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### Title

Characterization of Surface Foraging Behaviors of Southern Resident Killer Whales from Aerial Photographs

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# CHARACTERIZATION OF SURFACE FORAGING BEHAVIORS OF SOUTHERN RESIDENT KILLER WHALES FROM AERIAL PHOTOGRAPHS

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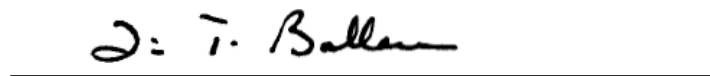
Chair – **John Durban, Ph.D.** | Leader of Cetacean Health and Life History Program at NOAA Southwest Fisheries Science Center



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**UC San Diego**

## ABSTRACT

The endangered Southern Resident Killer Whale (SRKW) population is an icon of the Pacific Northeast. The population has experienced a 10 percent decline in population since 2005 and now number only 76 individuals, the lowest abundance in more than 30 years. The SRKWs have been shown to be food-limited with declines in survival and reproduction in years following low salmon availability. Diet studies conducted on the SRKWs have shown a strong prey preference for Chinook salmon (*Oncorhynchus tshawytscha*) in the summer, yet uncertainty remains about prey preferences and foraging behavior. To help fill this data gap, I used high-resolution aerial images to quantify and describe foraging behavior from a new perspective. Specifically, I reviewed images collected by a small unmanned hexacopter during five individual month-long field efforts between 2015 and 2017. From this collection 29 distinct foraging events were documented in 2,384 images that allowed for photogrammetry measurements of fish size, and species identification of fish preyed upon. The data show that there is a clear difference in the size of fish chased versus the size of fish confirmed to be captured and shared with other members of the pod, suggesting that the whales may be selectively targeting certain size or age classes of fish. Most of the fish observed within the study were determined to be Chinook salmon with the possibility of other salmonid species also being preyed upon. Of the 18 successful foraging events, prey-sharing occurred 88% of the time, with 62.5% of prey-sharing behavior occurring between mothers and calves. This knowledge is important to the successful management and protection of this unique and critically endangered population. Knowing targeted species and size classes of fish can allow for better fishing and recovery strategies, which may lead to increased foraging success of the SRKWs.

## INTRODUCTION

The Southern Resident killer whale population is a distinct population of killer whales (*Orcinus orca*) that ranges widely along the west coast of North America, but aggregate in the summer months in the US-Canada transboundary Salish Sea around southern Vancouver Island, including Puget Sound, the San Juan Islands, Strait of Georgia, and the Strait of Juan de Fuca (Figure 1, Hauser, *et al.*, 2007). This population is reproductively and socially isolated from the Northern Resident Killer Whale population that occurs mainly around northern Vancouver Island (Hoelzel *et al.*, 1998; Barrett-Lennard, 2000; Ford *et al.*, 2000; Barrett-Lennard and Ellis, 2001). SRKWs specialize in feeding on Chinook salmon (Ford and Ellis, 2006; Hanson *et al.*, 2010) and most of the population aggregates in the summer months in waters around southern Vancouver Island to feed on local salmon runs. Studies conducted on the SRKW diet have shown a key preference for Chinook Salmon, estimated to be 90% of the populations diet during summer, particularly stocks returning to the Fraser River watershed (Ford and Ellis, 2006; Hanson *et al.*, 2011).

The population is socially structured into three pods (termed “J”, “K”, and “L” pods) of preferentially associating matriline, (Parsons *et al.*, 2009) and these pods use the inshore waters of the Salish Sea to different extents (Hauser *et al.*, 2007). The population currently numbers 76

individual whales (J-pod = 23, K-pod = 18, L-pod = 35) based on monitoring conducted by The Center for Whale Research on San Juan Island.

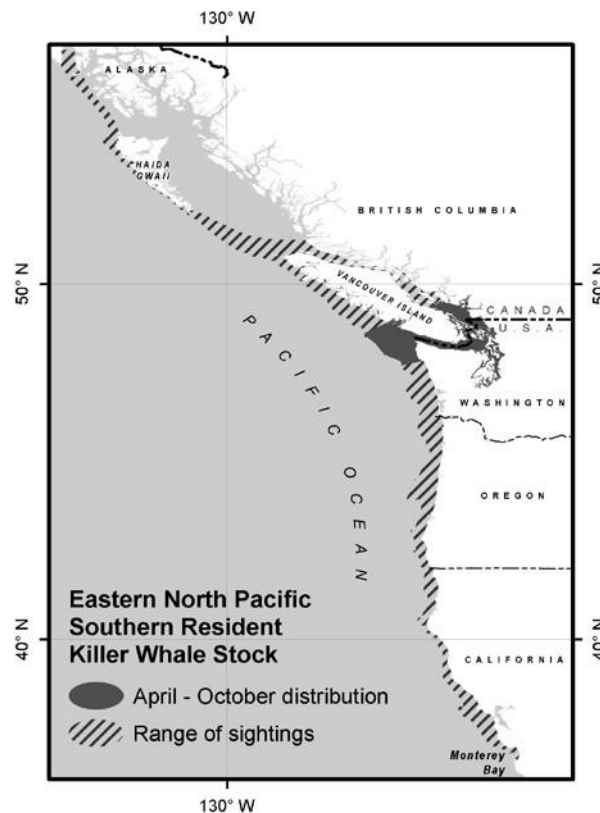


Figure 1. Displays the Southern Resident killer whale approximate range, April -October distribution (shaded area) and range of sightings (diagonal lines). Map produced by NMFS Office of Protected Resources, March 2017.

