Sablefish are on the Menu for Southern Resident Killer Whales, but at What Cost?

by

Janine Rhian McNeilly

Bachelor of Science, Simon Fraser University, 2018

Project Submitted in Partial Fulfilment of the
Requirements for the Degree of
Master of Science

in the
Ecological Restoration Program

Faculty of Environment (SFU)
and
School of Construction and the Environment (BCIT)

SIMON FRASER UNIVERSITY
BRITISH COLUMBIA INSTITUTE OF TECHNOLOGY
Summer 2024

Declaration of Committee

Name:	**Janine Rhian McNeilly**
Degree:	**Master of Science**
Title:	**Sablefish are on the Menu for Southern Resident Killer Whales, but at What Cost?**
Committee:	**Ruth Joy** Supervisor and Chair Faculty, SFU **Douglas Ransome** Examiner Faculty, BCIT

Ethics Statement

Abstract

The Southern Resident killer whale (SRKW) population is declining, with prey availability predicted to be the largest threat to their recovery. Decreasing quality and quantity of Chinook salmon have forced SRKWs to turn to alternative prey sources. One alternative is the sablefish, a lipid-dense groundfish found along the continental slope of British Columbia. I created a bioenergetics model to compare the foraging effort required for SRKWs to pursue sablefish instead of Chinook salmon. The model assessed the distribution, depth, body mass, and lipid density of both prey species and the daily energy requirements, cost of transport, and aerobic dive limits of SRKWs. The model found that SRKWs would need to consume more Chinook than sablefish to meet their daily energy requirements, but there was no significant difference in SRKW foraging efforts when pursuing either species. These results indicate that sablefish are a viable prey alternative to SRKWs if Chinook salmon are unavailable. The management of commercial sablefish fisheries may change if SRKW or Chinook populations continue to decline.

Keywords: bioenergetics; Chinook salmon; foraging effort; prey availability; sablefish; southern resident killer whales

Dedication

For Bjossa, the whale who started it all!

Acknowledgements

There are a ton of people on my team who helped me cross this finish line!

First, thank you to Dr. Ruth Joy for being such a wonderful, kind, intelligent, and hilarious supervisor! Your dedication, encouragement, and assistance over the past two years has been greatly appreciated.

I am forever grateful to Dr. Sheila Thornton, Scott Toews, Christine Konrad Clarke, Raina Fan, Fanny Couture, and the rest of DFO's Marine Mammal Conservation Physiology team for welcoming me aboard for their 2023 field season. Spending sunny days watching killer whales splash around would have been an incredible experience on its own, but each of you made my time on the water even more enjoyable. I love a Nitinat day!

Thank you to Dr. Marla Holt and Dr. Jennifer Tennessen for providing me with the SRKW DTAG data, and to Kendra Holt for your extremely helpful suggestions on the best sources of sablefish data.

Finally, to R-Pod: Rachel Fairfield-Checko, Mikayla Young, and Sam Broadley. I am so fortunate to have experienced the ups and downs of this program alongside the three of you. Thank you for the gossip, the giggles, and the support. I am so excited to see what the marine gals do next!

Table of Contents

List of Tables

List of Figures

List of Acronyms

BC	British Columbia
BMR	Basal metabolic rate
cADL	Calculated aerobic dive limit
COT	Cost of transport
DFO	Department of Fisheries and Oceans
DPER	Daily Prey Energy Requirements
FMR	Field Metabolic Rate
NRKW	Northern Resident Killer Whale
SRKW	Southern Resident Killer Whale

Glossary

Aerobic Dive Limit	How long an animal can hold its breath before lactate begins to build up in the blood. The aerobic dive limit has not been directly measured on a killer whale, so the calculated aerobic dive limit (cADL) is used instead.
Basal Metabolic Rate	The energy required for an organism to perform basic life-sustaining functions.
Bioenergetics	The study of the balance between an organism's energy intakes and energy expenditures.
Cost of Transport	The energetic cost of swimming, measured in kcal/kg/m.
Digestive Efficiency	The percentage of calories consumed that are digested and used by the organism.
Ecotype	A genetically distinct population within a species which has adapted to the unique conditions of their environment.
Field Metabolic Rate	The total energy expenditure of a free-living organism.
Gompertz Function	A mathematical model that can be used to estimate growth over time.
Kcal	Kilocalories, a unit used to measure energy.
Metabolism	Chemical reactions within an organism that convert food into energy.

Chapter 1. Introduction

1.1. Background

Two distinct populations of *Orcinus orca* (killer whales), Southern Residents (SRKW) and Northern Residents (NRKW), overlap in distribution in the Salish Sea, the coastal waters of southern British Columbia (BC) and northern Washington (Figure 1).

