Assessing the movements and occurrence of Southern Resident Killer Whales relative to the U.S. Navy's Northwest Training Range Complex in the Pacific Northwest

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Executive Summary

1. Remotely deployed telemetry tags were used to assess the movements and occurrence of the whales in the winter, and passive acoustic recorders deployed in areas thought to be frequently used by the whales, were used to assess their seasonal occurrence in these areas. These data will be used to provide information to better understand their seasonal occurrence in relation to the U.S. Navy's Northwest Training Range Complex (NWTRC) in the Pacific Northwest.

2. We compiled all locations for satellite tagged killer whales up through 2015 and created duration of occurrence and state-space models to identify areas of high use and travel corridors. SRKW detections from an enhanced array of acoustic recorders was summarized through summer 2015.

3. Enhancement of the acoustic recorder array increased the number of detections by 35%. SRKW were detected to occur in, or to the south of, the NWTRC, indicating year-round use of the complex. SRKWs were not detected on a mooring located off the continental shelf. Fishery interactions likely impacted the recovery of some recorders.

Range

4. The range of satellite tagged whales from K/L pods, which included from northern California to central Vancouver Island, British Columbia, was smaller than from available opportunistic sighting data. J pod range, being mostly in the waters of the Salish Sea was about the same as the available opportunistic sighting data.

5. Throughout their range K/L pods occurred almost exclusively on the continental shelf; primarily on the Washington coast with high use areas mainly between Grays Harbor and the Columbia River. J pods primary high areas were in the northern Strait of Georgia and the western entrance to the Strait of Juan de Fuca.

Overlap with NWTRC

6. Tagged SRKWs occurred only in NWTRC areas W237A, B, and E. Only about 9.7% of the NWTRC was used by satellite tagged SRKWs, and only the most shoreward portion of the range. Overall, for all three pods, only about 16.4% of their collective winter range was in W237, although for K/L pods this was 17.5% and for J pod it was 10.3%. Overall, all three pods spent only about 15% of their time in the NWTRC. K/L pods occurred much more frequently in the NWTRC than J pod, spending on average about 19.7% of their time there compared to 3.1% for J pod. Only about 10% of high use cells

were in the NWTRC, which were all associated with K/L pods. Median visit duration to the NWTRC was estimated to be about 13.3 hours with a median of about 2.6 days between visits.

Distance from Shore

7. Tagged SRKWs mostly occurred within 34 km of shore (95% of locations), of which 50% were within 10km of the coast. Only 5% percent of the locations occurred more than 34 km off the coast but did not exceed 75 km.

8. Seventy-five percent (75%) of the tag locations on the outer coast were in a 16 km wide corridor (3-19 km offshore).

Depth

9. Most locations of tagged SRKW were in waters less than 100m in depth, and 49% were between 18 m and 54 m with a median in that depth range of 36m.

Speed

10. The tagged whales tended to travel faster off the coasts of Oregon and California compared to the Washington coast.

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List of Acronyms

EAR - Ecological Acoustic Recorder

ESA - Endangered Species Act

GIS – Geographic Information System

MCMC - Markov Chain Monte Carlo

MCP - Minimum Convex Polygon

MOA – Military Operations Area

NWTRC – Northwest Training Range Complex

PODs – Pacific Orcinus Distribution survey

SEAK - Southeast Alaska

SRKW - Southern resident killer whale

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Introduction

Killer whales are the most widespread of cetacean species, occurring in all oceans; from tropical to polar waters. Within these regions are overlapping communities of killer whales, or ecotypes, with dietary specializations. The season availability of preferred prey likely plays an important role in the movements patterns of these of animals during the year. Photo-Id has provided some insights into the ranges these whales occupy, but more recently the advent of remotely deployable tags and acoustic recorders has provided a fuller picture on their movement and occurrence patterns. Identification of preferred areas is important to aid in proper management actions of species, particularly those that are listed under the U.S. Endangered Species Act (ESA), due to the mandate to designate Critical Habitat. Southern resident killer whales (SRKW) were listed under the ESA in 2005 and although Critical Habitat was designated for much of what is their summer range, the inland waters of Washington, a primary data gap identified in the Recovery Plan was their winter distribution.

SRKWs are ”resident” in the inland waters of the Salish Sea during the summer months (Hauser et al. 2007), feeding primarily on Chinook salmon returning to the Fraser River system (Hanson et al. 2010). As such they are frequently observed there and their movements have been well monitored in this area for the 40 years that this population has been distinguishable using photo-ID (Center for Whale Research 2016). However, by late September most of the Chinook runs returning to this region have moved into the rivers and the whales begin to switch species (Ford et al. 2016, NWFSC unpubl. data) and expand into other areas, i.e., Puget Sound, Northern Strait of Georgia, and coastal waters for extended periods of time. As a result of their greater dispersion into more remote areas where there are few members of the general public, and no whale watch operations or dedicated research activities, as well as being in seasons of frequent inclement weather and shorter day-length, all conspire to reduce sighting opportunities. As a result little sighting information has been available for this whale population from fall to spring for the past 40 years (Figure 1, Appendix A), limiting our ability to discern their movements and occurrence patterns during these seasons.