The historical population size of SRKWs was estimated to be approximately 200 individuals, but the population has never fully recovered after a live capture fishery for marine parks in the 1960s and 70s, which removed 45 individuals, mainly young females, from the population (Bigg and Wolman, 1975). The population recovered from 70 individuals post-exploitation to 98 individuals in 1995, but experienced a dramatic 20% drop in numbers in the following six years (NMFS, 2008).

In 2003, the National Oceanic and Atmospheric Administration (NOAA) began a research program into the Southern Resident Killer Whales, and the population was listed under the Endangered Species Act in 2005 as a distinct population, the first of any killer whale population in the world. Under the Endangered Species Act the population's critical habitat was established as all inland waters of Washington state, due to this areas importance for foraging on local salmon runs. Researchers identified three main risk factors threatening the SRKWs; limited prey availability, contaminants, and disturbance from vessel traffic and its associated noise pollution (Krahn, *et al.*, 2004). Previous studies have documented that an increase in the levels of vessel traffic and noise pollution resulted in an increase in the amount of time SRKWs spent traveling, and a decrease in the amount of time spent foraging (Lusseau *et al.*, 2009 and Noren, *et al.*,

2009). These results suggest that these threats are likely compounding, and their impacts are exacerbated in times of reduced prey availability. This population is hypothesized to be food limited, and declines in the availability of Chinook salmon have been correlated with increased mortality, decreased fecundity, changes in social cohesion and declines in adult size (Ford *et al.*, 2009; Ward *et al.*, 2009; Parsons *et al.*, 2009; Fearnbach *et al.*, 2011; Foster *et al.*, 2012). Most recently, declines in body condition of individual SRKW have been documented preceding mortality in several cases (Fearnbach *et al.*, 2018).

Researchers at the NOAA Southwest Fisheries Science Center pioneered the use of manned aircraft to collect aerial images to estimate body size and assess the body condition of individual whales using photogrammetry, the science of making measurements from photographs (e.g. Perryman and Lynn, 2002; Miller *et al.*, 2012; Fearnbach, *et al.*, 2011, 2018). In collaboration with non-governmental research groups, these methods have been used to monitor the SRKW population since 2008 (Fearnbach *et al.*, 2011, 2018), with a shift from using manned aircraft to using small unmanned hexacopter drones in 2015 (Durban *et al.*, 2015). This technology allows researchers to collect high-resolution images from a much lower altitude with a significant reduction in both risk and cost to researchers, while remaining non-invasive to the whales (Durban *et al.*, 2015; Durban *et al.*, 2016).

## **OBJECTIVES**

This study analyzed high resolution aerial images to characterize the surface foraging behavior of the SRKWs in the coastal waters of the Salish Sea. I reviewed images from hexacopter flights during five individual month-long field efforts during three years (2015-2017), and identified all foraging events photographed from the air. From these high-resolution images I was able to: 1) describe foraging behaviors; 2) evaluate foraging success of individual and groups of killer whales; 3) measure and calculate the real length of each fish; 4) identify the species of each fish; 5) identify the composition of whale groups involved in surface foraging; and 6) assess the extent of prey-sharing between individual whales.

The results from these analyses provide data on the surface foraging behavior and preferred prey of SRKWs, including the size and species of salmon involved in foraging events. These data will help fill a key gap in our knowledge of prey selection by the SRKWs. Quantifying prey capture behaviors and evaluating foraging success can provide insight into the ecological importance of certain individuals to the population, particularly regarding prey-sharing. Prey-sharing is a unique behavior that has been documented in many dolphin species (Baird and Dill, 1995; Wright *et al.*, 2016), including the Southern Residents, but it is difficult to identify and observe from boat-based platforms (Hanson *et al.*, 2010). This study provides detailed information with respect to foraging and prey-sharing, which is important for informing management groups involved in making decision concerning the conservation and recovery of this unique and critically endangered population.

## **METHODS AND MATERIALS**

Images used in this study were collected from an APH-22 hexacopter (Aerial Imaging Solutions, Old Lyme, CT; Figure 2). The application of this system for killer whale photogrammetry was

described in Durban *et al.* (2015). In my current study, the hexacopter was successfully deployed and retrieved by hand during 332 flight missions launched from the upper deck of an 8.2 m SeaSport boat. This methodology was safe and repeatable, due to the stable flight and low weight of the hexacopter; the only payload was a camera (Olympus E-PM2, 0.23 kg; Olympus M.Zuiko 25 mm F1.8 lens, 0.13 kg) and hexacopter battery (QuadroPower 6200 mAh Lipo Flat; 0.58 kg).



Figure 2. Image showing the APH-22 hexacopter (Aerial Imaging Solutions, Old Lyme, CT) that was used to fly 332 successful flights to collect vertical photogrammetry images of killer whales at sea. Here shown with the Olympus E-PM2 camera and interchangeable lens system; the camera mounts on the underside of the hexacopter to be downward-facing (Durban *et al.*, 2015).

All flights were conducted with wind speeds less than 5 m/s (10 knots), which allowed for detailed imagery of whales beneath the surface. Notably, the camera and lens have been shown to have a resolution of <2cm per pixel, and the image is flat and undistorted, allowing photogrammetry measurements across the full field of view (Durban *et al.*, 2015). The hexacopter was typically flown at altitudes of just above 30m (100ft); at this altitude each frame covered a water footprint of  $21\text{m} \times 16\text{m} = 323\text{m}^2$  (Figure 3).



Figure 3. Displays the original (uncropped) footprint of an image and the relative size of an individual killer whale and fish. The red box is a cropped and zoomed in version of the same image displaying the high-resolution of the images and the detail that can be observed.