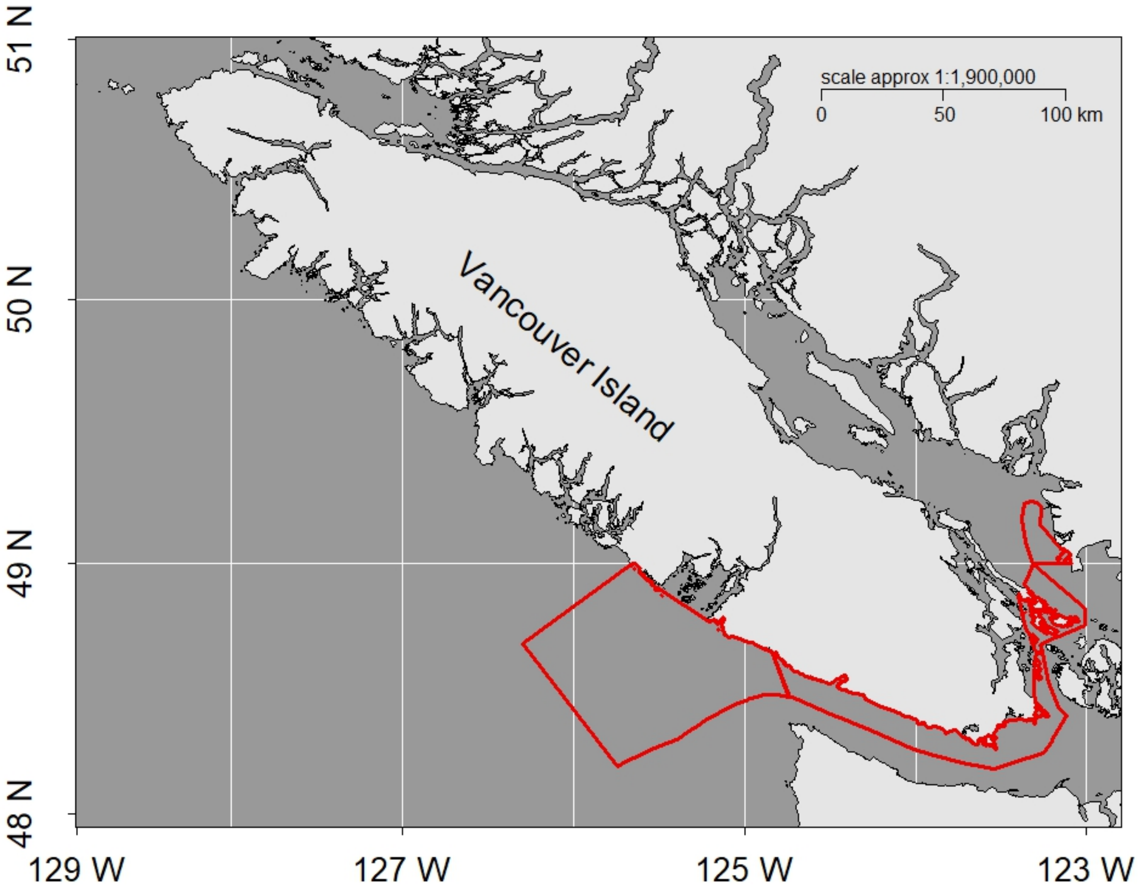

Figure 1 **Southern Resident killer whale habitat within the Salish Sea and along the west coast of Vancouver Island. The Salish Sea encompasses the Strait of Georgia, Strait of Juan de Fuca, and Puget Sound. SRKW critical habitat is outlined in red, including the southern end of the Strait of Georgia, the waters around the Southern Gulf Islands, the Strait of Juan de Fuca, and Swiftsure Bank, the last of which is a known SRKW foraging location (Thornton et al. 2022). Note that this map only outlines SRKW habitat north of the Canada-USA border.**

Though this region is federally protected as critical habitat for resident killer whales (Fisheries and Oceans Canada 2018a) the SRKW population has declined since the late 1990s and was designated as endangered in 2001 (COSEWIC 2008). Prey availability is predicted to be the largest threat to SRKW population recovery (Lacy et al. 2017), compounding with additional negative impacts through interactions with other anthropogenic disturbance factors (Murray et al. 2019; Thornton et al. 2022).

The principal prey species for SRKWs is *Oncorhynchus tshawytscha* (Chinook salmon) (Herman et al. 2005, Ford and Ellis 2006, Ford et al. 2016, Fisheries and Oceans Canada 2018a). Many populations of Chinook salmon are listed as endangered, facing additional pressure from commercial and recreational fisheries (Hanson et al. 2021). Present-day Chinook salmon are less abundant and have smaller body sizes when compared to their historic populations, forcing SRKWs to work harder to catch smaller fish (Argue & Marshal 1966; Chasco et al. 2017). This additional exertion may be a major contributing factor to the higher death rates and lower birth rates experienced by SRKWs (Noren 2011). One compensatory mechanism SRKWs may explore if their traditional prey is insufficient is to engage in prey switching behaviours by supplementing their diet with other species of fish to meet their daily nutritional demands.