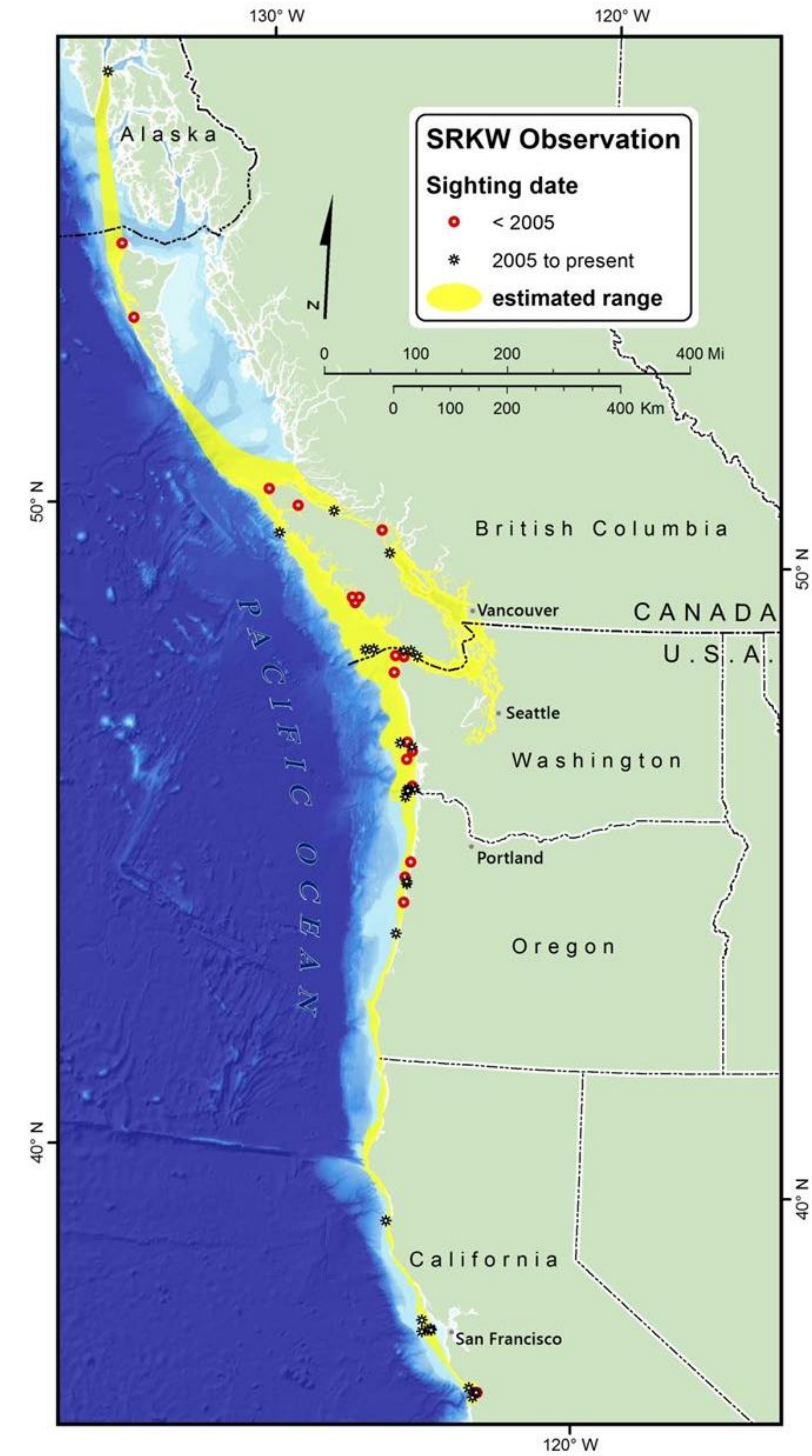

Figure 1. Locations of visual sightings of SRKW outside the Salish Sea during fall, winter, and spring, from 1975 to 2016.

Remotely deployed telemetry tags were used to assess the movements and occurrence of the whales in the winter and passive acoustic recorders, deployed in areas thought to be frequently used by the whales, were used to assess their seasonal occurrence in these areas. These data will be use to provide information to better understand their seasonal occurrence in relation to the U.S. Navy's Northwest Training Range Complex (NWTRC) in the Pacific Northwest (Figure 2).

Methods

Satellite-linked tagging

We deployed satellite-linked tags (Wildlife Computers Spot 5) on SRKW in Puget Sound or in the coastal waters of Washington and Oregon between 2012 and 2016. These tags transmitted to the Argos system, providing multiple locations per day. Due to variability in the error associated with each location, these were filtered with Douglas filter (available at: http://alaska.usgs.gov/science/biology/spatial/douglas.html) based on maximum potential velocity and turning angle.

Analyzing tracking data

Home range size

Home range was estimated from the ARGOS locations utilizing a modified minimum convex polygon (MCP) approach. A MCP provides a relatively straightforward method for calculating range areas from tracking data or any coordinate based set of observations. In general, an area is constructed by using the smallest possible convex polygon around an entire spatial data series. However, this process is prone to overestimating home range size (Burgman and Fox, 2003), which we also encountered when applying it to Alaska resident-type killer whales.

In order to diminish the effects of area overestimation, we developed an aggregated MCP that was generated using overlapping time periods. As others have discovered (Burgman and Fox, 2003), we found that a single MCP did not represent the large spatial and temporal extent of the data in a realistic manner. Instead, we treated each killer whale's 24-hour period (0-24) as an individual dataset, and developed a unique MCP for each animal by day. Additionally, in order to avoid gaps between 24-hour periods, we calculated a set of days that were offset by 12 hours (12-36).

With the resulting set of MCPs, the entire series was merged into a single GIS theme in ArcGIS v. 9.2 (ESRI), where each killer whale day (and overlapping day) was characterized by a unique polygon feature. All features were then dissolved into a single polygon encompassing all killer whale days. This feature became the estimated MCP home range for tagged killer whales. It is not suggested that this shape delineates the population's entire range, but is instead an

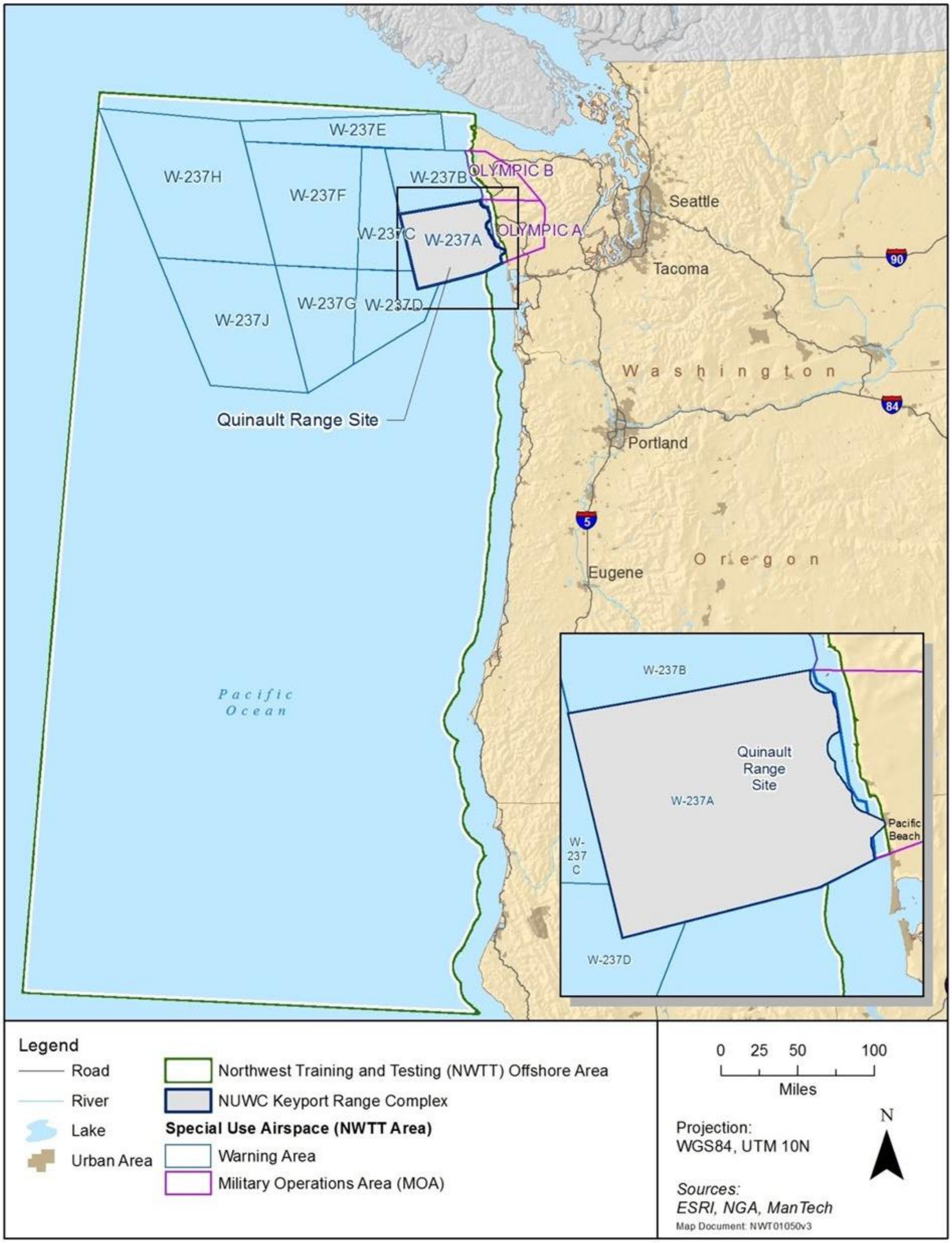

Figure 2. Study Area map showing the Navy's Northwest Training Range Complex.

approximation for the tagged animals in our data series.

