sightings of humpback whales in this area 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).

The tagging of humpback whales in northern Washington represents the first Washington deployments as part of this CESU agreement, providing some of the first long-term tracking information of humpback whales from this area. The Oregon tag deployments represent the third year of tagging humpbacks in Oregon, albeit with fairly small sample sizes, due to the lack of large concentrations of humpback whales off the Oregon coast and the difficult weather conditions of the unprotected Oregon coastline. Both the overall latitudinal ranges in feeding areas and the home ranges calculated from tracks greater than 30 d in length showed overlap in the distribution of humpback whales tagged in Oregon and Washington, and between whales tagged in Oregon and California, but not between whales tagged in Washington and California (see Mate et al. 2018a for California tracks and ranges). Humpback whales feeding in southern

British Columbia/northern Washington have been considered a separate feeding aggregation to humpbacks feeding in California and Oregon (Calambokidis et al. 2015, Wade et al. 2016). 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 (Calambokidis et al. 2008). Our tracking results support the distinction of whales from southern British Columbia/northern Washington from California, but not from Oregon, and instead provide evidence of some degree of mixing between Oregon whales and those from adjoining states. Both the movement of a humpback tagged off central Oregon in 2017 to Cape Flattery, northern Washington, and Vancouver Island, British Columbia (incorrectly assigned a deployment location of northern Oregon in Mate et al. [2018a]), and the genetic results of humpbacks tagged in Washington and Oregon (described more fully in **Section 4.4** below) support the mixing of Oregon and southern British Columbia/northern Washington whales.

Genetic and photographic identification information suggest that the majority of humpback whales in southern British Columbia/northern Washington migrate there from breeding areas in Hawaii or Mexico, with a smaller number coming from Central America (Calambokidis et al. 2008, Wade et al. 2016). The majority of humpback whales in California and Oregon are from Mexico, with a smaller number from Central America (Wade et al. 2016). While limited in sample size, our tracking results prior to 2018 provide further evidence for these migratory connections, with two whales tagged in Oregon traveling to mainland Mexico and one whale tagged in California traveling to Guatemala (Mate et al. 2018a). One of the humpbacks tagged in Washington in 2018 was last located off the coast of Baja California, Mexico, after a large gap in transmissions, and because only a single transmission was received we cannot confirm whether the whale was destined for a breeding area in Mexico or transiting through on its way to Central America. To more fully understand the extent of mixing or separation of humpback whale DPSs on the feeding grounds, additional migratory routes and destinations are desirable. Longer tag attachments, tagging later in the feeding season, and/or tagging on the breeding grounds would help us achieve this goal.

The high density of locations as well as the overlapping core areas for eight whales in the Strait of Juan de Fuca provides further evidence that humpback whales have returned to the Salish Sea (Strait of Juan de Fuca, Strait of Georgia, and Puget Sound), as reported by Calambokidis et al. (2017). Humpbacks were largely eliminated in the waters of southern British Columbia and northern Washington through commercial whaling in the early 1900s (Calambokidis et al. 2017). Over 5,600 whales were taken from British Columbia whaling stations from 1908 to 1967, the majority of which were killed by 1917 (Calambokidis et al. 2017). Most sightings of humpback whales in the 1990s and early 2000s were from waters outside the Salish Sea (Calambokidis et al. 2015), but beginning in the late 2000s sightings inside the Salish Sea have increased dramatically, most notably in 2015 (Calambokidis et al. 2017). The majority of locations from our Washington deployments in 2018 were concentrated in the western part of the Strait of Juan de Fuca, whereas many of the sightings noted by Calambokidis et al. (2017) occurred in the central Strait of Juan de Fuca and also extended far into Puget Sound. This could represent inter-annual variation in movements in this area, or perhaps a preponderance of sighting effort closer to population centers in the earlier studies. In any case, there is great potential for overlapping distributions of whales, ship traffic, and fishing operations throughout the Salish Sea, putting the whales at increased risk for ship strikes, entanglements in fishing gear, and noise impacts.

The satellite tagging of a fin whale off central Oregon represents the first time this species has been tagged in Oregon waters. Most of the fin whale locations off central Oregon were over shelf and shelf edge waters, which was not very different than that of humpback whales tagged in Oregon in 2018. Approximately a quarter of the fin whale locations, however, were further from shore, over the western edge of the continental slope. Localized movements off central Oregon were recorded for a fin whale satellite-tagged off southern Washington in 2013 (Schorr et al. 2013), and off southern Oregon for fin whales tagged off southern California by OSU in 2014 and 2015 (Mate et al. 2018b), highlighting the Oregon coast not only as an area of transit along the US West Coast, but also as feeding habitat for fin whales, at least in some years.

The locations off Queen Charlotte Sound for this fin whale were in a similar area as locations from previous fin whale tagging by OSU off southern California in 2006 and 2015 (Mate et al. 2018b) and also similar to offshore British Columbia sightings reported by Nichol et al. (2018). Their location was in contrast to locations within Hecate Strait and Queen Charlotte Sound for a fin whale tagged in southern California in 2016 (Mate et al. 2018b), and those reported by Nichol et al. (2018). The offshore area appears to be important feeding habitat for fin whales in some years, but whether this offshore versus inshore difference represents individual variation in habitat preference or inter-annual variation in oceanographic conditions and prey distribution remains unclear.

### 4.1.1 Use of Navy Training Areas

All of the humpback whales tagged in Washington and Oregon (from 2016-2018) had locations within the NWTT. This is not surprising, as 61 percent of tag deployments took place within NWTT, and the remaining 39 percent took place within 14 km of the range. With a mean residency in NWTT of 14.0 d for all whales, and maximum residencies ranging from 28.9 d for Washington whales and 86.5 d for Oregon whales, NWTT clearly represents important feeding habitat for humpbacks. Area W237, within the NWTT, was predominantly used by humpback whales tagged in Washington, with 95 percent of these whales having locations there, compared to only one humpback whale tagged in Oregon having locations there. This may represent spatial separation of humpback whales from Oregon and northern Washington, but it may also reflect the timing and duration of tracking periods. The one humpback from Oregon that traveled to area W237, did so in November and December 2017. The last location received from humpback whales tagged in Oregon in 2018 was early November, so late fall distribution of these whales was unknown. As our Oregon tag deployments have always taken place in September or October, and we haven't tracked these whales into the spring and summer, we cannot rule out the possibility that Oregon whales may also use more northerly parts of the NWTT or area W237 earlier in the feeding season. Tagging more whales in Oregon and Washington earlier in the feeding season or longer tag attachments would improve our understanding of Navy range use and potential spatial separation of these whales.

As noted in Mate et al. (2018a), no humpback whales tagged in California (out of 27 tracks) spent time in area W237, and only 15 percent of whales tagged in California had locations in the NWTT (**Table A1** in

Appendix I), with most of the locations occurring in the southern half of the range. With the exception of one migrating whale (tagged in Oregon in 2017) transiting through SOCAL, no whales from Oregon or Washington spent time in southern California training ranges. Presumably, humpback whales migrating to and from breeding areas in Mexico or Central America would pass briefly through SOCAL in winter and spring, as the range extends approximately 1,200 km offshore, otherwise we have no evidence of Oregon or Washington whales spending extended periods of time in the southern ranges.

At least eight of the 12 days the fin whale spent in a localized area off central Oregon were within the NWTT, supporting previous findings that some fin whales utilize habitat within the range for extended periods of time (Schorr et al. 2013, Mate et al. 2018b), in addition to transiting through the area. The fin whale tracked in this study was found within the NWTT in the month of September, but previous tracking studies have reported fin whales in NWTT during seven months (February to August; Schorr et al. 2013) and also in September, October and December (Mate et al. 2018b). While we interpolated locations in area W237 in September during a gap in tracking data for the fin whale in this study, it seems clear that the whale did little more than transit through W237, as it had to travel over 900 km during the 10-d gap between central Oregon and central British Columbia. Previous tracking studies have shown fin whales both transiting through W237 and spending extended periods of time there, with locations occurring in W237 during several months (February, March, August, September, October, and December; Schorr et al. 2013, Mate et al. 2018b).

### 4.1.2 Use of BIAs

The occupancy of US West Coast feeding BIAs also suggests spatial separation of humpback whales throughout feeding areas, as no humpbacks tagged in Washington spent time in BIAs south of Washington, and only one whale tagged in California was found in a BIA north of California, spending less than one day in the Stonewall BIA in Oregon (Mate et al. 2018a). Such spatial separation was not as clear for whales tagged in Oregon, with one Oregon whale spending time in the NWA BIA and the OCNMS in northern Washington, and others spending time in the PSG, Fort Bragg, and the Gulf of the Farallones BIAs in California. It is worth noting that the Oregon whales with locations in the more southern BIAs (Fort Bragg and Gulf of the Farallones) were animals tagged in southern Oregon, whereas the southernmost BIA used by whales tagged in central or northern Oregon was PSG. Only three humpbacks tagged in California (out of 27) spent time in the PSG BIA or further north, and two of these whales were tagged within the PSG BIA (the other was tagged off central California). These results further support, not only a potential separation of humpbacks from Washington with those from California, but also a decline in connectivity with latitudinal separation as reported by Calambokidis et al. (2017).

The extensive use of the NWA BIA and the OCNMS by whales tagged in Washington reflects not only the location of tag deployments in Washington, within or very close to the BIA and/or sanctuary, but also speaks to the whales' affinity for the regions, as evidenced by the substantial residency (average 18.3 d in NWA and 23.1 d in OCNMS) and the seasonal extent (August through October) of locations there. Approximately 40 percent of locations of humpbacks tagged in Washington occurred east of the western edge of the NWA BIA, throughout the Strait of Juan de Fuca, and approximately 52 percent of locations of Washington-tagged whales occurred in Canadian waters (north of the US Exclusive Economic Zone).

This high density of locations at the southwestern tip of Vancouver Island reveals this area to be of importance to feeding humpback whales, and were it not for international boundaries, inclusion of this area as part of a BIA seems reasonable.

## 4.2 Dive Behavior

The generally similar dive behavior observed in tagged whales off both Washington and Oregon suggests whales in both areas were feeding in a similar way, or on a similar prey, despite regional differences in movement patterns, with Oregon whales roaming more widely and Washington whales remaining closer to the tagging area. The diel trend observed in dive behavior across both areas is characteristic of rorqual krill-feeding behavior, with lunges and deeper, long-duration dives occurring during the day (Calambokidis et al. 2007, Goldbogen et al. 2008, Mate et al. 2017). Off Washington, the diel effect was most pronounced for dives that occurred within the Strait of Juan de Fuca, raising the possibility that tagged whales were targeting different prey inside the Strait compared to outside, as they are known to be capable of feeding on both fish and krill (Clapham et al. 1997, Fleming et al. 2016). However, a large proportion of the dives outside the Strait of Juan de Fuca occurred over Swiftsure Bank, where water depths are < 100 m, compared to > 200 m for other parts of the study area, including within the Strait. Thus daytime dive depths of tagged whales using Swiftsure Bank were limited by bottom depth, reducing the possibility of an observable diel change in dive behavior in that area. Additionally, aggregations of surface feeding whales were observed on multiple occasions in the area of Swiftsure, coincident with observations of krill in the water and red defecation from whales in the area. Thus tagged whales appear to have been feeding on krill throughout their range, while the topography of Swiftsure Bank acted to concentrate prey at shallower depths in that area (Genin 2004) giving the appearance of a regional difference in behavior.

Tagged whales spent over half of their reported time near the surface (< 30 m depth) and, off Washington, they occupied waters that are heavily used by a wide range of commercial, military and recreational vessels. Ship strikes of large whales are a growing concern (Silber et al*.* 2012, Panigada et al*.* 2006, Redfern et al*.* 2013) and the Strait of Juan de Fuca is used to access the fifth (Port of Vancouver) and seventh (Port of Seattle) largest commercial shipping ports in North America. The draft of the type of medium to large container ships using the Strait is 14 - 16 m (Calambokidis et al*.* 2019) and whales submerged at one to two times the depth of a vessel's draft are at an increased probability of being impacted by the vessel (Silber et al*.* 2010). Thus, the high proportion of time spent near the surface and high occupancy of the Strait of Juan de Fuca suggests the tagged whales are at an elevated risk of potential collision with large vessels moving through the area. Additionally, diel differences in dive behavior, similar to those observed in this study, have been shown to increase the vulnerability of whales to vessel collision at specific times of day as they spend more time near the surface at night (Calambokidis et al. 2019). The shallower water depth of Swiftsure Bank may also act to increase the chance of vessel collision as whales are forced to occupy portions of the water column closer to the surface. While tagged whales in this study were often near the surface, humpback whales tagged off central and southern California feeding areas in another study spent even more time at < 30 m depth (69% to 88% of their time during the day and night, respectively; Calambokidis et al. 2019). The greater time spent at shallow depth by California whales may be related to behavioral differences associated with local variation in the distribution and type of prey between Washington and California waters. Further work is needed to more accurately examine the potential risk of ship strikes for humpback whales using the Strait of Juan de Fuca.

Reported dive behavior of whales tagged off Oregon was similar to that of whales tagged there in 2016 and 2017 (Mate et al. 2018a), suggesting feeding behavior is consistent across years, although the sample size is relatively small. The spatial distribution of dive durations was more evenly distributed in 2018 compared to previous years. However, this may be the result of all 2018 tags having been deployed off Newport, central Oregon, while tags in other years were deployed at locations ranging from off Brookings, southern Oregon, up to the waters off the Columbia River, northern Oregon. The more even spatial distribution of dive durations in 2018 is somewhat surprising as high concentrations of krill are most often found in highly localized upwelling regions or near canyons and other steep bathymetric features (Santora et al. 2018, Santora et al. 2011), and may indicate prey was less concentrated compared to previous years.

## 4.3 Ecological Relationships

### 4.3.1 Humpback whales

Satellite tracking of 56 humpback whales off the US West Coast over the period 2004-2018 revealed that they occurred throughout this environment during the feeding season, although there was evidence for areas of concentration at hotspots along the coast from the mouth of the Strait of Juan de Fuca at the north to Point Conception at the south. These areas corresponded well the areas of highest overlap in individual home ranges as well as with the previously established BIAs (**sections 3.3.1-3.3.3**). The concentration of locations at the mouth of the Columbia River suggests this area may have been previously overlooked for consideration as a BIA in Calambokidis et al. (2015).

ARS mode was the dominant behavior for SSSM/hSSSM locations, with an overall classification of 63.0 percent, ranging from as high as 90.1 percent (2005CA) to as low as 50.0 percent (2005CA2) in individual tagging years/seasons and with one year that only yielded uncertain classifications (2016OR). However, given the limited number of tags available for SSSM/hSSSM analysis in some years, it is difficult to make meaningful inferences about differences in movement behavior between tagging areas or between years. Similarly, there were some differences in environmental conditions between tagging years/seasons (e.g., SST was particularly warm in 2004CA, 2005CA, and 2017OR) that may be explained by oceanographic anomalies (Fleming et al. 2016, Becker et al. 2019), but small sample sizes for some of these years limit our ability to interpret these results.

The combination of tracking data across multiple years, however, permits us to make a more robust characterization of ecological relationships for the study area (with the caveat that unaccounted for interannual effects may also drive some of the observed variations). When analyzed with respect to behavioral mode classification, tracked humpback whales moved at a median speed of 0.61 km/h while engaging in ARS behavior and of 2.74 km/h while transiting. While in ARS, tracked humpback whales occurred at a median depth of 146 m, over southwest-facing seafloor with median slope of 0.55°, and at median distances of 4.6 km from the shelf break and 21.8 km from shore. In contrast, while transiting whales were found at a median depth of 376 m, over seafloor slopes that faced west-southwest with a steeper median slope of 0.74°, and at median distances of 13.5 km from the shelf break and 39.2 km from shore.

This indicates that while occupying waters off the US West Coast during the feeding season, tracked humpback whales spent the majority of their time foraging over relatively shallow continental shelf waters, while spending time in deeper, more offshore waters beyond the shelf break during transiting activities. Although there were no corresponding differences in SST or SSTG while the whales were engaged in these two behaviors, this interpretation is supported by the higher CHL content associated with locations classified as ARS compared to transiting (median = 1.42 versus 0.93 mg/m$^3$). Indeed, a recent study using a similar approach determined that blue whale (*Balaenoptera musculus*) behavioral states in the California Current ecosystem could be predicted on the basis of a combination of static and dynamic environmental variables within the framework of a habitat model (Palacios et al. 2019a).

Analyzing data by latitudinal block partitions also proved fruitful for purposes of informing the habitat requirements of the species over the span of the US West Coast during the feeding season. There was an apparent pattern in the proportion of locations in ARS behavior across blocks, being lowest (below 62 percent) off northern California, southern Oregon, and northern Oregon, implying that whales may spend less time foraging there compared to other blocks where the proportion of ARS locations was higher (above 75 percent). However, the overall distance and speed between location pairs within the blocks with lower proportion of ARS locations were not appreciably different from the other blocks, suggesting that these movement characteristics are relatively invariant, at least along an open coast. In contrast, both the distance and speed between location pairs were lower within the northernmost block encompassing the Strait of Juan de Fuca and adjacent waters than for the other seven blocks. The semi-enclosed conditions imposed by the Strait of Juan de Fuca result in distinct physiographic characteristics, as reflected in the more southerly (or even easterly) aspect of the seafloor slope, as well as in the much closer median distance to the shelf break and to shore for the locations occurring within this block. For the other seven blocks, median distance to shore gradually decreased from north to south while median distance to the shelf break was similar, reflecting the narrowing width of the continental shelf along the US West Coast, and the preference for humpbacks to forage over the continental shelf. Finally, the strong trend in SST among blocks, being lowest in the north and highest in the south was a reflection of the well-known global latitudinal temperature gradient (Becker et al. 2019, Palacios et al. 2019a), and not indicative of differential temperature preferences by the whales within the study area. From this analysis it can be concluded that while other results in this study suggest spatial separation (or at least limited exchange) between BIAs and areas of whale aggregation along the US West Coast (see **sections 3.3.1-3.3.3**), the movement characteristics and environmental conditions do not suggest that these areas, or the humpback whale DPSs they support, have different habitat requirements.

### 4.3.2 Fin whale

The wide-ranging movements of the single tracked fin whale in this study contrast with the more coastal habits of the tracked humpback whales, despite a relatively short tracking period (37 d). This track had a high proportion of locations classified by the SSSM as ARS (80.8 percent) and no locations were classified as transiting, although the 10-d gap occurred during this whale's movement between the coastal and oceanic environment, when transiting behavior would likely have been recorded. Despite this, the overall distance and speed between location pairs were higher for this fin whale's track than for the humpbacks (19.3 km versus 17.3 km and 0.80 km/h versus 0.72 km/h, respectively). Although the sample size was very small, this result is supported by previous results from 28 fin whales tagged in the Eastern North Pacific (see Mate et al. 2018b) that point at inter-species differences in movement speed. Similarly, deeper depths and larger distances to the shelf break and to shore for the fin whale locations compared to the humpbacks' reflect the more oceanic habits of the species (see Mate et al. 2018b).

## 4.4 Genetics

### 4.4.1 Population Structure of Feeding Areas

In the previous analyses of samples collected in the SPLASH program (Baker et al. 2013), whales feeding off of Oregon were considered to be closely affiliated with California feeding grounds, referred to as CA/OR (see **Figure 52**). However, this previous assumption was based on a collection of only three samples from Oregon in the SPLASH program (Baker et al. 2013). Here, the larger number of samples available from the Oregon tagging samples (**Figure 53**) showed a closer affinity with the Southern British Columbia/Washington feeding area (SBC/WA in **Figure 52**). This suggests a degree of differentiation between feeding areas not previously accounted for by the SPLASH program (Baker et al. 2013) but noted in the results of previous tagging, with a smaller sample size (Mate et al. 2018a). A larger sample size for Oregon and finer-scale spatial analyses are needed to confirm this difference and to delineate the most appropriate boundary for feeding areas along the US West Coast.

By comparison to the revised analysis for the Oregon samples, the Washington tagging samples (**Figure 53**) showed no significant differences with the previous analysis of SPLASH samples from SBC/WA, and showed only weak (non-significant) differences with Northern British Columbia (NBC; see **Figure 52**). However, a larger sample and further analyses are required to consider alternate stratification of samples for delineation of population structure along the Washington and British Columbia boundary.

### 4.4.2 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-ID (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 haplotypes characteristics of the Central America DPS are less frequent off the coast of Oregon). By comparison, the relative likelihood scores of assignments for the whales tagged in Washington showed the greatest affinity with the Hawaiian DPS. Again, this was consistent with the similarity of mtDNA haplotype frequencies from Washington tagging sample and those from Hawaii. The differences in assignment probabilities and mtDNA haplotype frequencies of the tagging samples are presumably due to differences in migratory connections and local habitat use along the US West Coast (see Calambokidis et al. 2017).

Although the results of the assignment procedure 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 dataset, 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 28**). The confidence in individual assignments of whales on the feeding grounds could be improved by increasing the number of loci in the reference dataset 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 the Central America DPS, however, there is a need to collect a larger and more representative number of reference samples, including currently unrepresented regions of southern Mexico.

## 4.5 Photo-identification

Photo-ID provided a useful complement to the tracking and genetic data for the purpose of better understanding the movements and migratory destinations of humpback whales off the US West Coast. By including photo-IDs of both tagged as well as untagged whales, we have obtained a more complete picture of the migratory connections not only for whales whose tags did not last until arrival at a migratory destination, but also for whales seen in the vicinity of tagged whales. Probabilistic genetic assignment of biopsy-sampled individuals to DPS is a promising approach in areas where DPSs mix, such as the feeding area off US West Coast, as we have demonstrated in this study. However, the general proportions of assignment to DPS did not always agree with the proportion of matches between feeding and breeding areas based on photo-ID. Specifically, the genetic assignment suggested that about 54 percent of the animals sampled in Washington and 13 percent of the animals sampled in Oregon had a high likelihood of assignment to the Hawaii DPS, while the photo-ID results (from tagged and untagged animals) indicated that about 65 percent of the whales photographed both off Washington and Oregon had matches to Mexico and a much lower proportion to Hawaii. Although differences in methodology, sample size, and robustness of the reference database used for these matches preclude a more formal comparison, such a difference suggests the possibility that humpback whales with Hawaii heritage may be spreading to breeding grounds in Mexico as the Hawaii DPS recovers. Indeed, photo-ID matches have been found in the past between Hawaii and Mexico (Darling and Jurasz 1983, Darling and McSweeney 1985, Baker et al. 1986, Forestell and Urbán-R 2007). However, any suggestion that such movement is operating more in one direction (i.e., from Hawaii to Mexico), is complicated by the recent resighting of a humpback whale in Mexico in 2014 and then in Hawaii in 2015 (Palacios et al. 2019b). Additional work is needed to improve the genetic reference database currently in use, as described in the previous section, and photo-ID can serve as an independent data source to validate this approach.

Photo-ID is a powerful tool for identifying whales over time and space, 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 have been able to overcome some of these limitations to make more connections between areas. As the number of photo-IDs submitted to Happywhale by other researchers continues to increase at a rapid pace, our capacity to expand the overall interpretation and significance of our tagging and genetic results will also improve. At the same time, since not all researchers submit their photo-IDs to Happywhale, additional efforts will be required to engage in direct collaboration with those researchers to get a more complete picture of where the tagged whales go after the tags have stopped transmitting, as well as to obtain as complete a picture as possible on their sighting histories.

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**Table 1. List of environmental data products used in the characterization of ecological relationships. Depth and the three dynamic oceanographic variables were obtained from ERDDAP† with the R package rerddapXtracto v. 0.4.1, while the derived static variables plus distance to shore were generated in ArcGIS. Columns include variable name (and abbreviation), measurement unit, data set and parameter names required by rerddapXtracto, satellite sensor or data product, and temporal and spatial resolution.**

| Variable | Unit | Data set | Parameter name | Sensor/Product | Temporal resolution | Spatial resolution |
|---|---|---|---|---|---|---|
| Depth (DEPTH) | m | ETOPO360 | altitude | ETOPO1 global relief model of Earth's surface | NA | 0.0167 deg (1.85 km) |
| Slope (SLOPE)[‡] | degrees | NA | NA | ETOPO1 | NA | 0.0167 deg (1.85 km) |
| Aspect (ASPECT)[‡] | degrees | NA | NA | ETOPO1 | NA | 0.0167 deg (1.85 km) |
| Distance to 200-m isobath (DISTSHELF)[‡] | km | NA | NA | ETOPO1 | NA | 0.0167 deg (1.85 km) |
| Distance to shore (DISTSHORE)[§] | km | cntry_06.shp | NA | ESRI World Countries 2006 | NA | 50 m |
| Sea surface temperature (SST) | °C | jplMURSST41SST | analysed_sst | Multi-scale Ultra-high Resolution (MUR) SST Analysis fv04.1 | 1 d | 0.01 deg (1.11 km) |
| Magnitude of sea surface temperature gradient (SSTG)[*] | °C/deg | erdMurFront41USWest | magnitude_gradient | Estimated MUR SST v4.1 gradient magnitude, US West Coast | 1 d | 0.01 deg (1.11 km) |
| Chlorophyll-*a* concentration (CHL) | mg $m^{-3}$ | erdMWchla8day[***] | chlorophyll | Moderate Resolution Imaging Spectroradiometer (MODIS) on Aqua satellite | 8 d[†] | 0.0125 deg (1.39 km) |

Key: d = days; deg = degrees; km = kilometers; m = meters; mg $m^{-3}$ = milligrams per cubic meter; NA = Not Applicable; °C = degrees Celcius.

[†]The base URL for the ERDDAP server in all rerddapXtracto calls was: https://upwell.pfeg.noaa.gov/erddap

[‡]The variables SLOPE, ASPECT, and DISTSHELF were not available on ERDDAP. They were derived from the bathymetry available in ArcGIS.

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

[*] SSTG is derived from MUR SST data as part of the procedures implemented for SST frontal edge detection on ERDDAP (van der Walt et al. 2014; https://rmendels.github.io/canny_doc.html)

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

**Table 2. Approach details for humpback whale tagging efforts in Washington and Oregon during 2018.**

| Season | # Days of Tagging Effort | # Whales Approached | # Whales Tagged | # Whales Tagged per Day | Average Time in Tagging Vessel (h/d) |
|---|---|---|---|---|---|
| **Washington 2018** | 17 | 334 | 20 | 1.2 | 9.1 |
| **Oregon 2018** | 3 | 73 | 5 | 1.7 | 9.1 |

KEY: h/d = hour per day; km = kilometer(s); # = number.

**Table 3. Responses to tagging and/or biopsy darting by humpback whales tagged and biopsy sampled in Washington and Oregon in 2018.**

| Number of whales | Response |
|---|---|
| **Humpback whales in Washington** | |
| **Tagging/biopsy darting** | |
| 7 | Medium tail flick |
| 6 | Mild tail flick |
| 4 | Hard tail flick |
| 1 | Hard tail flick and tail slap |
| 1 | Fast dive |
| **Biopsy darting alone** | |
| 5 | No response |
| 1 | Medium tail flick |
| 1 | Mild tail flick |
| **Humpback whales in Oregon** | |
| **Tagging/biopsy darting** | |
| 3 | Medium tail flick |
| 1 | Hard tail flick |
| 1 | Roll and dive |
| **Biopsy darting alone** | |
| 1 | No response |
| **Fin whales in Oregon** | |
| **Tagging/biopsy darting** | |
| 1 | No response |

**Table 4. Resight information and tag site descriptions for humpback whales tagged off Washington, 2018. Wound size estimates are approximate.**

| Tag#/Sex | Tagging Date | Resighting Dates | # Days Post-Tagging | Tag Present/ Tag Transmitting | Body Condition | Tag Site Condition |
|---|---|---|---|---|---|---|
| 4177/Male | 8/3/18 | 9/20/19 | 413 | No/No | Good | Very small divot ~5-cm diameter and 2-cm deep with some skin discoloration. No swelling. |
| 5801/Male | 8/6/18 | 9/19/19 | 409 | No/No | Good | Shallow divot ~12-cm diameter and 2-cm deep with some skin discoloration. No swelling |
| 5883/Female | 8/7/18 | 9/21/18 | 38 | Yes/No | Good | Small divot ~4-cm diameter and 2-cm deep with some white tissue visible. No Swelling. |
| 10839/Female | 8/10/18 | 8/20/18 | 10 | Yes/Yes | Good | Moderate swelling around tag. ~50-cm diameter and 10-cm high. |
| 23029/Female | 8/10/18 | 9/21/18 | 22 | Yes/Yes | Good | Red tissue ~8-cm diameter around tag. No divot and no swelling. |
| 23029/Female | 8/10/18 | 10/1/19 | 417 | No/No | Good | Divot ~10-cm diameter and 1-cm deep. Some skin discoloration. No swelling. |
| 5654/Unknown | 8/12/18 | 8/13/18<br>8/14/18 | 1<br>2 | Yes/Yes<br>Yes/Yes | Good<br>Good | Area of rough skin around tag site ~5-cm diameter. |
| 5654/Unknown | 8/12/18 | 9/14/18<br>10/19/18<br>10/24/18 | 33<br>68<br>73 | Yes/No<br>Yes/No<br>Yes/No | Good<br>Good<br>Good | Divot ~20-cm diameter and 4-cm deep. No swelling |
| 5700/Female | 8/13/18 | 8/16/18 | 3 | Yes/Yes | Good | Some rough skin around tag ~4-cm diameter. No swelling. |
| 5700/Female | 8/13/18 | 9/19/19 | 402 | No/No | Good | Deep divot ~20-cm diameter and at least 8-cm deep in the center. Some skin discoloration in divot. No swelling. |
| 5790/Male | 8/14/18 | 9/19/18 | 36 | Yes/Yes | Good | Tag surrounded by divot ~20-cm diameter and 5-cm deep. No swelling. |
| 5823/Male | 8/17/18 | 8/20/18 | 3 | Yes/Yes | Good | Some rough skin within ~5-cm diameter around tag. No swelling. |
| 5923/Male | 8/18/18 | 9/14/18 | 27 | Yes/Yes | Good | Drone footage shows red area ~10-cm wide near tag, but not surrounding tag. No swelling obvious from photo. |

KEY: cm = centimeter; # = number; ~ = approximately.

**Table 5. Deployment and performance data by tag type for satellite-monitored radio tags deployed on humpback whales in Washington in 2018. See Section 2.3.1 for location filtering method. Also included is the genetic assignment to Distinct Population Segment (DPS) using the highest relative likelihood reported in Table 29 and shown in Figure 51.**

| Tag # | Sex | Lab ID | Deployment Locality | Deployment Date | Tag Type | Biopsy | Fluke ID Photo | # Days Tracked | # Filtered Argos Locations | Total Distance (km) | DPS Assignment |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4177 | Male | Mno18WA-4177 | WA | 3-Aug-18 | ADB | Yes | Yes | 12.5 | 148 | 590 | Hawaii |
| 5640 | Male | Mno18WA-5640 | WA | 10-Aug-18 | DUR+ | Yes | Yes | 39.2 | 221 | 3,215 | Hawaii |
| 5650 | Male | Mno18WA-5650 | WA | 14-Aug-18 | DUR+ | Yes | Yes | 13.0 | 79 | 1,068 | Cent Amer |
| 5654 | Unknown | no biopsy | WA | 12-Aug-18 | DUR+ | No | Yes | 45.0 | 255 | 2,359 | - |
| 5700 | Female | Mno18WA-5700 | WA | 13-Aug-18 | DUR+ | Yes | Yes | 39.0 | 270 | 1,933 | Cent Amer |
| 5709 | Male | Mno18WA-5709 | WA | 13-Aug-18 | DUR+ | Yes | Yes | 16.4 | 100 | 1,520 | Hawaii |
| 5719 | Female | Mno18WA-5719 | WA | 14-Aug-18 | DUR+ | Yes | Yes | 13.9 | 123 | 1,254 | Hawaii |
| 5726 | Male | Mno18WA-5726 | WA | 14-Aug-18 | DUR+ | Yes | No | 25.2 | 196 | 1,685 | Hawaii |
| 5790 | Male | Mno18WA-5790 | WA | 14-Aug-18 | DUR+ | Yes | Yes | 110.6 | 155 | 4,808 | Hawaii |
| 5823 | Male | Mno18WA-5823 | WA | 17-Aug-18 | DUR+ | Yes | Yes | 73.9 | 303 | 3,491 | Hawaii |
| 5923 | Male | Mno18WA-5923 | WA | 18-Aug-18 | DUR+ | Yes | Yes | 34.0 | 245 | 2,451 | Cent Amer |
| | | | | | **DUR+ tags** | | **Mean**<br>**Median** | **41.0**<br>**36.5** | **195**<br>**208** | **2,378**<br>**2,146** | |
| 5801 | Male | Mno18WA-5801 | WA | 6-Aug-18 | DM | Yes | No | 17.0 | 104 | 1,046 | Hawaii |
| 5838 | Male | Mno18WA-5838 | WA | 6-Aug-18 | DM | Yes | Yes | 30.6 | 199 | 1,525 | West Pac |
| 5883 | Female | Mno18WA-5883 | WA | 7-Aug-18 | DM | Yes | No | 15.5 | 134 | 963 | Mexico |
| 10825 | Male | Mno18WA-10825 | WA | 8-Aug-18 | DM | Yes | Yes | 52.1 | 297 | 2,531 | Cent Amer |
| 10836 | Male | Mno18WA-10836 | WA | 9-Aug-18 | DM | Yes | No | 19.2 | 145 | 1,273 | Hawaii |
| 10839 | Female | Mno18WA-10839 | WA | 10-Aug-18 | DM | Yes | Yes | 35.4 | 305 | 1,659 | Hawaii |
| 23029 | Female | Mno18WA-23029 | WA | 10-Aug-18 | DM | Yes | Yes | 28.4 | 247 | 1,671 | Hawaii |
| 23033 | Unknown | Mno18WA-23033 | WA | 10-Aug-18 | DM | No | Yes | 6.7 | 47 | 288 | - |
| 23039 | Male | Mno18WA-23039 | WA | 10-Aug-18 | DM | Yes | No | 11.4 | 72 | 1,057 | Hawaii |
| | | | | | **DM tags** | | **Mean**<br>**Median** | **24.0**<br>**19.2** | **172**<br>**145** | **1,335**<br>**1,273** | |

KEY: ADB = Wildlife Computers MK10 Advanced Dive Behavior tag; Cent Amer = Central America DPS; DM = Telonics RDW-665 Dive-Monitoring tag; DUR+ = Telonics RDW-665 Duration Plus tag (no depth); ID = Identification; km = kilometer(s); West Pac = Western Pacific DPS; # = number.