One such alternative food source is *Anoplopoma fimbria* (sablefish), a lipid-dense groundfish found along the Pacific coast from Alaska to California (Sogard and Berkeley 2017, Cox et al. 2023). Sablefish spawn from January to April along the continental slope, with peak spawning occurring in February in BC waters (Gibson et al. 2019, Cox et al. 2023). Sablefish lay an average of 180,000 – 280,000 eggs each year, with some larger females laying up to 1,000,000 eggs (Gibson et al. 2019). Young-of-year sablefish swim up onto the continental shelf by the end of their first summer, and juvenile sablefish remain in protected coastal waters until they reach maturity at approximately five years old (Beamish et al. 1979, Mason et al. 1983, Cox et al. 2023). Adult sablefish can be found as deep as 2700 m below the surface, but they are known to move onto the continental shelf off the coast of Vancouver Island during the summer and fall (Fisheries and Oceans Canada 2005, Cox et al. 2023).

Observing SRKW foraging efforts is difficult under the best conditions, so researchers collect prey fragments and fecal samples to identify prey species (Ford et al. 2016). Prey fragments include scales, tissues, or pieces of flesh that remain at the surface after a successful foraging event. Prey fragments can occur after a solo hunt or after SRKWs partake in prey-sharing, when fish are caught by one whale and passed to or left behind for another (Shedd 2018). Prey-sharing is common when SRKWs forage for Chinook salmon, but it is unknown is sablefish are shared between whales (Shedd 2018). Sampling of prey segments is inherently biased as it favours prey species that are caught at the surface, are large enough that SRKWs cannot consume them whole, and are likely to shed scales that can be easily spotted from a research vessel (Hanson et al. 2021).

An alternative method of determining the diet of marine mammals is collecting fecal samples. SRKW fecal samples provide an estimate of what the whale consumed over multiple foraging events (Ford et al. 2016). Genetic analysis of the DNA found within the feces can identify the different species that make up the SRKW’s diet without a bias towards species that are consumed at the surface or torn apart during foraging (Ford et al. 2016, Hanson et al. 2021). Fecal samples are likely to contain prey from multiple feeding events, captured over a longer period and greater geographic region than a single prey sample (Hanson et al. 2021). However, this method has its own weaknesses. Enzymes within SRKW digestive systems break down different prey components at diverse rates, which could result in some species being better represented in feces than others (Tollit et al. 2003). Prey DNA analysis is a relatively new method of determining predator diet composition and it requires further development and validation to support the findings (Bowen and Iverson 2013).

Despite these potential biases, recent fecal samples indicate that sablefish now contribute to a significant portion of SRKW diets. Fecal samples collected from 2008 to 2011 were made up of less than 0.01% sablefish, but some samples collected over the summer of 2022 contained almost exclusively sablefish DNA (Ford et al. 2016, McSheffrey 2023). The 2015-year class of Canadian sablefish was estimated to be eight times the historical average, making them a plentiful prey option for SRKWs over the past decade (Fisheries and Oceans Canada 2022, McSheffrey 2023).

The true contribution of sablefish to SRKW diets is currently unknown, and many unanswered questions have resulted in the scientific community underrepresenting a potentially significant component to SRKW recovery (Fisheries and Oceans Canada 2013). Are sablefish found in waters shallow enough for SRKWs to reach them, given that the maximum recorded SRKW dive was 350 m (Miller et al. 2010; Tennessen et al. 2019)? Are SRKWs exceeding their aerobic dive limits to reach this alternative prey source (Figure B1)? Understanding the relative importance of sablefish to the SRKW population will help to focus recovery efforts beyond Chinook salmon to other prey species of SRKWs.

1.2. Objectives

My research goal was to determine linkages between SRKWs and sablefish within the critical habitat boundary off Southwestern Vancouver Island and in the Salish Sea. I had four proposed research questions:

1. Does the distribution of sablefish overlap with SRKW distribution?
2. Are sablefish found at depths that are easily accessible to SRKWs, or would the whales have to exceed their aerobic dive limits to reach them?
3. How many sablefish would each SRKW need to eat to meet their daily caloric requirements?
4. Is there a significant difference in energy expenditure between foraging for Chinook salmon versus foraging for sablefish?

Chapter 2. Methods

2.1. Sablefish Distribution

Sablefish are a commercially valuable resource for fisheries across the North Pacific, bringing in a landed value of $16.3 million to Canadian fisheries in 2013 (Fisheries and Oceans Canada 2016). Fishing records are inherently biased towards areas with sablefish larger than the legal catch limit of 55 cm (K. Holt 2023, DFO, personal communication). For example, the BC longline trap fleet voluntarily stopped fishing for sablefish in mainland inlets in 1994 as most of the fish they caught were juveniles, so there is limited fishing data on sablefish abundance in these waters (Cox et al. 2023).