High use areas – Duration of Occurrence Model

We developed maps to assess high-usage areas in ArcGIS using the reduced satellite tag location data set (i.e. using only one of each pair or trio of individuals acting in concert). All data were summarized using a vector grid composed of 5 × 5 km cells that encompassed the range of all the tracking locations. We chose grid cells of 5 × 5 km because they are large enough to account for error in Argos locations. A spatial join was used to associate locations within grid cells. Additionally, track lines were developed by connecting the locations in temporal sequence and intersecting the resulting features by the overlay grid which all allowed for the estimation of durations in defined areas and travel speeds. The density for each cell was calculated for total visit duration in each cell, with a late start (only location data were included after a duration of time sufficient for the tagged whale to reach the maximum distance from tagging location) following Baird et al. (2012).

High use areas – State-space models

We also fit a Bayesian state-space movement model to the location data following the approach of Jonsen et al. (2005). State-space movement models have been applied to a wide range of tracking data from terrestrial and aquatic species (Jonsen et al. 2003). One of the advantages of these methods is that they improve the precision of estimated locations (and resulting estimates of rates of travel) because they partition the total variance in the observed track into process variance (changes in speeds and turning angles) and observation variance (representing the measurement uncertainty associated with the Argos location quality of each individual location).

Like previous state-space analyses of animal movement (Jonsen et al. 2005), we conducted Bayesian estimation using the JAGS language and the R2jags package in R (Plummer 2003, R Core Development Team 2015, Su and Yajima 2015). We generated 10000 Markov Chain Monte Carlo (MCMC) samples across 4 parallel chains.

Travel speed, habitat depth use, travel corridor analyses

Evaluation of travel speeds, habitat depth distributions, and travel corridor analysis were examined across regional summary zones whose boundaries were demarcated in inland waters based on distinct water bodies (i.e., Puget Sound, Strait of Georgia, Strait of Juan de Fuca) and in coastal waters the boundaries roughly aligned with state borders, except in Washington State where the coast was divided into South and North Coast areas (the latter which included W237), to allow for comparisons of other portions of the whale's range with W237.

Acoustic recorders

Our second dataset consists of detections of stereotypic calls of SRKW collected on autonomous passive acoustic recorders deployed off the coast of California, Oregon, and Washington in most years since fall 2006. The Ecological Acoustic Recorder (EAR) (Lammers et al. 2008) was use for all deployments since 2008. These recorders are programmed to record at a sample rate of 25 kHz with an approximate 5% duty cycle of recording 30 seconds every 10 minutes (additional details in Hanson et al. 2013). Recovered hard drives from the acoustic recorders are manually scored, with vocalizations categorized by species. While each of the three Southern Resident pods has unique vocalizations, two of the three pods are often not differentiable (K and L pod). Because these latter groups spend more time on the outer coast and were the focus of the satellite tagging, we focused on the combined vocalizations of these groups (assuming they traveled together).

The results of acoustic monitoring from up to seven locations (see Hanson et al. 2013, Figure 4) from 2006 through 2011 detected SRKW 131 times (Hanson et al. 2013). The number of recorders deployed off the Washington coast was increased to 17 sites in the fall of 2014 to better assess the residency of the whales (Figure 3).

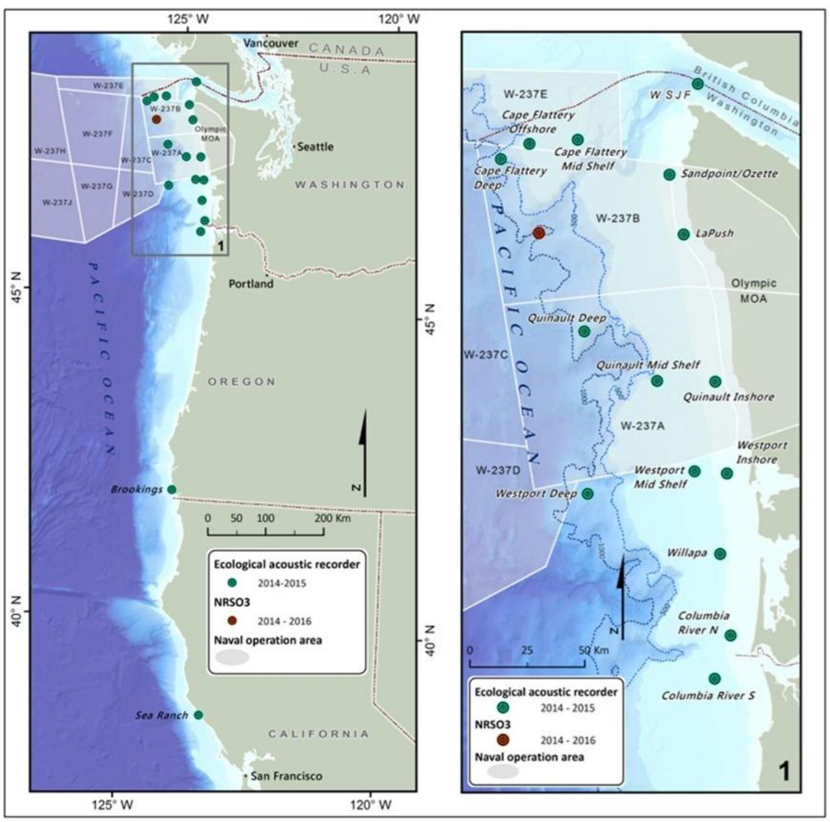

Figure 3. Locations of passive acoustic recorders deployed beginning in the fall of 2014.

Results

Satellite-linked tagging

Between 2012 and 2016 satellite tags were deployed on eight SRKW (Table 1). Three tags were deployed on J pod members, two on K pod, and three on L pod. All tags were deployed on adult males. One of the tag deployments (L88) occurred while K25 was tagged, but because K and L pods were together during the duration of this deployment the L88 data were not included in these analyses. A total of 323 days were monitored for these unique whales (duration of signal contact ranged 3-96 days) yielding 3145 locations for all whales. The seasonal duration of satellite tag data spanned from late December to mid-May.

Table 1. Satellite tag deployment information for Southern resident killer whales.

Whale ID	Pod association	Date of tagging	Duration of signal contact (days)
J26	J	20 Feb. 2012	3
L87	J	26 Dec. 2013	31
J27	J	28 Dec. 2014	49
K25	K	29 Dec. 2012	96
L88*	L	8 Mar. 2013	8
L84	L	17 Feb. 2015	93
K33	K	31 Dec. 2015	48
L95	L	23 Feb. 2016	3

*whale was tagged and monitored during K25 deployment when K and l pods were together and therefore not included analyses

Range

The winter locations of tagged whales included both inland and coastal waters. Their range in inland waters spanned the entire Salish Sea (northern end of the Strait of Georgia and Puget Sound) and in coastal waters from central west coast of Vancouver Island, British Columbia (B.C to northern California (Figure 4), a total MCP area encompassing approximately 49,590km^2. J pod moved primarily between the northern Strait of Georgia and the western entrance of the Strait of Juan de Fuca with only limited excursions into coastal waters, an area totaling 17,403km^2. Conversely, K and L pods had a primarily coastal distribution; from the western entrance to the Strait of Juan de Fuca to Pt. Reyes California, an area of 40,228km^2.