**Table 6. Percentage of filtered locations (including the deployment location) and time spent inside the NWTT and W237 areas for humpback whales tagged off Washington in 2018. See Section 2.3.1 for location filtering method.**

| Tag # | Deployment Locality | Tag Type | Species | Total | | NWTT | | | W237 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | # Locs | # Days | % Locs | % of Days | # Days | % Locs | % of Days | # Days |
| 4177 | Washington | ADB | Humpback | 246 | 12.5 | 47.2 | 50.7 | 6.3 | 26.8 | 36.1 | 4.5 |
| 5640 | Washington | DUR+ | Humpback | 222 | 39.2 | 59.0 | 66.4 | 26.1 | 33.3 | 42.7 | 16.8 |
| 5650 | Washington | DUR+ | Humpback | 80 | 13.3 | 28.8 | 33.8 | 4.4 | 1.3 | 2.9 | 0.4 |
| 5654 | Washington | DUR+ | Humpback | 256 | 45.0 | 9.4 | 9.4 | 4.2 | 5.9 | 6.7 | 3.0 |
| 5700 | Washington | DUR+ | Humpback | 271 | 39.0 | 30.6 | 33.3 | 13.0 | 12.2 | 10.4 | 4.0 |
| 5709 | Washington | DUR+ | Humpback | 101 | 16.4 | 8.9 | 6.2 | 1.0 | 1.0 | 0.2 | 0.03 |
| 5719 | Washington | DUR+ | Humpback | 124 | 13.9 | 3.2 | 4.9 | 0.7 | 0.8 | 0.2 | 0.03 |
| 5726 | Washington | DUR+ | Humpback | 197 | 25.2 | 29.4 | 25.4 | 6.4 | 0.5 | 0.2 | 0.1 |
| 5790 | Washington | DUR+ | Humpback | 156 | 110.6 | 12.8 | 26.2 | 28.9 | 1.9 | 10.0 | 11.1 |
| 5823 | Washington | DUR+ | Humpback | 304 | 73.9 | 28.9 | 23.7 | 17.5 | 8.9 | 4.0 | 2.9 |
| 5923 | Washington | DUR+ | Humpback | 246 | 34.0 | 40.7 | 36.8 | 12.5 | 13.4 | 12.2 | 4.1 |
| 5801 | Washington | DM | Humpback | 105 | 17.0 | 36.2 | 29.3 | 5.0 | 4.8 | 4.3 | 0.7 |
| 5838 | Washington | DM | Humpback | 200 | 30.6 | 93.0 | 94.1 | 28.8 | 60.0 | 51.2 | 15.7 |
| 5883 | Washington | DM | Humpback | 135 | 15.5 | 38.5 | 45.3 | 7.0 | 19.3 | 22.9 | 3.5 |
| 10825 | Washington | DM | Humpback | 298 | 52.1 | 40.3 | 41.5 | 21.6 | 5.7 | 6.1 | 3.2 |
| 10836 | Washington | DM | Humpback | 146 | 19.2 | 41.1 | 41.7 | 8.0 | 5.5 | 4.6 | 0.9 |
| 10839 | Washington | DM | Humpback | 306 | 35.4 | 40.2 | 48.4 | 17.1 | 17.0 | 17.8 | 6.3 |
| 23029 | Washington | DM | Humpback | 248 | 28.4 | 14.9 | 13.1 | 3.7 | 8.1 | 6.7 | 1.9 |
| 23033 | Washington | DM | Humpback | 48 | 6.7 | 2.1 | 0.2 | 0.01 | - | - | - |
| 23039 | Washington | DM | Humpback | 73 | 11.4 | 24.7 | 27.4 | 3.1 | 20.5 | 19.4 | 2.2 |
| | | | **Mean** | **188.1** | **32.0** | **31.5** | **32.9** | **10.8** | **13.0** | **13.6** | **4.3** |
| | | | **Median** | **198.5** | **26.8** | **30.0** | **31.3** | **6.7** | **8.1** | **6.7** | **3.0** |

KEY: ADB = Wildlife Computers MK10 Advanced Dive Behavior tag; DM = Telonics RDW-665 Dive-Monitoring tag; DUR+ = Telonics RDW-665 Duration Plus tag; Locs = Locations; # = number; % = percentage.

**Table 7. Geodesic distances (km) to nearest point on shore in Navy training ranges for humpback whales tagged off Washington in 2018 (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 # | Deployment Location | Tag Type | Species | NWTT | | | | W237 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | n | Mean | Median | Max | n | Mean | Median | Max |
| 4177 | Washington | ADB | Humpback | 116 | 44 | 48 | 79 | 66 | 63 | 71 | 79 |
| 5640 | Washington | DUR+ | Humpback | 131 | 36 | **32** | 97 | 74 | 51 | 51 | 97 |
| 5650 | Washington | DUR+ | Humpback | 23 | 19 | 20 | 30 | 1 | 30 | 30 | 30 |
| 5654 | Washington | DUR+ | Humpback | 24 | 17 | 15 | 34 | 15 | 21 | 17 | 34 |
| 5700 | Washington | DUR+ | Humpback | 83 | 33 | 23 | 70 | 33 | 56 | 62 | 70 |
| 5709 | Washington | DUR+ | Humpback | 9 | 14 | 10 | 41 | 1 | 41 | 41 | 41 |
| 5719 | Washington | DUR+ | Humpback | 4 | 55 | 63 | 78 | 1 | 65 | 65 | 65 |
| 5726 | Washington | DUR+ | Humpback | 58 | 16 | 18 | 44 | 1 | 27 | 27 | 27 |
| 5790 | Washington | DUR+ | Humpback | 20 | 23 | 15 | 61 | 3 | 58 | 60 | 61 |
| 5823 | Washington | DUR+ | Humpback | 88 | 27 | 23 | 65 | 27 | 46 | 46 | 65 |
| 5923 | Washington | DUR+ | Humpback | 100 | 24 | 21 | 47 | 33 | 33 | 35 | 47 |
| 5801 | Washington | DM | Humpback | 38 | 20 | 15 | 77 | 5 | 57 | 72 | 77 |
| 5838 | Washington | DM | Humpback | 186 | 44 | 46 | 105 | 120 | 57 | 56 | 105 |
| 5883 | Washington | DM | Humpback | 52 | 34 | 30 | 77 | 26 | 51 | 54 | 77 |
| 10825 | Washington | DM | Humpback | 120 | 21 | 17 | 75 | 17 | 55 | 64 | 75 |
| 10836 | Washington | DM | Humpback | 60 | 21 | 20 | 42 | 8 | 34 | 34 | 42 |
| 10839 | Washington | DM | Humpback | 123 | 32 | 27 | 69 | 52 | 49 | 48 | 67 |
| 23029 | Washington | DM | Humpback | 37 | 32 | 32 | 62 | 20 | 46 | 46 | 62 |
| 23033 | Washington | DM | Humpback | 1 | 7 | 7 | 7 | 0 | - | - | - |
| 23039 | Washington | DM | Humpback | 19 | 24 | 22 | 58 | 15 | 27 | 25 | 58 |
| | | | **Mean** | **65** | **27** | **25** | 61 | 26 | 46 | 48 | **62** |
| | | | **Median** | **55** | **24** | **22** | **64** | **16** | **49** | **48** | **65** |

KEY: ADB = Wildlife Computers MK10 Advanced Dive Behavior tag; DM = Telonics RDW-665 Dive-Monitoring tag; DUR+ = Telonics RDW-665 Duration Plus tag; n = number of locations (sample size) within the area; # = number.

**Table 8. Percentage of filtered locations (including the deployment location) and time spent inside Biologically Important Areas (BIAs) and the Olympic Coast National Marine Sanctuary (OCNMS) for humpback whales tagged off Washington in 2018. See Section 2.3.1 for location filtering method.**

| | | Filtered Locations | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tag # | Tag Type | Total | | Northern WA | | | Stonewall-Heceta | | | Pt.St.George | | | OCNMS | | |
| | | # Locs | # Days | % Locs | % of Days | # Days | % Locs | % of Days | # Days | % Locs | % of Days | # Days | % Locs | % of Days | # Days |
| 4177 | ADB | 246 | 12.5 | 36.2 | 40.5 | 5.1 | - | - | - | - | - | - | 25.6 | 26.5 | 3.3 |
| 5640 | DUR | 222 | 39.2 | 36.0 | 43.9 | 17.2 | - | - | - | - | - | - | 53.6 | 58.9 | 23.1 |
| 5650 | DUR | 80 | 13.3 | 22.5 | 28.5 | 3.7 | - | - | - | - | - | - | 28.8 | 36.3 | 4.7 |
| 5654 | DUR | 256 | 45.0 | 0.4 | 1.3 | 0.6 | - | - | - | - | - | - | 10.5 | 10.2 | 4.6 |
| 5700 | DUR | 271 | 39.0 | 26.6 | 29.2 | 11.4 | - | - | - | - | - | - | 29.2 | 33.9 | 13.2 |
| 5709 | DUR | 101 | 16.4 | 5.9 | 4.6 | 0.8 | - | - | - | - | - | - | 10.9 | 10.5 | 1.7 |
| 5719 | DUR | 124 | 13.9 | 0.8 | 1.3 | 0.2 | - | - | - | - | - | - | 1.6 | 2.1 | 0.3 |
| 5726 | DUR | 197 | 25.2 | 22.8 | 19.2 | 4.8 | - | - | - | - | - | - | 27.9 | 25.0 | 6.3 |
| 5790 | DUR | 156 | 110.6 | 10.9 | 3.3 | 3.6 | - | - | - | - | - | - | 12.2 | 4.0 | 4.5 |
| 5823 | DUR | 304 | 73.9 | 18.8 | 16.7 | 12.4 | - | - | - | - | - | - | 25.3 | 21.8 | 16.1 |
| 5923 | DUR | 246 | 34.0 | 20.7 | 20.5 | 7.0 | - | - | - | - | - | - | 37.4 | 33.5 | 11.4 |
| 5801 | DM | 105 | 17.0 | 26.7 | 23.6 | 4.0 | - | - | - | - | - | - | 39.0 | 30.7 | 5.2 |
| 5838 | DM | 200 | 30.6 | 43.0 | 51.1 | 15.7 | - | - | - | - | - | - | 52.5 | 59.1 | 18.1 |
| 5883 | DM | 135 | 15.5 | 20.7 | 25.0 | 3.9 | - | - | - | - | - | - | 33.3 | 36.7 | 5.7 |
| 10825 | DM | 298 | 52.1 | 33.6 | 35.1 | 18.3 | - | - | - | - | - | - | 38.3 | 43.1 | 22.5 |
| 10836 | DM | 146 | 19.2 | 35.6 | 37.4 | 7.2 | - | - | - | - | - | - | 37.0 | 37.9 | 7.3 |
| 10839 | DM | 306 | 35.4 | 25.8 | 29.3 | 10.4 | - | - | - | - | - | - | 31.7 | 33.6 | 11.9 |
| 23029 | DM | 248 | 28.4 | 5.2 | 3.8 | 1.1 | - | - | - | - | - | - | 16.1 | 12.7 | 3.6 |
| 23033 | DM | 48 | 6.7 | - | - | - | - | - | - | - | - | - | 2.1 | 0.4 | 0.03 |
| 23039 | DM | 73 | 11.4 | 6.8 | 11.1 | 1.3 | - | - | - | - | - | - | 30.1 | 31.1 | 3.5 |
| **Mean** | | **188.1** | **32.0** | **21.0** | **22.4** | **6.8** | **-** | **-** | **-** | **-** | **-** | **-** | **27.2** | **27.4** | **8.4** |
| **Median** | | **198.5** | **26.8** | **22.5** | **23.6** | **4.8** | **-** | **-** | **-** | **-** | **-** | **-** | **29.0** | **30.9** | **5.4** |

KEY: ADB = Wildlife Computers MK10 Advanced Dive Behavior tag; DM = Telonics RDW-665 Dive-Monitoring tag; DUR+ = Telonics RDW-665 Duration Plus tag; Locs = Locations; # = number; % = percentage.

**Table 9. Sizes of HRs and CAs of use calculated from hierarchical state-space modeled (hSSSM) locations for humpback whales tagged off Washington and Oregon, 2018. 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 (km²) | CA Size (km²) |
|---|---|---|---|---|
| **Humpback Whales Washington** | | | | |
| 5640 | 118 | Male | 3,694 | 1,095 |
| 5654 | 136 | Unknown | 2,723 | 250 |
| 5700 | 117 | Female | 2,454 | 505 |
| 5790 | 136 | Male | 2,026 | 508 |
| 5823 | 222 | Male | 2,541 | 724 |
| 5838 | 92 | Female | 4,165 | 395 |
| 5923 | 102 | Male | 4,316 | 330 |
| 10825 | 157 | Male | 2,121 | 390 |
| 10839 | 107 | Female | 1,912 | 245 |
| **Humpback Whales Oregon** | | | | |
| 23035 | 181 | Male | 3,721 | 425 |
| **Mean** | | | 3,024 | 487 |

KEY: $km^2$ = square kilometers; # = number; HR = home range; CA = core area.

**Table 10. Deployment and performance data for satellite-monitored radio tags deployed on humpback whales and a fin whale in Oregon in 2018. See Section 2.3.1 for location filtering method. Also included is the genetic assignment to DPS for humpback whales using the highest relative likelihood reported in Table 29 and shown in Figure 51.**

| Tag # | Sex | Lab ID | Deployment Locality | Deployment Date | Tag Type | Biopsy | Fluke ID Photo | # Days Tracked | # Filtered Argos Locations | Total Distance (km) | DPS Assignment |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Humpback Whales** | | | | | | | | | | | |
| 1083 | Male | Mno18OR- | OR | 7-Sep-18 | DUR+ | Yes | Yes | 18.0 | 74 | 1,333 | Hawaii |
| 2303 | Male | Mno18OR- | OR | 7-Sep-18 | DUR+ | Yes | Yes | 16.5 | 104 | 1,164 | Hawaii |
| 2303 | Male | Mno18OR- | OR | 7-Sep-18 | DUR+ | Yes | Yes | 12.3 | 74 | 1,039 | Mexico |
| 2303 | Male | Mno18OR- | OR | 8-Sep-18 | DUR+ | Yes | Yes | 60.2 | 273 | 3,815 | Hawaii |
| 2304 | Male | Mno18OR- | OR | 8-Sep-18 | DUR+ | Yes | Yes | 9.2 | 58 | 698 | Mexico |
| | | | | | | | **Mean** | **23.2** | **116** | **1,610** | |
| | | | | | | | **Median** | **16.5** | **74** | **1,164** | |
| **Fin Whale** | | | | | | | | | | | |
| 5882 | Female | Bph18OR-5882 | OR | 6-Sep-18 | LO | Yes | - | 35.9 | 103 | 1,963 | - |

KEY: DUR+ = Telonics RDW-665 Duration Plus tag; km = kilometer(s); ID = Identification; LO = Wildlife Computers SPOT6 Location Only tag; # = number.

**Table 11. Percentage of filtered locations (including the deployment location) and time spent inside the NWTT and W237 areas for humpback and a fin whale tagged off Oregon in 2018. See Section 2.3.1 for location filtering method.**

| Tag # | Deployment Locality | Tag Type | Species | Total | | NWTT | | | W237 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | # Locs | # Days | % Locs | % of Days | # Days | % Locs | % of Days | # Days |
| 10834 | Oregon | DUR+ | Humpback | 75 | 18.1 | 53.3 | 67.0 | 12.1 | - | - | - |
| 23030 | Oregon | DUR+ | Humpback | 105 | 16.5 | 76.2 | 72.6 | 12.0 | - | - | - |
| 23032 | Oregon | DUR+ | Humpback | 75 | 12.3 | 37.3 | 39.9 | 4.9 | - | - | - |
| 23035 | Oregon | DUR+ | Humpback | 274 | 60.2 | 73.4 | 73.9 | 44.5 | - | - | - |
| 23041 | Oregon | DUR+ | Humpback | 59 | 9.2 | 89.8 | 95.0 | 8.7 | - | - | - |
| | | **Mean+** | **Humpback** | **117.6** | **23.3** | **66.0** | **69.7** | **16.4** | - | - | - |
| | | **Median** | **Humpback** | **75** | **16.5** | **73.4** | **72.6** | **12.0** | - | - | - |
| 5882 | Oregon | LO | Fin | 103 | 35.9 | 15.4 | 40.0 | 14.4 | 0 | 10.8 | 3.9 |

KEY: DUR+ = Telonics RDW-665 Duration Plus tag; LO = Wildlife Computers SPOT6 Location Only tag; Locs = Locations; # = number; % = percentage.

**Table 12. Geodesic distances (km) to nearest point on shore in Navy training ranges for humpback whales and a fin whale tagged off Oregon in 2018 (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 # | Deployment Location | Tag Type | Species | NWTT | | | | W237 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | n | Mean | Median | Max | n | Mean | Median | Max |
| 10834 | Oregon | DUR+ | Humpback | 40 | 38 | 36 | 73 | 0 | - | - | - |
| 23030 | Oregon | DUR+ | Humpback | 80 | 40 | 39 | 56 | 0 | - | - | - |
| 23032 | Oregon | DUR+ | Humpback | 28 | 38 | 36 | 72 | 0 | - | - | - |
| 23035 | Oregon | DUR+ | Humpback | 201 | 40 | 40 | 73 | 0 | - | - | - |
| 23041 | Oregon | DUR+ | Humpback | 53 | 41 | 41 | 58 | 0 | - | - | - |
| | | | **Mean** | **80** | **39** | **38** | **66** | **0** | **-** | **-** | **-** |
| | | | **Median** | **53** | **40** | **39** | **72** | **0** | **-** | **-** | **-** |
| 5882 | Oregon | LO | Fin | 16 | 55 | 49 | 91 | 0 | - | - | - |

KEY: DUR+ = Telonics RDW-665 Duration Plus tag; LO = Wildlife Computers SPOT6 Location Only tag; Max = Maximum; n = number of locations (sample size); # = number.

**Table 13. Percentage of filtered locations (including the deployment location) and time spent inside BIAs and the OCNMS for humpback whales tagged off Oregon in 2018. See Section 2.3.1 for location filtering method.**

| | | Filtered Locations | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tag # | Tag Type | Total | | Northern WA | | | Stonewall-Heceta | | | Pt.St.George | | | OCNMS | | | |
| | | # Locs | # Days | % Locs | % of Days | # Days | % Locs | % of Days | # Days | % Locs | % of Days | # Days | % Locs | % of Days | # Days | |
| 10834 | DUR+ | 75 | 18.1 | - | - | - | 8.0 | 7.6 | 1.4 | 2.7 | 2.0 | 0.4 | - | - | - | |
| 23030 | DUR+ | 105 | 16.5 | - | - | - | 13.3 | 12.1 | 2.0 | 3.8 | 3.2 | 0.5 | - | - | - | |
| 23032 | DUR+ | 75 | 12.3 | - | - | - | - | - | - | - | - | - | - | - | - | |
| 23035 | DUR+ | 274 | 60.2 | - | - | - | 14.6 | 12.2 | 7.4 | - | - | - | - | - | - | |
| 23041 | DUR+ | 59 | 9.2 | - | - | - | 55.9 | 49.6 | 4.6 | - | - | - | - | - | - | |
| **Mean** | | **117.6** | **23.3** | - | - | - | **23.0** | **20.4** | **3.8** | **3.2** | **2.6** | **0.4** | - | - | - | |
| **Median** | | **75** | **16.5** | - | - | - | **14.0** | **12.2** | **3.3** | **3.2** | **2.6** | **0.4** | - | - | - | |

KEY: DUR+ = Telonics RDW-665 Duration Plus tag; Locs = Locations; # = number; % = percentage.

**Table 14. Mean (and SD) tracking duration, total distance traveled, home range, and core area for 30 humpback whales tagged by OSU off Oregon and Washington from 2016 to 2018. Tracking results from the ADB tag deployed off Washington in 2018 is not included here because of its planned shorter tracking duration (for recovery).**

| | Tracking Duration (d) | | | Total Distance (km) | | | Home Range ($km^2$) | | | Core Area ($km^2$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | n | Mean | SD | n | Mean | SD | n | Mean | SD | n | Mean | SD |
| 2016-2017OR | 6 | 45.6 | 52.3 | 6 | 2944.5 | 4201.6 | 4 | 17215.8 | 16861.0 | 4 | 1929.2 | 1802.8 |
| 2018WA | 19 | 33.0 | 25.1 | 19 | 1884.0 | 1066.8 | 9 | 2609.2 | 793.6 | 9 | 603.4 | 289.4 |
| 2018OR | 5 | 23.2 | 20.9 | 5 | 1609.8 | 1254.5 | 1 | 4561.0 | - | 1 | 823.0 | - |

KEY: d = days; km = kilometers; $km^2$ = square kilometers; n = number of whales (sample size); SD = standard deviation.

**Table 15. Mean and maximum number of days spent inside the NWTT, W237, PT MUGU, SOCAL, and SOAR areas for 31 humpback whales tagged off Oregon and Washington from 2016 to 2018. Area W237 is located within area NWTT, so whale occurrence in W237 is also counted as occurrence in NWTT, as the two areas were analyzed separately.**

| | # Days | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Season (# Whales Tracked)** | **NWTT** | | | **W237** | | | **PT MUGU** | | | **SOCAL** | | | **SOAR** | | |
| | **n** | **Mean** | **Max** | **n** | **Mean** | **Max** | **n** | **Mean** | **Max** | **n** | **Mean** | **Max** | **n** | **Mean** | **Max** |
| 2016-2017OR (6) | 6 | 22.6 | 86.5 | 1 | 14.3 | 14.3 | 0 | - | - | 1 | 1.8 | 1.8 | 0 | - | - |
| 2018WA (20) | 20 | 10.8 | 28.9 | 19 | 4.3 | 16.8 | 0 | - | - | 0 | - | - | 0 | - | - |
| 2018OR (5) | 5 | 16.4 | 44.5 | 0 | - | - | 0 | - | - | 0 | - | - | 0 | - | - |
| **All Seasons (31)** | **31** | **14.0** | **86.5** | **20** | **4.8** | **16.8** | **0** | **-** | **-** | **1** | **1.8** | **1.8** | **0** | **-** | **-** |

KEY: n = number of whales (sample size); # = number.

**Table 16. Geodesic distances (km) to nearest point on shore in Navy training ranges for humpback whales tagged off Oregon and Washington from 2016 to 2018 (including mean, median, and maximum distances to shore). PT MUGU and SOAR are not included here because no whales had locations there.**

| Season (# Whales Tracked) | NWTT | | | | W237 | | | | SOCAL | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | n | Mean | Median | Max | n | Mean | Median | Max | n | Mean | Median | Max |
| 2016-2017OR (6) | 6 | 49 | 49 | 67 | 1 | 73 | 73 | 73 | 1 | 317 | 317 | 317 |
| 2018WA (20) | 20 | 27 | 22 | 105 | 19 | 46 | 48 | 105 | 0 | - | - | - |
| 2018OR (5) | 5 | 40 | 39 | 73 | 0 | - | - | - | 0 | - | - | - |
| **Mean** | | **39.3** | **37** | **81.7** | | **59.5** | **60.5** | **89** | | **-** | **-** | **-** |
| **Median** | | **40** | **39** | **73** | | **59.5** | **60.5** | **89** | | **-** | **-** | **-** |

KEY: km = kilometers; Max = Maximum; n = number of whales (sample size); # = number.

**Table 17. Mean and maximum number of days spent inside the West Coast BIAs for 31 humpback whales tagged off Oregon and Washington from 2016 to 2018.**

| | # 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** |
| 2016-2017OR (6) | 0 | - | - | 0 | - | - | 0 | - | - | 1 | 2.2 | 2.2 | 4 | 3.3 | 4.4 | 4 | 3.9 | 9.9 | 1 | 7.4 | 7.4 | 1 | 8.6 | 8.6 |
| 2018WA (20) | 0 | - | - | 0 | - | - | 0 | - | - | 0 | - | - | 0 | - | - | 0 | - | - | 19 | 6.8 | 18.3 | 20 | 8.3 | 23.1 |
| 2018OR (5) | 0 | - | - | 0 | - | - | 0 | - | - | 0 | - | - | 2 | 0.4 | 0.5 | 4 | 3.8 | 7.3 | 0 | - | - | 0 | - | - |
| **All Years (31)** | **0** | **-** | **-** | **0** | **-** | **-** | **0** | **-** | **-** | **1** | **2.2** | **2.2** | **6** | **2.4** | **4.4** | **8** | **3.9** | **9.9** | **20** | **6.8** | **18.3** | **21** | **8.4** | **23.1** |

KEY: Max = Maximum; n = number of whales (sample size); # = number.

**Table 18. Dive data summarized by 24 DM and DUR+ tags and one ADB tag deployed on humpback whales off Washingto and Oregon from August to September 2018.**

| Tag # | Tag type | Summary period (days) | # Dives | % Track summarized | Median dives per day | Minimum dives per day | Maximum dives per day |
|---|---|---|---|---|---|---|---|
| 5801 | DM | 17.0 | 1608 | 71.9 | 83.5 | 21 | 154 |
| 5838 | DM | 30.6 | 2555 | 66.1 | 80 | 2 | 134 |
| 5883 | DM | 15.0 | 1726 | 82.3 | 113.5 | 33 | 144 |
| 10825 | DM | 51.9 | 4647 | 69.6 | 89 | 20 | 143 |
| 10836 | DM | 19.0 | 2277 | 74.1 | 116.5 | 7 | 179 |
| 10839 | DM | 35.3 | 3039 | 70.5 | 79 | 3 | 139 |
| 23029 | DM | 28.4 | 3016 | 78.7 | 104.5 | 16 | 156 |
| 23033 | DM | 6.3 | 448 | 79.4 | 65 | 3 | 93 |
| 23039 | DM | 11.3 | 1306 | 80.7 | 110 | 15 | 133 |
| 5640 | DUR+ | 39.2 | 5418 | 76.9 | 135 | 4 | 202 |
| 5650 | DUR+ | 13.2 | 1712 | 92.5 | 132.5 | 40 | 170 |
| 5654 | DUR+ | 44.9 | 5293 | 72.8 | 118 | 30 | 177 |
| 5700 | DUR+ | 38.7 | 5069 | 74.9 | 134 | 19 | 187 |
| 5709 | DUR+ | 16.4 | 2088 | 95.5 | 127 | 20 | 168 |
| 5719 | DUR+ | 13.8 | 1650 | 82.9 | 117 | 32 | 174 |
| 5726 | DUR+ | 25.2 | 2912 | 68.0 | 117 | 9 | 166 |
| 5790 | DUR+ | 110.5 | 3492 | 22.9 | 91 | 1 | 144 |
| 5823 | DUR+ | 73.7 | 7107 | 52.9 | 96 | 6 | 211 |
| 5923 | DUR+ | 33.8 | 4718 | 87.7 | 138 | 20 | 172 |
| 10834 | DUR+ | 18.0 | 2356 | 73.8 | 128 | 31 | 203 |
| 23030 | DUR+ | 16.1 | 1522 | 66.4 | 96 | 26 | 143 |
| 23032 | DUR+ | 12.3 | 1745 | 93.0 | 138 | 9 | 171 |
| 23035 | DUR+ | 60.1 | 7135 | 71.2 | 123 | 4 | 200 |
| 23041 | DUR+ | 9.1 | 1263 | 89.4 | 132 | 9 | 178 |
| 4177 | ADB | 12.4 | 320 | 22.6 | 22 | 10 | 45 |
| | **Mean** | **30.1** | **2976.9** | **72.7** | **107.4** | **15.6** | **159.4** |

KEY: ADB = Wildlife Computers MK10 Advanced Dive Behavior tag; DM = Telonics RDW-665 Dive-Monitoring tag; DUR+ = Telonics RDW-665 Duration Plus tag; # = number; % = percentage.

**Table 19. Summary of the number of tracks used in SSSM/hSSSM analyses, the number of generated locations, and the geographic extent covered by the SSSM/hSSSM locations for each tagging year/season (CA = California, OR = Oregon, WA = Washington). The migrating portions of tracks, as well as locations that occurred on land and those with high estimation uncertainty were removed prior to analysis.**

| Season | Number of tags | Number of locations | Minimum longitude | Maximum longitude | | Minimum latitude | Maximum latitude |
|---|---|---|---|---|---|---|---|
| | | | | Humpback whales | | | |
| 2004CA | 6 | 253 | -124.9 | -120.7 | | 34.9 | 42.9 |
| 2005CA | 3 | 91 | -124.5 | -120.9 | | 34.5 | 40.7 |
| 2005CA2 | 3 | 116 | -125.4 | -120.6 | | 34.1 | 42.8 |
| 2016OR | 2 | 28 | -124.8 | -124.2 | | 40.7 | 44.7 |
| 2017CA | 13 | 484 | -126.5 | -119.7 | | 34.3 | 45.1 |
| 2017OR | 4 | 202 | -126.5 | -123.8 | | 38.6 | 48.7 |
| 2018OR | 5 | 121 | -124.8 | -124.0 | | 40.7 | 46.3 |
| 2018WA | 20 | 598 | -129.2 | -123.0 | | 45.7 | 50.7 |
| **Total** | **56** | **1893** | **-129.0** | **-120.0** | | **34.1** | **50.7** |
| | | | | Fin whale | | | |
| 2018OR | 1 | 26 | -133.8 | -124.2 | | 44.7 | 51.1 |

**Table 20. Summary of the number of SSSM/hSSSM locations with their behavioral classification used in the ecological characterization of the tracking data, and the percentage of the total (%), for each tagging year/season (CA = California, OR = Oregon, WA = Washington). The migrating portions of tracks, as well as locations that occurred on land and those with high estimation uncertainty were removed prior to analysis.**

| | | Total | Transiting | | Uncertain | | ARS | |
|---|---|---|---|---|---|---|---|---|
| **Season** | **# tags** | **# locs** | **# locs** | **%** | **# locs** | **%** | **# locs** | **%** |
| **Humpback whales** | | | | | | | | |
| 2004CA | 6 | 253 | 1 | 0.4% | 33 | 13.0% | 219 | 86.6% |
| 2005CA | 3 | 91 | 0 | 0 | 9 | 9.9% | 82 | 90.1% |
| 2005CA2 | 3 | 116 | 9 | 7.8% | 49 | 42.2% | 58 | 50.0% |
| 2016OR | 2 | 28 | 0 | 0 | 28 | 100.0% | 0 | 0 |
| 2017CA | 13 | 484 | 32 | 6.6% | 33 | 6.8% | 419 | 86.6% |
| 2017OR | 4 | 202 | 36 | 17.8% | 27 | 13.4% | 139 | 68.8% |
| 2018OR | 5 | 121 | 14 | 11.6% | 9 | 7.4% | 98 | 81.0% |
| 2018WA | 20 | 598 | 22 | 3.7% | 39 | 6.5% | 537 | 89.8% |
| **Total** | **56** | **1893** | **114** | **6.0%** | **227** | **12.0%** | **1552** | **82.0%** |
| **Fin whale** | | | | | | | | |
| 2018OR | 1 | 26 | NA | NA | 5 | 19.2% | 21 | 80.8% |

KEY: ARS = Area Restricted Search; locs = locations; NA = Not Applicable; # = number; % = percentage.

**Table 21. Summary statistics (median and MAD) for PWDIST and PWSPEED computed for the SSSM/hSSSM locations in each tagging year/season (CA = California, OR = Oregon, WA = Washington). The total number of SSSM/hSSSM locations and the number of locations available for the calculations are given. The migrating portions of tracks, as well as locations that occurred on land and those with high estimation uncertainty were removed prior to analysis.**

| | Total | PWDIST (km) | | | PWSPEED (km/h) | | |
|---|---|---|---|---|---|---|---|
| **Season** | **# locs** | **# locs** | **Median** | **MAD** | **# locs** | **Median** | **MAD** |
| **Humpback whales** | | | | | | | |
| 2004CA | 253 | 247 | 21.6 | 14.8 | 247 | 0.90 | 0.62 |
| 2005CA | 91 | 88 | 22.3 | 19.0 | 88 | 0.93 | 0.79 |
| 2005CA2 | 116 | 113 | 33.8 | 25.0 | 113 | 1.41 | 1.04 |
| 2016OR | 24 | 24 | 24.6 | 20.3 | 24 | 1.03 | 0.85 |
| 2017CA | 462 | 460 | 14.8 | 13.4 | 460 | 0.62 | 0.56 |
| 2017OR | 196 | 195 | 22.5 | 23.0 | 195 | 0.94 | 0.96 |
| 2018OR | 111 | 111 | 14.7 | 12.6 | 111 | 0.61 | 0.53 |
| 2018WA | 560 | 559 | 13.9 | 12.5 | 559 | 0.58 | 0.52 |
| **Total** | **1813** | **1797** | **17.3** | **15.7** | **1797** | **0.72** | **0.65** |
| **Fin whale** | | | | | | | |
| 2018OR | 24 | 24 | 19.3 | 12.7 | 24 | 0.80 | 0.53 |

KEY: km = kilometers, km/h = kilometers per hour; locs = locations; MAD = Median Absolute Deviation; PWDIST = Pairwise Distance; PWSPEED = Pairwise Speed; # = number.

**Table 22. Summary statistics (median and MAD) for PWDIST and PWSPEED computed for each behavioral mode (BMODE). The total number of SSSM/hSSSM locations and the number of locations available for the calculations are given. The migrating portions of tracks, as well as locations that occurred on land and those with high estimation uncertainty were removed prior to analysis.**

| | Total | PWDIST (km) | | | PWSPEED (km/h) | | |
|---|---|---|---|---|---|---|---|
| **BMODE** | **# locs** | **# locs** | **Median** | **MAD** | **# locs** | **Median** | **MAD** |
| **Humpback whales** | | | | | | | |
| Transiting | 114 | 114 | 65.8 | 32.1 | 114 | 2.74 | 1.34 |
| Uncertain | 221 | 211 | 32.9 | 25.1 | 211 | 1.37 | 1.05 |
| ARS | 1478 | 1472 | 14.6 | 12.3 | 1472 | 0.61 | 0.51 |
| **Total** | **1813** | **1797** | **17.3** | **15.7** | **1797** | **0.72** | **0.65** |
| **Fin whale** | | | | | | | |
| Transiting | NA | NA | NA | NA | NA | NA | NA |
| Uncertain | 3 | 3 | 29.3 | 32.8 | 3 | 1.22 | 1.37 |
| ARS | 21 | 21 | 19.3 | 7.6 | 21 | 0.80 | 0.32 |
| **Total** | **24** | **24** | **19.3** | **12.7** | **24** | **0.80** | **0.53** |

KEY: ARS = Area Restricted Search; km = kilometers, km/h = kilometers per hour; locs = locations; MAD = Median Absolute Deviation; NA = Not Applicable; PWDIST = Pairwise Distance; PWSPEED = Pairwise Speed; # = number.