The Department of Fisheries and Oceans Canada (DFO) has conducted various groundfish surveys within the Salish Sea and off the coast of Vancouver Island. They use a combination of longline and bottom trawl surveys to record the location, depth, species, and weight of each fish collected (Fisheries and Oceans Canada 2018b, 2018c, 2020a, 2020b). The four surveys I used to create my distribution map were the West Coast of Vancouver Island Synoptic Bottom Trawl Survey, the Strait of Georgia Synoptic Bottom Trawl Survey, the Inside South Hard Bottom Longline Survey, and the Outside South Hard Bottom Longline Survey (Table 1) (Fisheries and Oceans Canada 2018b, 2018c, 2020a, 2020b).

Table 1 Surveys used to map Sablefish distribution in BC waters.

Survey Name	Survey Dates	Sampling Effort	Sampling Method
West Coast of Vancouver Island Synoptic Bottom Trawl Survey	Biennially in May and June since 2004	1345 sets	Bottom Trawl
Strait of Georgia Synoptic Bottom Trawl Survey	March 2012 and May 2015	93 sets	Bottom Trawl
Inside South Hard Bottom Longline Survey	Biennially in August and September since 2005	455 sets	Longline
Outside South Hard Bottom Longline Survey	Biennially in August and September since 2007	1356 sets	Longline

Survey data were imported to R Studio to create maps for total survey effort and sablefish distribution. Bathymetry data was added to the maps to create a visual representation of the depths preferred by sablefish. Finally, SRKW critical habitat was outlined to determine whether sablefish were found in locations frequented by SRKWs.

2.2. SRKW Bioenergetics Model

2.2.1. SRKW Energetic Requirements

I developed a bioenergetics model to determine the different energetic costs of SRKWs foraging for sablefish versus Chinook salmon (Figure 2, Table A1). Bioenergetics models explain how an animal takes energy from their prey and uses it to perform various bodily functions, such as growth, maintenance, and reproduction (Pirotta 2022). My model compared the energy an SRKW gained from consuming Chinook salmon or sablefish with the associated energetic costs of foraging for each species.

I gathered SRKW census information from The Whale Museum to create a dataset of all SRKW individuals in the current population, noting their age, sex, parentage, and which pod they belonged to (The Whale Museum 2023). I separated SRKWs into different life stage categories (Table 2) depending on their age, sex, and reproductive status. The life stages were based on a previously established two-sex stage-structured model (Vélez-Espino et al. 2014). Calves (0 – 1 years old) were excluded from my bioenergetics model as SRKWs exclusively nurse for the first year of their life and do not need to forage for themselves (Noren 2011).

Table 2 Life stage categories of Southern Resident killer whales.

Life Stage	Sex	Age
Calf	Male/Female	0 – 1
Juvenile	Male/Female	1 – 9
Young Mature Male	Male	10 – 21
Old Mature Male	Male	22+
Young Reproductive Female	Female	10 – 30
Mother	Female (with calf < 2 years old)	10 – 50
Old Reproductive Female	Female	31 – 50
Post-Reproductive Female	Female	51+