High use areas

J pod and K and L pods displayed preferences for several areas within their respective ranges. Overall, J pod's high use areas, based on the duration of occurrence model (0-3 Standard

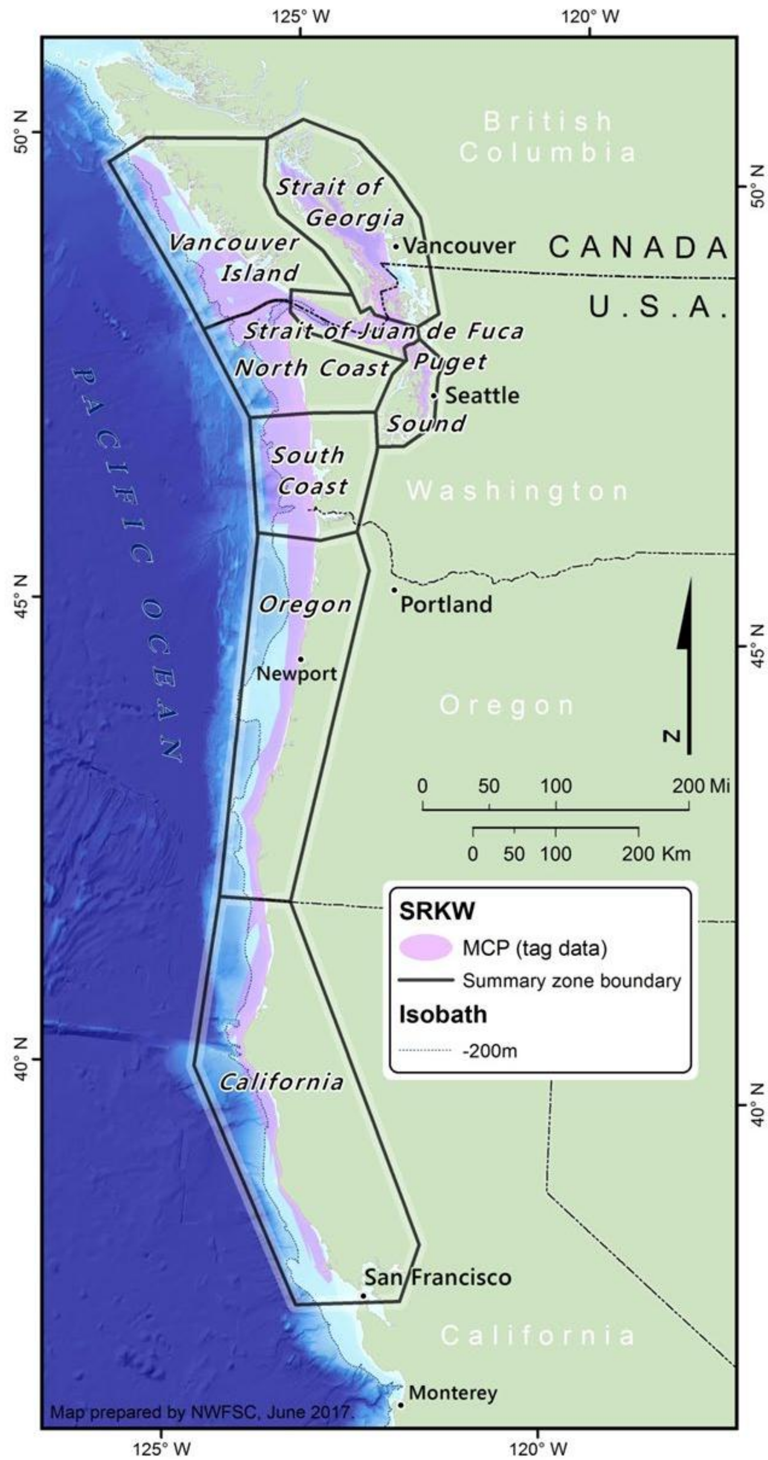

Figure 4. Minimum Convex Polygon range and Regional Summary Areas of all tagged SRKWs as determined from satellite tagging**.**

Deviations) included an area that represented only 33.2% of their range (Figure 5) but where they spent 70.9% of their time.

J pod had two discrete high use areas; the northern Strait of Georgia area and the western end of the Strait of Juan de Fuca. Together, both high use areas (1-3 Standard Deviations) represented only 7.3% of the total area, but they spent for 29.5% of their time there. However, the north Strait of Georgia was about twice as large as the western Strait of Juan de Fuca area (approximately 800 km^2 vs 450 km^2) representing only 4.7% and 2.6% of their overall range respectively, but accounted for 18.7% and 10.8% of their time. Similar patterns of use were observed from the 90% and 50% posterior density plots from the state-space model (Figure 6).

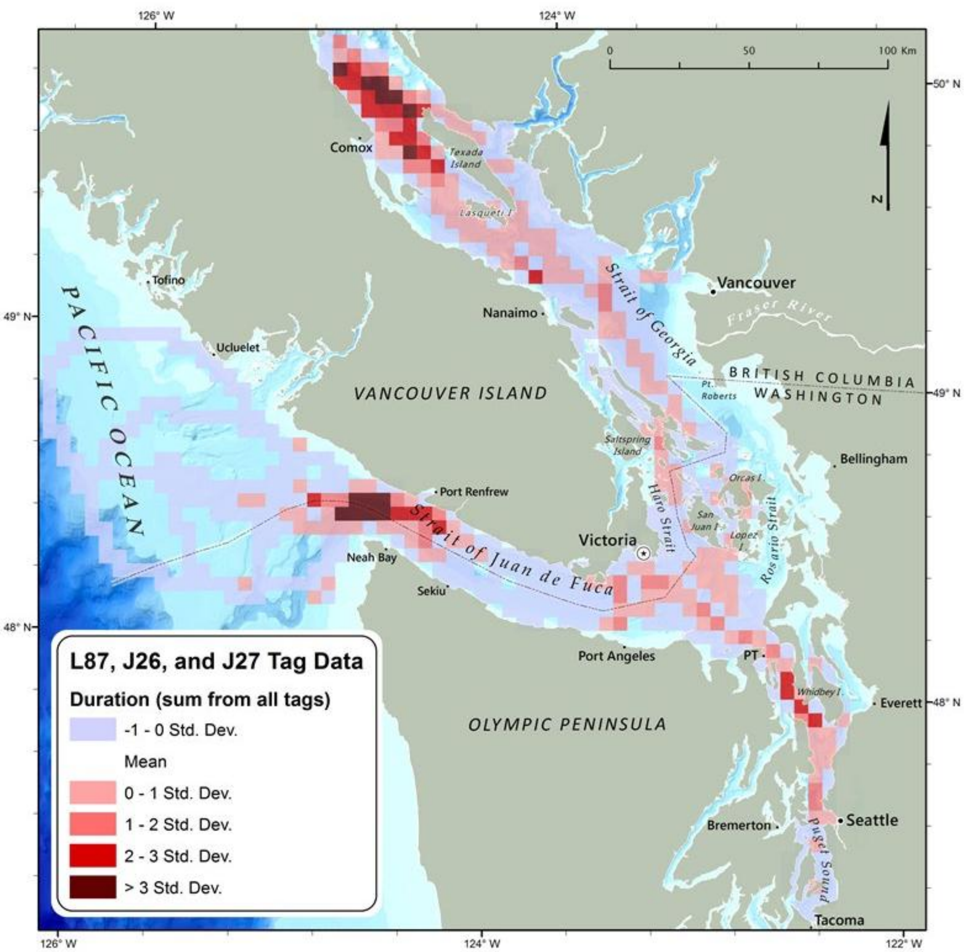

Figure 5. Duration of occurrence model output for J pod tag deployments.