**Table 23. Summary statistics (median and MAD) for the seafloor relief variables obtained for the SSSM/hSSSM locations in each tagging year/season (CA = California, OR = Oregon, WA = Washington). The total number of SSSM/hSSSM locations and the number of locations that received an annotated value for the different variables are given. The migrating portions of tracks, as well as locations that occurred on land and those with high estimation uncertainty were removed prior to analysis.**

| | Total | DEPTH (m) | | | SLOPE (deg) | | | ASPECT (deg) | | | DISTSHELF (km) | | | DISTSHORE (km) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Season | # locs | # locs | Median | MAD | # locs | Median | MAD | # locs | Median | MAD | # locs | Median | MAD | # locs | Median | MAD |
| **Humpback whales** | | | | | | | | | | | | | | | | |
| 2004CA | 253 | 248 | -113.0 | 75.6 | 248 | 0.37 | 0.44 | 248 | 233.6 | 27.4 | 248 | 9.2 | 8.8 | 248 | 28.2 | 13.2 |
| 2005CA | 91 | 88 | -240.0 | 292.8 | 88 | 1.05 | 1.12 | 88 | 235.8 | 36.0 | 88 | 18.9 | 23.5 | 88 | 26.5 | 27.0 |
| 2005CA2 | 116 | 115 | -299.0 | 293.6 | 115 | 0.99 | 1.00 | 115 | 258.9 | 31.8 | 115 | 6.3 | 6.2 | 115 | 25.6 | 12.4 |
| 2016OR | 28 | 25 | -112.0 | 38.6 | 25 | 0.24 | 0.19 | 25 | 260.9 | 52.1 | 25 | 11.6 | 12.2 | 25 | 26.9 | 18.3 |
| 2017CA | 484 | 476 | -119.0 | 69.7 | 476 | 0.53 | 0.57 | 476 | 235.5 | 29.9 | 476 | 7.2 | 8.2 | 476 | 27.3 | 16.2 |
| 2017OR | 202 | 202 | -185.5 | 110.5 | 202 | 0.73 | 0.81 | 202 | 264.8 | 42.9 | 202 | 5.3 | 6.0 | 202 | 35.6 | 22.6 |
| 2018OR | 121 | 121 | -143.0 | 41.5 | 121 | 0.37 | 0.29 | 121 | 279.0 | 39.5 | 121 | 7.2 | 7.2 | 121 | 32.2 | 12.4 |
| 2018WA | 598 | 591 | -183.0 | 74.1 | 591 | 0.61 | 0.55 | 591 | 193.6 | 55.1 | 591 | 3.1 | 2.9 | 591 | 9.0 | 6.6 |
| **Total** | **1893** | **1866** | **-153.0** | **93.4** | **1866** | **0.57** | **0.61** | **1866** | **230.8** | **52.2** | **1866** | **5.1** | **5.8** | **1866** | **23.7** | **19.6** |
| **Fin whale** | | | | | | | | | | | | | | | | |
| 2018OR | 26 | 26 | -2378.0 | 1112.7 | 26 | 0.57 | 0.43 | 26 | 239.2 | 66.9 | 26 | 74.9 | 102.7 | 26 | 94.3 | 94.2 |

KEY: deg = degrees; DISTSHELF = Distance to the 200-m isobath; DISTSHORE = Distance to Shore; km = kilometers; locs = locations; m = meters, MAD = Median Absolute Deviation; # = number.

**Table 24. Summary statistics (median and MAD) for the seafloor relief variables obtained for the SSSM/hSSSM locations computed for each behavioral mode (BMODE). The total number of SSSM/hSSSM locations and the number of locations that received an annotated value for the different variables are given. The migrating portions of tracks, as well as locations that occurred on land and those with high estimation uncertainty were removed prior to analysis.**

| | Total | DEPTH (m) | | | SLOPE (deg) | | | ASPECT (deg) | | | DISTSHELF (km) | | | DISTSHORE (km) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BMODE | # locs | # locs | Median | MAD | # locs | Median | MAD | # locs | Median | MAD | # locs | Median | MAD | # locs | Median | MAD |
| **Humpback whales** | | | | | | | | | | | | | | | | |
| Transiting | 114 | 113 | -376.0 | 413.7 | 113 | 0.74 | 0.83 | 113 | 245.6 | 64.6 | 113 | 13.5 | 14.8 | 113 | 39.2 | 31.3 |
| Uncertain | 227 | 219 | -191.0 | 158.6 | 219 | 0.79 | 0.87 | 219 | 243.5 | 46.4 | 219 | 10.4 | 11.2 | 219 | 28.7 | 17.7 |
| ARS | 1552 | 1534 | -146.0 | 84.5 | 1534 | 0.55 | 0.58 | 1534 | 227.4 | 52.6 | 1534 | 4.6 | 5.0 | 1534 | 21.8 | 18.9 |
| **Total** | **1893** | **1866** | **-153.0** | **93.4** | **1866** | **0.57** | **0.61** | **1866** | **230.8** | **52.2** | **1866** | **5.1** | **5.8** | **1866** | **23.7** | **19.6** |
| **Fin whale** | | | | | | | | | | | | | | | | |
| Transiting | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Uncertain | 5 | 5 | -1409.0 | 1500.4 | 5 | 0.25 | 0.05 | 5 | 209.1 | 139.2 | 5 | 43.4 | 47.7 | 5 | 83.3 | 74.5 |
| ARS | 21 | 21 | -2387.0 | 1067.5 | 21 | 0.72 | 0.48 | 21 | 241.8 | 59.7 | 21 | 110.1 | 95.9 | 21 | 139.8 | 75.1 |
| **Total** | **26** | **26** | **-2378.0** | **1112.7** | **26** | **0.57** | **0.43** | **26** | **239.2** | **66.9** | **26** | **74.9** | **102.7** | **26** | **94.3** | **94.2** |

KEY: ARS = Area Restricted Search, deg = degrees; DISTSHELF = Distance to the 200-m isobath; DISTSHORE = Distance to Shore; km = kilometers; locs = locations; m = meters, MAD = Median Absolute Deviation; NA = Not Applicable; # = number.

**Table 25. Summary statistics (median and MAD) for the remotely sensed oceanographic variables obtained for the SSSM/hSSSM locations in each tagging year/season (CA = California, OR = Oregon, WA = Washington). The total number of SSSM/hSSSM locations and the number of locations that received an annotated value for the different variables are given for each year/season. The migrating portions of tracks, as well as locations that occurred on land and those with high estimation uncertainty were removed prior to analysis.**

| | Total | SST (°C) | | | SSTG (°C/deg) | | | CHL (mg/m$^3$) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Season | # locs | # locs | Median | MAD | # locs | Median | MAD | # locs | Median | MAD |
| **Humpback whales** | | | | | | | | | | |
| 2004CA | 253 | 253 | 14.5 | 1.1 | 253 | 0.18 | 0.09 | 253 | 2.54 | 2.61 |
| 2005CA | 91 | 91 | 14.2 | 0.8 | 91 | 0.16 | 0.07 | 90 | 2.61 | 2.61 |
| 2005CA2 | 116 | 116 | 12.3 | 0.7 | 116 | 0.15 | 0.08 | 112 | 1.08 | 0.80 |
| 2016OR | 28 | 28 | 13.5 | 0.9 | 28 | 0.30 | 0.16 | 28 | 2.59 | 1.89 |
| 2017CA | 484 | 484 | 15.5 | 1.2 | 484 | 0.20 | 0.11 | 428 | 1.06 | 0.84 |
| 2017OR | 202 | 202 | 12.2 | 1.4 | 202 | 0.17 | 0.11 | 201 | 1.24 | 1.08 |
| 2018OR | 121 | 121 | 13.8 | 1.3 | 121 | 0.26 | 0.15 | 121 | 1.08 | 0.45 |
| 2018WA | 598 | 598 | 12.6 | 0.9 | 598 | 0.12 | 0.07 | 529 | 1.43 | 0.98 |
| **Total** | **1893** | **1893** | **13.6** | **1.9** | **1893** | **0.17** | **0.10** | **1762** | **1.39** | **1.09** |
| **Fin whale** | | | | | | | | | | |
| 2018OR | 26 | 22 | 14.7 | 1.6 | 22 | 0.20 | 0.09 | 22 | 1.08 | 0.46 |

KEY: deg = degree; locs = locations; MAD = Median Absolute Deviation; mg/m$^3$ = milligrams per cubic meter; °C = degrees Celcius; SST = Sea Surface Temperature; SSTG = Magnitude of Sea Surface Temperature Gradient; # = number.

**Table 26. Summary statistics (median and MAD) for the remotely sensed oceanographic variables obtained for the SSSM/hSSSM locations computed for each behavioral mode (BMODE). The total number of SSSM/hSSSM locations and the number of locations that received an annotated value for the different variables are given. The migrating portions of tracks, as well as locations that occurred on land and those with high estimation uncertainty were removed prior to analysis.**

| | Total | SST (°C) | | | SSTG (°C/deg) | | | CHL (mg/m³) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **BMODE** | **# locs** | **# locs** | **Median** | **MAD** | **# locs** | **Median** | **MAD** | **# locs** | **Median** | **MAD** |
| **Humpback whales** | | | | | | | | | | |
| Transiting | 114 | 114 | 13.4 | 2.0 | 114 | 0.17 | 0.11 | 106 | 0.93 | 0.62 |
| Uncertain | 227 | 227 | 13.4 | 1.6 | 227 | 0.16 | 0.10 | 215 | 1.46 | 1.19 |
| ARS | 1552 | 1552 | 13.7 | 1.9 | 1552 | 0.17 | 0.10 | 1441 | 1.42 | 1.13 |
| **Total** | **1893** | **1893** | **13.6** | **1.9** | **1893** | **0.17** | **0.10** | **1762** | **1.39** | **1.09** |
| **Fin whale** | | | | | | | | | | |
| Transiting | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Uncertain | 5 | 5 | 13.0 | 0.5 | 5 | 0.21 | 0.15 | 5 | 1.58 | 0.80 |
| ARS | 21 | 17 | 14.8 | 1.5 | 17 | 0.20 | 0.07 | 17 | 1.00 | 0.42 |
| **Total** | **26** | **22** | **14.7** | **1.6** | **22** | **0.20** | **0.09** | **22** | **1.08** | **0.46** |

KEY: ARS = Area Restricted Search; deg = degree; locs = locations; MAD = Median Absolute Deviation; mg/m$^3$ = milligrams per cubic meter; °C = degrees Celcius; SST = Sea Surface Temperature; SSTG = Magnitude of Sea Surface Temperature Gradient; # = number.

**Table 27. Frequency and identity of 14 mtDNA haplotypes, including GenBank codes, for the 54 whales sampled off California, Oregon and Washington during 2016-2018. Numbers in parentheses are for the six whales sampled in Oregon in 2018.**

| Haplotype code | GenBank code | California tagging (2017) | Oregon tagging (2016-18) | Washington tagging (2018) |
|---|---|---|---|---|
| A+ | KF477244 | _ | 4 | 7 |
| A- | KF477245 | _ | (2) | 9 |
| A3 | KF477246 | _ | _ | 1 |
| E1 | KF477249 | 1 | 2 | 1 |
| E2 | KF477256 | _ | 1 | _ |
| E4 | KF477258 | 2 | 2 | 2 |
| E5 | KF477259 | _ | _ | 2 |
| E7 | KF477261 | _ | (1) | 1 |
| E13 | KF477253 | 1 | _ | _ |
| E15 | KF477255 | 1 | _ | _ |
| F1 | KF477265 | _ | (1) | 1 |
| F2 | KF477266 | 3 | (2) | _ |
| F3 | KF477271 | 4 | _ | _ |
| F6 | KF477267 | 2 | _ | _ |
| **Total** | | **14** | **15** | **24** |

**Table 28. Results of pairwise tests of differentiation of mtDNA haplotype frequencies between the California, Oregon and Washington tagging samples 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 52. 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 n = 14 | | Oregon tagging n = 15 | | Washington tagging n = 24 | |
|---|---|---|---|---|---|---|---|
| **Population** | **n** | **$F_{ST}$** | **p-value** | **$F_{ST}$** | **p-value** | **$F_{ST}$** | **p-value** |
| **Feeding Areas** | | | | | | | |
| Russia (RUS) | 70 | 0.1159 | 0.0004 | 0.0473 | 0.0298 | 0.1113 | 0.0001 |
| *Western Aleutians (WAL)* | *8* | *0.0385* | *0.1398* | *0.0000* | *0.7766* | *0.0401* | *0.156* |
| Bering (BER) | 114 | 0.1298 | 0.0003 | 0.0026 | 0.3620 | 0.0573 | 0.0069 |
| Eastern Aleutians (EAL) | 36 | 0.0929 | 0.0022 | 0.0000 | 0.6685 | 0.0324 | 0.0777 |
| Western Gulf of Alaska (WGOA) | 96 | 0.1065 | 0.0008 | 0.0000 | 0.5574 | 0.0356 | 0.0267 |
| Northern Gulf of Alaska (NGOA) | 233 | 0.1540 | 0.0002 | 0.0163 | 0.1865 | 0.0000 | 0.3915 |
| Southeast Alaska (SEA) | 183 | 0.3964 | <0.0001 | 0.2318 | 0.0001 | 0.0742 | 0.0198 |
| Northern British Columbia (NBC) | 104 | 0.3321 | <0.0001 | 0.1542 | 0.0042 | 0.0310 | 0.0976 |
| Southern British Columbia/Washington (SBC/WA) | 51 | 0.1144 | 0.0007 | 0.0000 | 0.8256 | 0.0069 | 0.2754 |
| California/Oregon (CA/OR) | 123 | 0.0378 | 0.0597 | 0.0345 | 0.0588 | 0.1524 | <0.0001 |
| **Breeding Grounds** | | | | | | | |
| *Philippines (PHI)* | *13* | *0.1961* | *0.0005* | *0.1330* | *0.0095* | *0.2483* | <0.0001 |
| Okinawa (OK) | 72 | 0.2290 | <0.0001 | 0.1537 | 0.0002 | 0.2427 | <0.0001 |
| Ogasawara (OG) | 159 | 0.1068 | 0.0005 | 0.0320 | 0.0538 | 0.0826 | 0.0002 |
| Hawaii (HI) | 227 | 0.1979 | <0.0001 | 0.0404 | 0.0706 | 0.0019 | 0.3264 |
| Mexico-Archipelago Revillagigedo (MX-AR) | 106 | 0.0998 | 0.0006 | 0.0000 | 0.4485 | 0.0490 | 0.0055 |
| Mexico-Baja California (MX-BC) | 110 | 0.0740 | 0.0018 | 0.0000 | 0.6859 | 0.0422 | 0.0062 |
| Mexico-Mainland (MX-ML) | 62 | 0.0678 | 0.0044 | 0.0000 | 0.8389 | 0.0525 | 0.0041 |
| Central America (CENTAM) | 36 | 0.0559 | 0.0586 | 0.0772 | 0.0165 | 0.2106 | <0.0001 |

KEY: n = sample size.

**Table 29. The relative likelihood of assignment for each biopsy-sampled whale 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 # | Lab ID | Sex | Assignment Likelihood to DPS | | | |
|---|---|---|---|---|---|---|
| | | | Western Pacific | Hawaii | Mexico-ML/AR | Central America |
| **Washington** | | | | | | |
| untagged | /Mno18WA001 | Male | 0.35 | **96.86** | 2.79 | 0.00 |
| untagged | /Mno18WA002 | Male | 0.00 | **99.35** | 0.65 | 0.00 |
| untagged | /Mno18WA003 and Mno18WA006 | Female | 7.51 | 2.86 | **87.00** | 2.64 |
| untagged | /Mno18WA004 | Male | 0.02 | **86.96** | 13.01 | 0.01 |
| untagged | /Mno18WA005 | Male | 23.41 | 16.64 | **59.93** | 0.03 |
| untagged | /Mno18WA007 | Male | 1.82 | 2.21 | **95.92** | 0.06 |
| 10825 | /Mno18WA008 | Male | 0.00 | 0.01 | 29.26 | **70.73** |
| 10836 | /Mno18WA009 | Male | 1.11 | **93.60** | 5.29 | 0.00 |
| 10839 | /Mno18WA010 | Female | 6.63 | **64.20** | 29.17 | 0.00 |
| 23029 | /Mno18WA011 | Female | 6.45 | **67.56** | 25.99 | 0.00 |
| 23039 | /Mno18WA012 | Male | 1.46 | **91.73** | 6.81 | 0.00 |
| 4177 | /Mno18WA013 | Male | 1.97 | **89.69** | 8.34 | 0.00 |
| 5640 | /Mno18WA014 | Male | 2.84 | **96.46** | 0.71 | 0.00 |
| 5650 | /Mno18WA015 | Male | 0.00 | 0.00 | 2.84 | **97.16** |
| 5700 | /Mno18WA016 | Female | 5.92 | 0.35 | 9.03 | **84.71** |
| 5709 | /Mno18WA017 | Male | 11.09 | **46.47** | 42.42 | 0.02 |
| 5719 | /Mno18WA018 | Female | 0.22 | **89.70** | 10.07 | 0.00 |
| 5726 | /Mno18WA019 | Male | 11.13 | **48.18** | 40.68 | 0.00 |
| 5790 | /Mno18WA020 | Male | 1.36 | **89.21** | 9.41 | 0.02 |
| 5801 | /Mno18WA021 | Male | 3.08 | **58.06** | 38.83 | 0.03 |
| 5823 | /Mno18WA022 | Male | 0.05 | **77.76** | 22.20 | 0.00 |
| 5838 | /Mno18WA023 | Male | **88.70** | 2.24 | 7.45 | 1.61 |
| 5883 | /Mno18WA024 | Female | 0.20 | 3.48 | **96.31** | 0.01 |
| 5923 | /Mno18WA025 | Male | 0.00 | 0.00 | 0.01 | **99.99** |
| **Oregon** | | | | | | |
| Untagged | /Mno18OR001 | Male | 0.01 | 0.05 | 0.24 | **99.71** |
| 10834 | /Mno18OR002 | Male | 0.90 | **85.41** | 13.67 | 0.01 |
| 23030 | /Mno18OR003 | Male | 0.50 | **57.97** | 41.51 | 0.02 |
| 23032 | /Mno18OR004 | Male | 0.02 | 0.03 | **96.35** | 3.60 |
| 23035 | /Mno18OR005 | Male | 0.00 | **90.41** | 9.45 | 0.14 |
| 23041 | /Mno18OR006 | Male | 0.07 | 10.61 | **88.37** | 0.96 |

KEY: # = number.

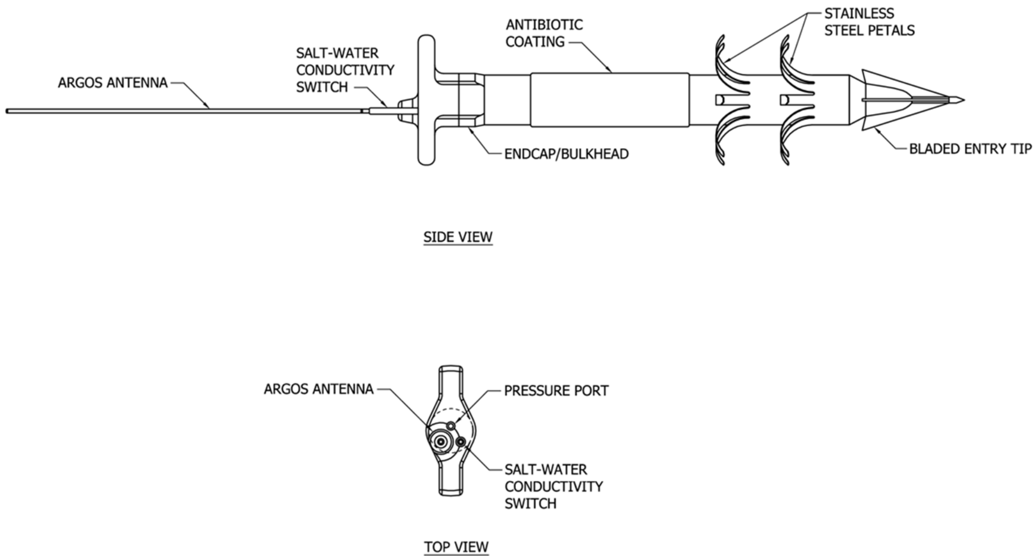


*Figure 1. Schematic diagram of the non-recoverable Telonics RDW-665 DM tag showing the main body, the distal endcap with the antenna and saltwater conductivity switch, as well as the penetrating tip and anchoring system.*

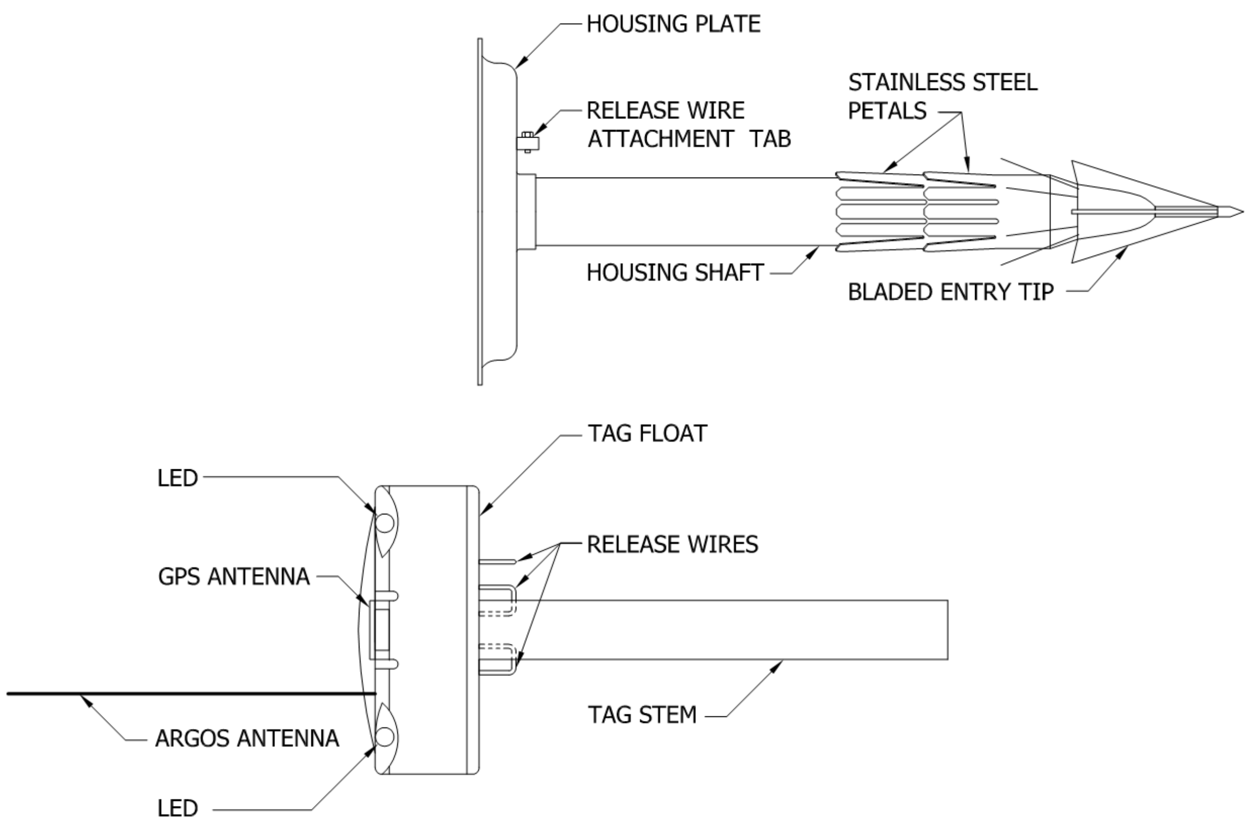


*Figure 2. Schematic diagram of the recoverable Wildlife Computers MK10 Advanced Dive Behavior (ADB) tag (bottom) with the OSU-designed housing (top). The housing shaft is designed for implantation beneath the whale's skin while the plate and tag float sit atop the whale's back.*

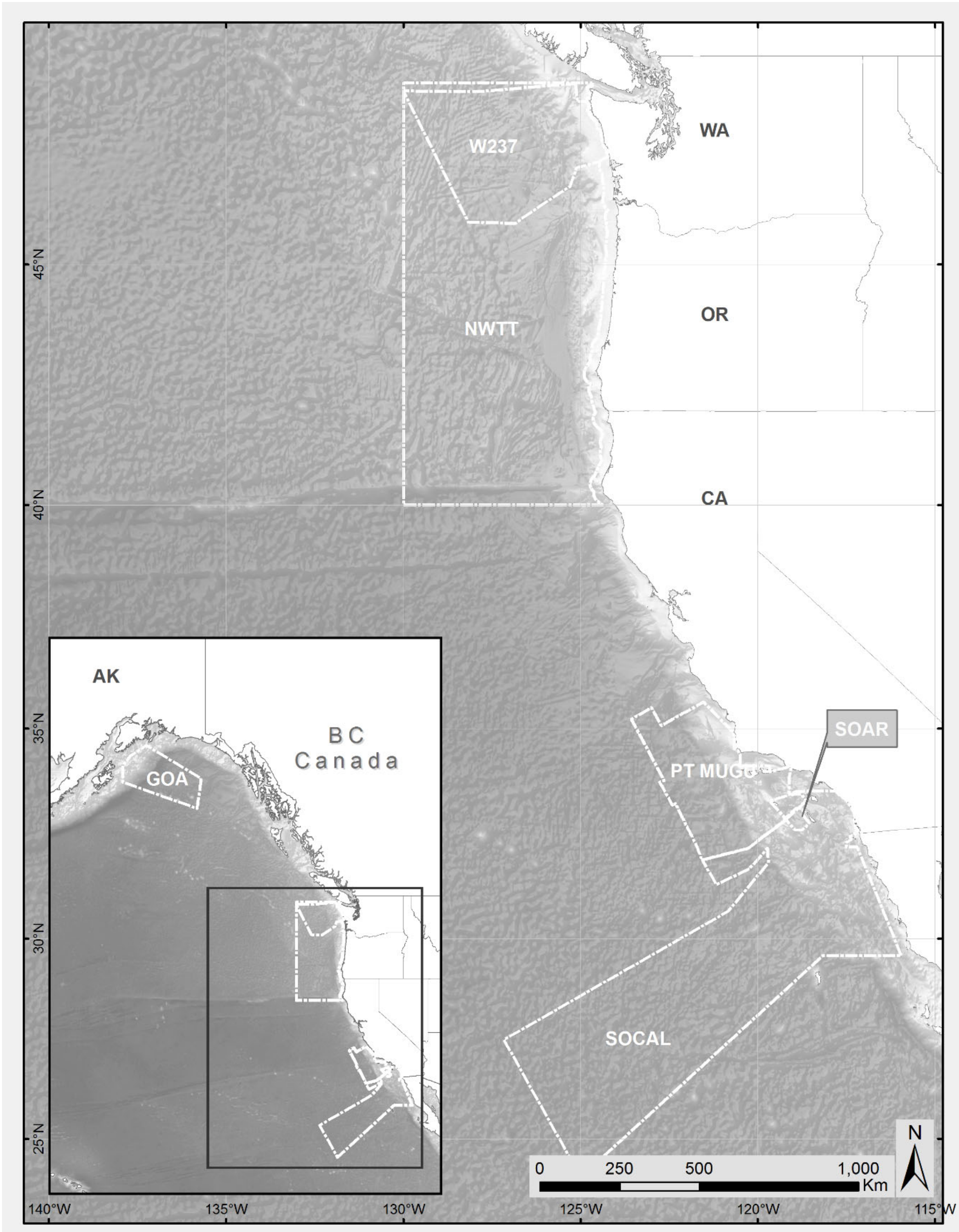


*Figure 3. Map showing the six U.S. Navy Training Areas considered in this report.*

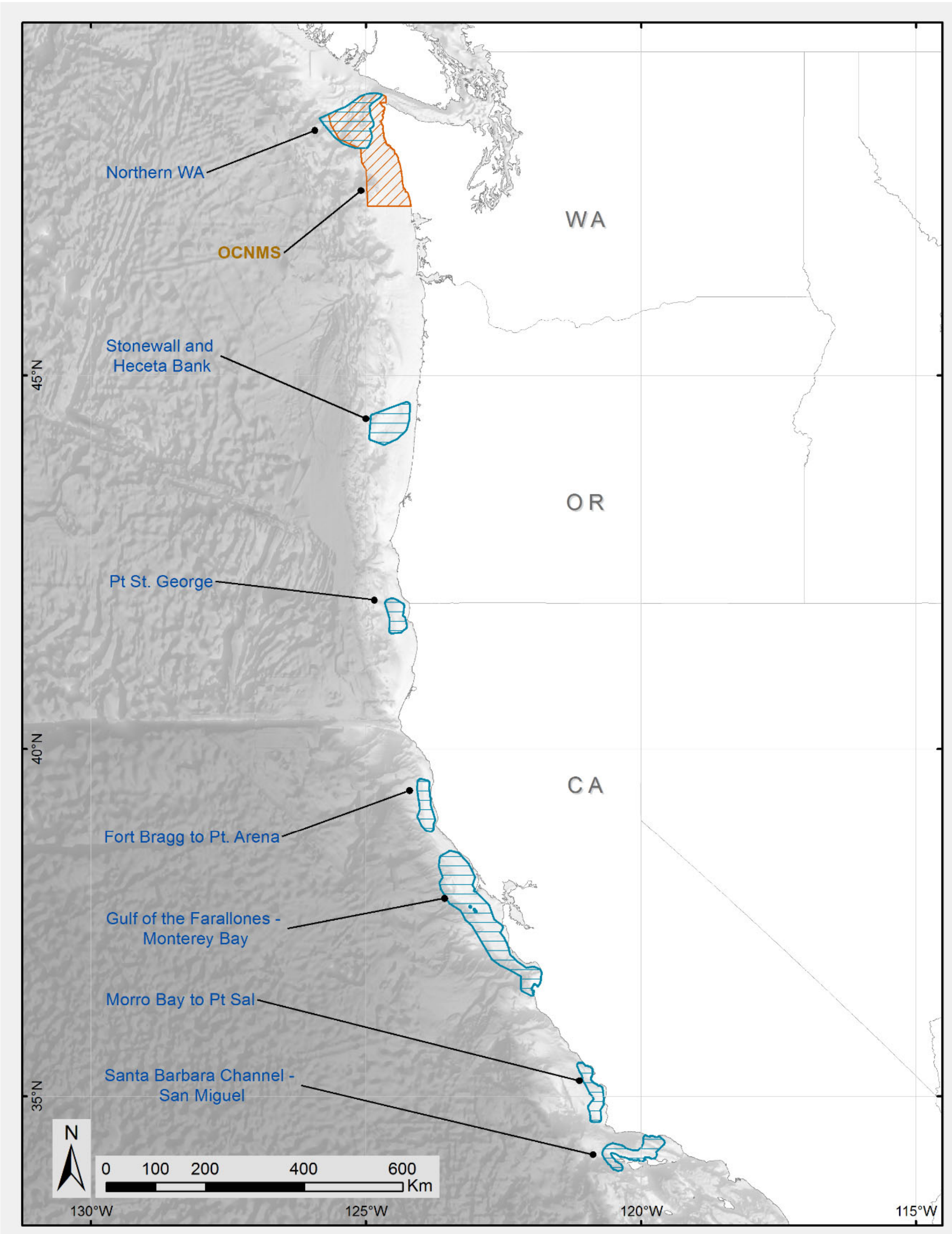


*Figure 4. Map showing the Olympic Coast National Marine Sanctuary (OCNMS) and the seven Biologically Important Areas (BIAs) for humpback whales considered in this report.*

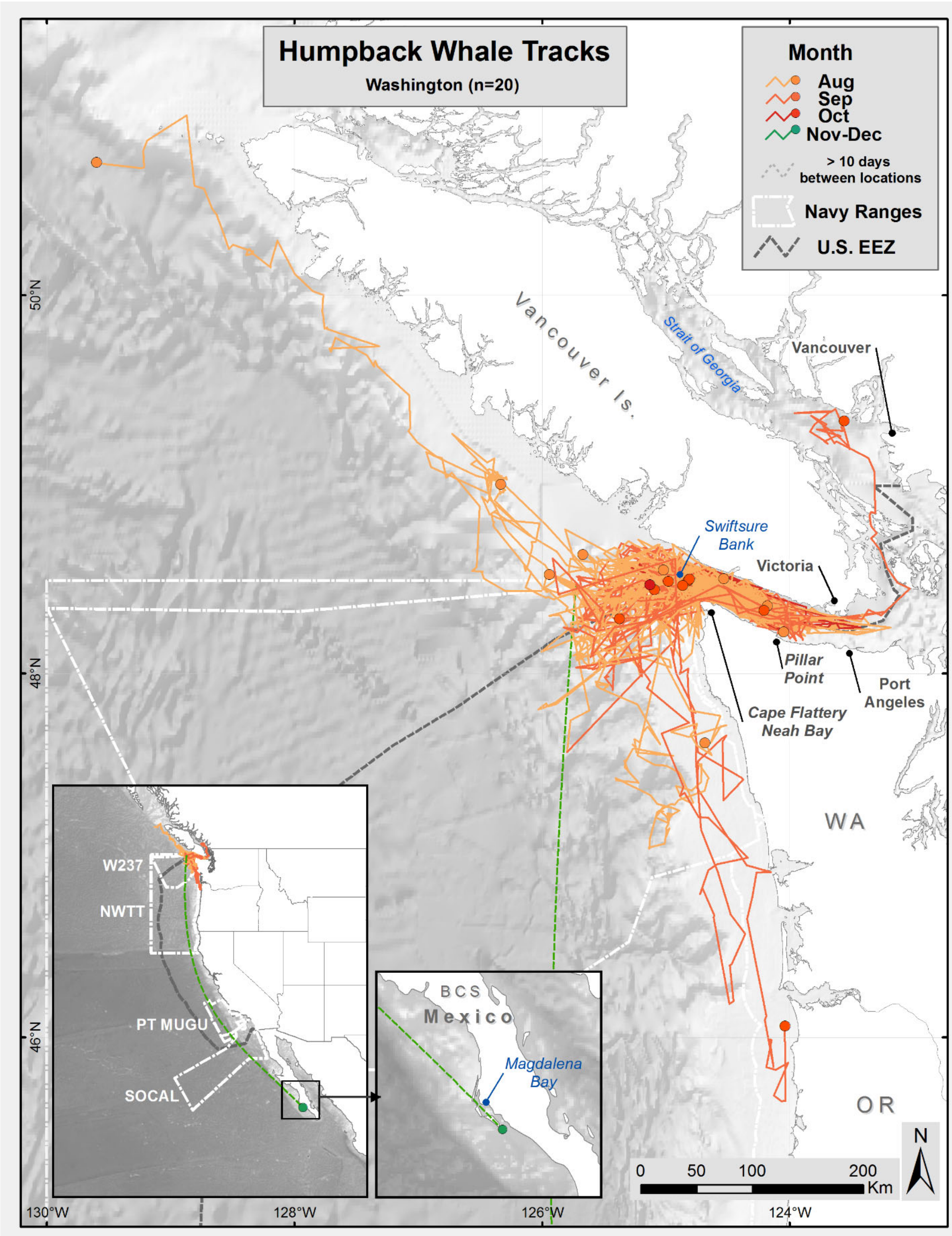


*Figure 5. Satellite-monitored tracks for humpback whales tagged off Washington in August 2018 (1 ADB tag, 9 DM tags, 10 DUR+ tags).*