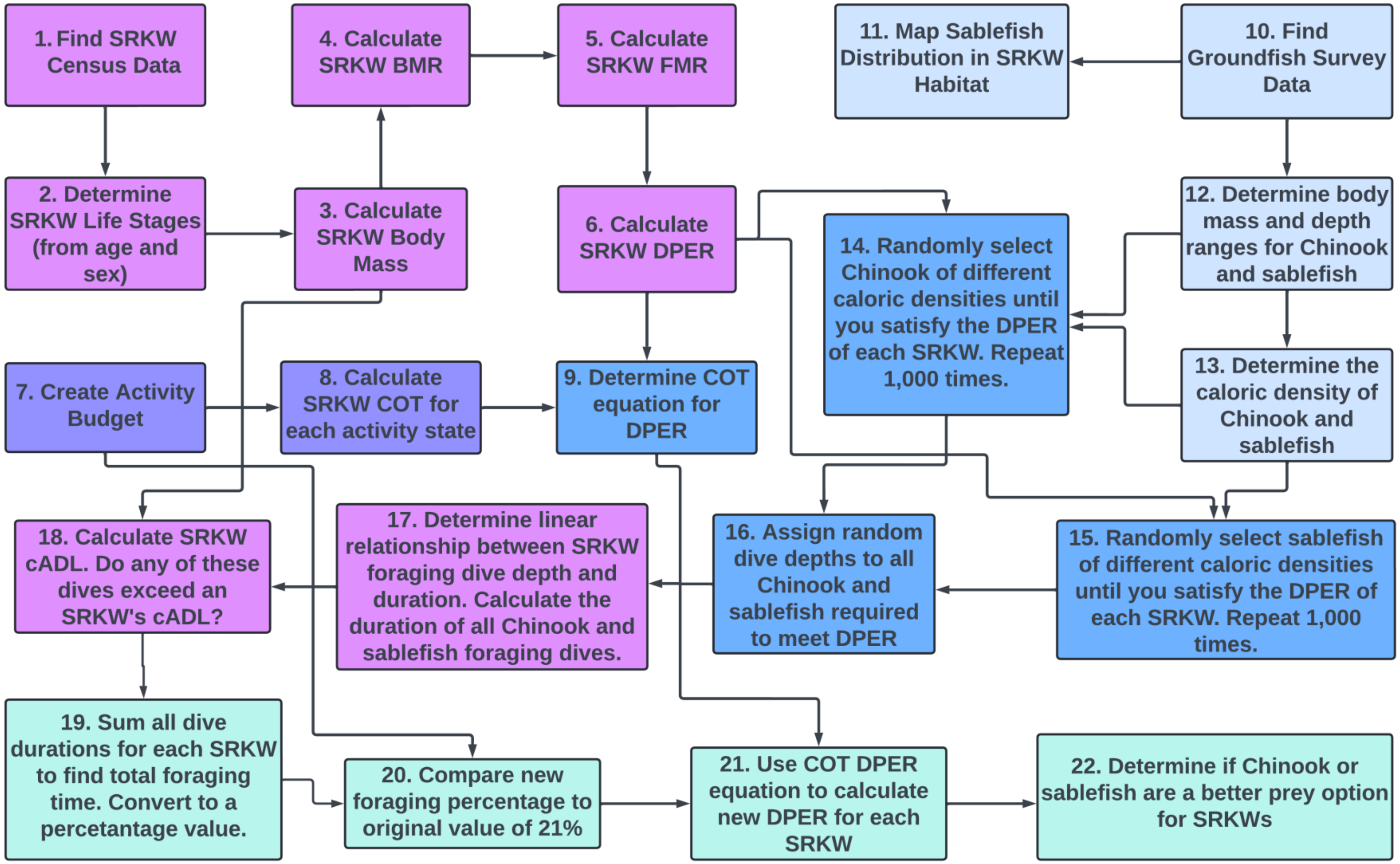

Figure 2 A summary of the steps in my bioenergetics model, showing how many components are interconnected.

I reviewed the existing literature to find established values for killer whale energetics. I compiled parameters from studies on three ecotypes found in BC waters, SRKWs, NRKWs, and Bigg's killer whales, as well as research conducted on captive killer whales from other populations.

I determined the body mass of each SRKW in the current population by comparing their age and sex to the predicted weight values calculated by Noren (2011). Killer whales are sexually dimorphic, with adult males growing to be significantly larger than adult females (Bigg and Wolman 1975, Clark et al. 2000, Noren 2011). To account for this, Noren modelled the growth trajectory of SRKWs aged 1 – 12 using a Gompertz growth function and used values previously reported for NRKWs to estimate the body masses of SRKWs aged 13 – 20 (Bigg and Wolman 1975, Clark et al. 2000, Noren 2011, Vincenzi et al. 2020). It is assumed that SRKWs reach their maximum body size at age 20 (Noren 2011).

Basal metabolic rates (BMR) represent the amount of energy required by a resting organism to sustain vital life functions, such as breathing and circulation (Kleiber 1975, Worthy et al. 2014, Gallagher et al. 2018). An organism's BMR can be estimated by using Kleiber's Law and the organism's body mass (Kleiber 1975, Smil 2000). Kleiber plotted the log of the mass of various terrestrial animals against the log of their BMR, determining a linear relationship of $70mass^{0.75}$ between an animal's weight and their daily energy expenditure (Kleiber 1975, Smil 2000). The BMRs of marine mammals do not follow this "mouse-to-elephant-line" exactly as living in a marine environment causes them to expend additional energy to sustain themselves, like expending energy to thermoregulate in cold water (Smil 2000). I used Kleiber's Law and the SRKW body mass estimates (M_{kw}) to calculate the BMR of each whale. M_{kw} is measured in kilograms and BMR is measured in kcal/day.

$$\mathrm{BMR} = 70M_{kw}^{0.75} \tag{1}$$

Field metabolic rates (FMR) estimate the amount of energy a free-ranging organism needs to survive (Williams et al. 1993, Molnár et al. 2009, Noren 2011, Pirotta 2022, Noren and Rosen 2023). The FMRs of SRKWs will vary depending on the whale's sex, life stage, mass, and how long the whale spends in each activity state (Williams and Noren 2009, Noren 2011, Noren and Rosen 2023). Previous studies of other marine mammals found that their FMRs were five to six times greater than their Kleiber-predicted BMRs (Williams et al. 1993, Williams and Noren 2009, Noren 2011, Costa and Maresh 2018). I multiplied Equation 1 for SRKW BMR by five and six to determine the lower and upper estimates for SRKW FMRs:

$$\text{Lower FMR} = 350M_{kw}^{0.75} \tag{2}$$

$$\text{Upper FMR} = 420M_{kw}^{0.75} \tag{3}$$

FMRs are measured in kcal/day and killer whale body masses (M_{kw}) are measured in kilograms.