The hexacopter was controlled by the pilot (John Durban) using a radio link (2.4 GHz). Finer-scale positioning of the hexacopter above whales was accomplished through guidance from a ground station operator (Holly Fearnbach) who viewed live analog video captured by the onboard camera and transmitted to a portable monitor on the boat using a 5.8 GHz link. The ground station also displayed telemetry information (910 MHz link), which enabled monitoring of altitude, flight time, and battery levels for flight management (Durban *et al.*, 2015). When whales were in the frame, the pilot used a remote link to trigger the capture of high-resolution (16 MP) still images at one second intervals (Figure 4).



Figure 4. 1) Image showing the hexacopter (circled) being deployed from the upper deck of a 8.2 m research vessel. 2) Images showing the hexacopter capturing vertical images of killer whales from an altitude of  $> 30\text{m}$ .

At the end of each flight, images were downloaded from the camera and archived by each flight number. Images were then inspected visually for the presence of foraging behavior by the killer whales. To be classified as a foraging event, both a fish and whale needed to be present within at least one frame during a sequence following a whale (or whales) (Figure 5). Images that contained whales and fish were then sorted by separate events, which were usually captured during a single flight. Flights lasted 10-15 minutes on average. The recovery of the hexacopter, switching batteries, and deployment ranged from 5 – 10 minutes. Therefore, foraging events over multiple flights were considered to be the same event, if the time between flights was less than 10 minutes, and the whales involved in the foraging behavior were the same. Only a single foraging event occurred over two flights within the data set.



Figure 5. Aerial images showing: 1) A lone killer whale (J-42) chasing a fish after tail slapping at the surface; 2) Two killer whales (J-35 and J-51) cooperatively foraging on a single fish.

After all images had been inspected for foraging behavior and placed into distinct events, each event was reviewed and classified by the types of foraging behavior observed; 1) fish chase, 2) fish in mouth, and 3) fish sharing. Fish chasing behavior was assigned when whales were observed chasing a fish apparent by clear behaviors of pursuit of fish, such as changes in speed and direction, cooperative hunting, and surface behaviors like tail slapping and sharking. Fish in mouth behavior was assigned when there was a clear presence of a fish, or parts of fish, in a whale's mouth. If chasing and fish in mouth behavior occurred within the same event it was considered a capture event. Prey-sharing behavior was assigned when passing fish between whales, or by dropping the fish, or fish parts, to be picked up by other whales was apparent (Figure 6).



Figure 6. Aerial images showing: 1) A young whale (L-121) chasing a fish; 2) L-91 and L-122 with a fish in the mouth of L-91; 3) Two whales (J-36 and J-52) passing pieces of a fish back and forth, commonly observed in prey-sharing.

The high-resolution images allowed for the photogrammetric measurement of the length of the fish involved in foraging events. The best image of each fish in each event was selected by reviewing all images and choosing the image where the fish was closest to a flat and straight-line orientation. Length measurements in pixels were made using the software Image –J. Real length estimates were calculated from these measurements using altitude and focal length to scale from image pixels to real scale. Altitude estimates were made using the air pressure sensor on the hexacopter, after correcting for take-off height (Durban *et al.*, 2015). Fish species identification was determined by expert review (Jeff Hard, Ph.D. NOAA Northwest Fisheries Science Center) after examining detailed images of the fish present in each foraging event, and with knowledge of their length estimates. Characteristics observable within the images that aided in the identification of fish species included overall length, caudal peduncle, fin margins, overall body shape, and other factors (Figure 7).



Figure 7. Aerial images showing detailed characteristics of fish present in foraging events.

Individual whales were identified from their unique markings, specifically the distinct pigmentation patterns of the saddle patch, based on an established aerial photo-id (Figure 8, see Fearnbach *et al.*, 2011, Fearnbach *et al.*, 2018). Once individual whales were identified in foraging events, their relationships to one another were described. The social structure and life histories of the SRKW population are well documented, thanks to long-term research by the Center for Whale Research, thus fine-scale relationships of individuals observed in prey-sharing behavior could be described.



Figure 8. Aerial images showing the unique saddle patch pigmentation of four individuals from the Southern Resident population (L-91, J-16, J-19, and J-40)

## RESULTS

### *Effort*

From 2015-2017, five research efforts (September 2015, 2016, 2017; May 2016, 2017) allowed for the collection of >20,000 high-resolution aerial images of SRKWs from 332 flights. A total of 29 distinct foraging events were captured over 30 flights. Foraging events observed in a single day ranged from 1 to 5, and there is no correlation between foraging events and time of day (Table 1).

Table 1. Displays part of the raw data collected from each foraging event.