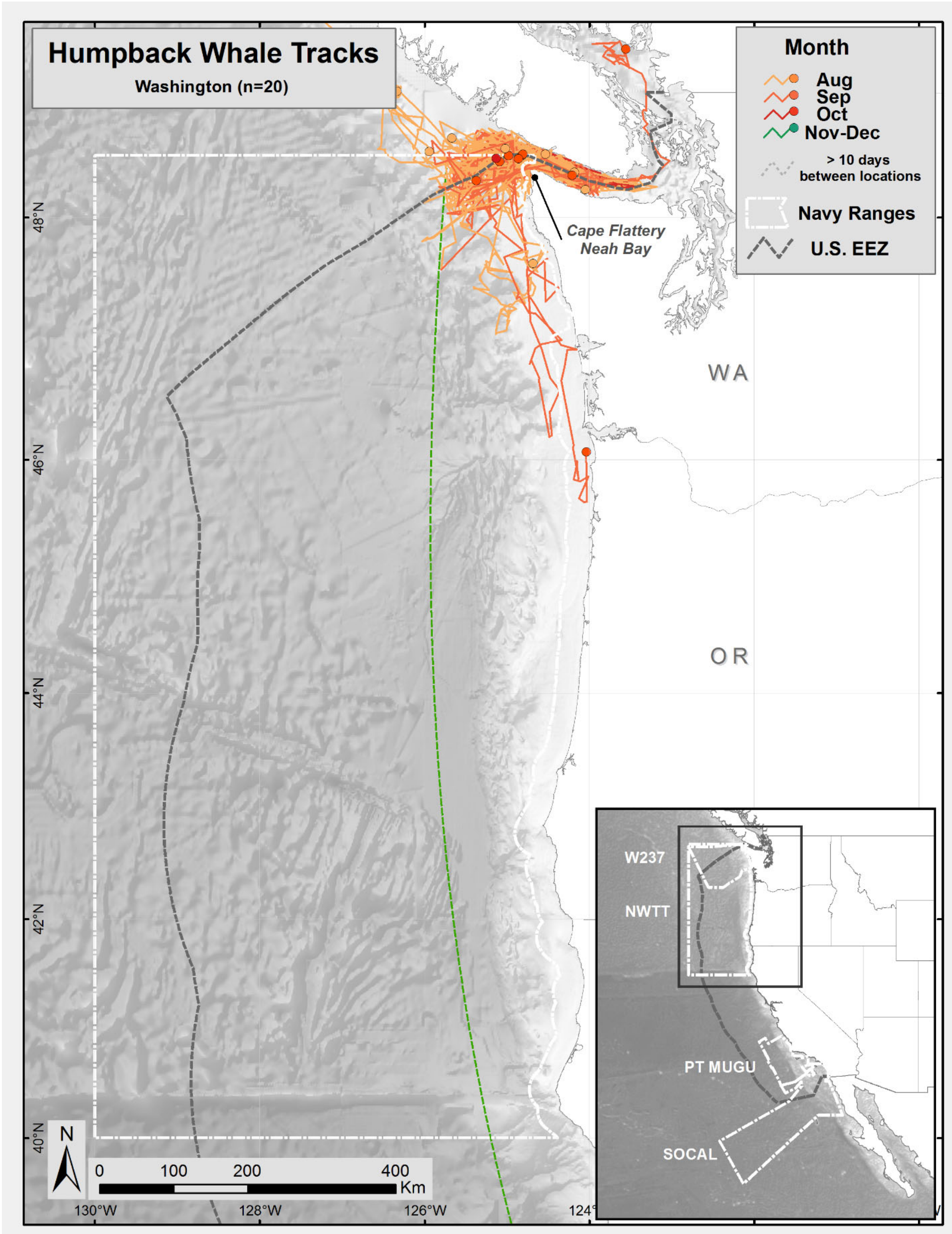


*Figure 6. Satellite-monitored tracks in NWTT for humpback whales tagged off Washington in August 2018 (1 ADB tag, 9 DM tags, 10 DUR+ tags).*

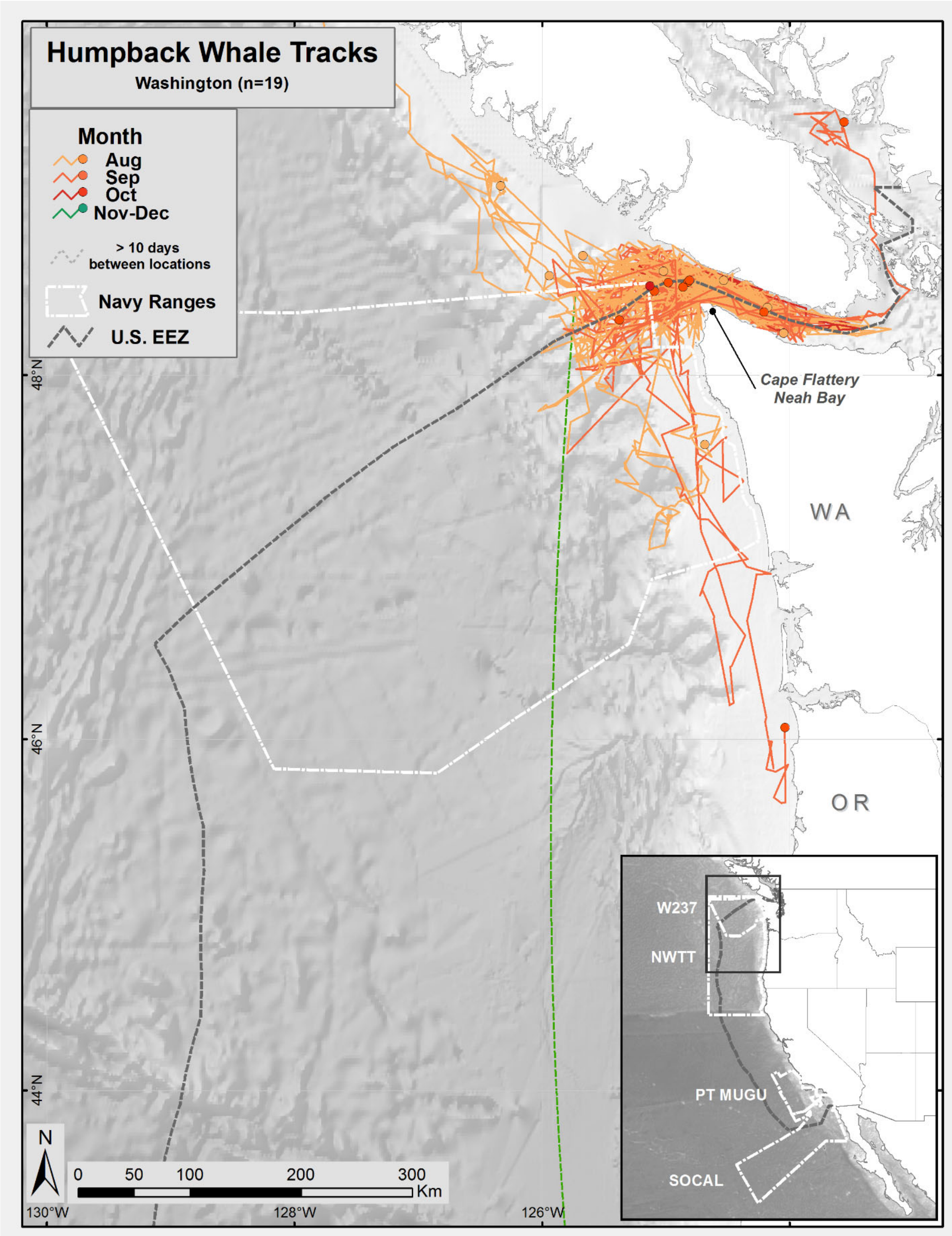


*Figure 7. Satellite-monitored tracks in Area W237 of the NWTT for humpback whales tagged off Washington in August 2018 (1 ADB tag, 8 DM tags, 10 DUR+ tags).*

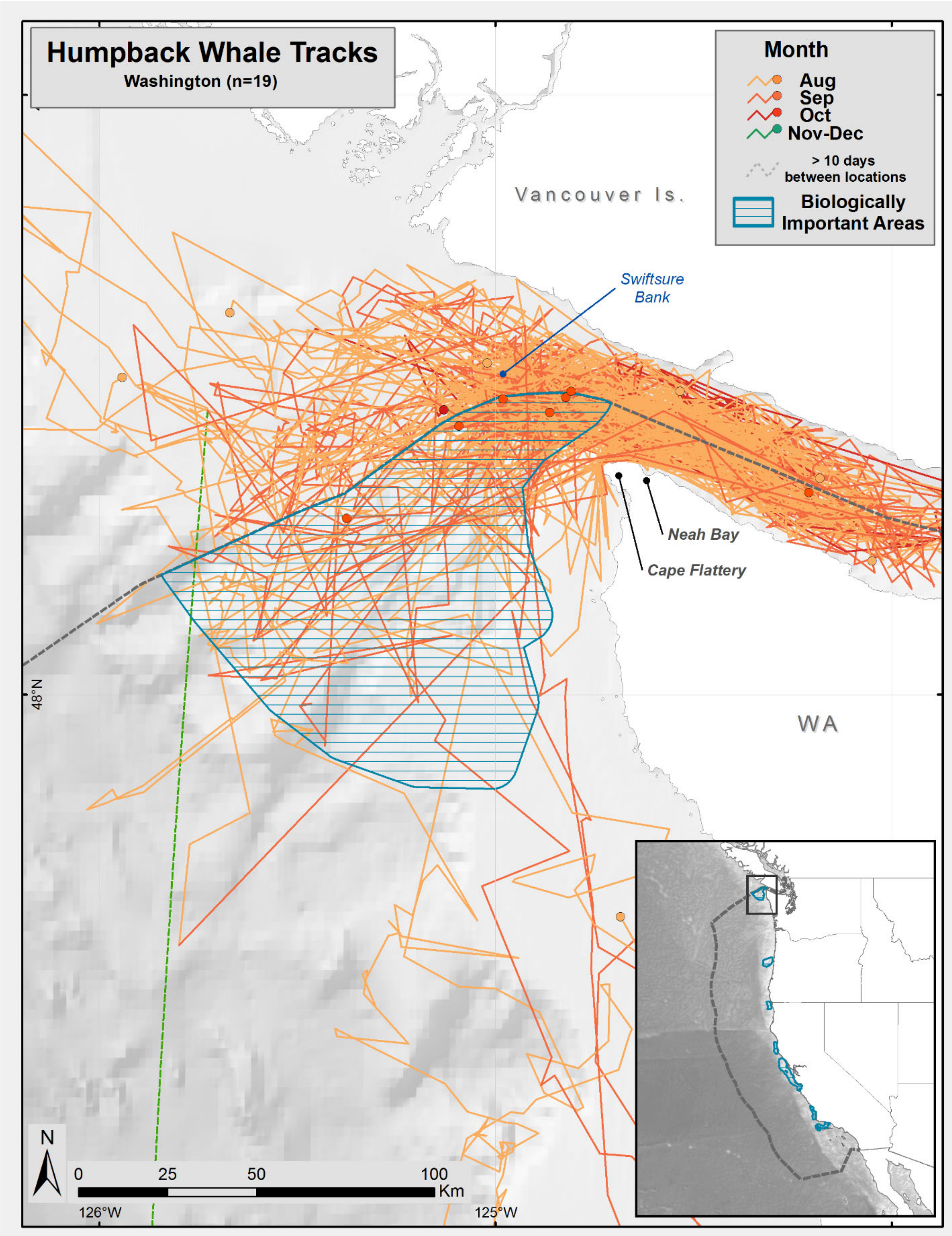


*Figure 8. Satellite-monitored tracks in the Northern Washington BIA for humpback whales tagged off Washington in August 2018 (1 ADB tag, 8 DM tags, 10 DUR+ tags).*

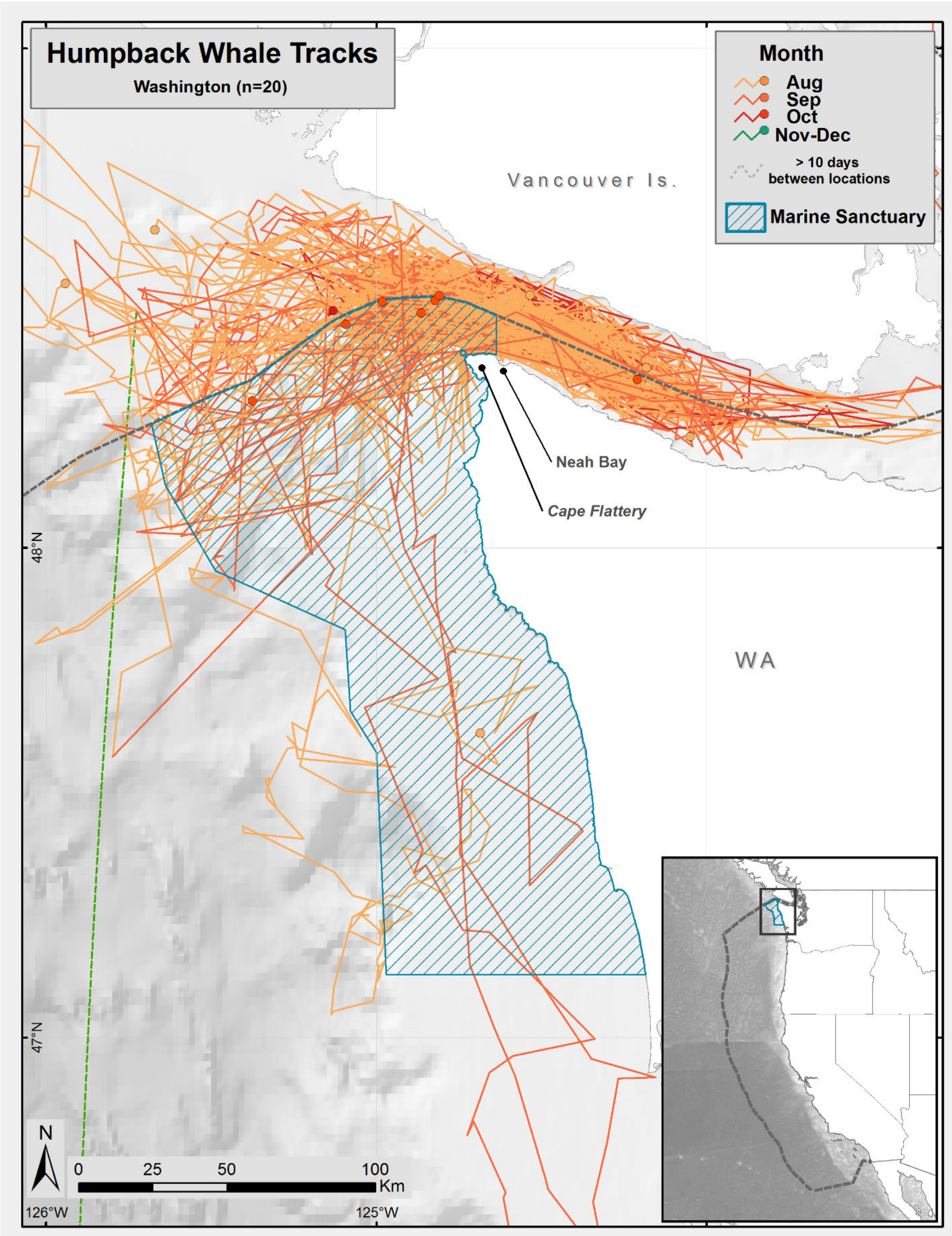


*Figure 9. Satellite-monitored tracks in the Olympic Coast National Marine Sanctuary for humpback whales tagged off Washington in August 2018 (1 ADB tag, 9 DM tags, 10 DUR+ tags).*

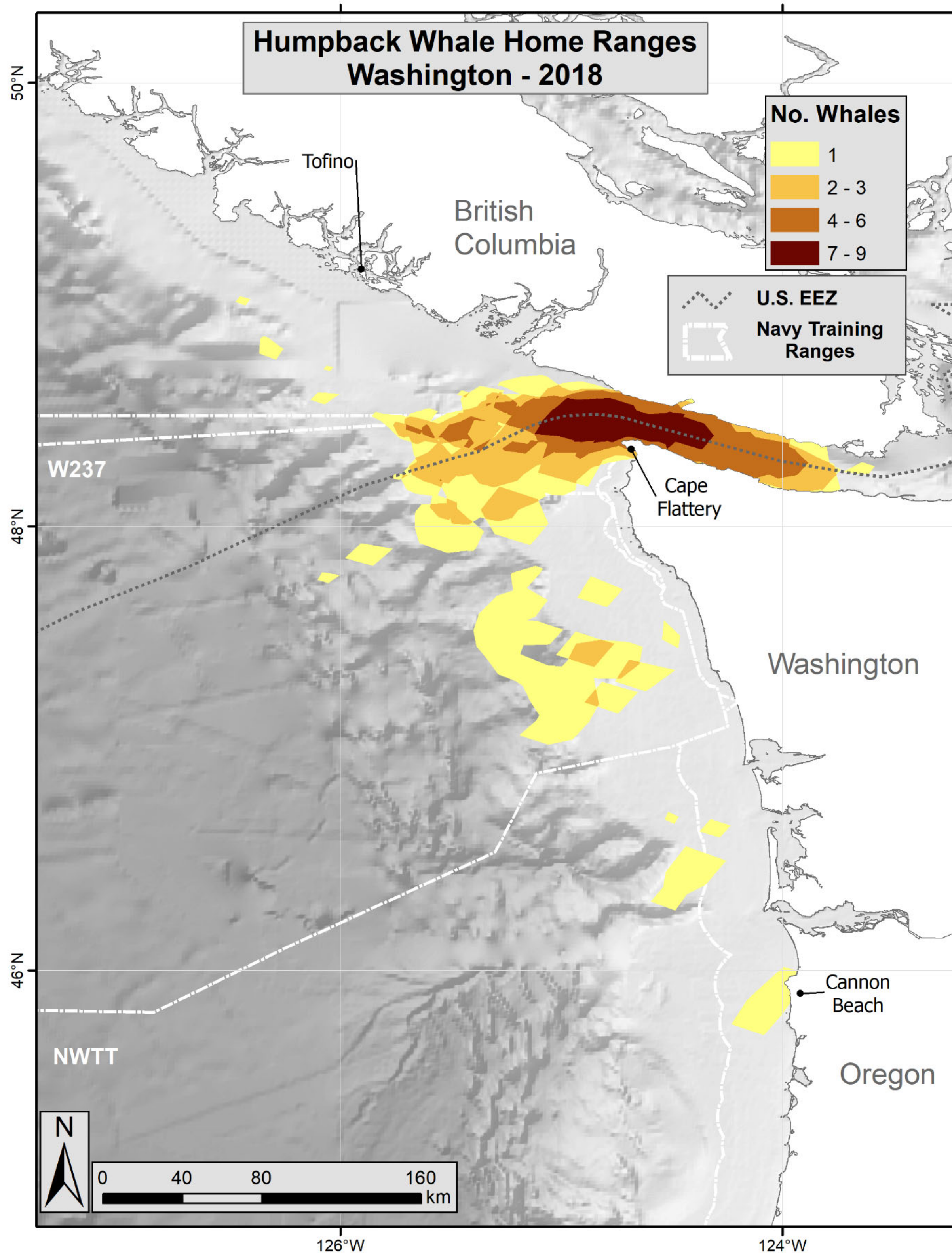


*Figure 10. Feeding area HRs for nine humpback whales tagged off Washington in August 2018. Shading represents the number of individual whales with overlapping HRs.*

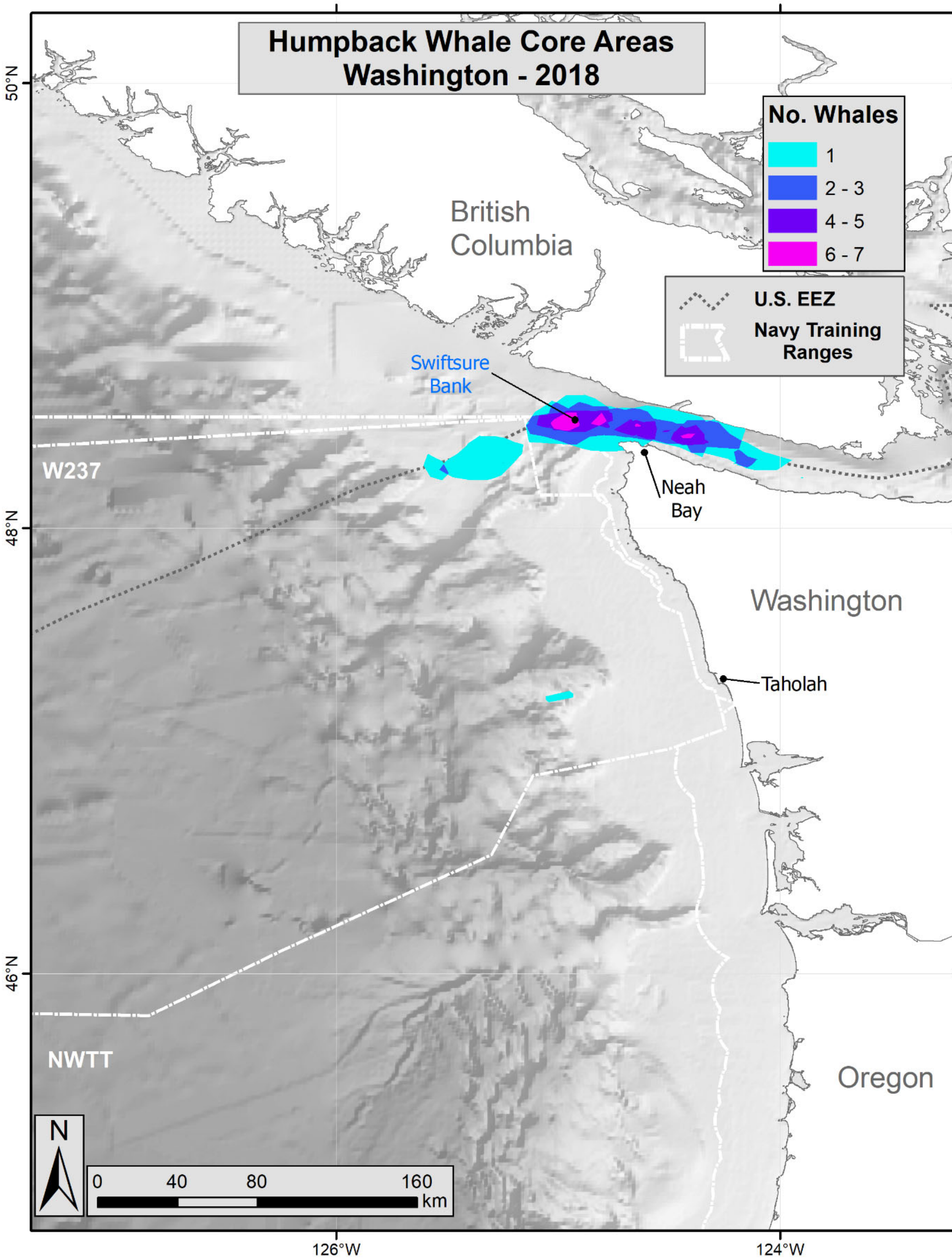


*Figure 11. Feeding area CAs for nine humpback whales tagged off Washington in August 2018. Shading represents the number of individual whales with overlapping CAs.*

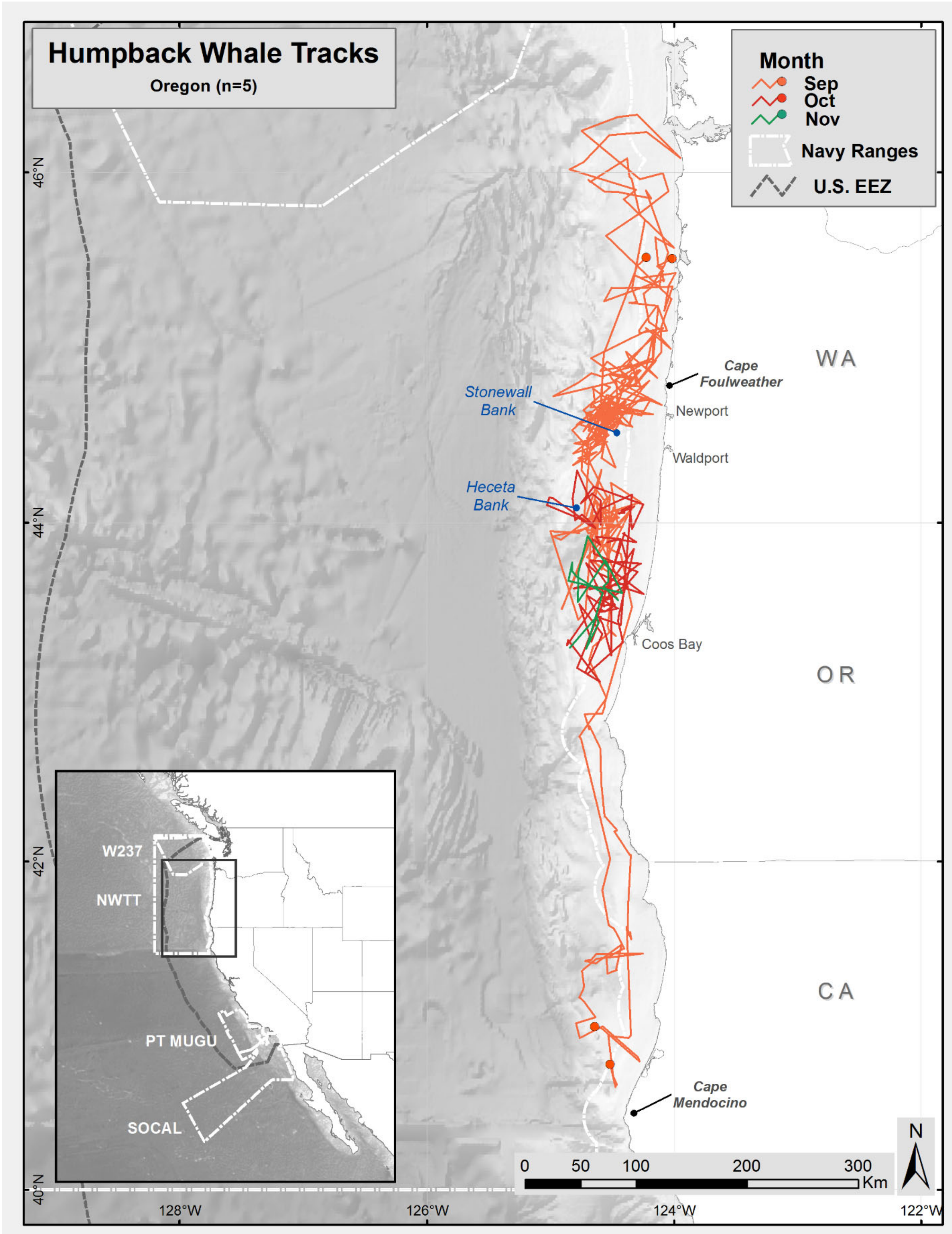


*Figure 12. Satellite-monitored tracks for humpback whales tagged off Oregon in September 2018 (5 DUR+ tags).*

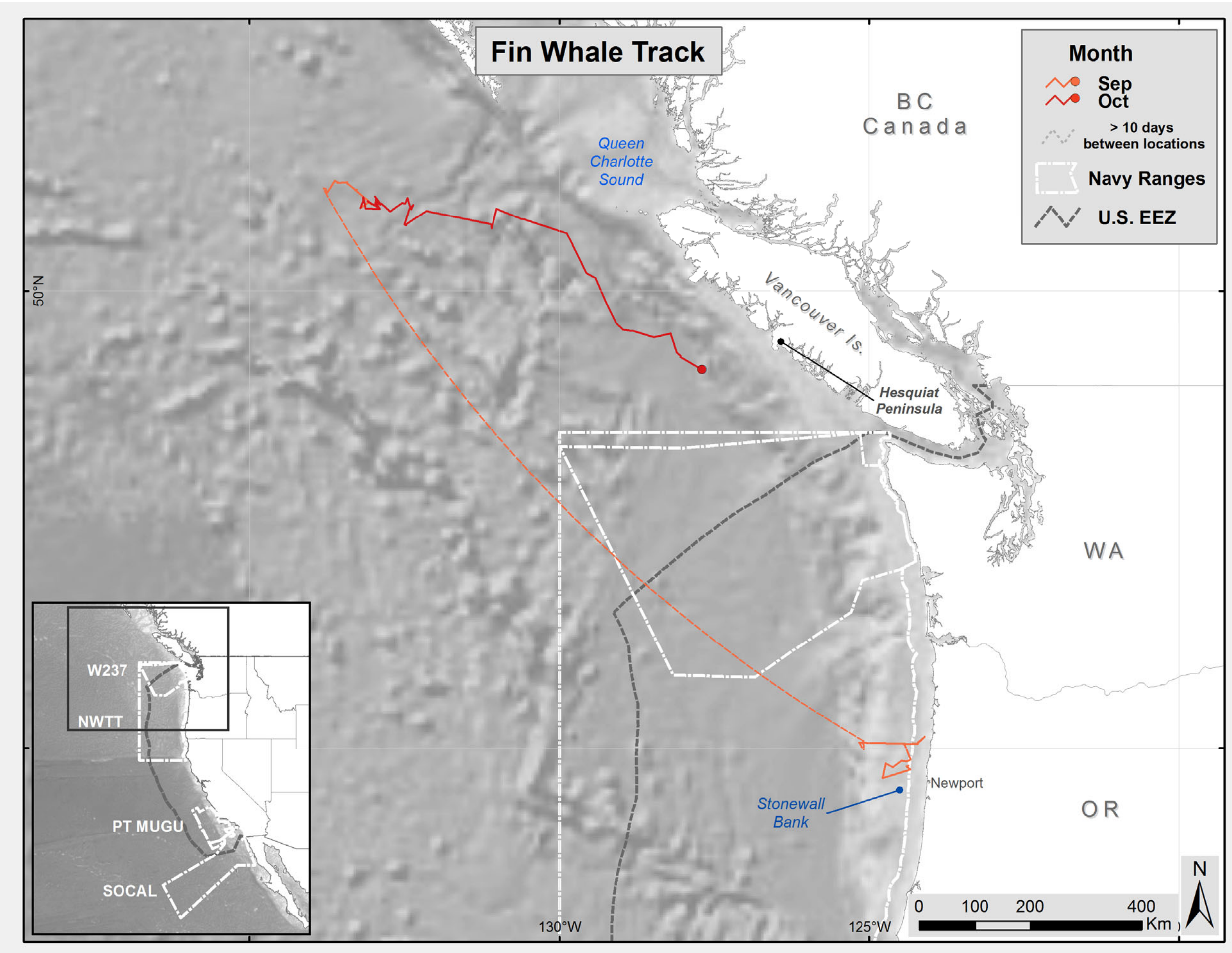


*Figure 13. Satellite-monitored track for a fin whale tagged off Oregon in September 2018 (1 LO tag).*

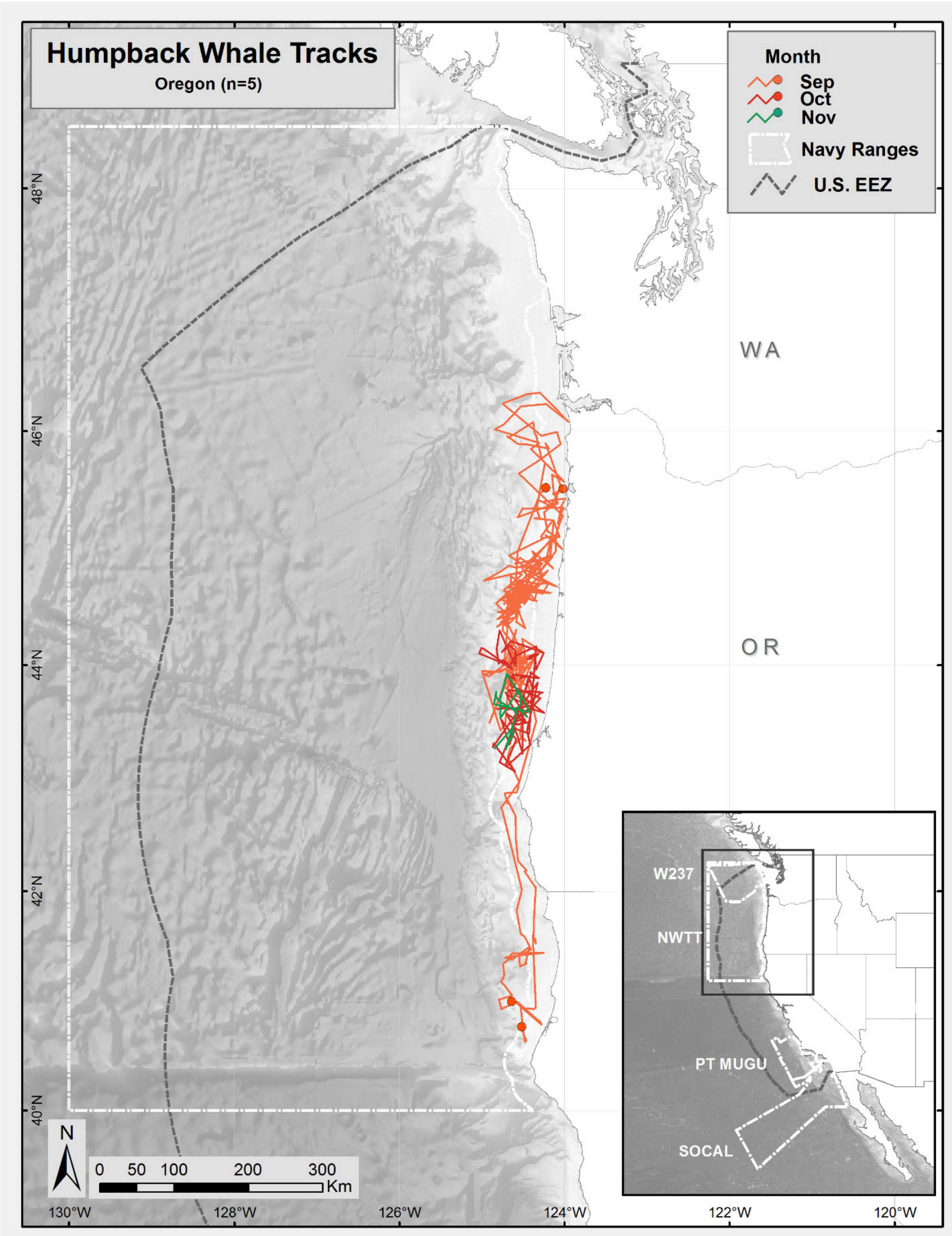


*Figure 14. Satellite-monitored tracks in NWTT for humpback whales tagged off Oregon in September 2018 (5 DUR+ tags).*

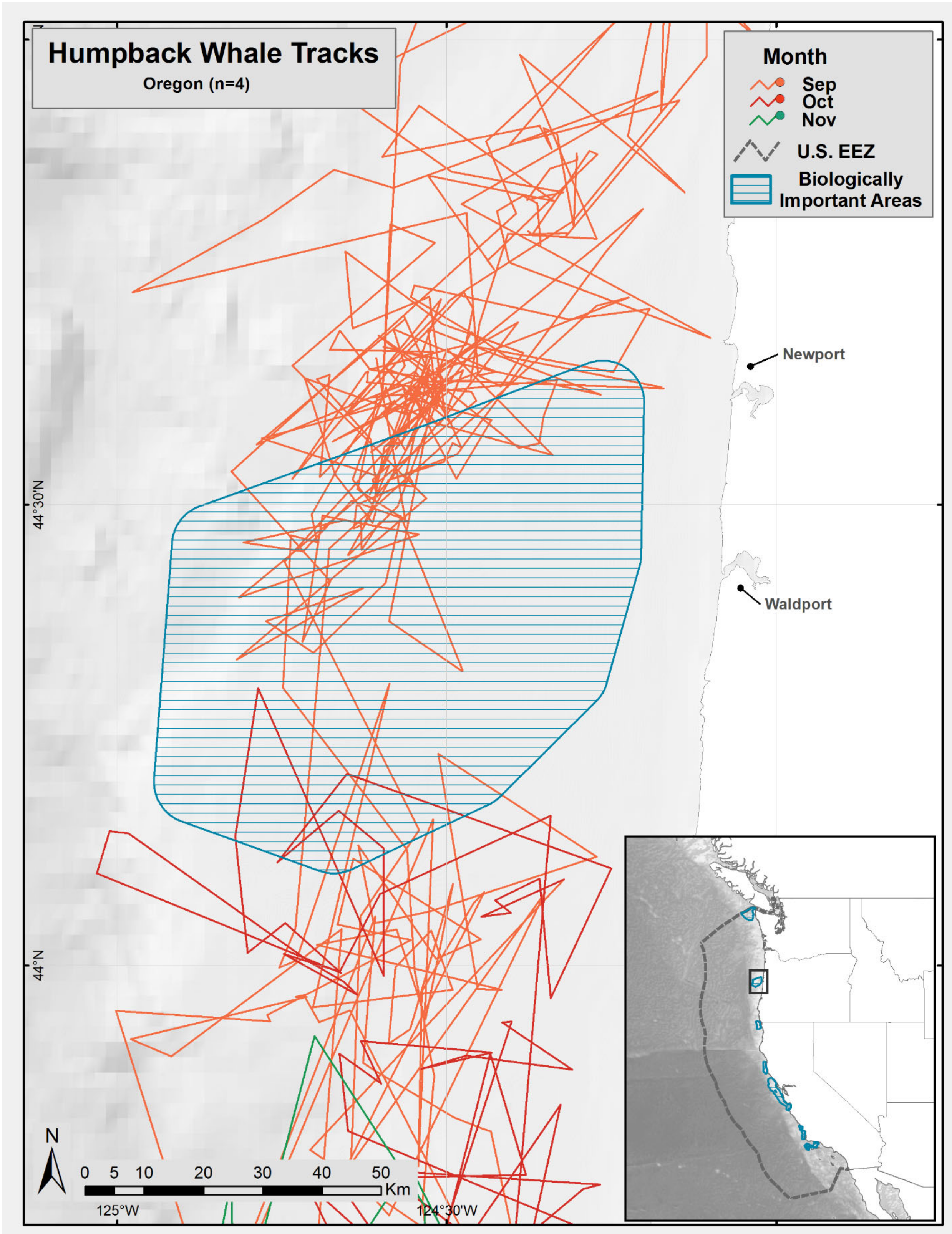


*Figure 15. Satellite-monitored tracks in the Stonewall and Heceta Bank BIA for humpback whales tagged off Oregon in September 2018 (4 DUR+ tags).*