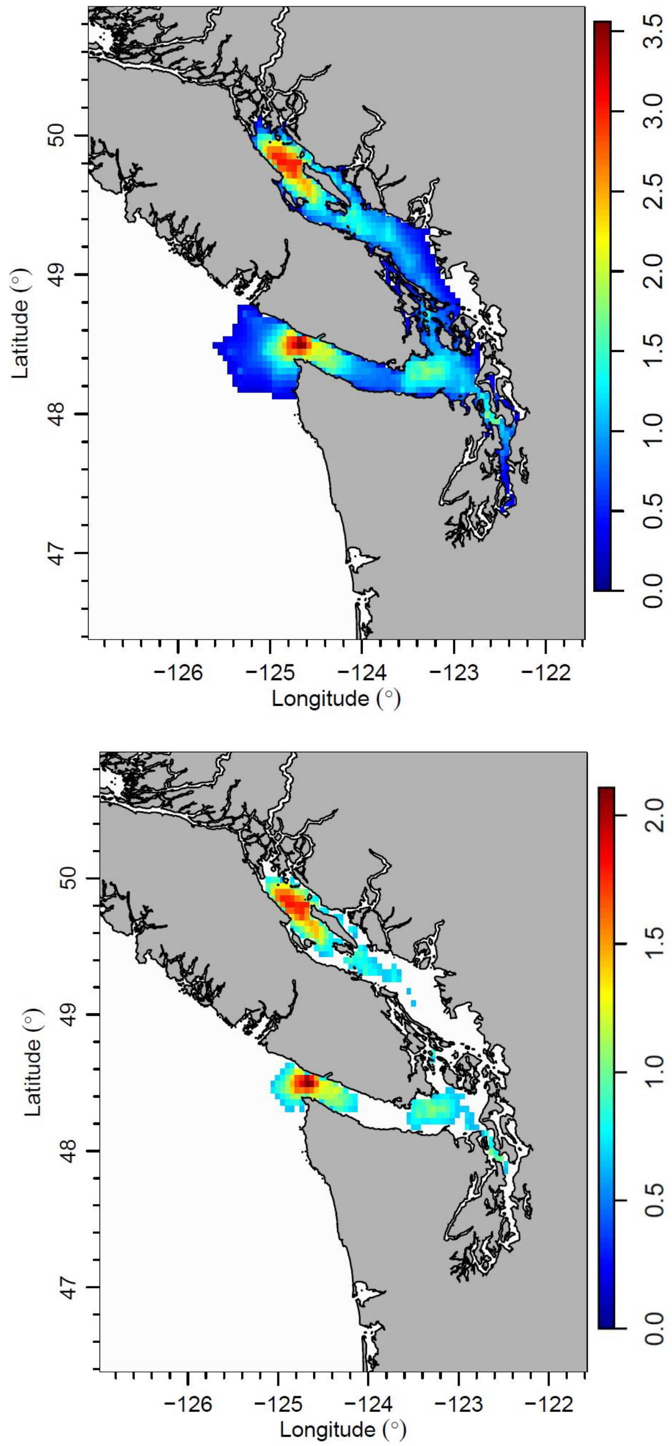

Figure 6. Highest 90% (top figure) and 50% (bottom figure) posterior density location plot of J27 and L87 based on satellite tag data. The color scale is relative to a uniform distribution within the colored area and is the dimensionless likelihood of being in a particular cell.

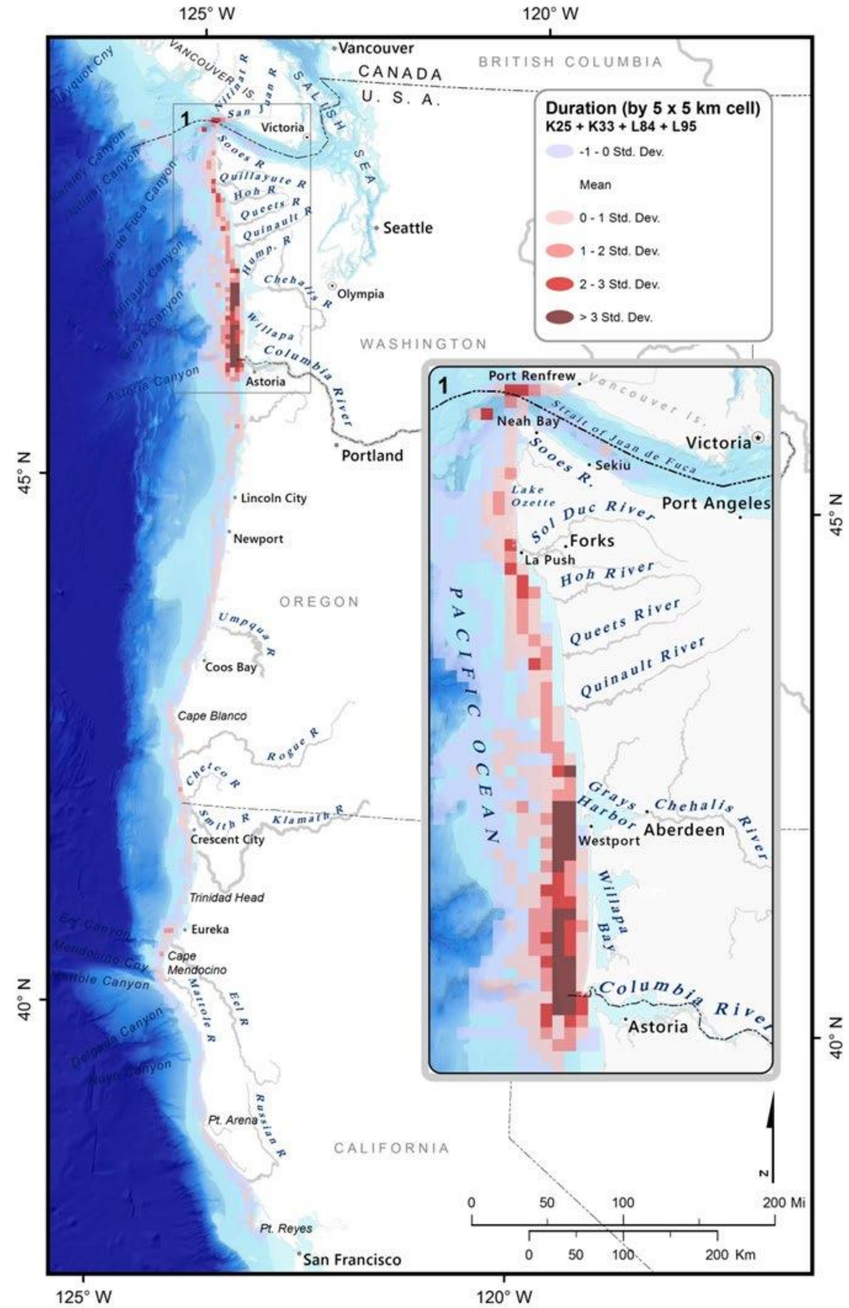

Figure 7. Duration of occurrence model for all unique K and L pod tag deployments.