SRKWs do not retain 100% of the calories they ingest as energy is expended during the digestion process (Kriete 1994, Noren et al. 2012, Booth et al. 2023). Their daily prey energy requirements (DPER), the total number of calories they must consume in a day, will be greater than their estimated FMRs to account for this energy loss. DPER are calculated by dividing an animal's FMR by their digestive efficiency, which describes the proficiency of an animal's digestive system to extract and use calories from their food (Booth et al. 2023). Killer whales have a digestive efficiency of 0.847 (Williams et al. 2004), therefore the equations for the lower and upper range of DPERs are:

$$\text{Lower bound DPER} = 413.2M_{kw}^{0.75} \tag{4}$$

$$\text{Upper bound DPER} = 495.5M_{kw}^{0.75} \tag{5}$$

with DPER reported in kcal/day and M_{kw} in kilograms.

Cost of transport (COT) is the amount of energy an SRKW uses when swimming at various speeds (Williams and Noren 2009). The cost of transport of NRKW males, females without calves, and females with calves was previously determined using the following mass-specific COT equations:

$$\text{Male COT} = 3S^{-0.96} \tag{6}$$

$$\text{Female without calf COT} = 2.2S^{-0.97} \tag{7}$$

$$\text{Female with calf COT} = 2.3S^{-0.66} \tag{8}$$

where S = average swimming speed in m/s for each activity and COT is measured in J/kg/m. Williams and Noren (2009) created these COT equations based on observations of mature NRKWs to limit the interference of the energetic costs of growth, meaning these equations only applied to males over the age of 15 and females over the age of 13 (Williams and Noren 2009). The current SRKW population's COT could be estimated by using Equation 6 for young mature males and old mature males; Equation 7 for young reproductive females, old reproductive females, and post-reproductive females; and Equation 8 for mothers with calves under two years old (Williams and Noren 2009). Noren's (2011) growth curve indicated that juvenile killer whales have the same growth rate regardless of their sex and can therefore use the same mass-specific COT equation. As the number of female juveniles and calves currently outweighs the number of males, I used Equation 7 to estimate the COT of the younger SRKWs.

SRKW swimming speed changes depending on which activity they are engaged in. I used the daily activity budget created by Noren (2011) to separate activities into four states: travelling, foraging, resting, and socializing (Table 3). The mean swimming speeds and the proportion of time SRKWs spend in each activity state were estimated from previous field observations (Noren 2011).

Table 3 The daily activity budgets of SRKWs.

Activity State	Mean Swimming Speed (m/s)	% of 24-hour day engaged in activity
Travelling	2.2	70.4
Foraging	1.1	21.0
Resting	0.8	6.8
Socializing	0.3	1.8

I assigned Equations 6 to 8 to each SRKW based on their life stage to determine their COT:

$$\mathrm{COT}_{\text{juvenile}} = 2.2 * (S_{Activity}^{-0.97}) / 4184 \quad (9)$$

$$\mathrm{COT}_{\text{young mature male}} = 3 * (S_{Activity}^{-0.96}) / 4184 \quad (10)$$

$$\mathrm{COT}_{\text{old mature male}} = 3 * (S_{Activity}^{-0.96}) / 4184 \quad (11)$$

$$\mathrm{COT}_{\text{young reproductive female}} = 2.2 * (S_{Activity}^{-0.97}) / 4184 \quad (12)$$

$$\mathrm{COT}_{\text{old reproductive female}} = 2.2 * (S_{Activity}^{-0.97}) / 4184 \quad (13)$$

$$\mathrm{COT}_{\text{post-reproductive female}} = 2.2 * (\mathrm{S}_{\mathrm{Activity}}^{-0.97}) / 4184 \quad (14)$$

$$\mathrm{COT}_{\text{mother with calf}} = 2.3 * (S_{Activity}^{-0.66}) / 4184 \quad (15)$$

COT is the cost of transport for a whale in each life stage in kcal/kg/m, $S_{Activity}$ is the mean swimming speed of an SRKW in each activity state in m/s, and 4184 kcal/J converts the final answer to kcal/kg/m. I used Equations 9 to 15 to calculate the COT of each SRKW when travelling (COT_T), foraging (COT_F), resting (COT_R), and socializing (COT_S).