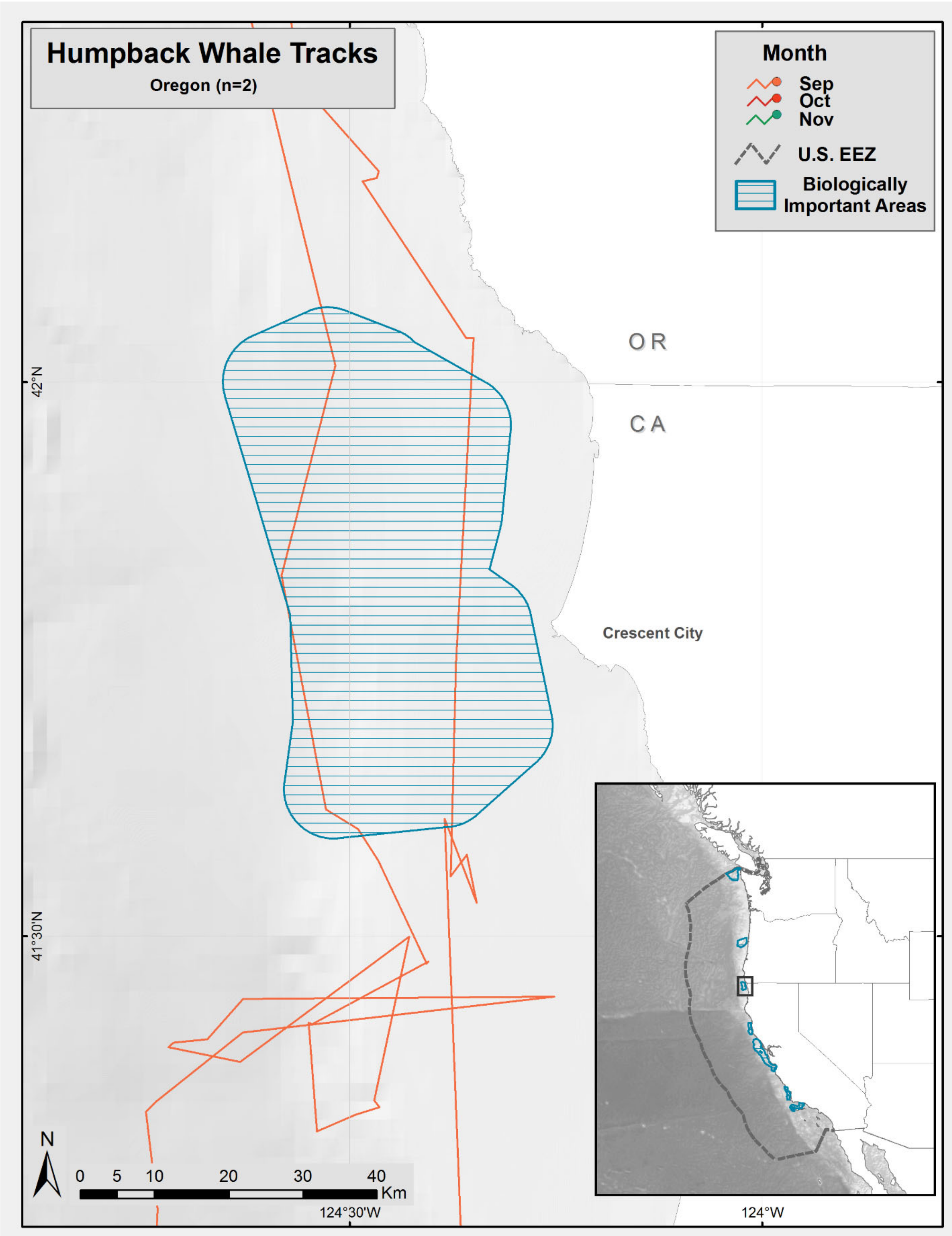


*Figure 16. Satellite-monitored tracks in the Point St. George BIA for humpback whales tagged off Oregon in September 2018 (2 DUR+ tags).*

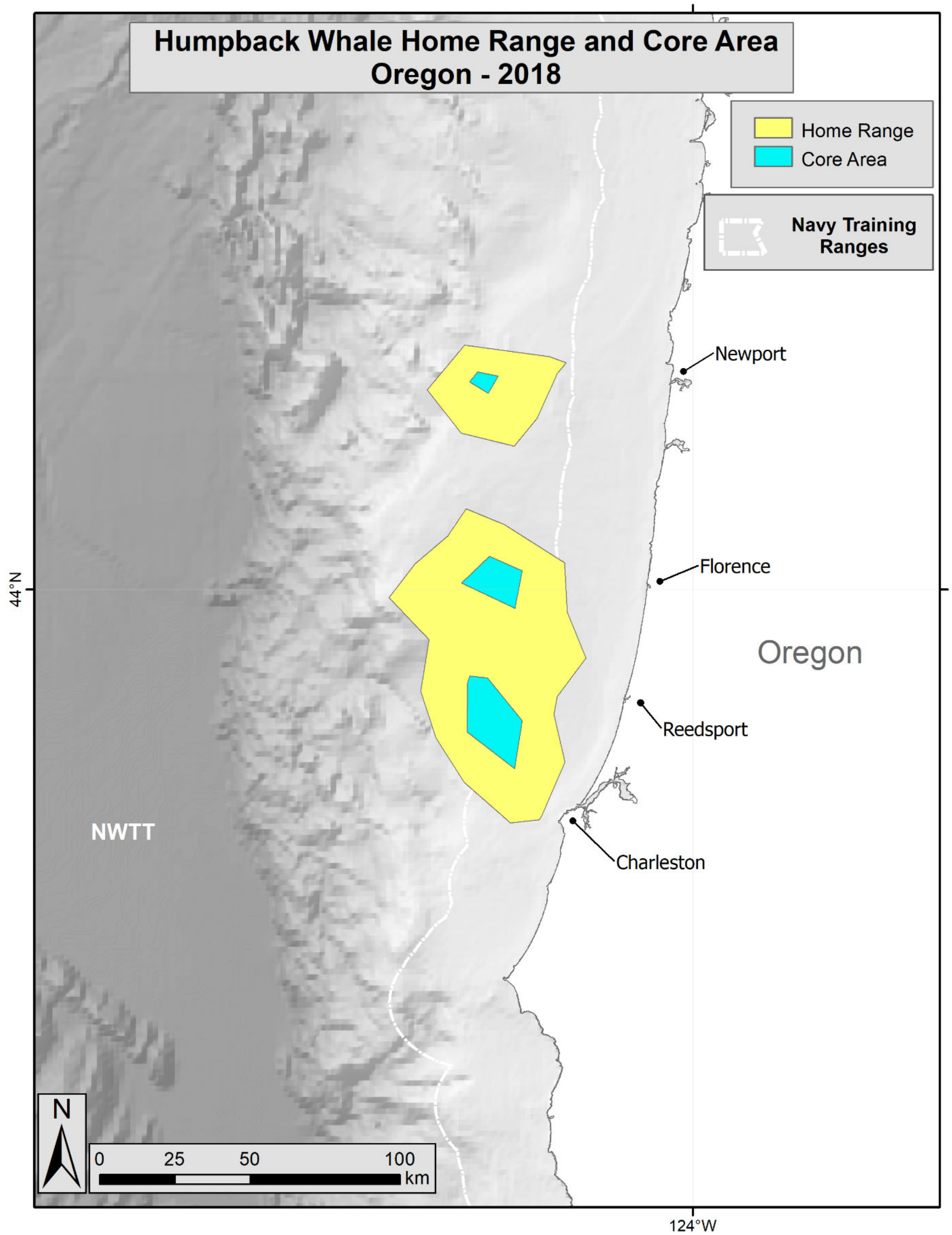


*Figure 17. Feeding area HR (yellow) and CA (blue) for one humpback whale tagged off Oregon in late summer 2018.*

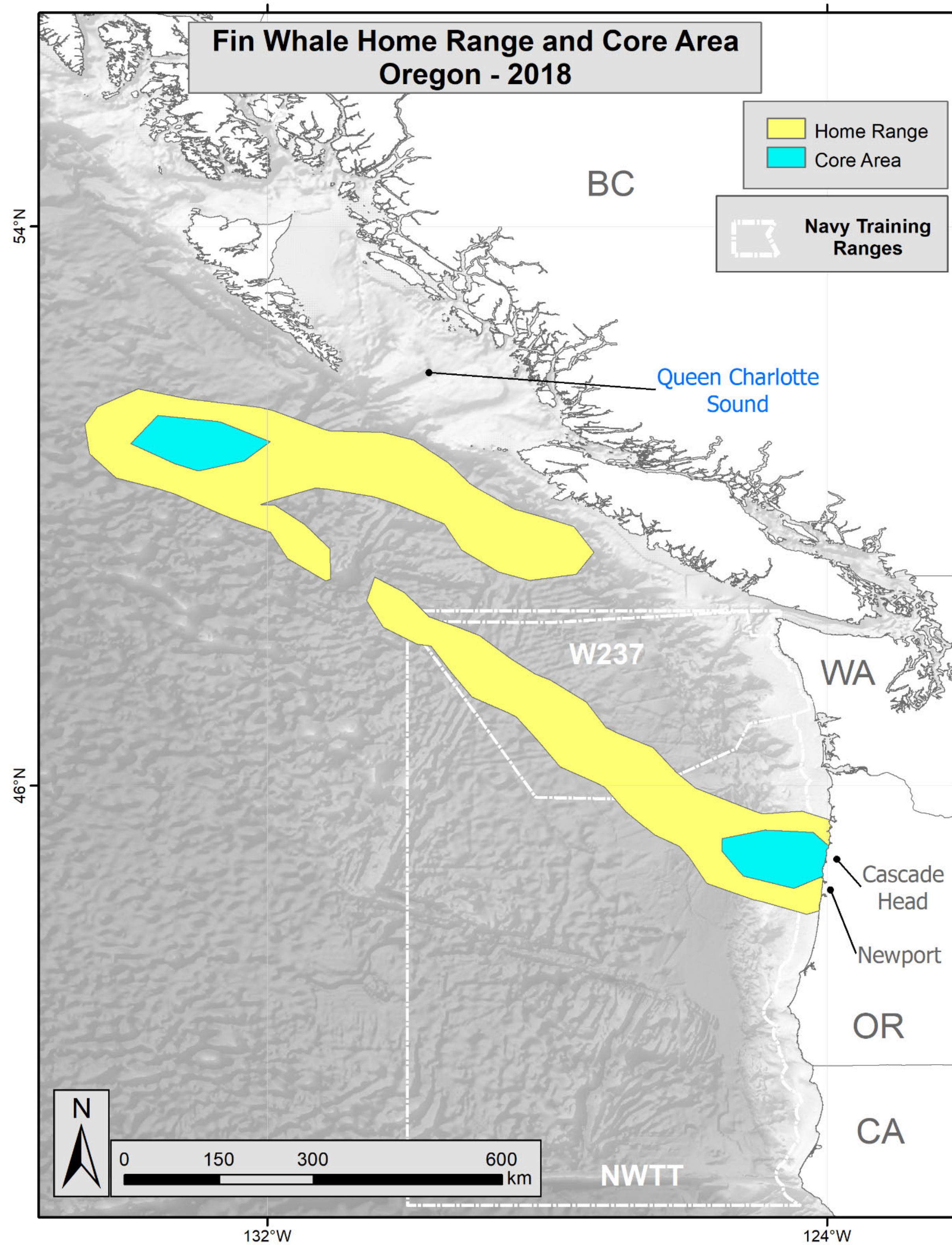


*Figure 18. Feeding area HR (yellow) and CA (blue) for one fin whale tagged off Oregon in late summer 2018.*

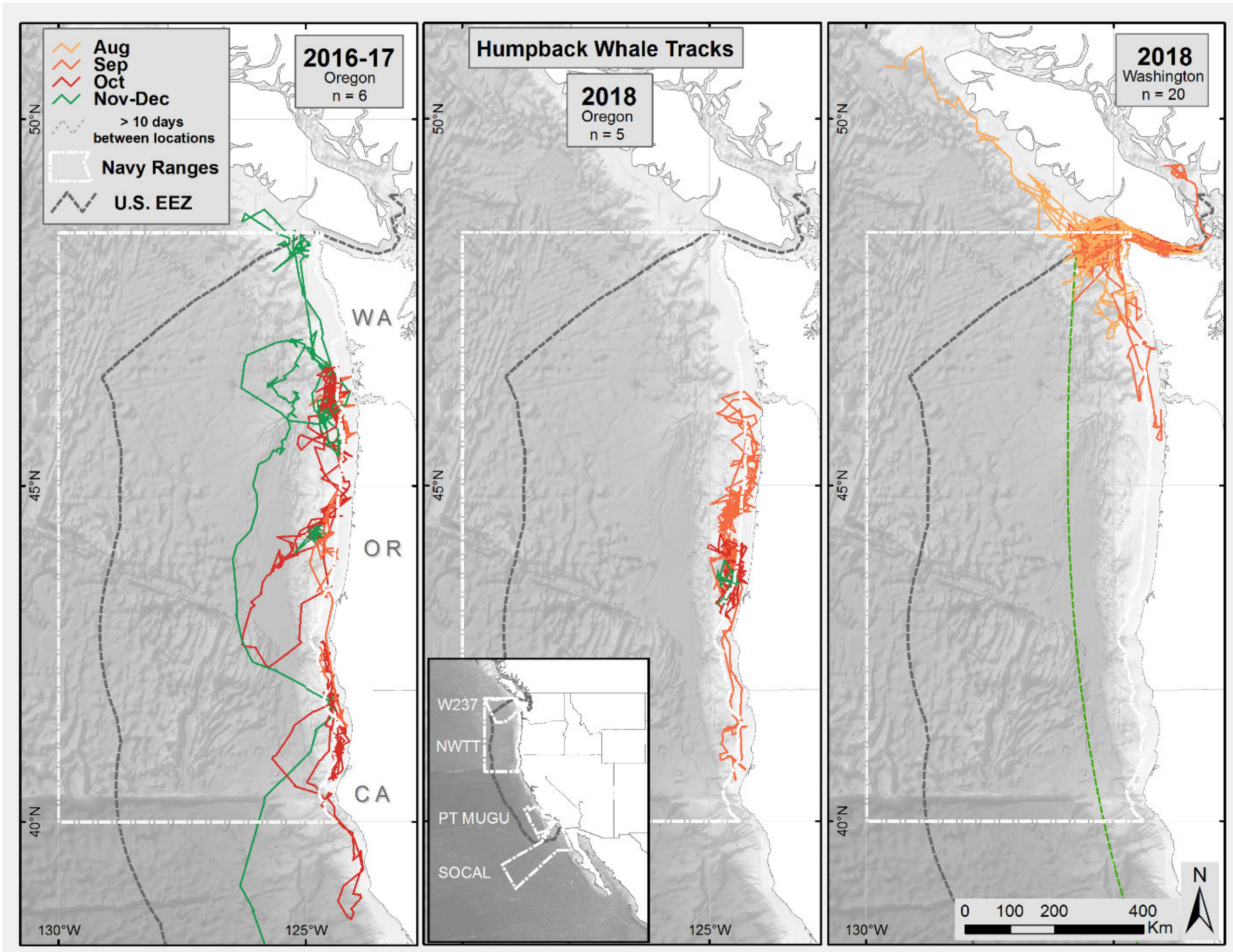


*Figure 19. Satellite-monitored tracks in the NWTT for humpback whales tagged off Oregon in 2016 and 2017 (6 tags; left panel), off Oregon in 2018 (5 tags; middle panel), and off Washington in 2018 (20 tags; right panel).*

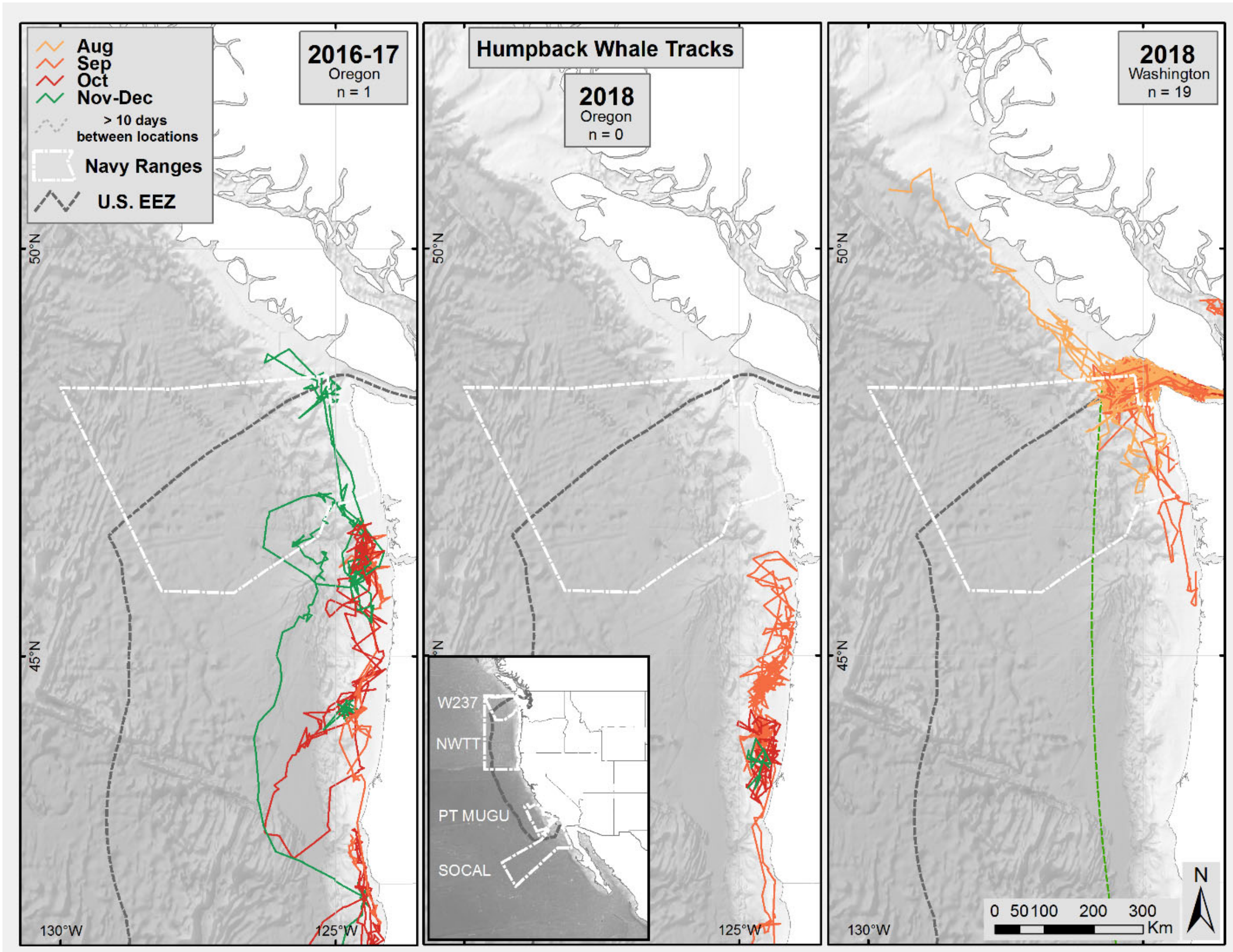


*Figure 20. Satellite-monitored tracks in Area W237 of the NWTT for humpback whales tagged off Oregon in 2016 and 2017 (1 tag; left panel), off Oregon in 2018 (0 tags; middle panel), and off Washington in 2018 (19 tags; right panel).*

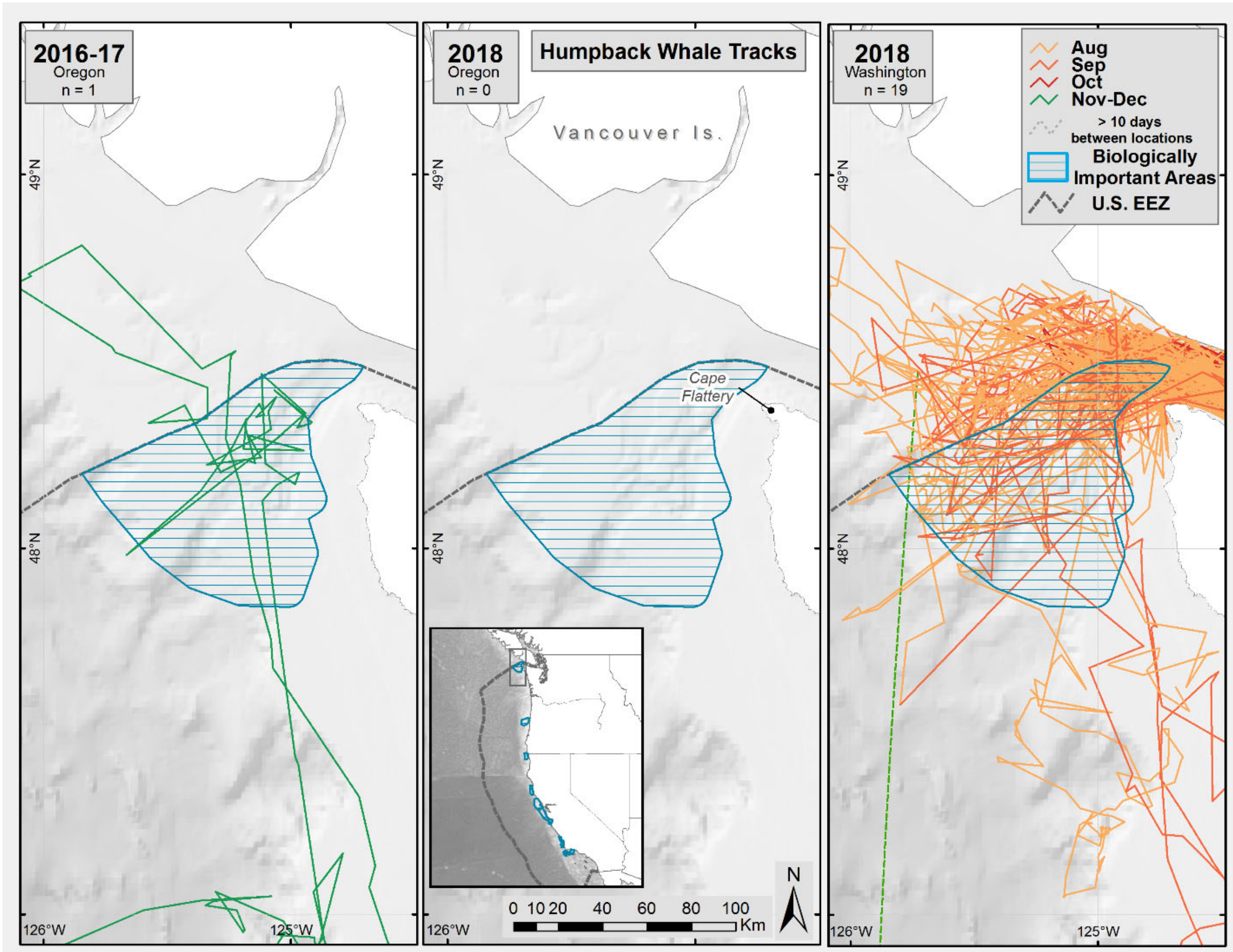


*Figure 21. Satellite-monitored tracks in the Northern Washington BIA for humpback whales tagged off Oregon in 2016 and 2017 (1 tag; left panel), off Oregon in 2018 (0 tags; middle panel), and off Washington in 2018 (19 tags; right panel).*

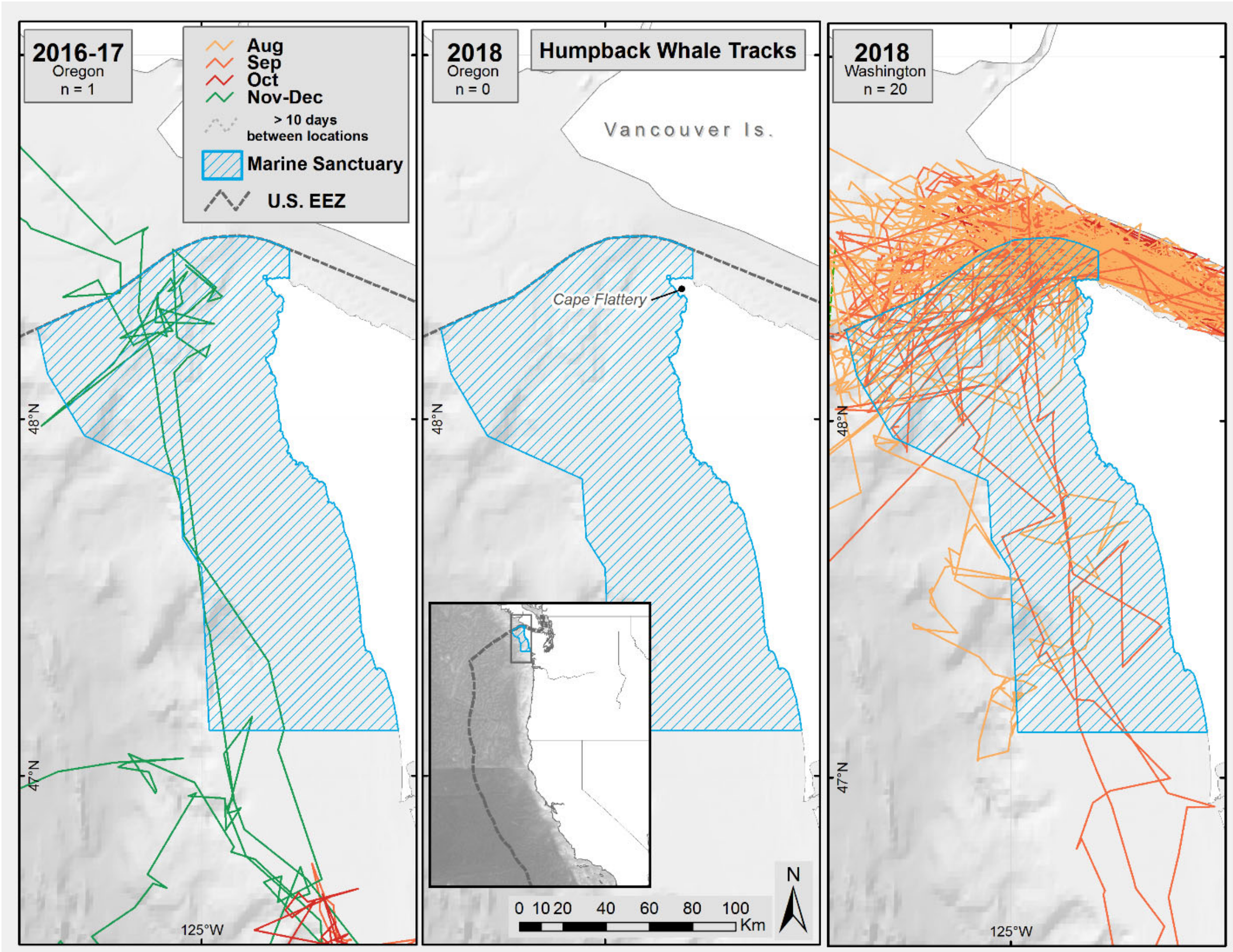


*Figure 22. Satellite-monitored tracks in the Olympic Coast National Marine Sanctuary for humpback whales tagged off Oregon in 2016 and 2017 (1 tag; left panel), off Oregon in 2018 (0 tags; middle panel), and off Washington in 2018 (20 tags; right panel).*

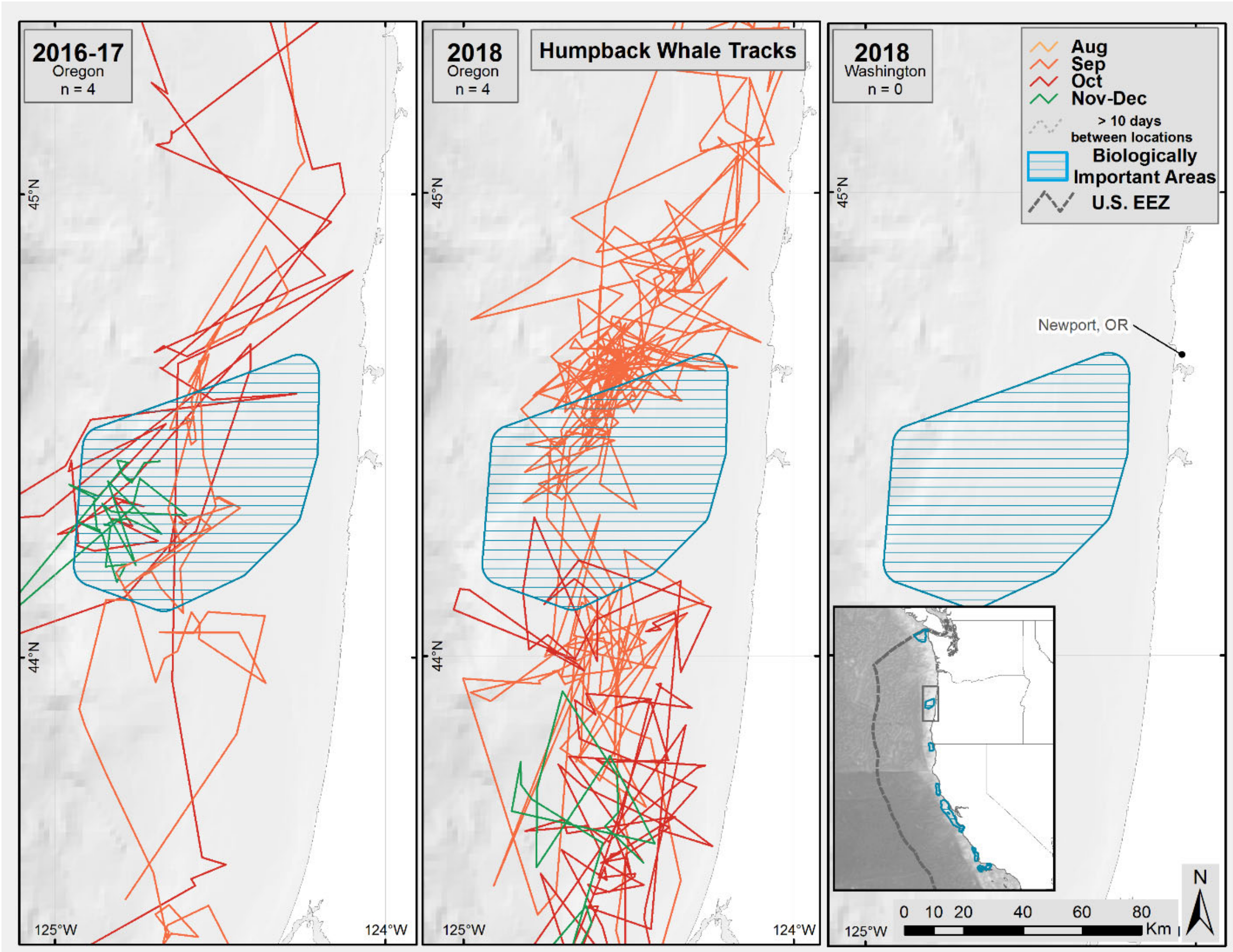


*Figure 23. Satellite-monitored tracks in the Stonewall and Heceta Bank BIA for humpback whales tagged off Oregon in 2016 and 2017 (4 tags; left panel), off Oregon in 2018 (4 tags; middle panel), and off Washington in 2018 (0 tags; right panel).*

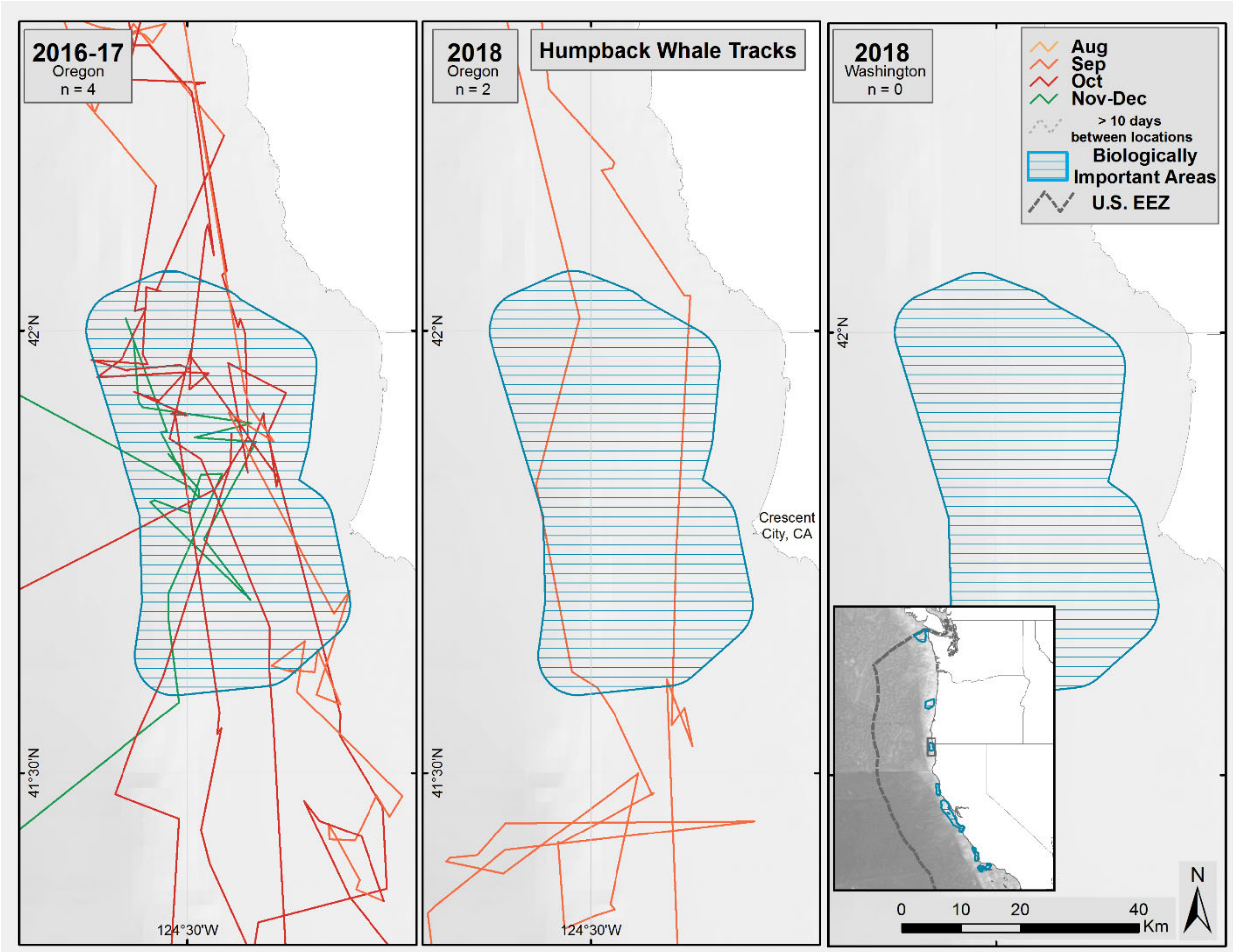


*Figure 24. Satellite-monitored tracks in the Point St. George BIA for humpback whales tagged off Oregon in 2016 and 2017 45 tags; left panel), off Oregon in 2018 (2 tags; middle panel), and off Washington in 2018 (0 tags; right panel).*