Although the high use areas (0-3 Standard Deviations) off the entire Washington coast represented only 16.2% of the total area they used, they spent 53.1% time of their time there. A contiguous area of concentrated high use (0-3 Standard Deviations) occurred between Grays Harbor and Columbia River. Although this area represented only 10.7% of their total range they spent 40.7% of their time there. The highest use area(>3 Standard Deviations) between Grays Harbor and the Columbia River (an area totaling approximately 675 km^2) was only 1.9% of their range, but was where they spent 19.1% of their total time. As was the case with J pod, the 90% and 50% posterior density plots from the state-space model also identified similar high use coastal areas as the duration of occurrence model for K/L pods (Figure 8).

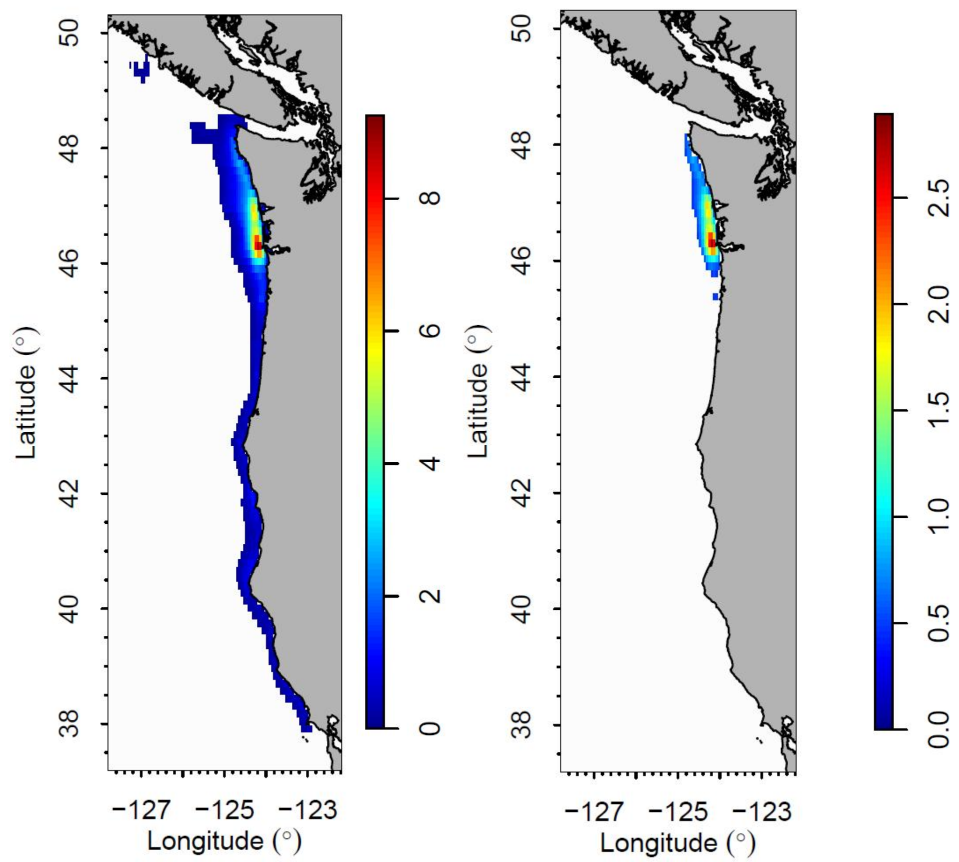

Figure 8. Highest 90% and 50% posterior density location plot of K25 and L84 based on satellite tag data. The color scale is relative to a uniform distribution within the colored area and is the dimensionless likelihood of being in a particular cell.

In general, there was minimal overlap between J pod and K and L pods (not including when K or L pods were known to be traveling with J pod). The general lack of overlap in the ranges of J and K/L was particularly notable in the comparison of relatively high use (0-3 Standard Deviations, Figures 5 and 7) as well as in the state-space models (Figures 6 and 8). The overlap in the high use areas from the duration of occurrence model included an area of only approximately 200km^2 near the western entrance to the Strait of Juan de Fuca, representing only 0.5% of all three pods total range. Further indicating a lack of overlap was the relative amount time estimated to have been spent in these high use cells with J pod spending 1.6% of their time there and K/L pods spend only 0.7% of their time there.

Occurrence within the Navy Northwest Training Range Complex

All of the tagged SRKWs occurred periodically in the waters of the Navy's Northwest Training Range Complex, including certain areas of W237 (see Figure 2 for map of W237 areas). K/Ls occurred in the most areas of W237 (areas A, B, and E), and most commonly in W237A, whereas J pod only occurred in W237E. Based on the duration of occurrence model, on average all three pods whales spent an estimated 15.0% of the total time they were monitored in W237. Tagged whales from K/L pods were estimated to occur there more frequently (19.7% of total time) compared to tagged J pod whales 3.1%). The greatest proportion of time spent in the training range by an individual tagged whale was L84 at 26.4%, compared to 17.7% and 12.2% for K25 and K33, respectively. Only five of the 51 cells with a Standard Deviation >2 from the duration of occurrence model were located in the NWTRC. The state-space model estimated the probability of occurrence in W237 for J pod at 0.4% and 1.2% for J27 and L87 respectively, whereas the probability of K/L pod occurring in W237 was estimated at 13.4% and 12.9% for K25 and L84, respectively.

During the 323 total days that the seven uniquely tagged individuals were monitored, they generally occurred in W237 in relatively well defined episodes ranging from a few hours to a few days. In addition, their general occurrence in nearshore waters resulted in frequent movements between W237A, and W237B, and the adjacent waters inshore of these two areas (0-3 miles offshore)., such that occurrences in this latter area are included in this summary due to their close proximity. For all seven uniquely tagged whales there were 32 episodes when they occurred in W237or adjacent nearshore waters. K/Ls occurred in these areas on 28 occasions during the 240 days members of these pods were tracked, and J pod occurred there 4 times during the 83 days the whales from these pods were tracked. The median duration of the episodes of all pods in W237 or adjacent nearshore waters was 13.3 hours with a minimum of 3.1 hours and maximum of 124.4 hours. K/L pods were estimated to spend slightly longer periods (median 12.6hrs) than J pod (median 8.1hrs) respectively, but J pod never occurred there for more than 19.9 hours compared to 10 of the 28 episodes for K/L pods that exceeded

19.9 hours. Overall, the median duration between SRKW visits was 2.6 days with inter-visit intervals as short as 0.4 days and as long as 24.2 days. K/L pods occurred there more often, with a median of 2.4 days between visits compared to 7.3 days for J pod.

The proportion of the area of all three pods total winter range that occurred within W237 represented 16.4%, and for K/L, and J pods it was 17.5% and 10.3%, respectively. However, all three pods only occupied 9.7% of W237, with K/L occupying 8.4% and J pod 2.1%, and in both cases they occupied only the more shoreward portion of W237.