An SRKWs DPER will vary depending on how long it spends in each activity state. To calculate this change, I combined the COTs for the four activity states, the percentage of the day spent in each activity state (P_X), Kleiber's Law for BMR, and SRKW digestive efficiency (Noren et al. 2012).

$$\text{DPER} = \frac{(\text{COT}_T * P_T + \text{COT}_F * P_F + \text{COT}_R * P_R + \text{COT}_S * P_S) * X * 70M_{kw}^{0.75}}{0.847} \tag{16}$$

To make the DPER calculated in Equation 16 equal to the lower or upper DPER estimates calculated in Equations 4 and 5, the Kleiber BMR component is multiplied by *X.* The value of *X* changes based on an SRKW's sex and life stage, ranging from 2.5 to 4.1. By determining the value of *X* for each SRKW, I can use Equation 16 to compare how the different COT_F associated with foraging for Chinook or sablefish affect an SRKWs overall energy requirements. If the DPER calculated for whales that forage for sablefish is significantly higher than those foraging for Chinook, sablefish may not be a viable prey alternative for SRKWs.

2.2.2. Prey Availability and Nutrient Content

Salmonids have historically made up the majority of SRKW diets, with Chinook salmon being their most preferred species (Ford and Ellis 2006, Williams et al. 2011, Ford et al. 2016, Chasco et al. 2017a). Analysis of SRKW fecal samples from 2008 to 2011 estimated that salmon made up >98.6% of SRKW diets, with Chinook salmon found in 80% of the samples (Ford et al. 2016). I used Chinook salmon values as the baseline parameters for my model to compare against the effort of SRKWs foraging for sablefish.

I used data from four surveys within known SRKW habitat to find the body mass and depth ranges of Chinook and sablefish: the West Coast of Vancouver Island Synoptic Bottom Trawl Survey, the Strait of Georgia Synoptic Bottom Trawl Survey, the Inside South Hard Bottom Longline Survey, and the Outside South Hard Bottom Longline Survey (Fisheries and Oceans Canada 2018b, 2018c, 2020a, 2020b). Sablefish were caught in all four surveys, but I chose to estimate sablefish depth ranges using only the two longline surveys. Bottom trawl surveys can catch fish on their way to and from their set depth, resulting in less accurate depth measurements. Longline surveys provide a better estimate of the true depth of the specimen caught (S. Thornton 2024, DFO, personal communication). Chinook salmon were significantly less abundant in these surveys than sablefish. Only 27 Chinook had their body mass recorded across the four surveys compared to 9628 sablefish. Chinook were not caught in either the Inside or Outside surveys, so all information on Chinook body mass and depth came from the two bottom trawl surveys. I determined the minimum, maximum, mean, median, and standard deviation of the body mass and depth values for Chinook salmon and sablefish.

The lower and upper estimates of SRKW DPERs were used to determine the number of fish an SRKW would need to consume each day. To find the number of Chinook required, I created a function that would randomly select Chinook salmon from their predetermined body mass range, with the range centered around their median weight value. These randomly selected Chinook body masses were converted to energetic content using the following equation:

$$\text{Chinook energy content} = M_c * 1.79 \tag{17}$$

where Chinook energy content is measured in kilocalories, M_c is the mass of the Chinook measured in grams, and 1.79 is the number of kilocalories per gram of a Chinook salmon (Jeffrey et al. 2017, U.S. Department of Agriculture 2019). The energetic content of each randomly selected Chinook was tallied until they reached the SRKWs daily energy requirements. The model would then move on to the next SRKW and repeat the process, computing the number of Chinook salmon SRKWs of varying ages, sexes, and life stages would have to consume to meet their DPERs. This portion of the model was run 1,000 times for both the lower and upper DPER estimates to increase confidence in the results and to reduce the impact of outliers.

The same function was applied to sablefish, randomly selecting sablefish masses from their positively skewed distribution. The energetic content of sablefish was determined with the following equation:

$$\text{Sablefish energy content} = M_s * 1.95 \tag{18}$$

where sablefish energy content is measured in kilocalories, M_s is the mass of sablefish measured in grams, and 1.95 is the caloric density per gram of sablefish (U.S. Department of Agriculture 2019). Sablefish were randomly selected until each SRKW had caught enough to meet their energy requirements. The upper and lower DPERs of each SRKW were run through the model 1,000 times to achieve a more accurate representation of their prey requirements.

2.2.3. SRKW Foraging Efforts

I obtained digital acoustic recording tag (DTAG) data from a previous study on SRKWs by Tennessen et al. (2019). DTAGs were deployed on SRKWs in the Salish Sea between 2010 to 2014, recording the dive depth, dive duration, movement, and acoustics of over 3,600 SRKW dives (Tennessen et al. 2023, 2019). These dives were separated into five categories based on SRKW acoustics and movement patterns: State 1 – deep prey pursuit/capture, State 2 – travel, State 3 – miscellaneous, State 4 – surface searching, and State 5 – respiration (Tennessen et al. 2019). I selected the State 1 – deep prey pursuit/capture dives to represent SRKW foraging efforts. I fit a simple linear regression between the duration and depths of these dives:

$$\text{Dive duration} = 1.45 * \text{dive depth} + 76.11 \tag{19}$$

where dive duration is in seconds and dive depth is in meters (Figure B2).