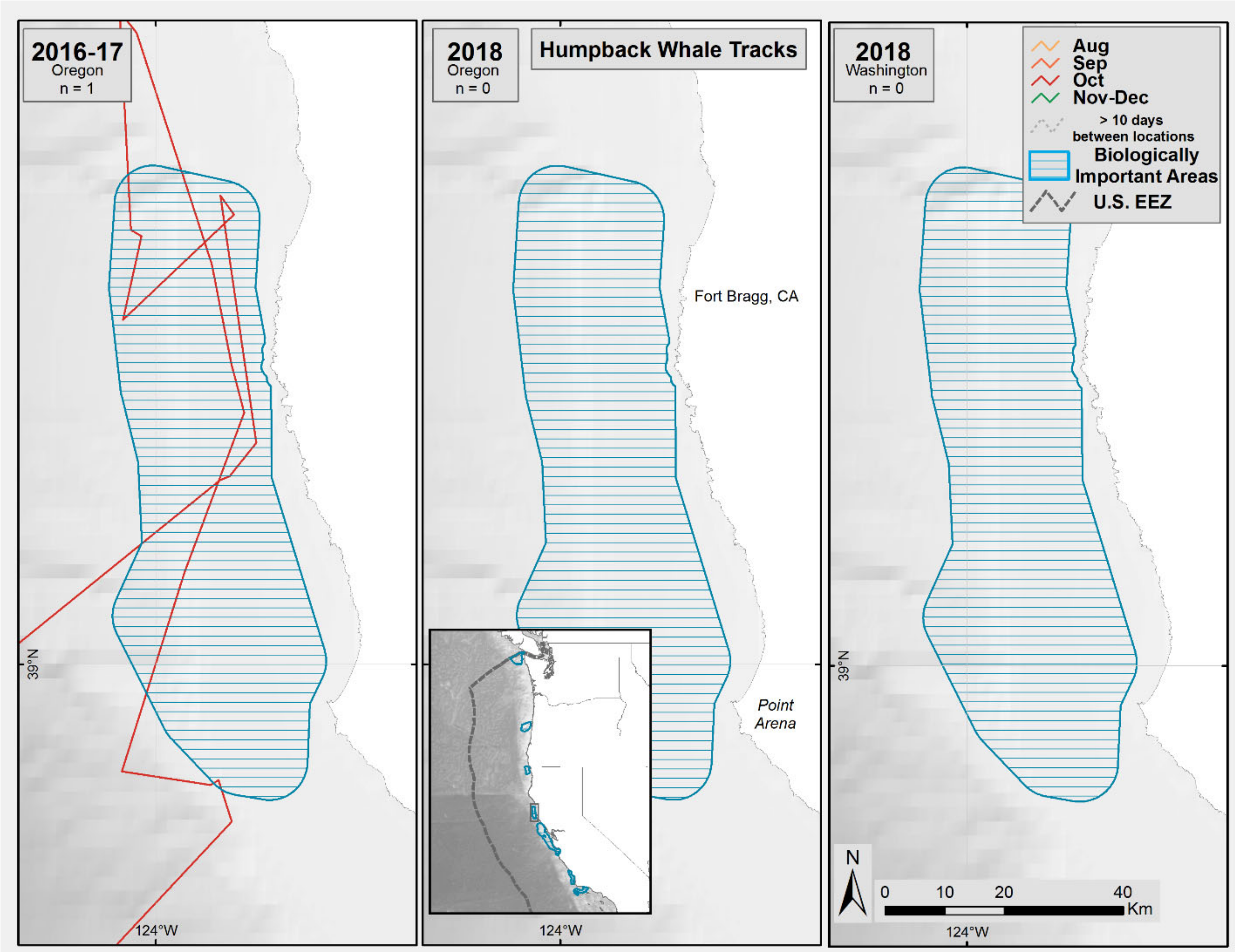


*Figure 25. Satellite-monitored tracks in the Fort Bragg to Point Arena BIA for humpback whales tagged off Oregon in 2016 and 2017 (1 tag; left panel), off Oregon in 2018 (0 tags; middle panel), and off Washington in 2018 (0 tags; right panel).*

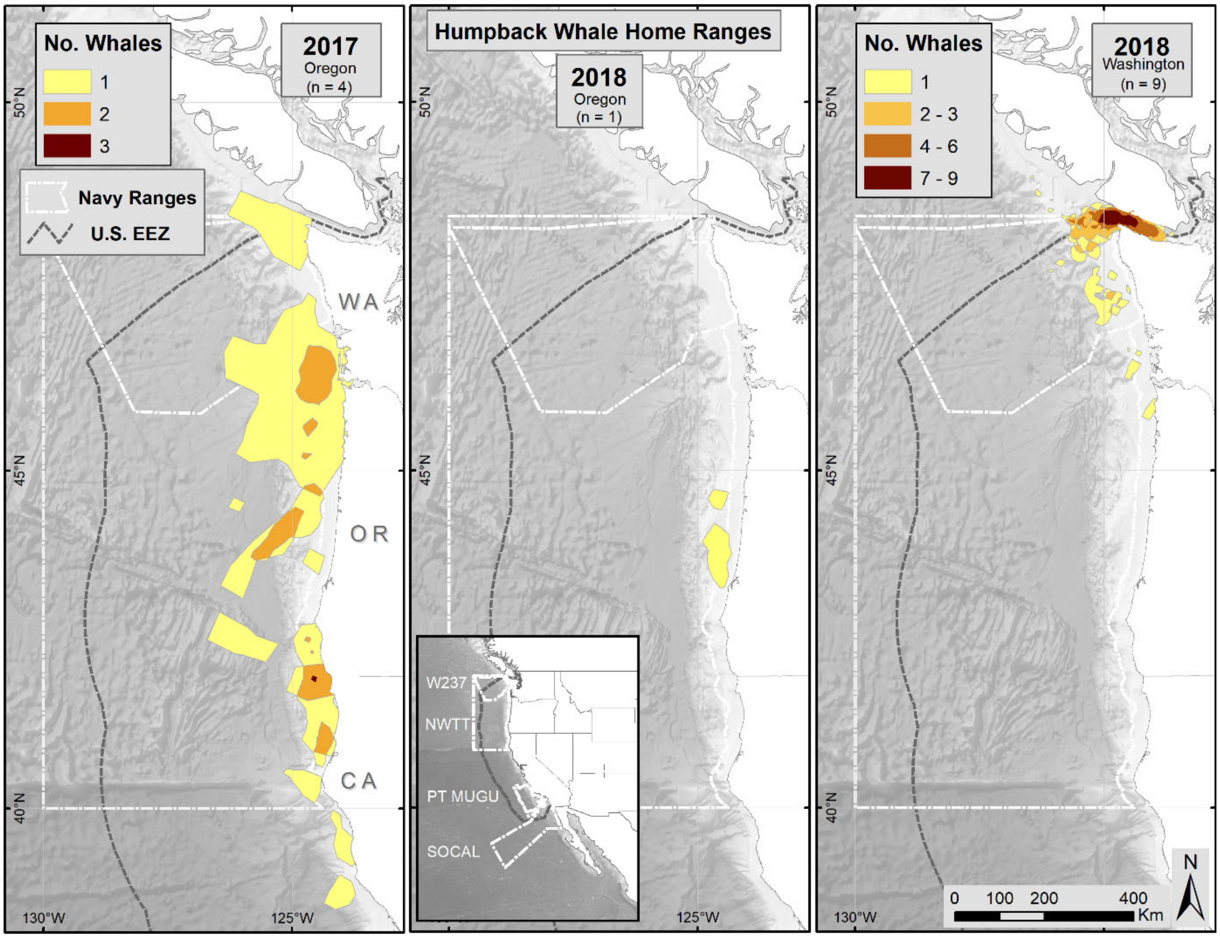


*Figure 26. Feeding area HRs for humpback whales tagged off Oregon in 2017 (4 tags; left panel), off Oregon in 2018 (1 tag; middle panel), and off Washington in 2018 (9 tags; right panel). Shading represents the number of individual whales with overlapping HRs.*

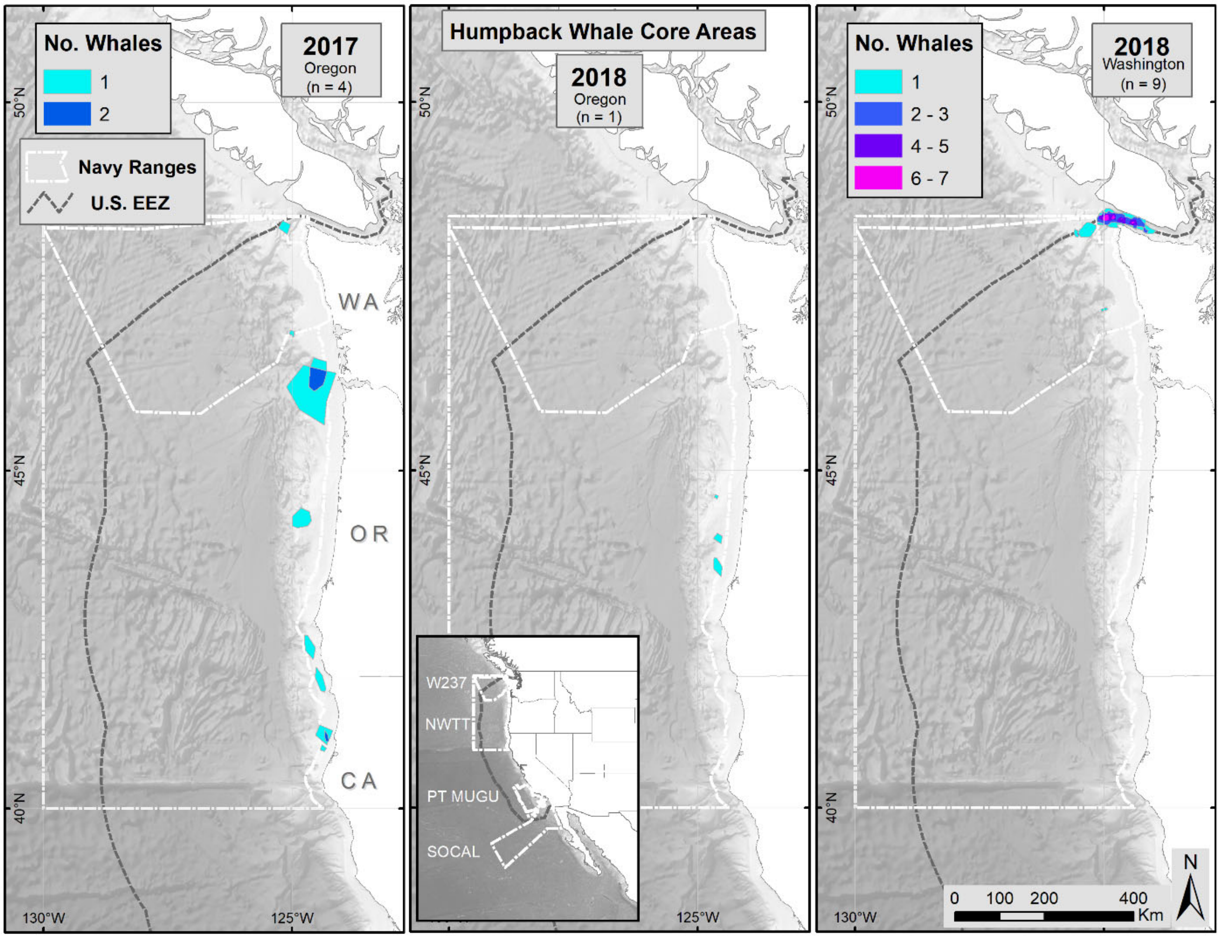


*Figure 27. Feeding area CAs for humpback whales tagged off Oregon in 2017 (4 tags; left panel), off Oregon in 2018 (1 tag; middle panel), and off Washington in 2018 (9 tags; right panel). Shading represents the number of individual whales with overlapping CAs.*

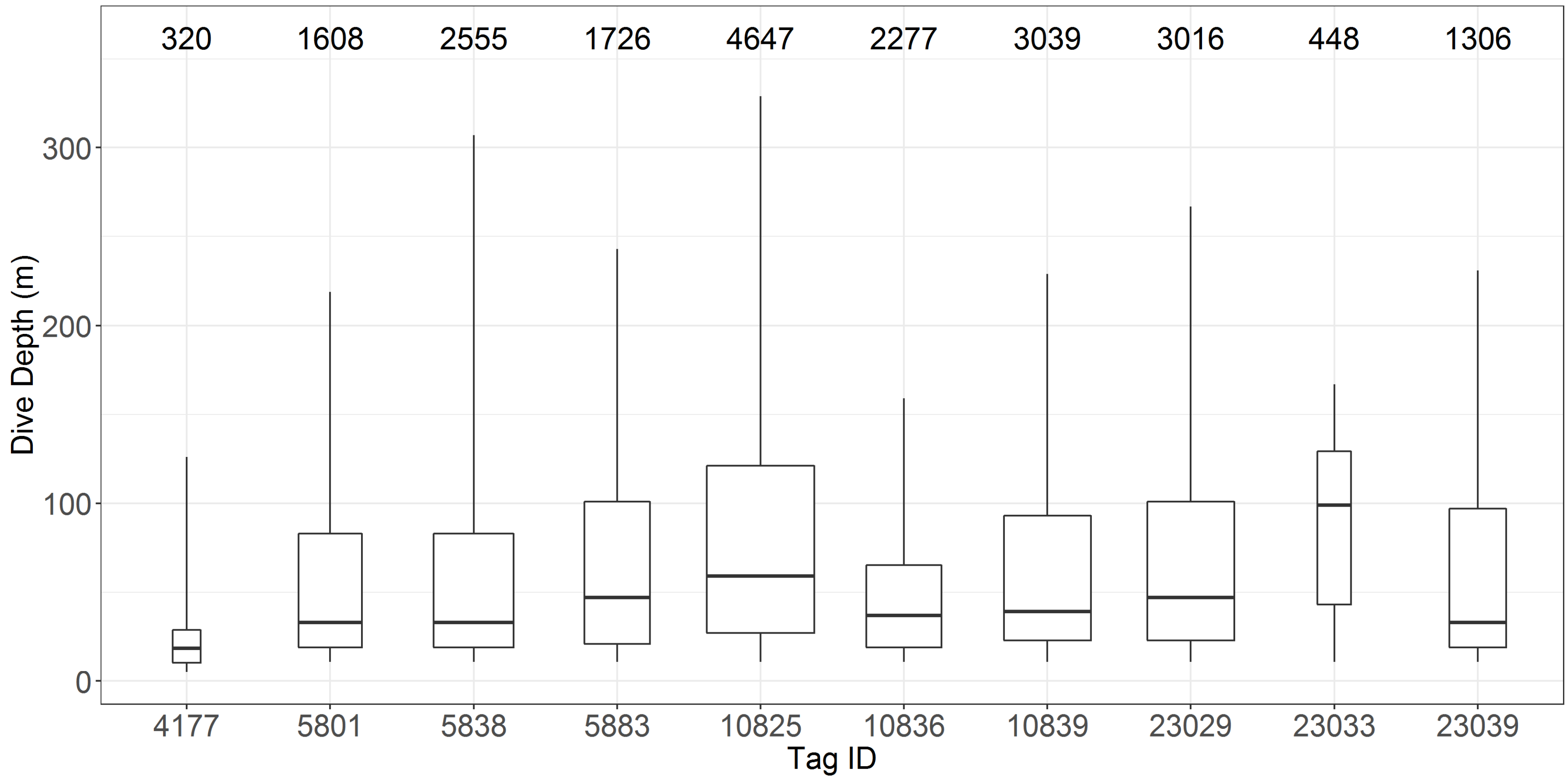


*Figure 28. Dive depth while on the feeding grounds of DM- and one ADB-tagged humpback whales (n = 10) tagged off Neah Bay, WA during August 2018. Boxes represent the first and third quartiles of the data. Box widths are proportional to the sample size, which is listed above each box.*

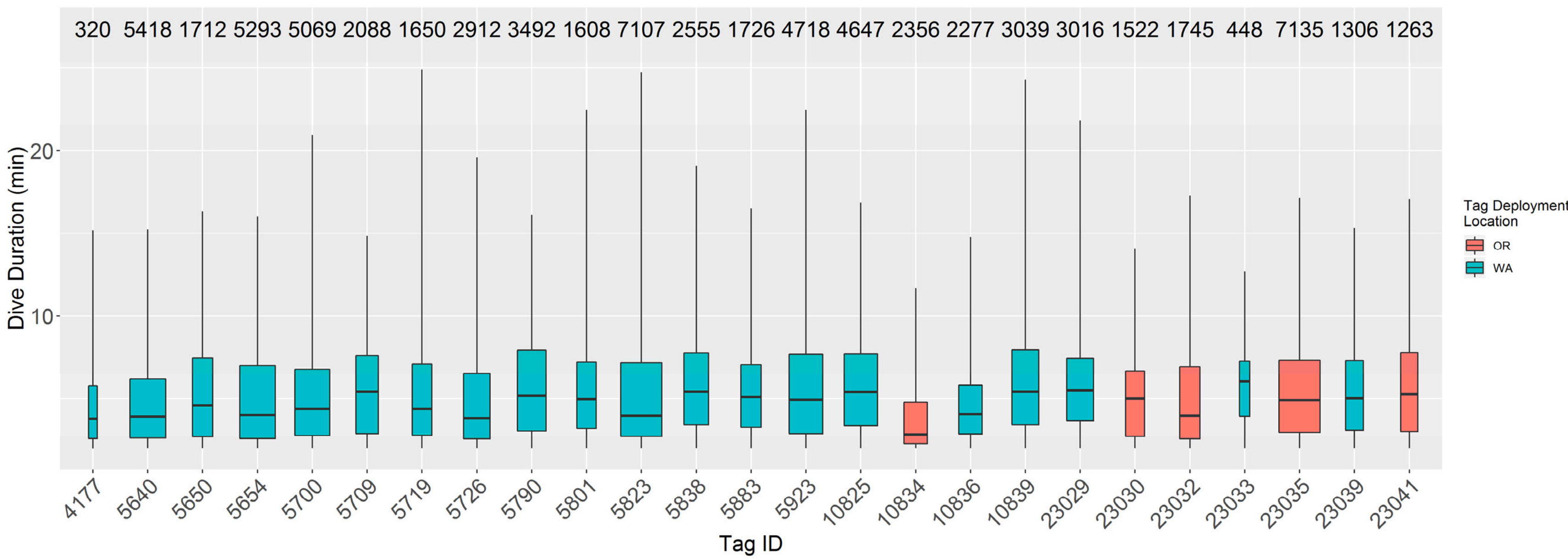


*Figure 29. Dive duration of DM-, DUR+- and one ADB-tagged humpback whales (n = 25) tagged off Neah Bay, WA during August 2018 and Newport, OR during September 2018. Boxes represent the first and third quartiles of the data. Box widths are proportional to the sample size, which is listed above each box. Tag deployment location is indicated by color.*

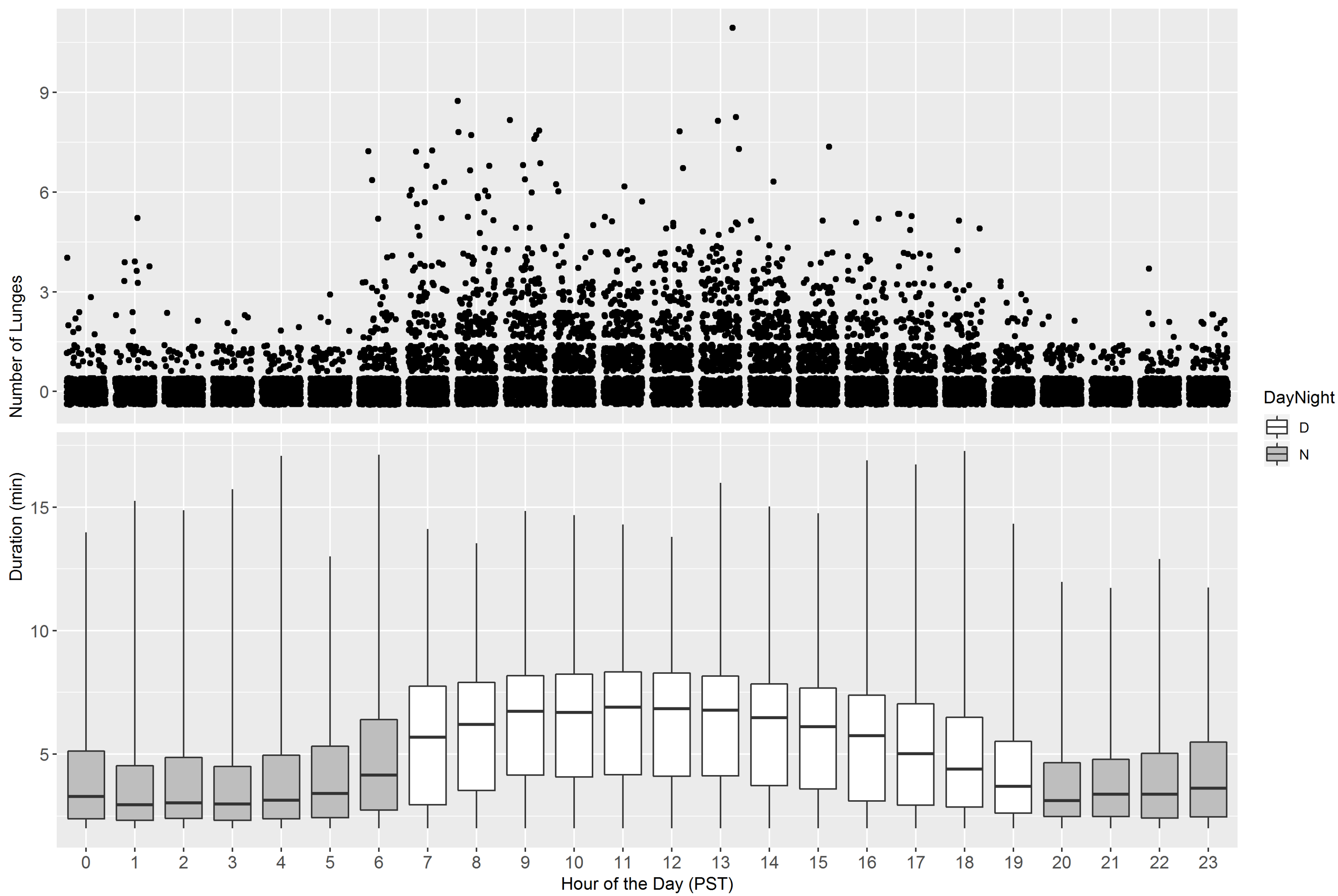


*Figure 30. Hourly distributions of number of lunges (top) and dive durations (bottom) for DUR+-tagged humpback whales (n = 5) tagged off Oregon during September 2018. Points in the upper panel are jittered for better visibility.*

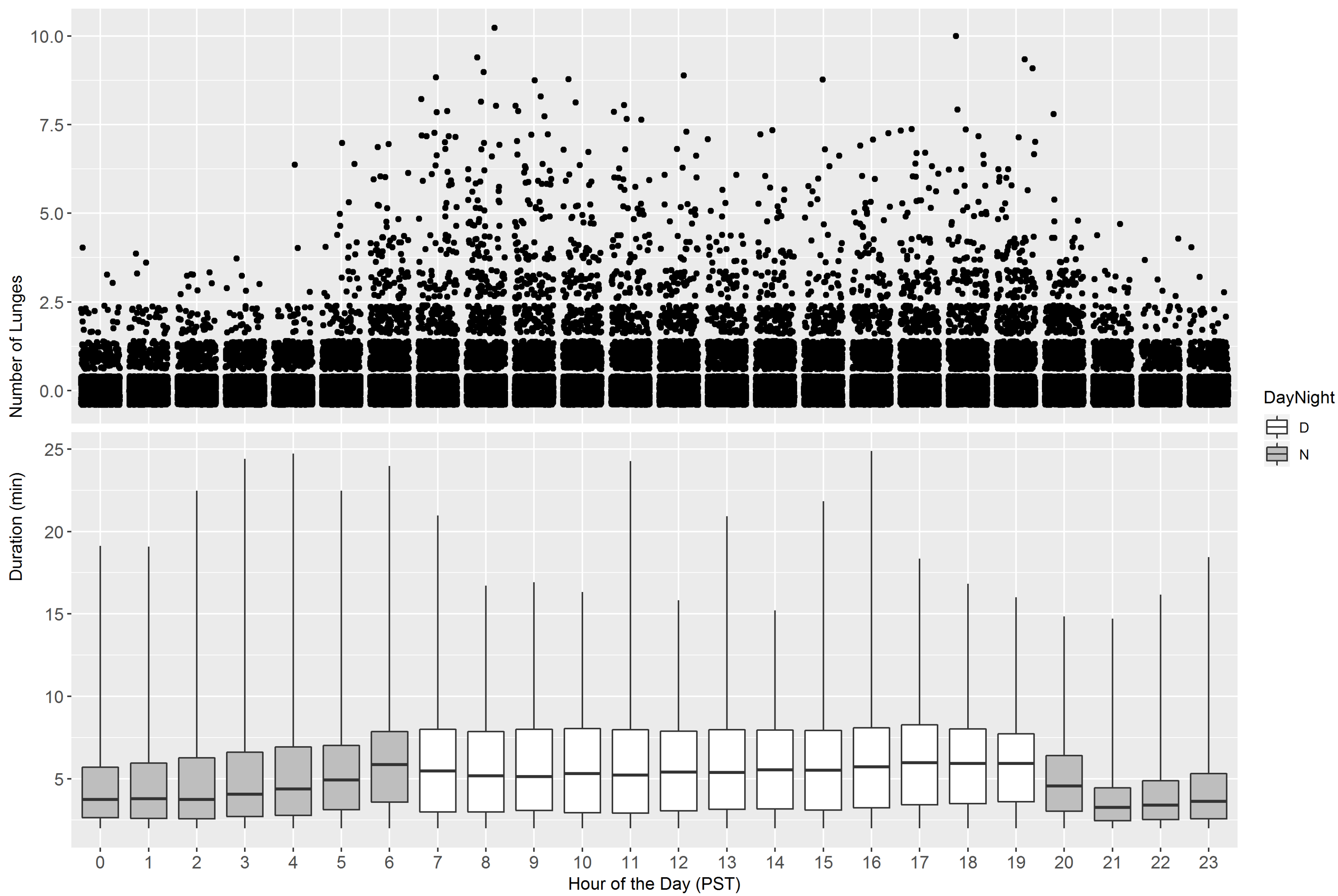


*Figure 31. Hourly distributions of number of lunges (top) and dive durations (bottom) for DM and DUR+-tagged humpback whales (n = 19) tagged off Washington during August 2018. Points in the upper panel are jittered for better visibility.*

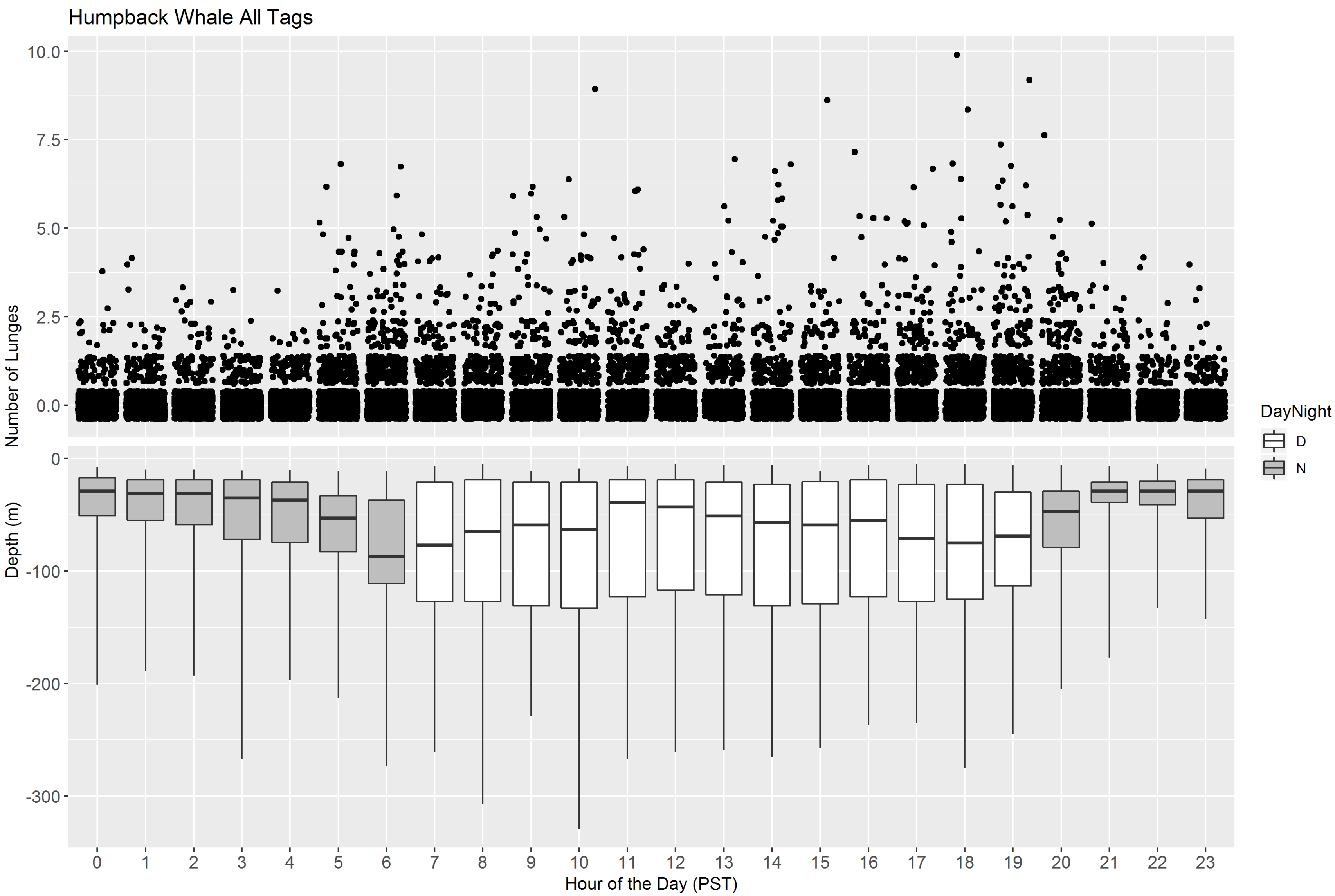


*Figure 32. Hourly distributions of number of lunges (top) and maximum dive depths (bottom) for DM-tagged humpback whales (n = 9) tagged off Neah Bay, WA during August 2018. Points in the upper panel are jittered for better visibility.*

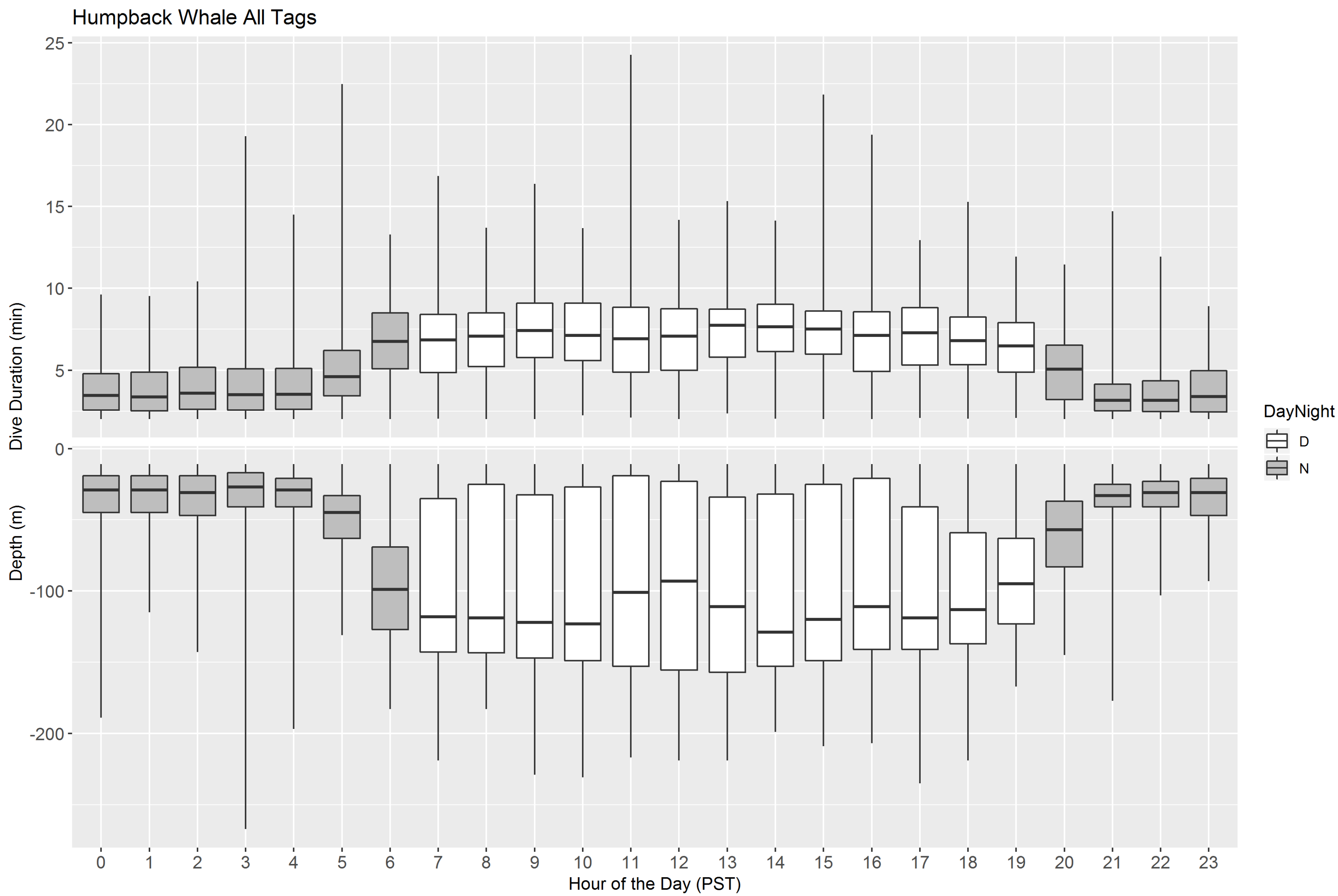


*Figure 33. Hourly distributions of dive durations (top) and maximum dive depths (bottom) for DM-tagged humpback whales (n = 9) while inside the Strait of Juan de Fuca.*