Travel speed

Overall, tagged SRKWs had a median travel speed of 6.6 km/hour (hr) across all summary zones (Table 2, Figure 4). However, some variability was displayed between whales and between regions. K pod whales tended to travel faster with the median rate of travel being 7.1 km/hr during the K25 tag deployment and 6.9 km/hr during the K33 deployment. L84's median travel speed was less than K pod (6.3 km/hr), but was still faster than either of the two J pod tag deployments at 6.1 km/hr (L87) and 5.8 km/hr, (J27) respectively. On the coast, the median travel speeds were slowest off the North and South Coast areas of Washington (6.0 and 6.1 km/hr, respectively). Their median travel speed was intermediate off Vancouver Island, (6.6 km/hr) and fastest off Oregon and California (both 7.2 km/hr).

Table 2. Median estimated travel speed (km/hr) of tagged SRKW by summary zone.

	Vancouver Island	North Coast	South Coast	Oregon	California	Strait of Georgia	Strait of Juan de Fuca	Puget Sound	Mean of all SRKW Medians
SRKW ID									
J26	6.5	6.5					8.5		7.2
L87	6.0	6.4				6.3	5.9	6.0	6.1
J27	6.1	4.7				5.8	6.7	5.9	5.8
K25	8.6	6.9	6.2	7.1	7.1	0.0	7.9	5.9	7.1
L84	6.5	5.3	5.4	6.7	7.7				6.3
K33	6.1	6.7	6.7	7.8	6.8	7.9	6.4	6.6	6.9
L95		5.7	5.9						5.8
Mean of all Zone Medians	6.6	6.0	6.1	7.2	7.2	6.7	7.1	6.1	6.6

Depth occurrence in coastal waters

Nearly all coastal locations (96.5%) of satellite tagged SRKW occurred on the continental shelf (depth of 200m or less). The majority of locations (77.7%) were in waters less than 100m in depth, but only 5.3% were in depths less than 18m. Nearly half (49.0%) of the locations occurred in waters between 18m and 54m with the mean depth in this band at 36m, however, this depth range represented only 18.3% of the total area within the coastal portion of their Minimum Convex Polygon (MCP),indicating a preference for these depths. Between the regional summary areas, depth use by the tagged whales showed that for 50% of the locations, the narrowest band (20-48m) was in the North Coast area, compared to the South coast which was between 12-46m, with California at 18-58m, and Oregon at 18-64m. However, when including 75% of their locations, the North coast had the broadest range of depths at 20-126m, followed by the South coast (12-84m) Oregon (18-92m), and California (18-84m), indicating that the North Coast area had the broadest range of depths used compared to the relatively similar range for all the other areas .

Distance from shore in coastal waters

Overall tagged SRKWs remained in nearshore waters with 95% of locations being within 34km of shore, with the vast majority (83%) occurring with 20km of shore, and over half (54%) were within 10km of shore. However, locations within 2 km of shore were rare (5%) as were locations far off shore, with only 5% being between 34 and 75 km offshore.

Corridor analysis

As a result of the whales' general propensity to primarily move in north/south trajectories, over three-quarters (76.3%) of their coast-wide locations occurred in a 16 km wide band (3-19 km) and half (53.6%) the locations occurred within an 8 km wide band between 3 and 11 km offshore. The relatively narrow band that the whales traveled in varied by region. Approximately 75% of their locations occurred within a 17 km wide band (3-20 km offshore) in the North and South coast areas, and 10km (2-12 km) and 8 km 2-6 km bands in Oregon and California, respectively. About 50% of the locations were in an 8 km (3-11 km) band in the North coast, a 9 km band (4-13 km) on the South coast, 6 km (2-8 km) band in Oregon, and 4 km 2-6 km) band in California.

Acoustic detections

Between 2006 and 2015 a total of 382 SRKW detections have been made during 13,080 days of monitoring. The increase from 7 to 17 acoustic recorders beginning the fall of 2014 resulted in a 77% increase in total days monitored in a year (3055 vs 1725) and a 35% increase in detections (77 vs 57) between 2013-14 and 2014-15. Because not all recorders were sited to optimize detections (some were located in areas of interest that tagged whales had not been documented to occur in), and not all recorders functioned properly or were recovered, the number of detections per day was lower than in previous years (0.76 vs 0.99 detections/day). Eight recorders were located in the NWTRC in 2014-15, but only five were recovered due to either loss due to fishery interactions or acoustic release failures. However, compared to the only two recorders located there in previous years, the total number of detections on recorders in W237 increased from 11 in 2014 (based on 430 days of effort), to 37 detections (based on 1472 days of effort), with about the same detection rate/day (0.77 vs 0.75 respectively).

Although monitoring effort was limited during summer months due to the need to recover and refurbish the moorings, there were detections in, or south of, the NWTRC in all months of the year which indicates that the NWTRC is periodically occupied by SRKW throughout the year. Including all years and recorders, detections exceeded 2.4 detections/month from January to June (and October) with a peak of 4.7 detections/month in both March and April.

Although SRKW were not detected on the Quinault Deep recorder (located in W237A and the only one of the three off shelf recorders to be recovered), they were detected periodically throughout the year on the Cape Flattery Offshore recorder which is located on the shelf near the continental shelf break in W237E (Figure 3).

Discussion

Home range size

The total range for all the tagged whales was not as extensive as documented from opportunistic visual sightings. In particular, tagged members of K and L pods did not travel further south than Pt. Reyes, in northern California, although they had been opportunistically sighted a few times as far south as Monterey Bay (Black et al. 2001, Appendix A, Figure 1). The satellite tag locations only occurred as far north as central Vancouver Island yet opportunistic sightings have documented the whales as far north as Chatham Strait, southeast Alaska (Hilborn et al 2012). Nor were tagged SRKWs observed to travel through the inside passage between Vancouver Island and mainland Canada from the north, as has been observed occasionally when the whales first return to the Salish Sea in the spring.

Despite several relatively long deployment durations in K/L pods, the coastal range associated with satellite tag data was less than documented from their opportunistic sighting range (~2,200 km). Reasons for K/Ls smaller range are unknown but could be related to small sample size, inter-annual variability (differences in acoustic detection rates have been noted between years suggesting different ranges between years, Hanson et al.2013), the subgroup in L pod that was tagged, or long-term changes in habitat use. Conversely, at approximately 500 km J pod's documented opportunistic sighting range is similar to the satellite tag determined range.

The linear distance K/L ranged was similar to Southeast Alaska (SEAK) resident whales (1,875 km) (Hanson et al. 2017a *In prep*.) but far less than Antarctic type B killer whales (4,700km, Durban and Pitman 2011) or northwest Atlantic killer whales (5,400 km, Matthews et al. 2011).

The MCP range of SRKW is much smaller, particularly for J pod, compared to SEAK whales (Hanson et al. 2017a *In prep.*), although it is important to note that southeast Alaska whales overlap with a relatively large population of Prince William Sound, Alaska whales (Matkin et. al 1997). Although home range size was not estimated for Northwest Atlantic killer whales or Antarctic Type B whales, based on the large linear travel distances observed for those populations (Matthews et al. 2011, Durban and Pitman 2011) their home ranges would be expected to be larger that SRKWs. Although the J pod's home range is less than half that of K/L pods, on number of whales in the pod/km^2 basis, J pod's home range is only about 2/3 of the size of K/L pods home range. Given that J pod recently produced more calves than K/L pod whales, despite occupying a smaller range, the inland waters they occupy could be more productive than the coastal waters K/L whales occupy.