| Foraging Events |                |            |              |            |       |          |         |                        |                                |                          |
|-----------------|----------------|------------|--------------|------------|-------|----------|---------|------------------------|--------------------------------|--------------------------|
| Event           | Flight #'s     | Time Start | Start Lat    | Start Long | Chase | In Mouth | Sharing | # of individual whales | Length of Fish                 | Real Length Alt (meters) |
| 07-Sep-15_E01   | 2015-09-07_F03 | 7:26:03    | -123.152552  | 48.5080144 |       | x        | x       | 4                      | 153.711                        | 0.778316996              |
| 09-Sep-15_E01   | 2015-09-09_F09 | 11:40:32   | -123.1353442 | 48.4974009 | x     |          |         | 2                      | 77.647, 73.055, 90.272, 86.672 | 0.41352950225 (mean)     |
| 15-Sep-15_E01   | 2015-09-15_F05 | 11:15:30   | -123.0732752 | 48.381218  |       | x        |         | 1                      | 155.606                        | 0.789032303              |
| 09-May-16_E01   | 2016-05-09_F02 | 4:59:57    | -122.9914974 | 48.4432504 |       | x        | x       | 4                      | 146.942                        | 0.727491997              |
| 09-May-16_E02   | 2016-05-09_F03 | 5:16:37    | -122.9889325 | 48.4353716 | x     |          |         | 3                      | 123.2032                       | 0.663741776              |
| 03-Sep-16_E01   | 2016-09-03_F08 | 9:46:21    | -123.2417316 | 48.6725358 |       | x        | x       | 3                      | 138.873                        | 0.705270159              |
| 04-Sep-16_E01   | 2016-09-03_F13 | 12:48:29   | -123.0835113 | 48.4416697 |       | x        | x       | 2                      | Just head of fish              |                          |
| 04-Sep-16_E02   | 2016-09-04_F02 | 3:54:18    | -123.1796429 | 48.5554883 |       | x        | x       | 2                      | 129.3215                       | 0.61212662               |
| 04-Sep-16_E03   | 2016-09-04_F04 | 5:20:39    | -123.2009025 | 48.5718848 | x     |          |         | 1                      | 108.5148                       | 0.520370348              |
| 04-Sep-16_E04   | 2016-09-04_F05 | 5:54:48    | -123.1821737 | 48.5629575 | x     |          |         | 1                      | 111.118                        | 0.529697199              |
| 04-Sep-16_E05   | 2016-09-04_F10 | 9:44:21    | -123.2008356 | 48.5838126 |       | x        |         | 1                      | 157.68                         | 0.843404875              |
| 08-Sep-16_E01   | 2016-09-08_F03 | 3:00:23    | -123.2155194 | 48.5455193 |       | x        | x       | 3                      | 144.2765                       | 0.691744746              |
| 08-Sep-16_E02   | 2016-09-08_F05 | 3:34:03    | -123.2029321 | 48.5387699 | x     |          |         | 1                      | 135.6136667                    | 0.613312096              |
| 10-Sep-16_E01   | 2016-09-10_F08 | 6:32:20    | -123.2324528 | 48.6800442 |       | x        | x       | 3                      | Fish head missing              |                          |
| 14-Sep-16_E01   | 2016-09-14_F05 | 7:45:17    | -123.1590429 | 48.5194598 | x     |          |         | 2                      | 139.428375                     | 0.687228721              |
| 14-Sep-16_E02   | 2016-09-14_F07 | 8:21:56    | -123.1728247 | 48.5428397 | x     |          |         | 2                      | 146.801                        | 0.730634576              |
| 14-Sep-16_E03   | 2016-09-14_F11 | 10:40:35   | -123.2254251 | 48.6672816 | x     |          |         | 2                      | 133.538                        | 0.63785929               |
| 14-Sep-16_E04   | 2016-09-14_F12 | 10:59:11   | -123.2293626 | 48.6665007 |       | x        | x       | 3                      | Fish head missing              |                          |
| 18-Sep-16_E01   | 2016-09-18_F10 | 11:29:39   | -123.0425541 | 48.4278478 | x     |          |         | 3                      | 143.36825                      | 0.675599866              |
| 18-Sep-16_E02   | 2016-09-18_F11 | 11:37:06   | -123.0405127 | 48.428717  | x     |          |         | 1                      | 74.6748                        | 0.362449381              |
| 20-Sep-16_E01   | 2016-09-20_F06 | 6:01:07    | -123.0080316 | 48.408189  | x     | x        | x       | 2                      | 165.969                        | 0.792388167              |
| 21-Sep-16_E01   | 2016-09-21_F11 | 8:44:52    | -123.2095556 | 48.6157334 | x     | x        | x       | 3                      | Fish head missing              |                          |
| 21-Sep-16_E02   | 2016-09-21_F13 | 10:09:04   | -123.2076136 | 48.5921941 |       | x        | x       | 2                      | Small pieces of fish           |                          |
| 13-May-17_E01   | 2017-05-13_F03 | 6:53:06    | -123.0813167 | 48.4755203 |       | x        | x       | 3                      | Just head of fish              |                          |
| 06-Sep-17_E01   | 2017-09-06_F14 | 9:42:15    | -123.0677429 | 48.4551066 |       | x        | x       | 3                      | 151.971375                     | 0.727223877              |
| 10-Sep-17_E01   | 2017-09-10_F03 | 8:16:56    | -122.9894172 | 48.4396749 |       | x        | x       | 3                      | Piece of fish                  |                          |
| 11-Sep-17_E01   | 2017-09-11_F01 | 4:19:15    | -123.0924684 | 48.4790694 | x     |          |         | 2                      | 195.8526667                    | 0.903483293              |
| 11-Sep-17_E02   | 2017-09-11_F02 | 4:31:31    | -123.0993337 | 48.4800541 |       | x        | x       | 2                      | 136.406                        | 0.637700211              |
| 11-Sep-17_E03   | 2017-09-11_F05 | 5:24:26    | -123.0726598 | 48.4680875 |       | x        | x       | 2                      | Pieces of fish                 |                          |

Although the range of the research vessel platform used extended throughout the Salish Sea, and the SRKWs were seen throughout the study area, foraging locations were clumped to the west side of San Juan Island in the Haro Strait (Figure 9).