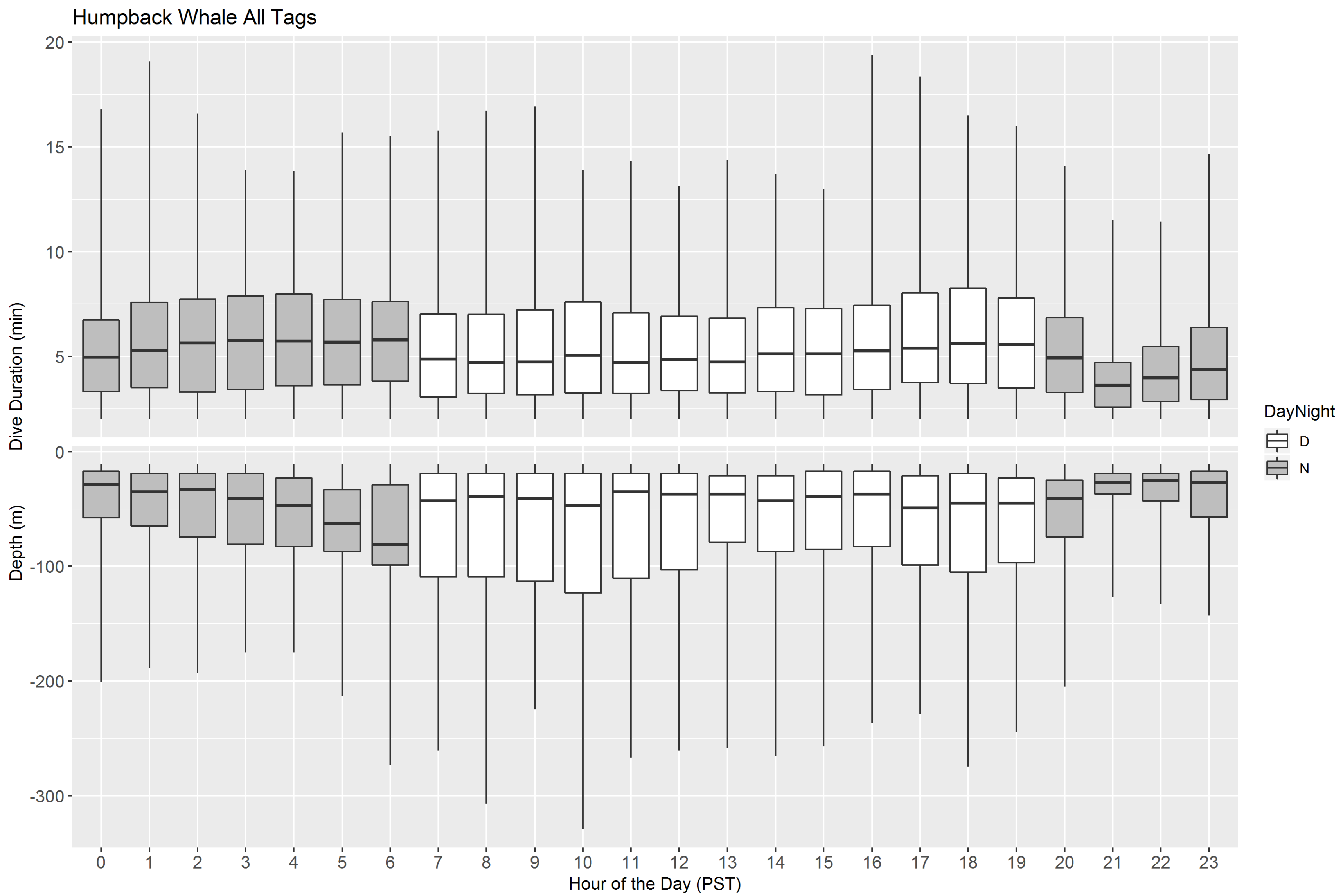


*Figure 34. Hourly distributions of dive durations (top) and maximum dive depths (bottom) for DM- and one ADB-tagged humpback whales (n = 10) while west of the Strait of Juan de Fuca.*

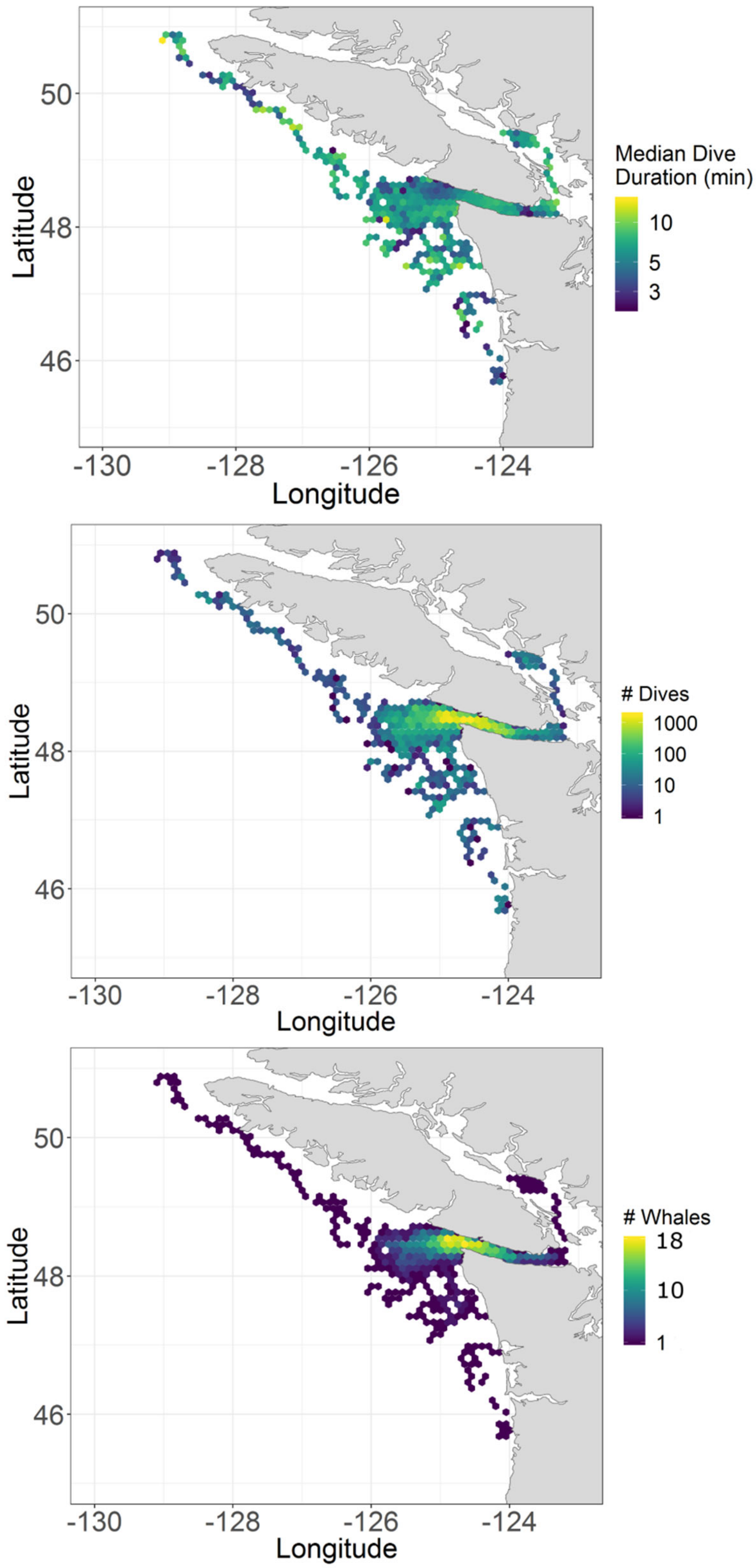


*Figure 35. Data from DM- and DUR+-tagged humpback whales tagged off Washington in August 2018 summarized in 0.1-degree hexagonal grids showing the median dive duration (top), number of dives (middle), and number of tagged whales (bottom) recorded in each grid cell.*

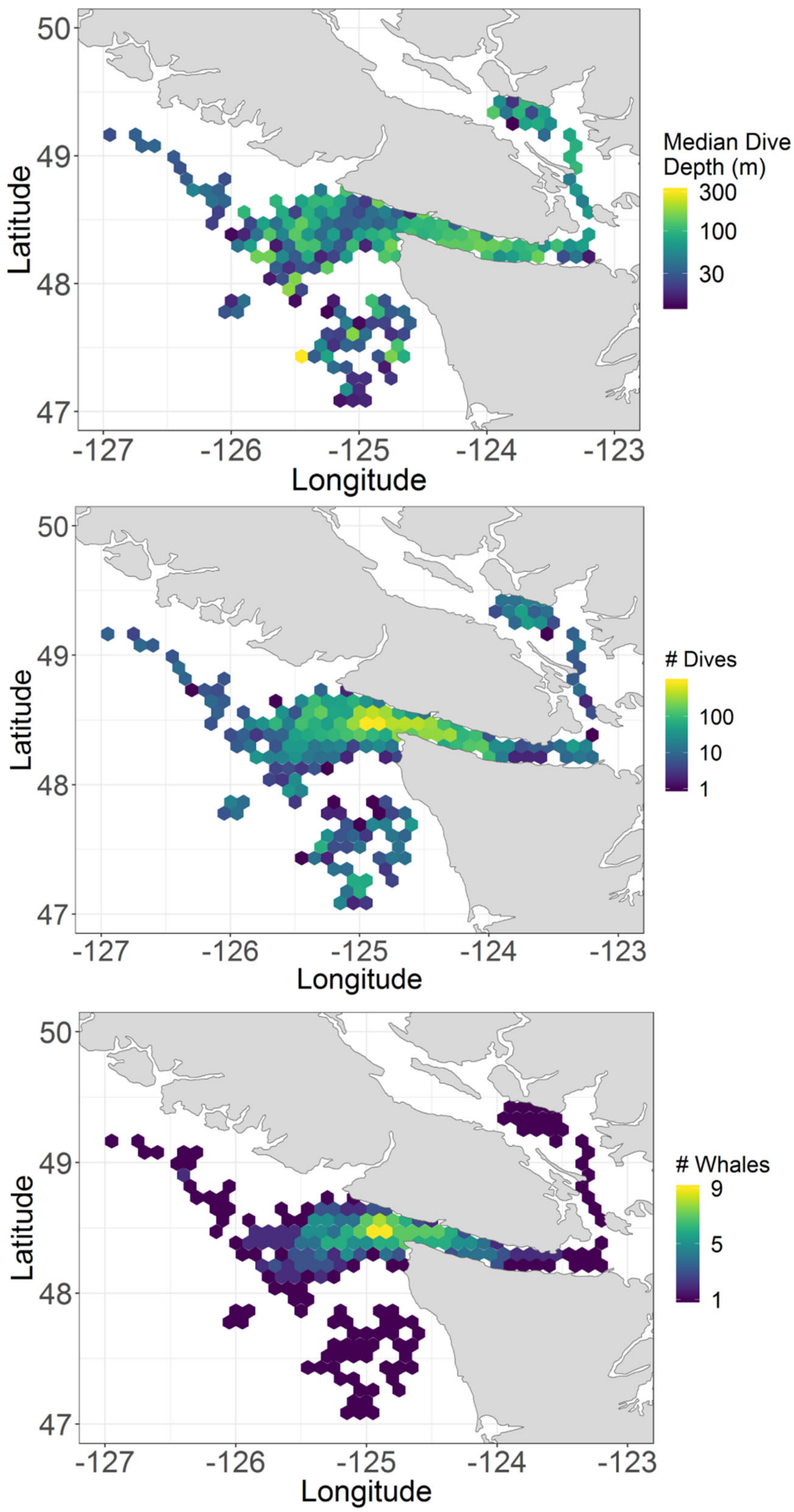


*Figure 36. Data from DM-tagged humpback whales tagged off Washington in August 2018 summarized in 0.1-degree hexagonal grids showing the median daytime maximum dive depth (top), number of dives (middle), and number of tagged whales (bottom) recorded in each grid cell.*

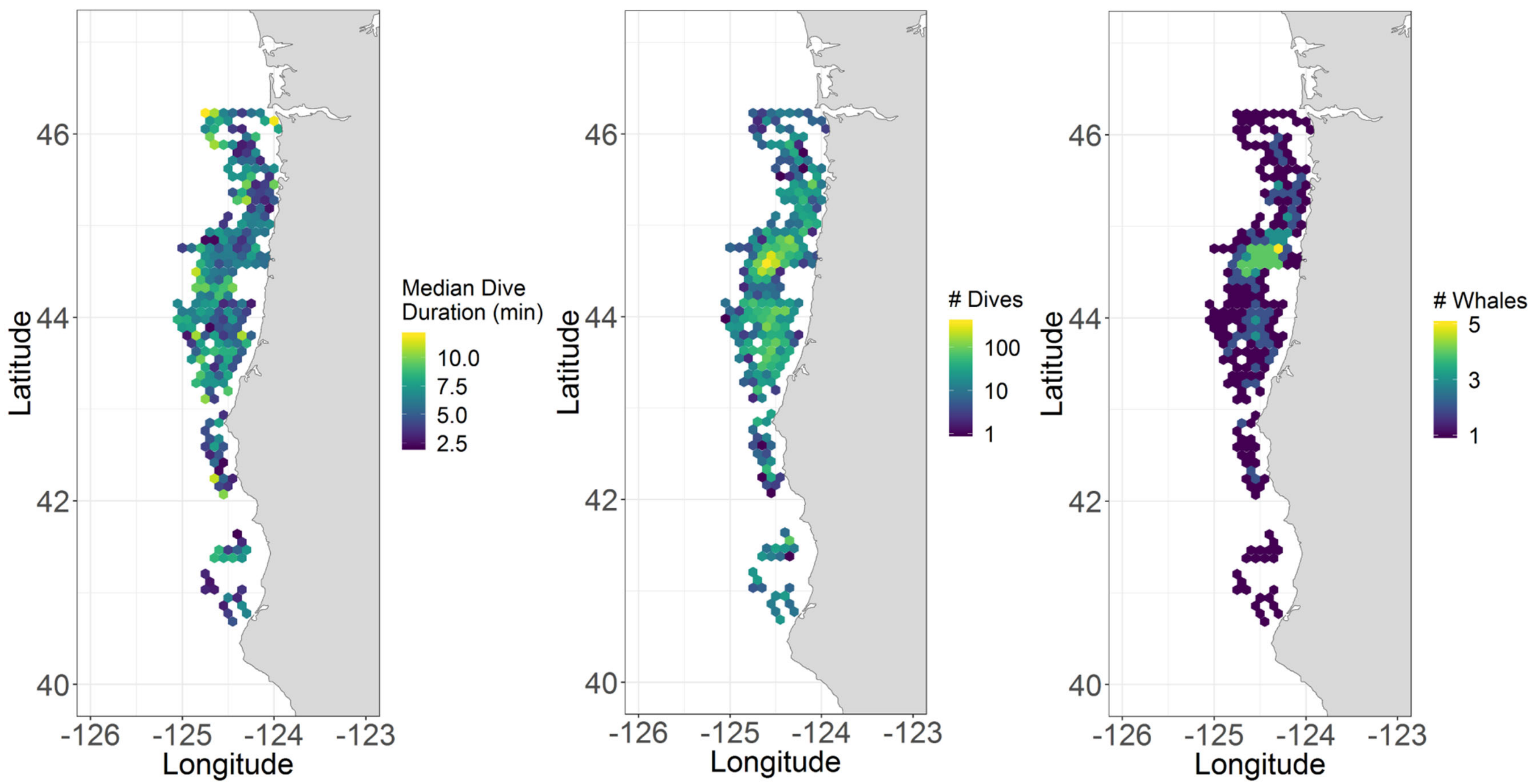


*Figure 37. Data from DUR+-tagged humpback whales tagged off Newport, OR in September 2018 summarized in 0.1-degree hexagonal grids showing the median daytime dive duration (left), number of dives (middle), and number of tagged whales (right) recorded in each grid cell.*

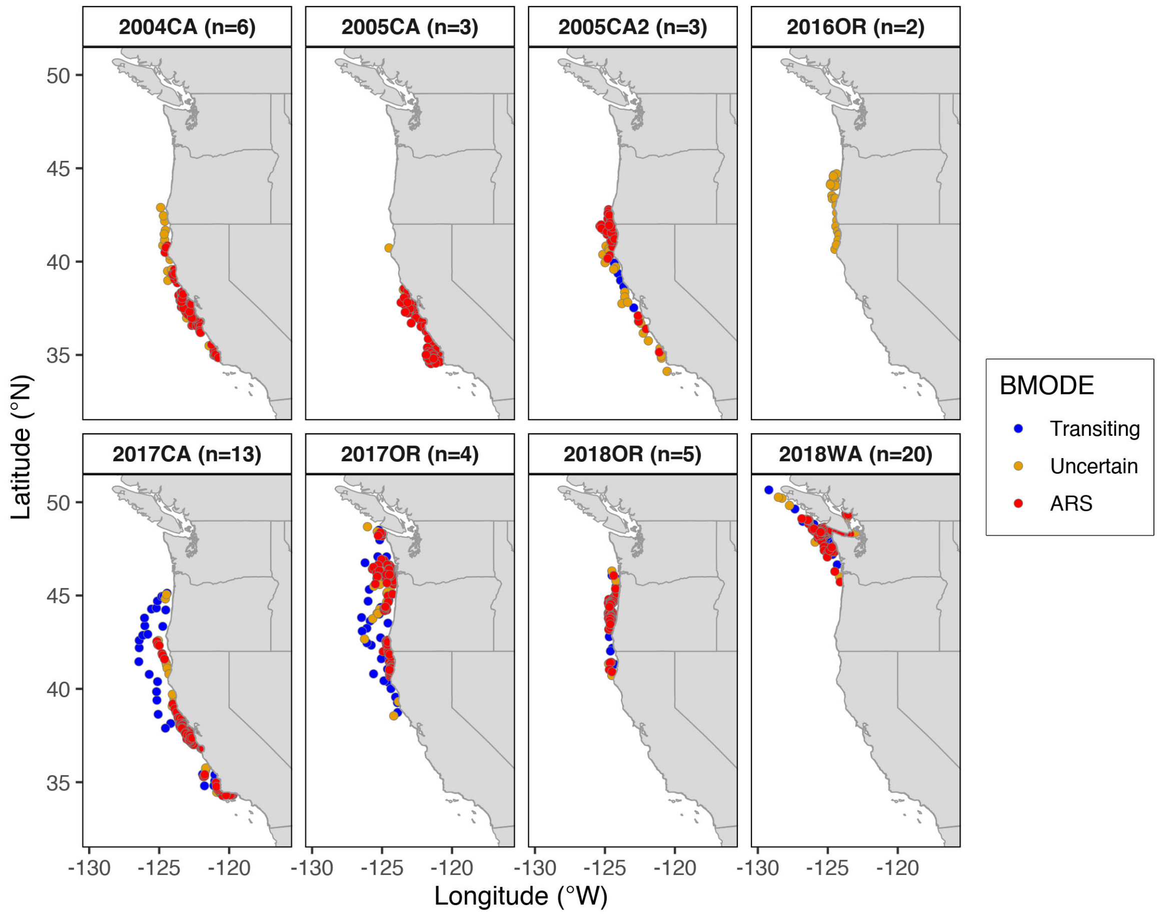


*Figure 38. The geographic distribution of SSSM/hSSSM locations colored by behavioral mode (BMODE) for each tagging year/season for 56 humpback whales tagged by OSU in feeding areas off the US West Coast from 2004 to 2018 (CA = California, OR = Oregon, WA = Washington). The number of SSSM/hSSSM tracks available in each year/season is indicated above each panel.*

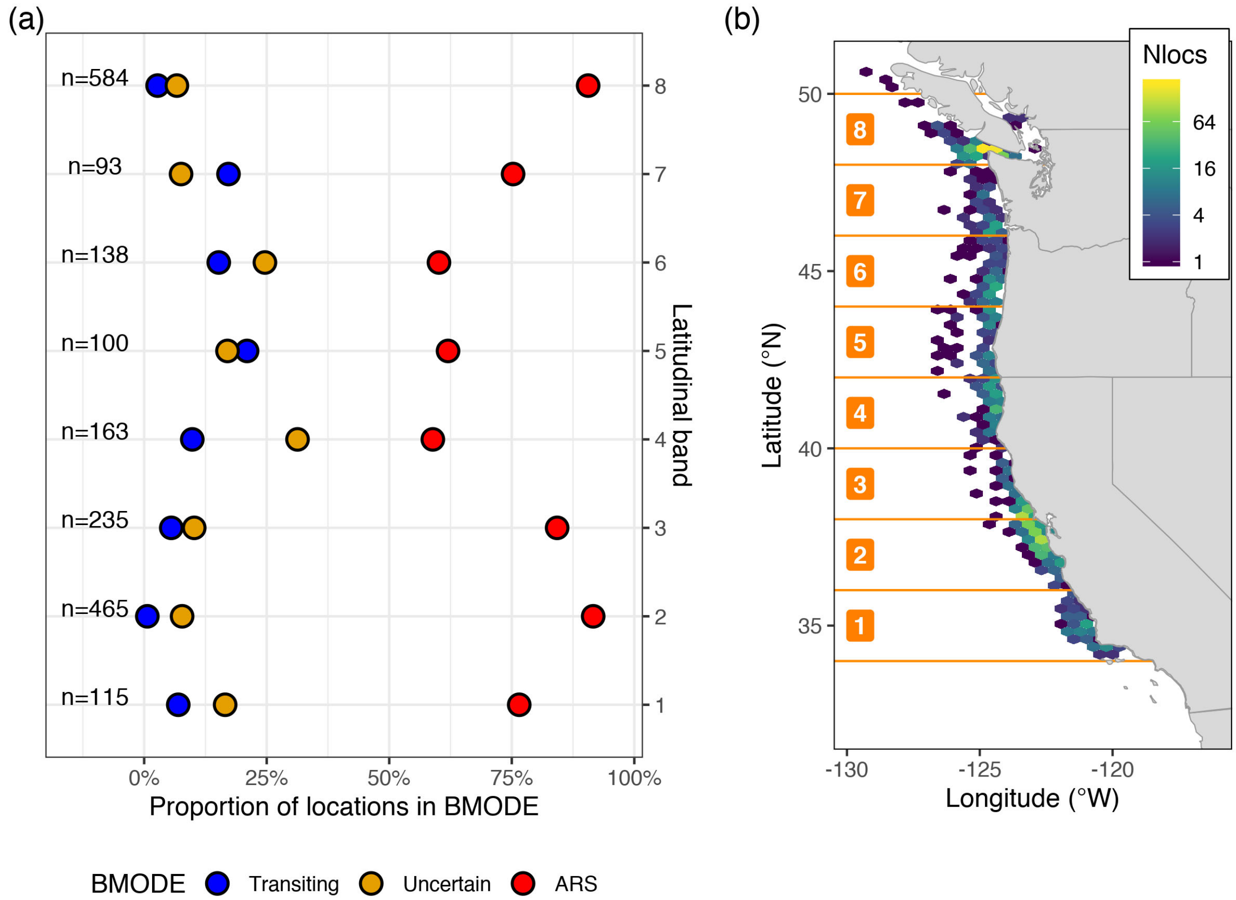


*Figure 39. (a) Dot plot showing the behavioral classification of SSSM/hSSSM locations in each of the eight 2-deg latitudinal blocks depicted in (b) as a percentage of the total number of locations in each block. (b) Map of hexagonal-binned SSSM/hSSSM locations for all humpback whales tagged by OSU off the US West Coast from 2004 to 2018 depicting the density of locations (Nlocs, in log scale). Also shown are the eight 2-deg latitudinal blocks that were used to aggregate the locations by behavioral mode classification, as shown in (a).*

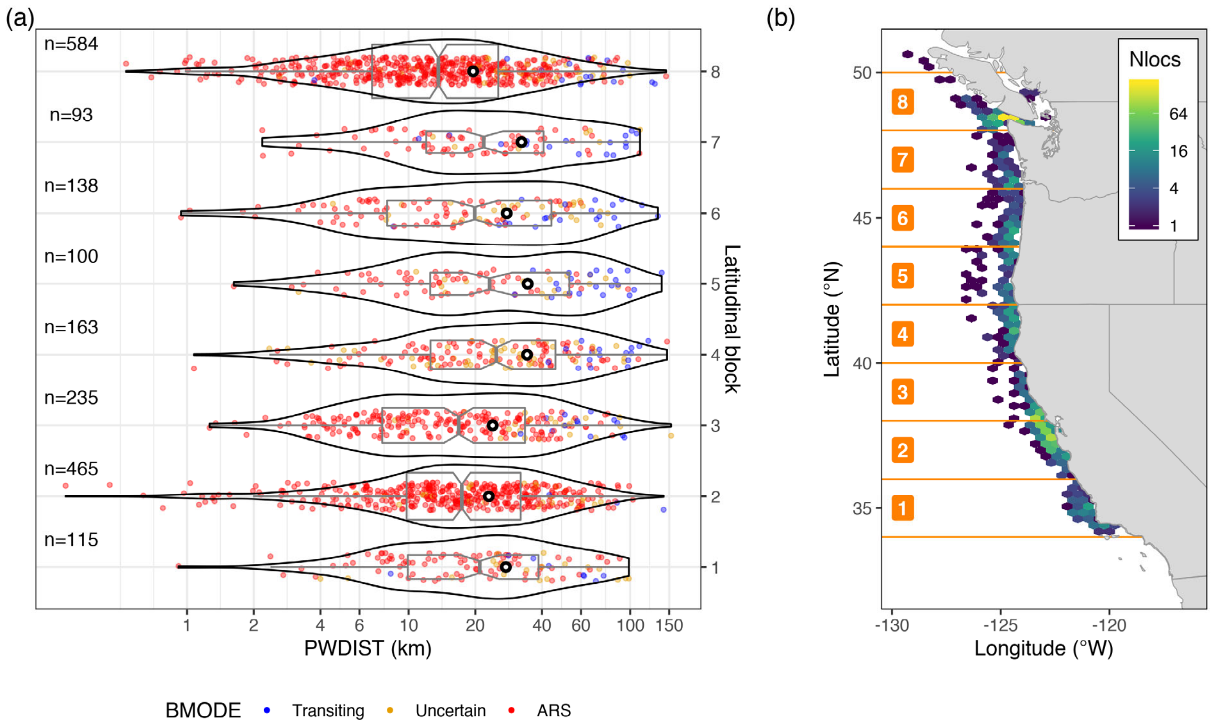


*Figure 40. (a) Box-violin plots showing the distributional characteristics of PWDIST (km) for SSSM/hSSSM locations (dots colored by BMODE) in each of the eight 2-deg latitudinal blocks depicted in (b). Black circles indicate the mean. The x-axis has been log-transformed to enhance visualization. (b) Map of hexagonal-binned SSSM/hSSSM locations for all humpback whales tagged by OSU off the US West Coast from 2004 to 2018 depicting the density of locations (Nlocs, in log scale). Also shown are the eight 2-deg latitudinal blocks that were used to aggregate the environmental data for ecological characterization, as shown in (a).*

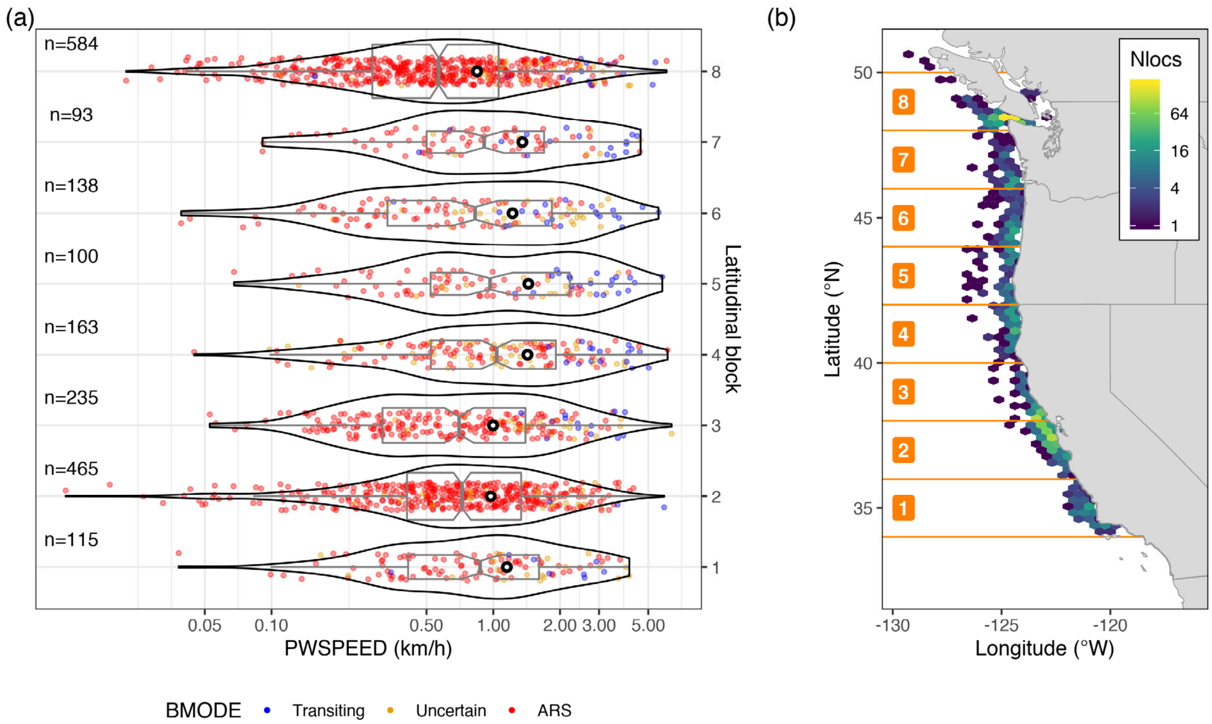


*Figure 41. (a) Box-violin plots showing the distributional characteristics of PWSPEED (km/h) for SSSM/hSSSM locations (dots colored by BMODE) in each of the eight 2-deg latitudinal blocks depicted in (b). Black circles indicate the mean. The x-axis has been log-transformed to enhance visualization. (b) Map of hexagonal-binned SSSM/hSSSM locations for all humpback whales tagged by OSU off the US West Coast from 2004 to 2018 depicting the density of locations (Nlocs, in log scale). Also shown are the eight 2-deg latitudinal blocks that were used to aggregate the environmental data for ecological characterization, as shown in (a).*

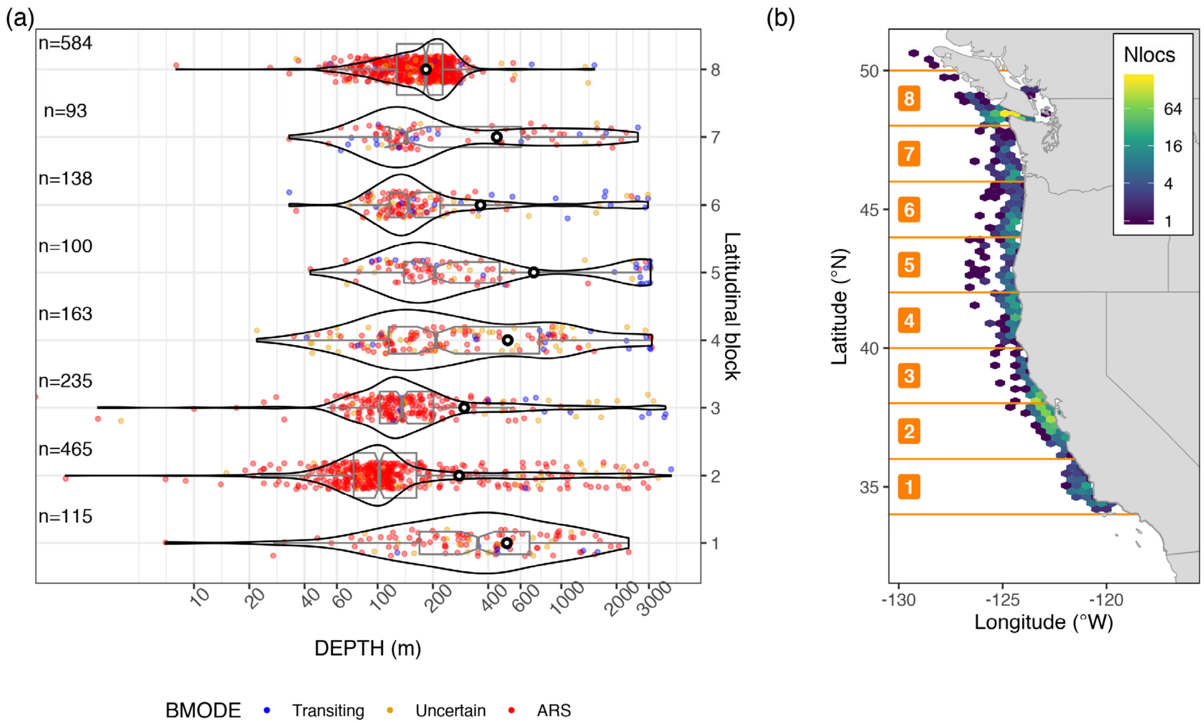


*Figure 42. (a) Box-violin plots showing the distributional characteristics of DEPTH (m) for SSSM/hSSSM locations (dots colored by BMODE) in each of the eight 2-deg latitudinal blocks depicted in (b). Black circles indicate the mean. The x-axis has been log-transformed to enhance visualization. (b) Map of hexagonal-binned SSSM/hSSSM locations for all humpback whales tagged by OSU off the US West Coast from 2004 to 2018 depicting the density of locations (Nlocs, in log scale). Also shown are the eight 2-deg latitudinal blocks that were used to aggregate the environmental data for ecological characterization, as shown in (a).*