Regional occurrence

Very little overlap of J and K/L pods ranges occurred during the winter. This documentation of "exclusive use areas" is similar to observations of limited spatial overlap within or between other killer whale communities or subgroups. For example, in Southeast Alaska resident pods (AF/AG pods) have near exclusive use of northern southeast Alaska, i.e., their range overlaps very little with neighboring with Northern resident pods and although they overlap regularly with Prince William Sound pods near Prince William Sound or Kodiak Island, the Prince William Sound residents do not occur in southeast Alaska (Hanson et al. 2017a *In prep.*). Similarly, G clan, of the Northern resident population, has nearly exclusive use of the offshore continental shelf waters of northern Washington State, i.e., they are routinely detected on the Cape Flattery offshore recorder, not the inshore recorders (NWFSC unpubl. data) and have only been observed during the NWFSC's Pacific Orcinus Distribution Survey cruises on the more offshore portion of the northern continental shelf (NWFSC unpubl.data).

High Use Areas

High use areas for SRKW in the winter were primarily located in three areas, 1) the Washington coast, particularly the area between Grays Harbor and the mouth of the Columbia River, 2) the western entrance of the Strait of Juan de Fuca, and 3) the northern Strait of Georgia. SRKWs spent 25-27% of their time in 3.5-5.4% of their home range, which was similar to 20-32% of the range satellite tagged southeast Alaska resident killer whales were observed to spend in only 4-8% of their range (Hanson et al. 2017a *In prep.*). These high use areas used by SRKW coincided with areas that killer whales were known to have preyed on salmon and other species of fish (Hanson et al. 2017b *In prep*.)

Travel speed

The difference in travel speeds of SRKW between areas may be reflective of differences in activities within these areas. The higher travel speeds observed in Oregon as well as the relatively linear routes they used there, may be related to the lack of foraging observed there (NWFSC unpubl. data). A similarly high travel speed was also observed in California although forging was documented in northern California (NWFSC unpubl. data) and was associated with less linear travel routes (NWFSC unpubl. data). Similar higher travel speeds were seen for tagged southeast Alaska resident killer whales as they made relatively linear transits between Southeast Alaska and the Kenai Peninsula, the former being an area where they likely forage (Hanson et al 2017b *In prep*.). SRKW generally travelled faster than tagged Antarctic killer whales that were in their "foraging" areas, but traveled slower than Antarctic killer whales that were making long distance transits to or from the waters off southeastern South America (Durban and Pitman 2011). The travel speeds observed for SRKW were generally greater than north Atlantic killer whales in the Admiralty and Prince Regent Inlets of the Canadian Arctic, but similar to the speeds observed for a tagged killer whale transiting in the open ocean (Matthews et al. 2011).

Corridor Analysis

Both K/L and J pods exhibited the use of travel corridors in the winter months, with J pod's being similar to the inland water corridors used in the summer (Hauser et al. 2007, McCluskey 2006) except that the northern extent stretches up to the northern of the Strait of Georgia. The use of a coastal corridor by K/L pod is similar to the travel corridors observed for tagged southeast Alaska killer whales traveling between Yakutat and the Kenai Peninsula (Hanson et al. 2017a In prep.) and Durban and Pitman (2011) noted the use of "a consistent route into the southwest Atlantic" by Antarctic killer whales.

Acoustic detections

The acoustic recorder data documented the use of coastal areas by SRKW in nearly all seasons (fall, winter, spring, and early summer) which is outside of the time of tag deployments (primarily limited to deployments in winter months). These detections included areas both inside and outside the NWTRC along the outer coast. These results indicate the near year-round use of coastal waters, including the NWTRC, by SRKW. The peak use of the coastal waters, including the NWTRC, in winter was similar to acoustic detections documented by Riera (2012) at their central Washington coast site.

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Appendix A. Locations of opportunistic sightings of SRKW outside the Salish Sea during fall, winter, and spring, since 2005.

DATE_	LOCATION	POD
2/26/1975	Catham Pt B.C.	L
10/21/1987	Coal Harbor B.C.	L
9/13/1989	No. WA coast	L
7/4/1995	Hippa Is. Queen Charlottes B.C.	SR
5/21/1996	Cape Scott, B.C.	SR
3/17/1996	Grays Harbor WA	L
9/20/1996	Sand Pt WA	L
4//1999	Depoe Bay OR	L
1/29/2000	Monterey Bay CA	K&L
3/21/2000	Yaquina Bay OR	L
4/14/2000	Depoe Bay OR	SR
4/14/2001	Tofino B.C.	K&L
4/15/2002	Long Beach WA	L60
4/27/2002	Tofino B.C.	L
5/12/2002	Tofino B.C.	K&L
3/13/2003	Monterey Bay CA	L
5/30/2003	Langara Is, B.C.	L
3/11/2004	Westport WA	L
3/11/2004	Westport WA	L
3/13/2004	Neah Bay WA	J
2/16/2005	Farallon Is CA	L
2/16/2005	Farallon Is CA	L
3/22/2005	Columbia River	L
6/9/2005	W. St of Juan de Fuca (SJdF)	L
9/7/2005	W. SJdF	L
10/23/2005	Columbia River	K
10/29/2005	Columbia River	K/L
1/26/2006	Pt Reyes CA	L
3/18/2006	western SJdF	J
3/30/2006	Columbia River	K,L
4/6/2006	Westport WA	KL
5/8/2006	Brooks Peninsula BC	L
3/18/2006	W. SJdF	J pod
1/24/2007	San Francisco CA	K
3/18/2007	Fort Bragg CA	L
3/24/2007	Monterey Bay, CA	K,L
3/25/2007	Monterey Bay, CA	K,L
6/1/2007	Chatham St., AK	L pod
2/8/2008	Monterey Bay, CA	K,L

2/29/2008	Sekui, WA	L
3/25/2008	Neah Bay, WA	J
3/25/2008	SJdF	J pod
1/21/2009	Depoe Bay, OR	L
1/24/2009	Depoe Bay, OR	L
3/5/2009	Monterey Bay, CA	L
3/7/2009	Farallon Is CA	L
3/26/2009	Westport WA	L
3/27/2009	Columbia River	L
6/4/2009	WA coast	L12 subpod
1/23/2010	Blackney Pass, Johnstone Strait B.C.	J Pod
1/24/2010	Florence , OR	K
5/13/2010	Campbell River B.C.	K and L
3/24/2011	WA coast	K12 subpod
2/20/2011	SJdF	J pod
3/4/2011	WA coast	L 12's
2/20/2012	W. SJdF	J pod
4/29/2012	WA coast	K and L p
7/24/2012	Vancouver Is. B.C.	L84
8/12/2012	Vancouver Is. B.C.	L pod
2/2/2013	WA coast	L 12 subpod
2/14/2013	OR coast	L pod
6/12/2013	Vancouver Is. B.C.	K pod
6/20/2013	Vancouver Is. B.C.	L88
10/16/2013	Vancouver Is. B.C.	K21
2/17/2015	WA coast	K and L pods
4/28/2014	CA coast	K and L p
6/17/2014	Tofino B.C.	L84
2/27/2016	WA coast	KL pods
3/7/2016	WA coast	J pod