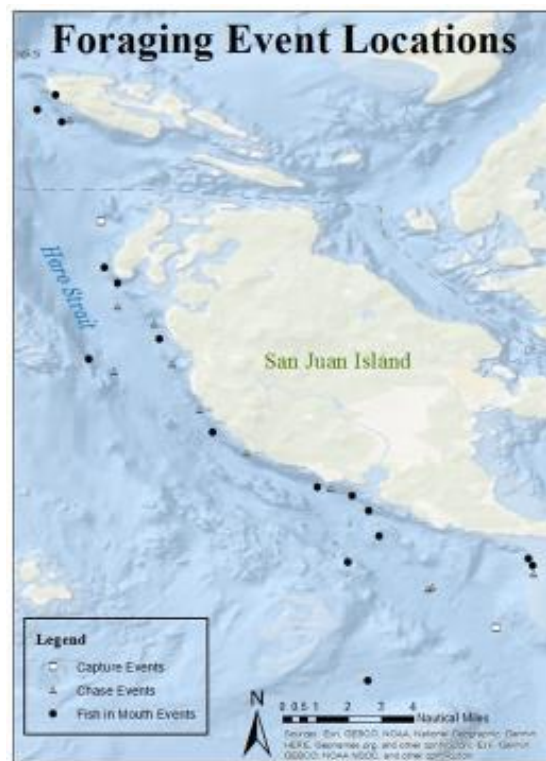


Figure 9. Map of foraging event locations, and distinguished by foraging behaviors.

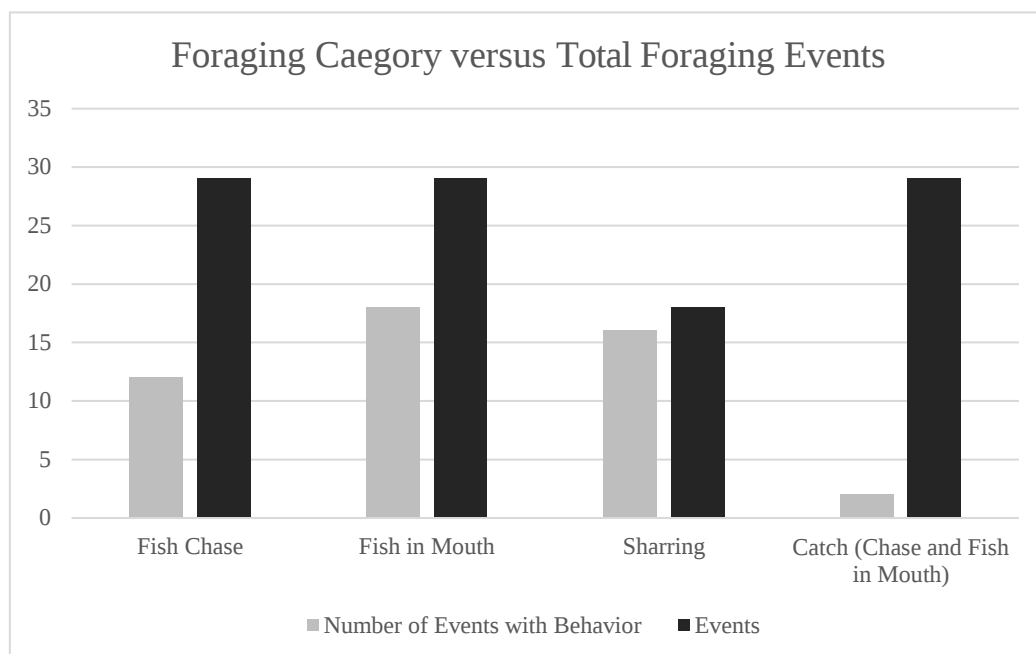
The number of flights per photogrammetry effort ranged from 24 to 126 and the number of foraging events per event ranged from 1 to 18. To calculate an estimate of effort, or time spent actively foraging on fish, the number of flights per collection effort was divided by the total number of flights per collection effort resulting in “effort-corrected salmon observations”, or the percentage of flights that contained fish presence (Table 2). Observed foraging events ranged from 0:02 seconds (only two frames captured both fish and whales) to 7:58 minutes. The average length of all events was 2:27 minutes, while the two capture events where the entire foraging sequence (fish chase to fish in mouth) were photographed averaged 7:44 minutes.

Table 2. The total number of flights per collection effort (S = September and M = May) and number of flights that captured foraging events. Effort-corrected salmon observations is the number of flights with foraging events divided by the total number of flights for that collection effort.

| Effort-Corrected Salmon Observations per Field Season |                              |               |                                      |
|-------------------------------------------------------|------------------------------|---------------|--------------------------------------|
| Collection                                            | Flights with foraging events | Total flights | Effort-Corrected Salmon Observations |
| 2015s                                                 | 3                            | 97            | 0.030927835                          |
| 2016m                                                 | 2                            | 24            | 0.083333333                          |
| 2016s                                                 | 18                           | 126           | 0.142857143                          |
| 2017m                                                 | 1                            | 32            | 0.03125                              |
| 2017s                                                 | 5                            | 53            | 0.094339623                          |

Of the 29 total foraging events, 12 events (41%) were classified as fish chases. A total of 18 events (62%) included fish in mouth behavior. Only 2 events (7%) were classified as capture events where fish chasing was followed by fish in mouth behavior. Since prey-sharing can only be observed in events where a fish was in mouth, the 16 prey-sharing events (88%) are compared to the total fish in mouth events instead of total events (Graph 1).