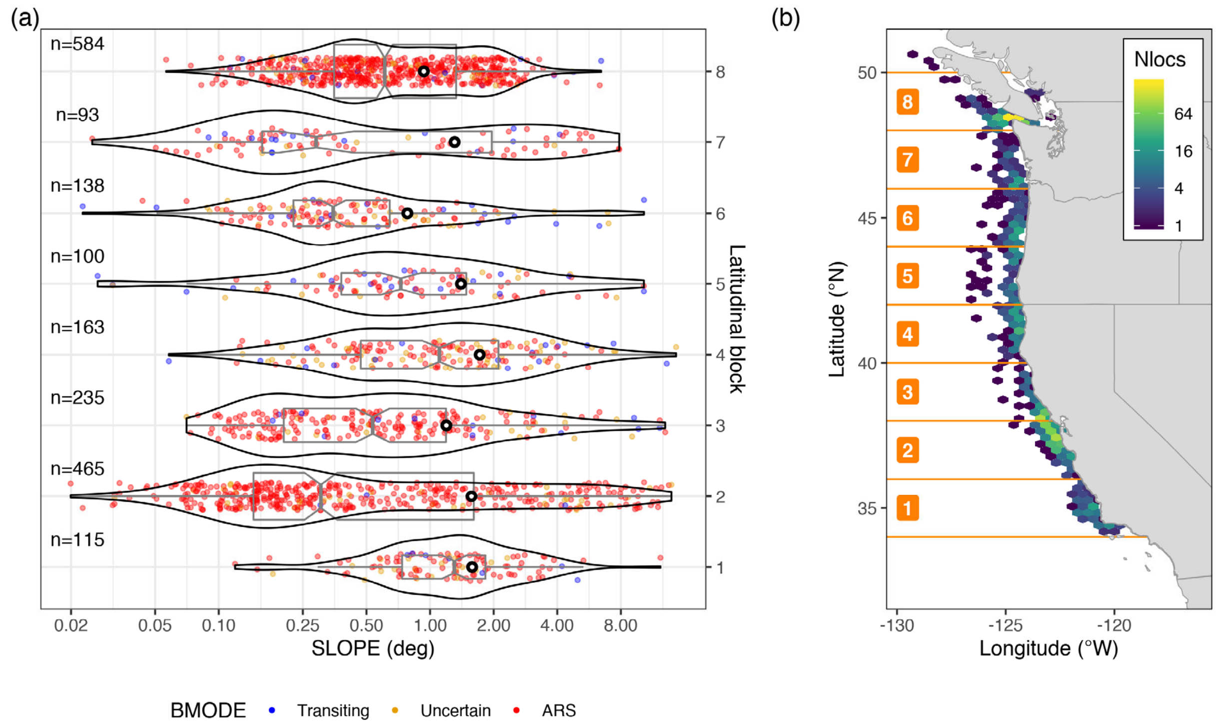


*Figure 43. (a) Box-violin plots showing the distributional characteristics of SLOPE (deg) for SSSM/hSSSM locations (dots colored by BMODE) in each of the eight 2-deg latitudinal blocks depicted in (b). Black circles indicate the mean. The x-axis has been log-transformed to enhance visualization. (b) Map of hexagonal-binned SSSM/hSSSM locations for all humpback whales tagged by OSU off the US West Coast from 2004 to 2018 depicting the density of locations (Nlocs, in log scale). Also shown are the eight 2-deg latitudinal blocks that were used to aggregate the environmental data for ecological characterization, as shown in (a).*

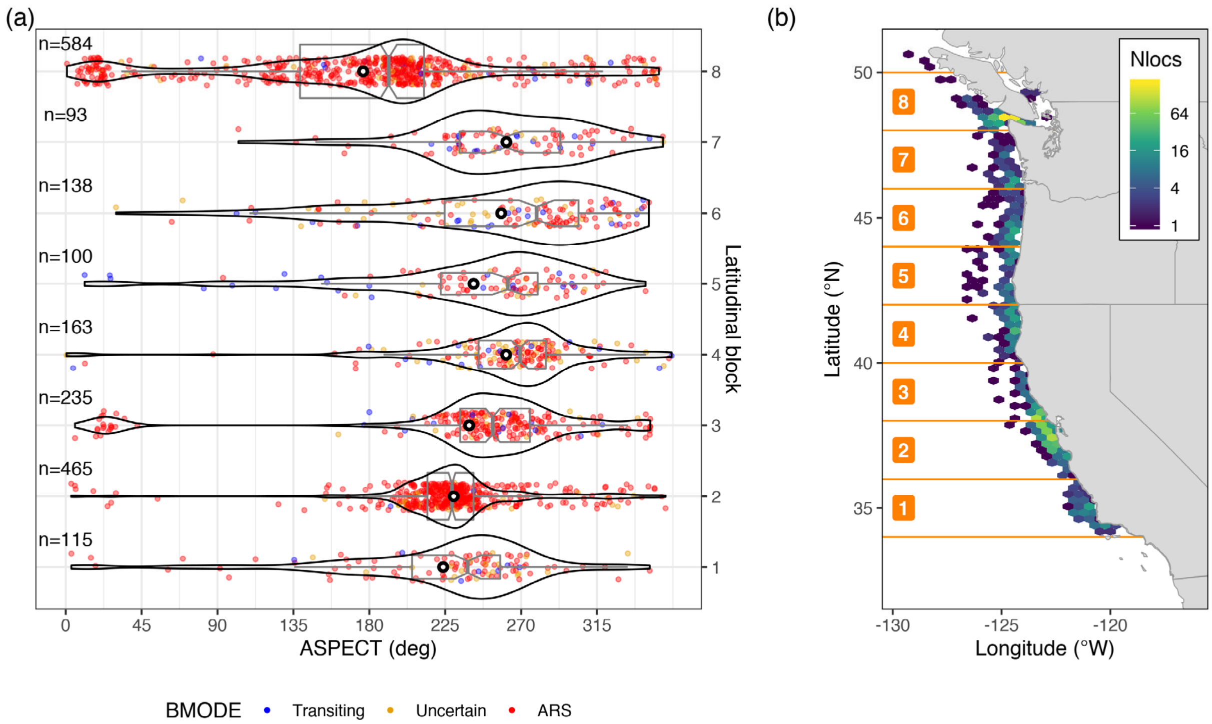


*Figure 44. (a) Box-violin plots showing the distributional characteristics of ASPECT (deg) for SSSM/hSSSM locations (dots colored by BMODE) in each of the eight 2-deg latitudinal blocks depicted in (b). Black circles indicate the mean. (b) Map of hexagonal-binned SSSM/hSSSM locations for all humpback whales tagged by OSU off the US West Coast from 2004 to 2018 depicting the density of locations (Nlocs, in log scale). Also shown are the eight 2-deg latitudinal blocks that were used to aggregate the environmental data for ecological characterization, as shown in (a).*

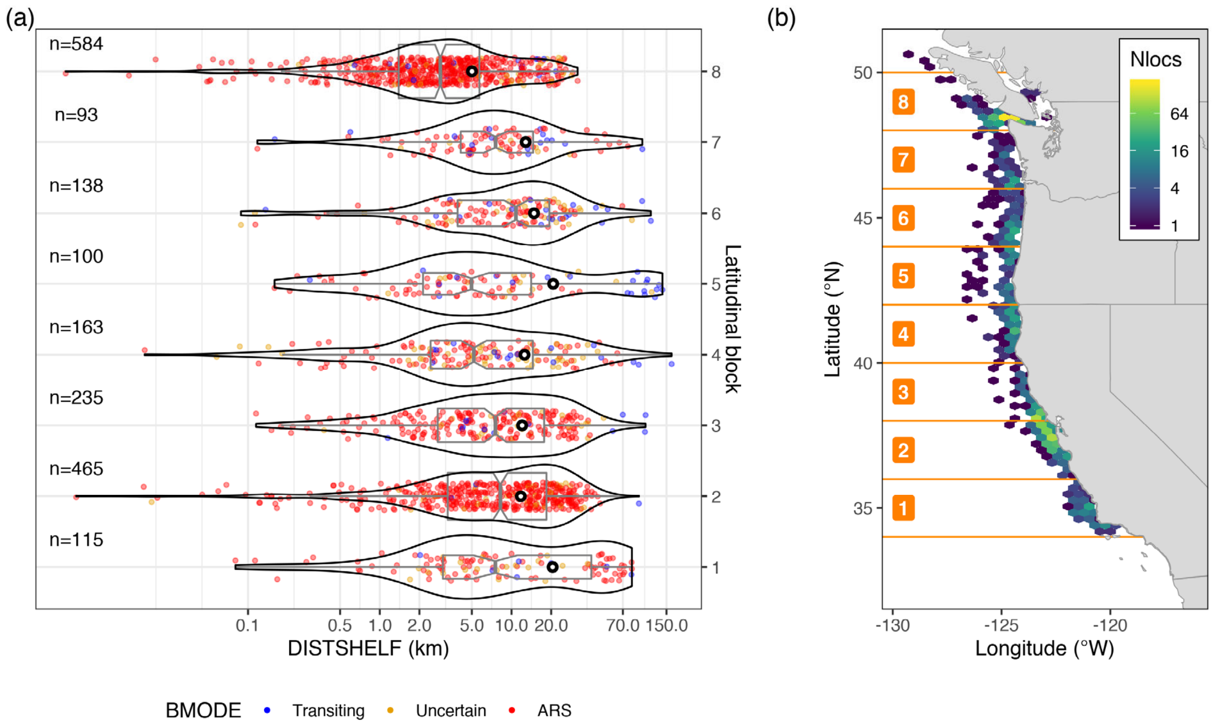


*Figure 45. (a) Box-violin plots showing the distributional characteristics of DISTSHELF (km) for SSSM/hSSSM locations (dots colored by BMODE) in each of the eight 2-deg latitudinal blocks depicted in (b). Black circles indicate the mean. The x-axis has been log-transformed to enhance visualization. (b) Map of hexagonal-binned SSSM/hSSSM locations for all humpback whales tagged by OSU off the US West Coast from 2004 to 2018 depicting the density of locations (Nlocs, in log scale). Also shown are the eight 2-deg latitudinal blocks that were used to aggregate the environmental data for ecological characterization, as shown in (a).*

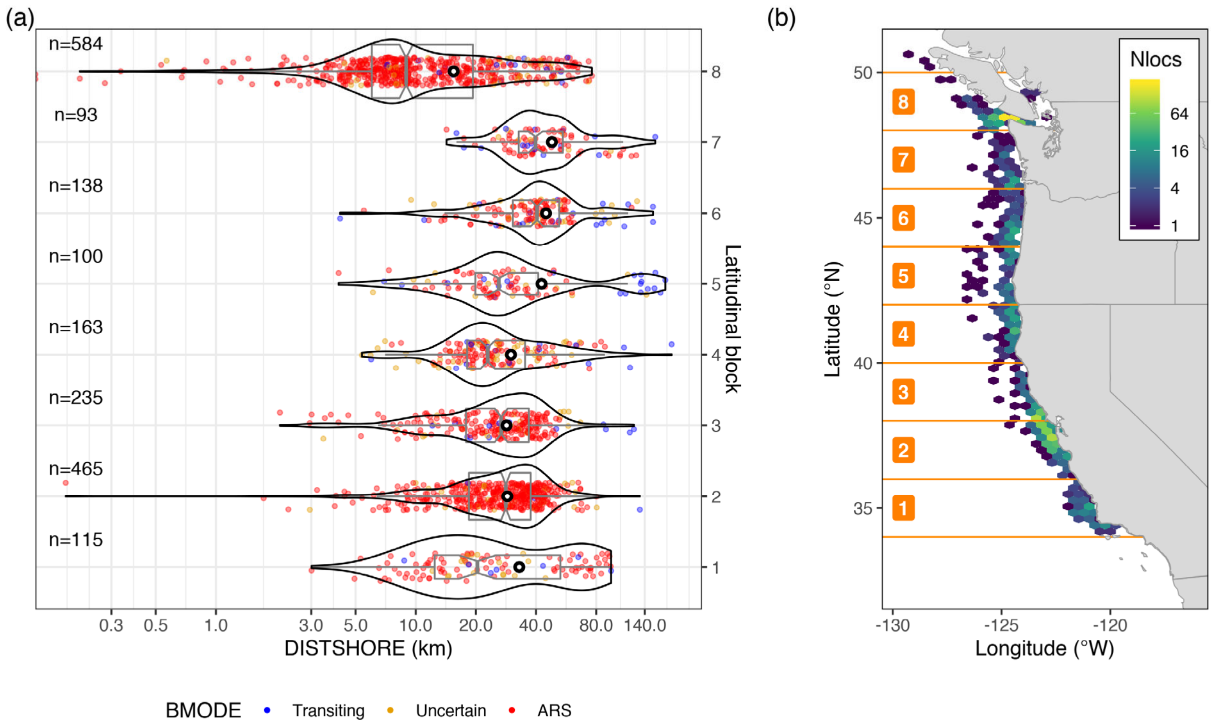


*Figure 46. (a) Box-violin plots showing the distributional characteristics of DISTSHORE (km) for SSSM/hSSSM locations (dots colored by BMODE) in each of the eight 2-deg latitudinal blocks depicted in (b). Black circles indicate the mean. The x-axis has been log-transformed to enhance visualization. (b) Map of hexagonal-binned SSSM/hSSSM locations for all humpback whales tagged by OSU off the US West Coast from 2004 to 2018 depicting the density of locations (Nlocs, in log scale). Also shown are the eight 2-deg latitudinal blocks that were used to aggregate the environmental data for ecological characterization, as shown in (a).*

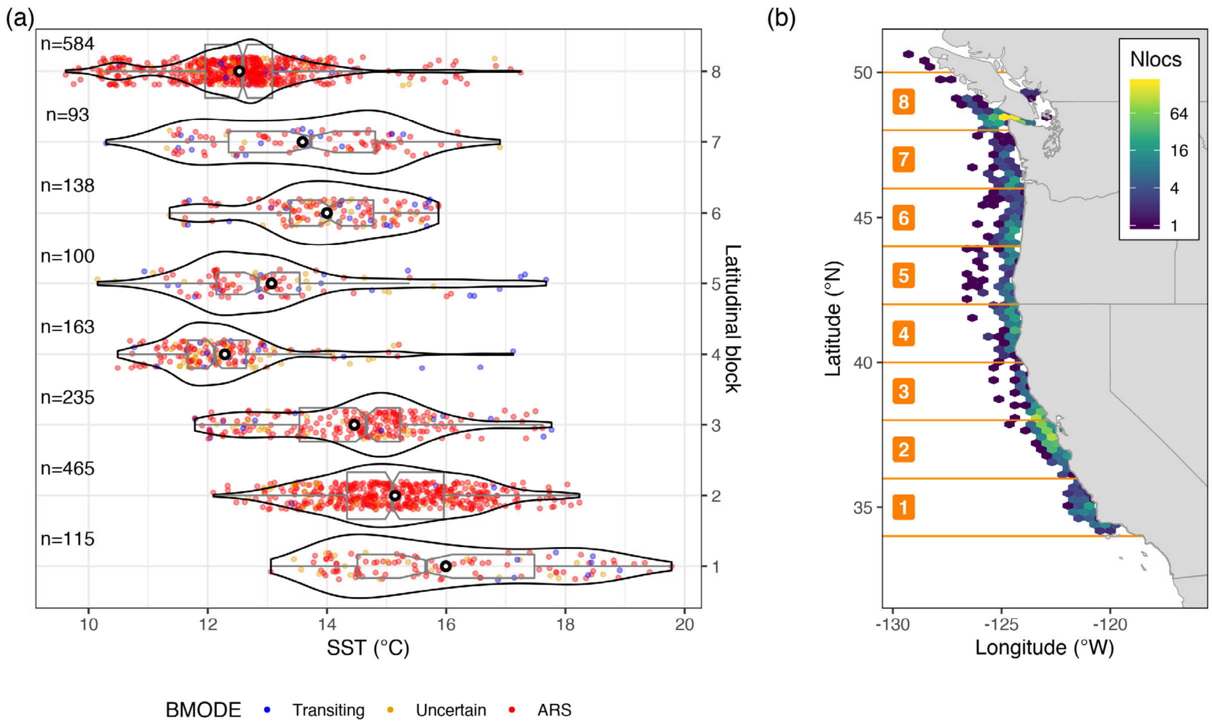


*Figure 47. (a) Box-violin plots showing the distributional characteristics of SST (°C) for SSSM/hSSSM locations (dots colored by BMODE) in each of the eight 2-deg latitudinal blocks depicted in (b). Black circles indicate the mean. (b) Map of hexagonal-binned SSSM/hSSSM locations for all humpback whales tagged by OSU off the US West Coast from 2004 to 2018 depicting the density of locations (Nlocs, in log scale). Also shown are the eight 2-deg latitudinal blocks that were used to aggregate the environmental data for ecological characterization, as shown in (a).*

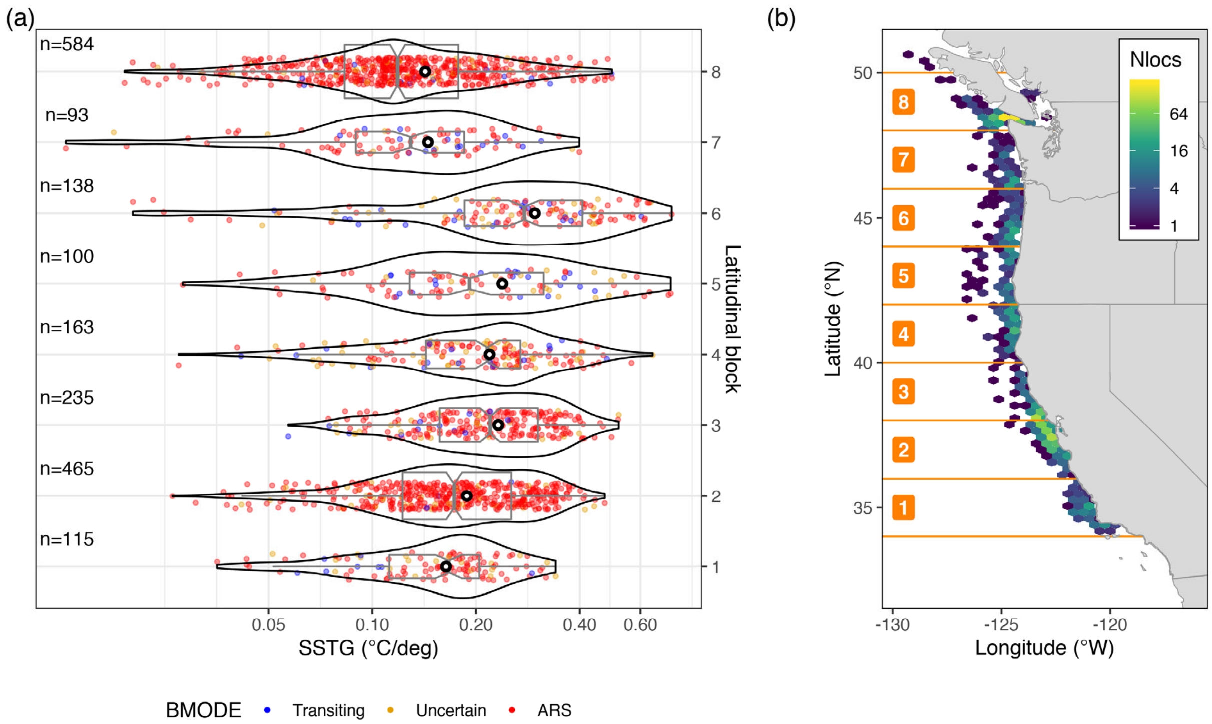


*Figure 48. (a) Box-violin plots showing the distributional characteristics of SSTG (°C/deg) for SSSM/hSSSM locations (dots colored by BMODE) in each of the eight 2-deg latitudinal blocks depicted in (b). Black circles indicate the mean. The x-axis has been log-transformed to enhance visualization. (b) Map of hexagonal-binned SSSM/hSSSM locations for all humpback whales tagged by OSU off the US West Coast from 2004 to 2018 depicting the density of locations (Nlocs, in log scale). Also shown are the eight 2-deg latitudinal blocks that were used to aggregate the environmental data for ecological characterization, as shown in (a).*

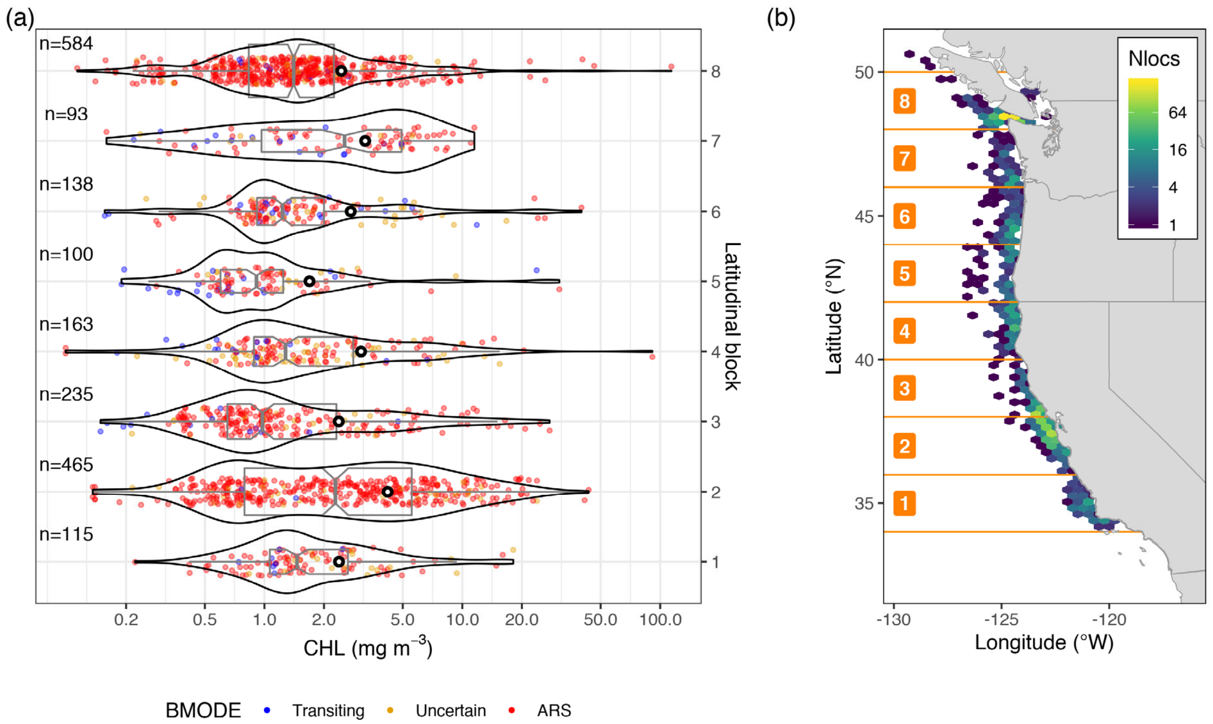


*Figure 49. (a) Box-violin plots showing the distributional characteristics of CHL (mg/m$^3$) for SSSM/hSSSM locations (dots colored by BMODE) in each of the eight 2-deg latitudinal blocks depicted in (b). Black circles indicate the mean. The x-axis has been log-transformed to enhance visualization. (b) Map of hexagonal-binned SSSM/hSSSM locations for all humpback whales tagged by OSU off the US West Coast from 2004 to 2018 depicting the density of locations (Nlocs, in log scale). Also shown are the eight 2-deg latitudinal blocks that were used to aggregate the environmental data for ecological characterization, as shown in (a).*

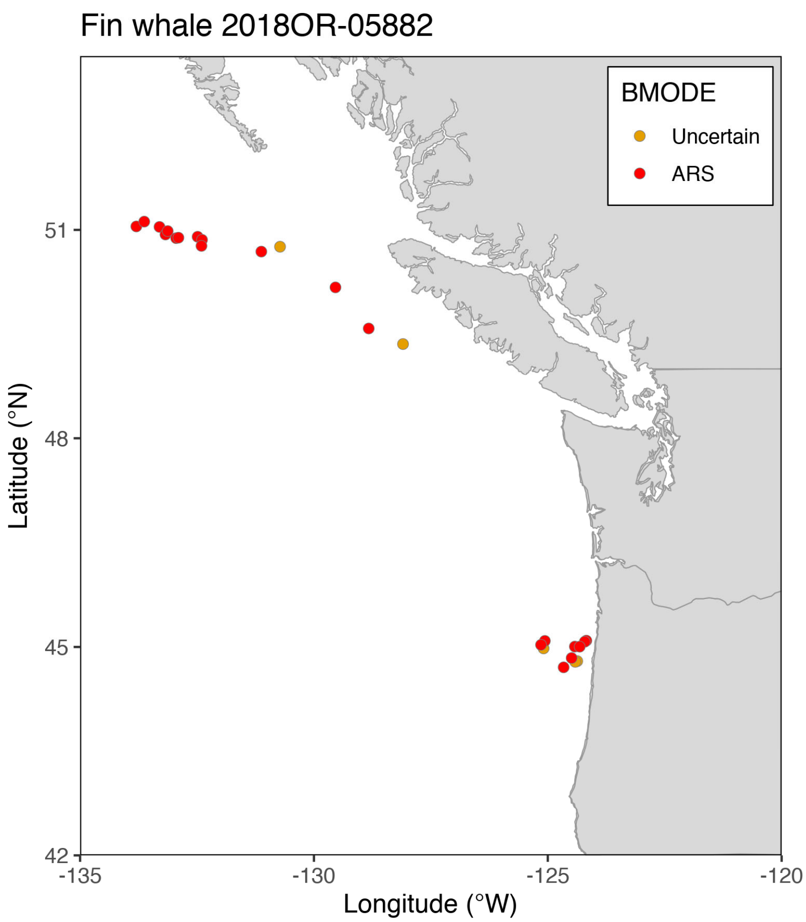


*Figure 50. The geographic distribution of SSSM locations colored by behavioral mode for the single fin whale tagged by OSU off Oregon in 2018.*

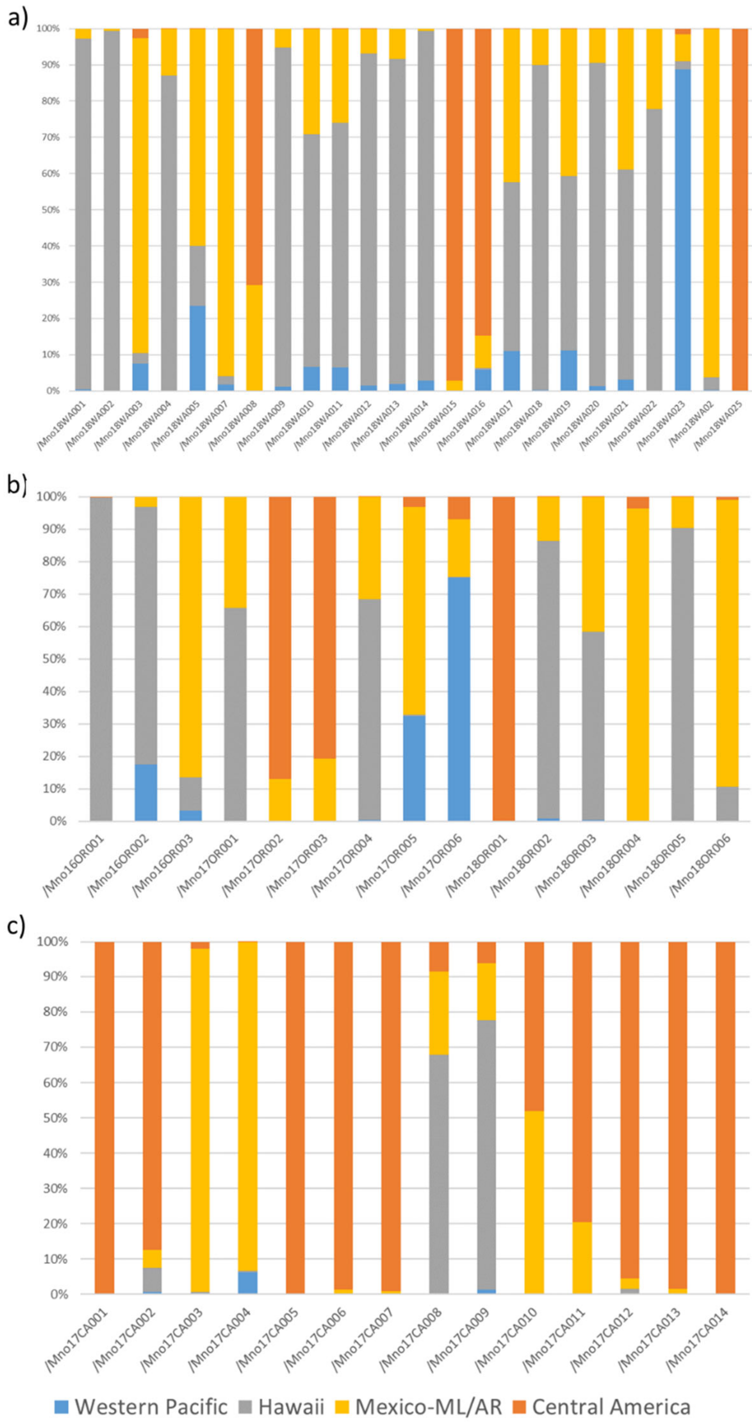


*Figure 51. Individual assignment of the a) Washington 2018, b) Oregon 2016-2018 and c) California 2017 tagging samples to the four Distinct Population Segments (DPS) recognized by the US Endangered Species Act. The stacked bars represent the relative likelihood of assignment for each whale to the four DPSs based on the program GeneClass2 and using the published SPLASH dataset as reference samples (Baker et al. 2013).*

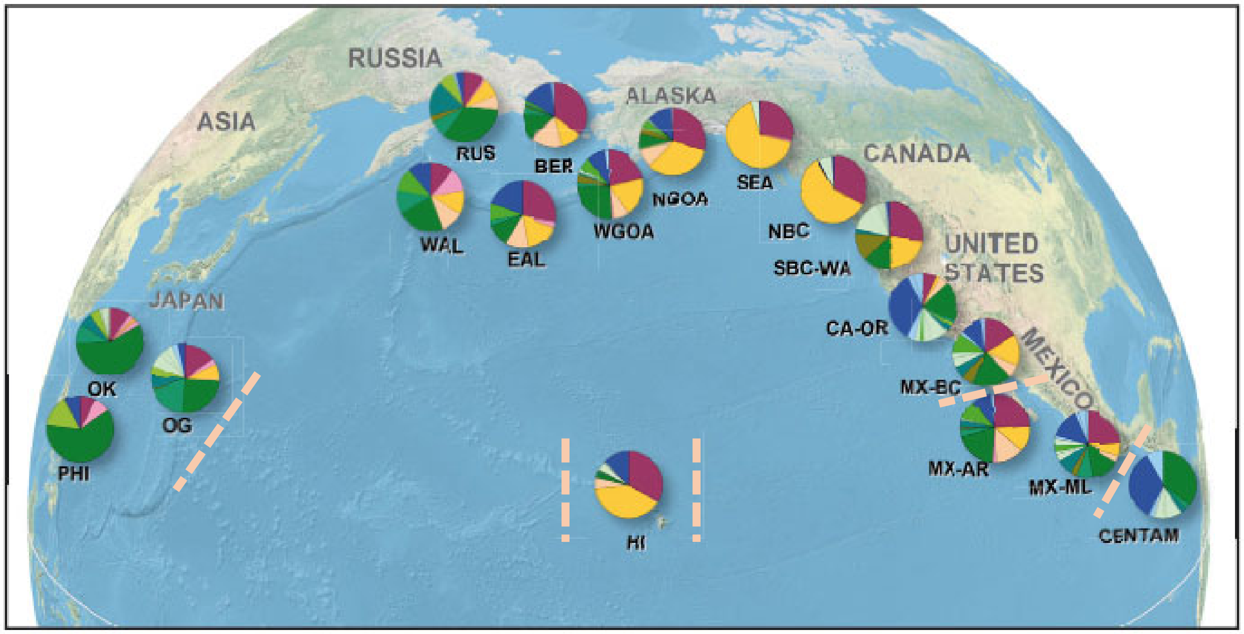


*Figure 52. Pie charts of mtDNA frequency for the 10 feeding areas and eight breeding grounds sampled during the SPLASH program, as modified from Figure 2 in Baker et al. (2013). The dashed lines indicate the stratification used to represent the reference database of the four DPSs: Central America, Mexico (MX-ML and MX-AR), Hawaii and the Western North Pacific (OK, OG, and PHI). Only samples from breeding grounds were used in the reference database for assignment to DPS; see text for details.*

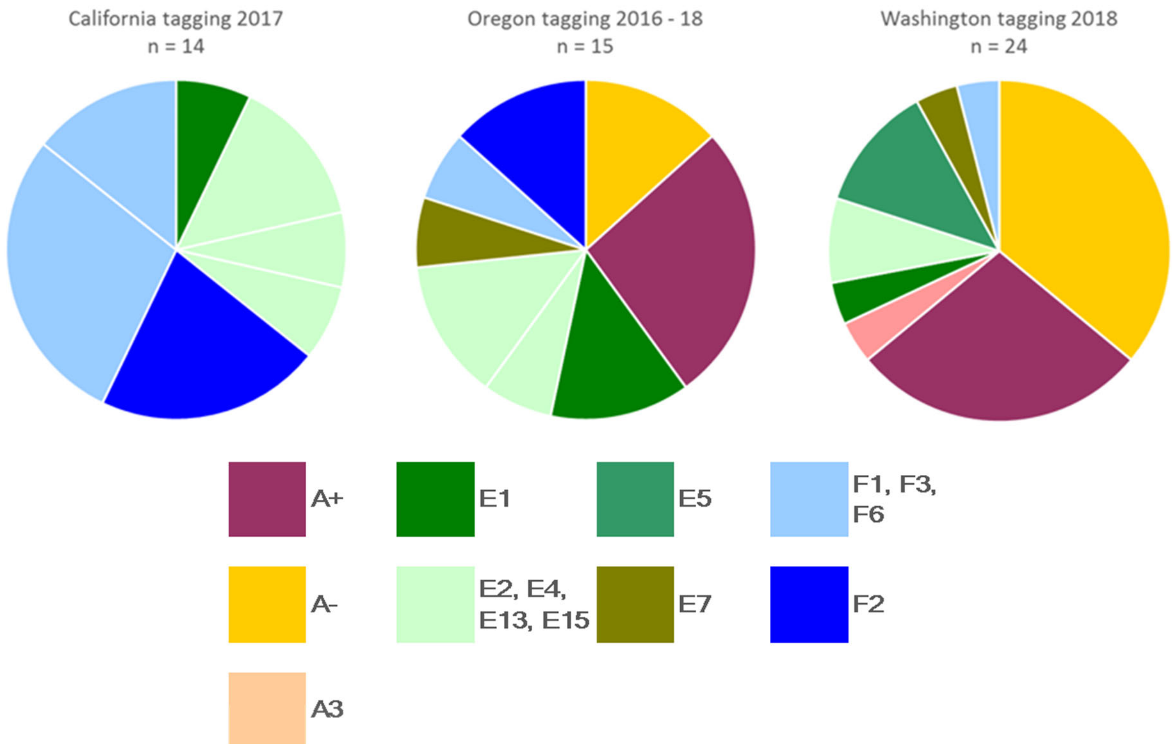


*Figure 53. Pie charts of mtDNA haplotype frequencies for the California, Washington, and Oregon tagging samples. The size of the slice reflects the relative frequency of each haplotype for each dataset. Several of the less common haplotypes have been combined into a single color representing related haplotypes, as indicated by the key.*

# 7 Appendix I

## 7.1 Erratum to Table 29 in Mate et al. (2018a).

**Table A30. 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. Amended numbers are presented in red.**

| | # 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 (13) | 1 | 2.8 | 2.8 | 3 | 16.2 | 33.8 | 4 | 7.6 | 12.7 | 0 | - | - | 0 | - | - |
| 2005OR (1) | 1 | 1.8 | 1.8 | 1 | 2.6 | 2.6 | 1 | 14.5 | 14.5 | 0 | - | - | 1 | 0.3 | 0.3 |
| 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.