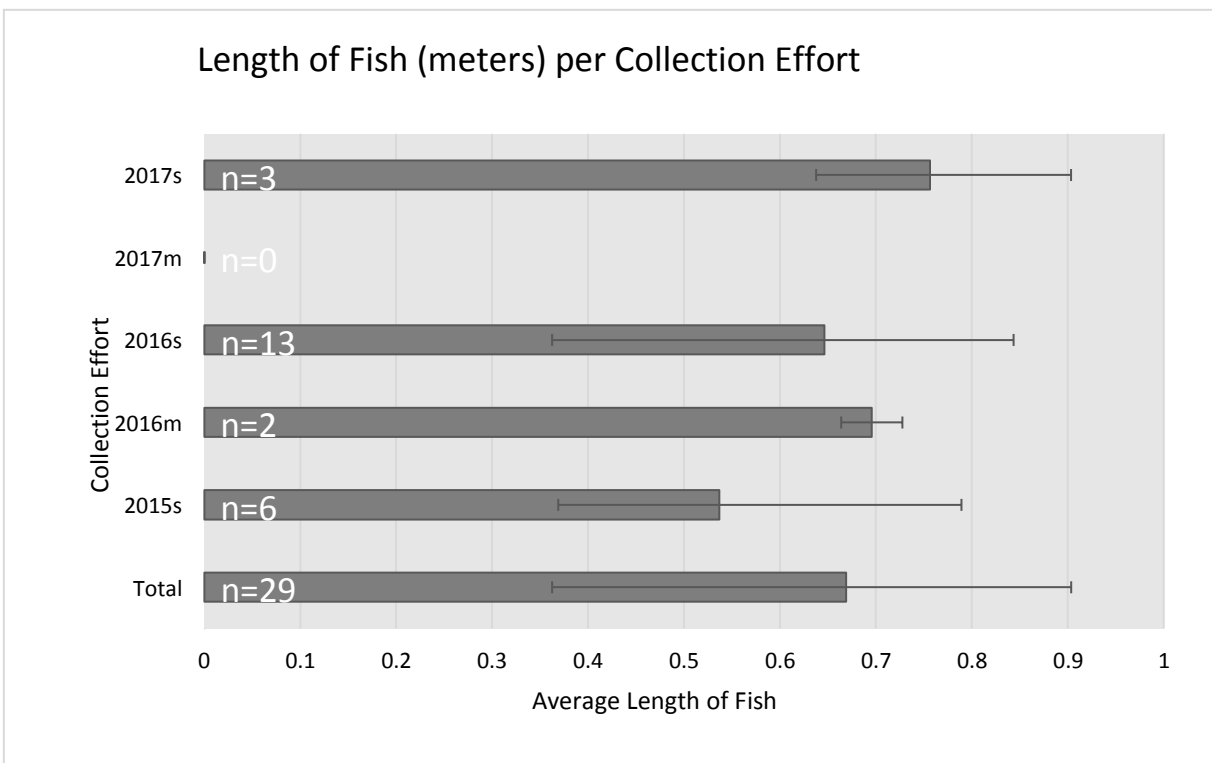
Graph 1. Visually displays the number of foraging behavior events to the total number of events.



## Fish

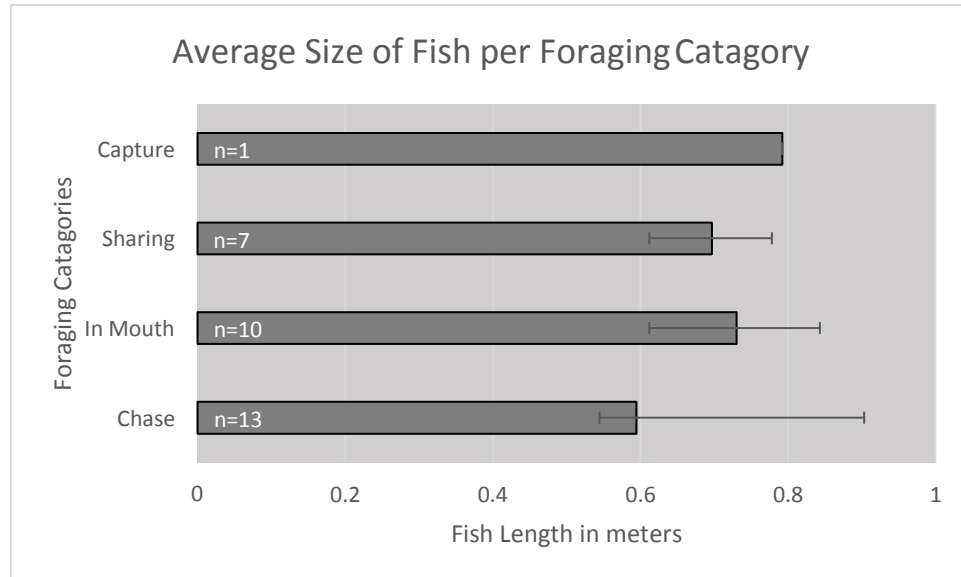
The average size of all fish observed within the study was 0.668 m, and a median close to that at 0.687 m (Graph 2). There was variability in the size of salmon between both years and seasons; note that there were no measurable images of fish in May 2017. Both the largest median and maximum salmon were measured in September 2017, with an average length 0.2 m greater than the average fish in September 2015.

Graph 2. Bar graph displaying the average measured length of fish from 29 events photographed from the air using unmanned hexacopter. Sample size and range bars have been added to the graph for visual representation. Length estimates calculated using standard photogrammetry techniques (see Durban *et al.*, 2015).



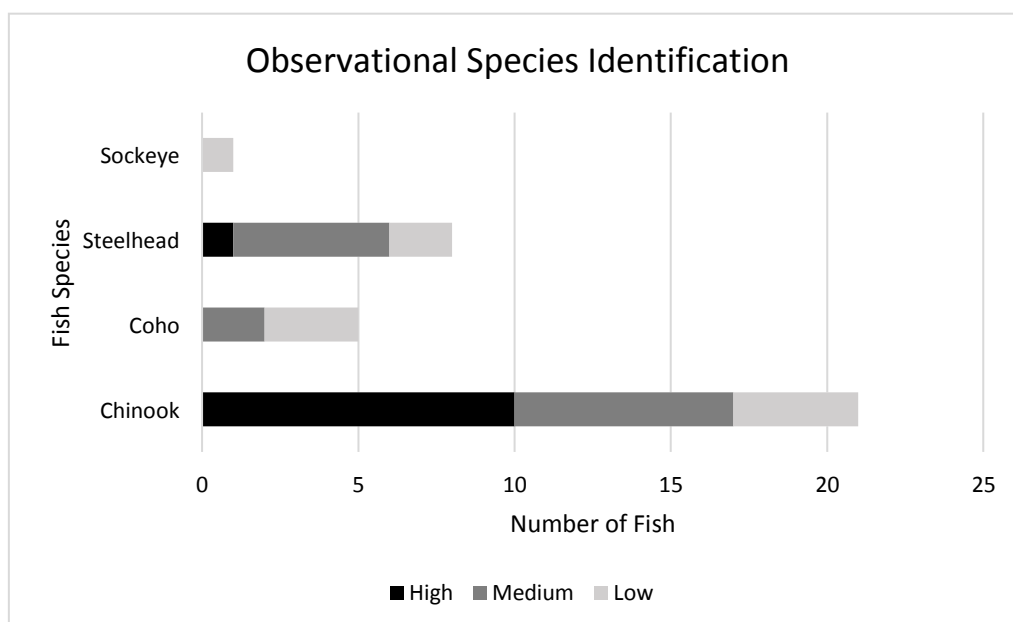
When the length of fish observed is broken down by foraging behavior displayed within the event, one can see a clear difference in the length of fish chased versus the fish in mouth and shared (Graph 3). Fish that were observed being chased, but never captured, have a wider range and shorter average length than any other foraging categories. The length of fish in fish in mouth, sharing, and capture categories are all similar.

Graph 3. Bar graph displaying the average measured length of fish in each behavioral category from 29 events photographed from the air using an unmanned hexacopter. Sample size and range bars have been added to the graph for visual representation. Length estimates calculated using standard photogrammetry techniques (see Durban *et al.*, 2015).



Of the 29 foraging events, an estimate for 20 fish species identifications were made by experts in the field of study. All 20 fish were given a probability of being Chinook salmon, as well as Coho salmon (*Oncorhynchus kisutch*), Sockeye (*Oncorhynchus nerka*), or Steelhead (*Oncorhynchus mykiss*), but 10 fish were identified as Chinook salmon with greater than 75% confidence (Graph 4). No other species of fish was identified with a confidence greater than 75%.

Graph 4. Displays the estimated fish species identification by species and confidence of positive identification; high, medium, and low confidence.

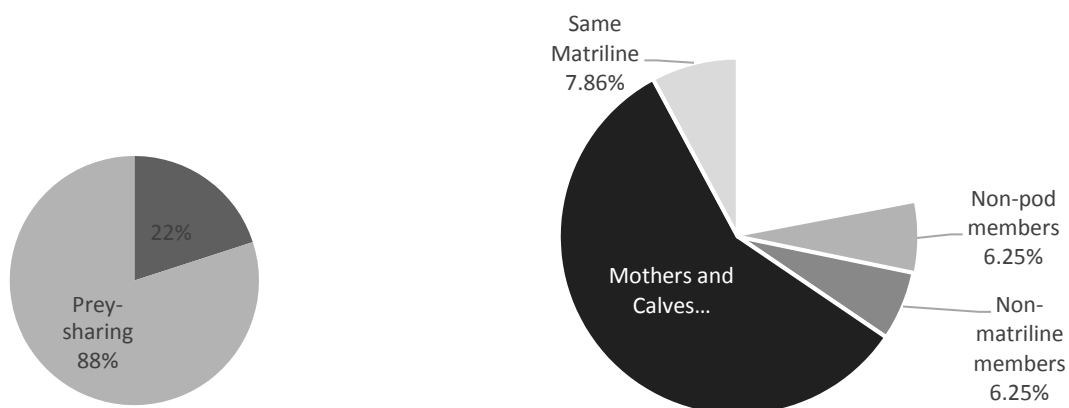


### Prey-sharing

A total of 33 individual whales were identified within this study (16 from J-pod, 3 from K-pod, and 14 from L-pod). Of the 29 total foraging events, only 6 contained individual whales. Chasing events averaged 2 whales, with a range from 1 to 3 whales. While sharing events, on the other hand, averaged 2.8 whales with a median of 3, and a range from 2 to 4 whales.

Once individual whales had been identified, they were compared to the known matriline of the Southern Residents. This allowed for analysis of relationships between whales involved in prey-sharing behaviors. Out of all 29 foraging events only one consisted of whales from different pods. In this instance, two sexually mature females, sisters, were observed chasing and sharing prey with a sexually mature male from another pod. Males often travel with another pod for a period of time to mate with females of that pod before returning to his matriline (Krahn *et al.* 2004). All other foraging behaviors occurred between members of the same pod, with three of these events occurring between members of two different matriline. Two of these events were with the same two whales on the same day, a sexually mature female and an adolescent male from another subgroup within the same pod. This group did not engage in prey-sharing behaviors, but did chase at least two different fish together. The third event involved prey-sharing, and occurred between two mothers with calves of relatively the same age. One of the mother and calf pairs was traveling linearly, then another mother and calf pair swim in from the side with a fish and shared it with the original mother. All other foraging events ( $n = 25$ ) were individual whales or members of the same matriline. The relationships within the matriline ranged from great grandmother to great granddaughter and cousin to cousin. Of the 16 prey-sharing events, 10 (62.5%) occurred between mothers and calves of varying ages (Graph 5).

Graph 5. Pie graph on the right displaying percent of prey-sharing behaviors observed from total events. The pie graph on the right breaks down the relationships between whales identified within prey-sharing behaviors.



## DISCUSSION

### *Effort*

Both collection efforts in the month of May resulted in very low numbers of foraging events from a lower overall number of flight missions, which has been suggested to be due to low returns of spring run Chinook salmon to the Fraser River over the past decade (Shields *et al.* 2018). As local salmon stock dwindle it appears that the SRKWs are altering their behavior and utilizing their range to different extents. The three collections efforts in September included more flights and more identified foraging events. Suggesting that the SRKW are not returning to their summer core habitat during the spring runs. This is supported by the data showing that larger fish were observed in foraging events in the September collection efforts versus the May efforts.

This study allowed for a large cross section of the populations, but was limited in the total number of full capture events. Therefore, the opportunity to evaluate individual success of whales, or groups of whales, could not be accomplished with great confidence. To answer these questions, a similar methodology could be used with the adjustment of targeting individual whales, or groups of whales, that appear to be displaying foraging behavior. Such a focus on target whales potentially would result in greater numbers of foraging events, and would strengthen the data set and results of success rates of individual whales, or groups of whales. While the broader focus of this study is an apparent limitation the methodology used resulted in the inclusion in this study of a large cross section of the population and many individuals.

### *Fish*

September 2017 recorded the longest fish by average and max length, which may be due to random selection, or the killer whales purposely targeting longer fish in years of low total abundance of prey. With declines in local salmon stocks, the killer whales may be targeting larger fish that would result in greater nutritional benefits than smaller fish. These results suggest that certain size classes, or age classes, of salmon are highly targeted by the whales. With this knowledge, managers and decision makers could specifically target these size classes of fish for recovery efforts, such as fishing regulations.

Beyond size of salmon, the SRKW targeted Chinook salmon more than other species of fish, which are more prevalent within the Salish Sea. This result supports earlier diet studies and research conducted on the SRKW. However, other species of fish may have been observed being preyed upon within this study, suggesting that the killer whale population may be exploring or utilizing alternative prey sources in low abundance years of Chinook salmon. Given that Chinook salmon continue to be the main source of food for the SRKW, efforts should continue and strengthen to protect and recover this specific salmon population, but at the same time, efforts need to address the strength of the other fish resources that are available to this SRKW population.

A clear result from photogrammetric analyses of the fish present in foraging effects was a great size difference in fish chased versus fish in mouth. These researchers suggest that this may be

due to younger whales practicing their foraging behaviors by chasing smaller fish, or that the smaller fish being chased near the surface are actually other fish species, such as Coho salmon that are more surface affiliated than the Chinook salmon. This would suggest that Chinook salmon are more likely to be captured at depth and brought to the surface as fish in mouth, than to be seen being chased near the surface. Chinook salmon were seen equally as being chased and fish in mouth within this data set, but this could be due to low sampling, or non-targeted sampling. Therefore, to answer these questions the modification to the methodology to target whales, or groups of whales, displaying foraging behaviors could increase the sample size.

### *Prey-sharing*

The data show that a greater number of individual whales participated in prey-sharing events, than in fish chase events. This may suggest that there are individual whales that are not participating in the fish chase, but are included in the sharing of that fish. This researcher suggests that this difference may be due to the presence of younger calves. They may be still learning to forage, and therefore do not participate in the chasing events, but are the recipients of sharing behavior once the fish is captured.

The data show that prey-sharing is an important behavior to this population, and is in line with previous assumptions that prey-sharing occurs between closest kin. However, there were a few instances within this study of prey-sharing between distant kin and different pod members, described above. Expanding our sample size would capture unique events likely to determine if they are indeed unique events.

## **CONCLUSION**

It is clear that the inland waters of the Salish Sea is an important foraging area for this population. As noted earlier in this report, the SRKW foraging location in this study were aggregated on the west side of San Juan Island in Haro Strait. These results suggest that continued attention should be given to recognition of this important area to the SRKW range.

Of the three major threats to this population noted by NOAA in the endangered species listing, this study affirms that low prey availability is a major concern. The population seems to be altering its use of critical habitat and behavior to forage on alternative food sources, versus historical sources. Therefore, adaptive management is the greatest strategy to aid in the recovery of this population. The three major threats are still of concern, but exclusive focus should not be given to those three targetable threats. The focus should shift to an ecosystem approach that can be adaptable and evolve as these issues continue to change.

Furthermore, the results of this study support previous diet and foraging research with respect to the preference for Chinook salmon and the tendency to share prey, but also fills knowledge gaps in prey selection and prey-sharing behavior that is difficult to assess with vessel based observations. The use of aerial drones has proved to be cost effective, safe, and provide new perspectives and insights into marine mammal research. Modifications to the methodology to focus hexacopter flights over whales demonstrating foraging behaviors can answer many more questions about the SRKWs. These answers need to continue to be shared publicly and available

to decision makers to best manage and protect this important and unique population of killer whales.

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