Dive depths were randomly selected from the predetermined ranges for Chinook and sablefish. These random depths were assigned to each of the Chinook or sablefish required to meet an SRKWs DPER (Fisheries and Oceans Canada 2018b, 2018c, 2020a, 2020b). Equation 19 converted each of these depth values into estimated SRKW dive durations.

An aerobic dive limit is the maximum duration of a dive before lactate begins to build up in an animal’s blood (Miller et al. 2010). The longer an animal remains underwater beyond this threshold, the longer their recovery (Miller et al. 2010). The calculated aerobic dive limit (cADL) for Bigg’s killer whales was estimated by Miller et al. (2010) with existing aerobic dive limit data from a bottlenose dolphin and the following equation:

$$cADL_{kw} = ADL_{bnd} \times (M_{kw} / M_{bnd})^{-0.25} \quad (20)$$

where $cADL_{kw}$ is the calculated aerobic dive limit of the killer whale in minutes, ADL_{bnd} is the aerobic dive limit of the bottlenose dolphin in minutes, M_{kw} is the mass of the killer whale in kilograms, and M_{bnd} is the mass of the bottlenose dolphin in kilograms. Using the 5.4-minute aerobic dive limit of a 187 kg bottlenose dolphin and the mass of each SRKW in the population, I calculated the aerobic dive limit of each whale. This established how long each whale can spend foraging for their prey without additional recovery time at the surface, effectively limiting how deep they can dive. The individual dive durations calculated for each SRKW with Equation 19 were compared to the whale's cADL to see if any SRKWs exceeded their aerobic dive limit when foraging for Chinook or sablefish.

The individual dive durations were then totalled for each SRKW to determine their total foraging dive time. Total dive time was converted to daily foraging percentage using Equation 21:

$$\text{Percent of Day Spent Foraging} = [(\Sigma \text{ dive durations}) / 86400] * 100 \quad (21)$$

where the dive durations are reported in seconds and 86400 is the number of seconds in a day.

Each SRKW now had 1,000 daily foraging percentage estimates for the following categories: lower DPER Chinook, upper DPER Chinook, lower DPER sablefish, and upper DPER sablefish. I generated a 95% confidence interval for the mean daily foraging percentage in these four categories for each SRKW. The mean daily foraging percentage values were compared to Noren's (2011) daily foraging percentage estimate of 21% to see how an all-Chinook or all-sablefish diet would alter the amount of time an SRKW spends foraging.

All SRKWs had an original daily travelling percentage of 70.4% and a daily foraging percentage of 21%. Any differences between the new foraging percentages and this original value of 21% were added to or subtracted from their daily travelling percentage. For example, an SRKW with a new mean foraging percentage of 25% would have a travelling percentage of 66.4%.

Finally, the new lower and upper DPERs for an all-Chinook and all-sablefish diet were calculated for each SRKW using Equations 9 to 16. COT was calculated using Equations 9 to 15 with the new foraging and travelling percentages, depending on the life stage of the SRKW. COT estimates for each activity state were totalled and multiplied by the SRKW's BMR and the previously calculated *X* value associated with its life stage. This value was divided by the digestive efficiency to find the new DPER of each SRKW. This process was repeated four times for each SRKW to account for the four DPER estimates: lower DPER Chinook, upper DPER Chinook, lower DPER sablefish, and upper DPER sablefish. New DPER values were compared to the original estimates calculated using Equations 4 and 5 to determine whether the foraging efforts associated with an all-Chinook or all-sablefish diet resulted in higher energy requirements.

Chapter 3. Results

3.1. Sablefish Distribution

Sablefish were encountered in all four surveys inside the Salish Sea and along the west coast of Vancouver Island (Figure 3, Figure 4). Sablefish surveyed in the Salish Sea were almost entirely juveniles, with only one legal adult caught between the two inside surveys. Surveys along the coast of Vancouver Island saw remarkably different results, with 40% of sablefish caught above the legal catch limit of 55 cm. Sablefish were most prevalent along the edge of the continental shelf and on the continental slope, with a greater catch density in May and June than in August and September (Table 4).

Table 4 Number of sets that sampled sablefish in each of the four surveys. The surveys with the highest sablefish catch rates were along the West Coast of Vancouver Island.

Survey Name	Survey Dates	Percent of Sets with Sablefish
West Coast of Vancouver Island Synoptic Bottom Trawl Survey	Biennially in May and June since 2004	64.0
Strait of Georgia Synoptic Bottom Trawl Survey	March 2012 and May 2015	14.0
Inside South Hard Bottom Longline Survey	Biennially in August and September since 2005	0.4
Outside South Hard Bottom Longline Survey	Biennially in August and September since 2007	31.4

Sablefish were surveyed within critical SRKW habitat (Figures 3 and 4). Most of these survey sets occurred in water that was less than 200 m deep, meaning the sablefish were within the depth range of foraging SRKWs.

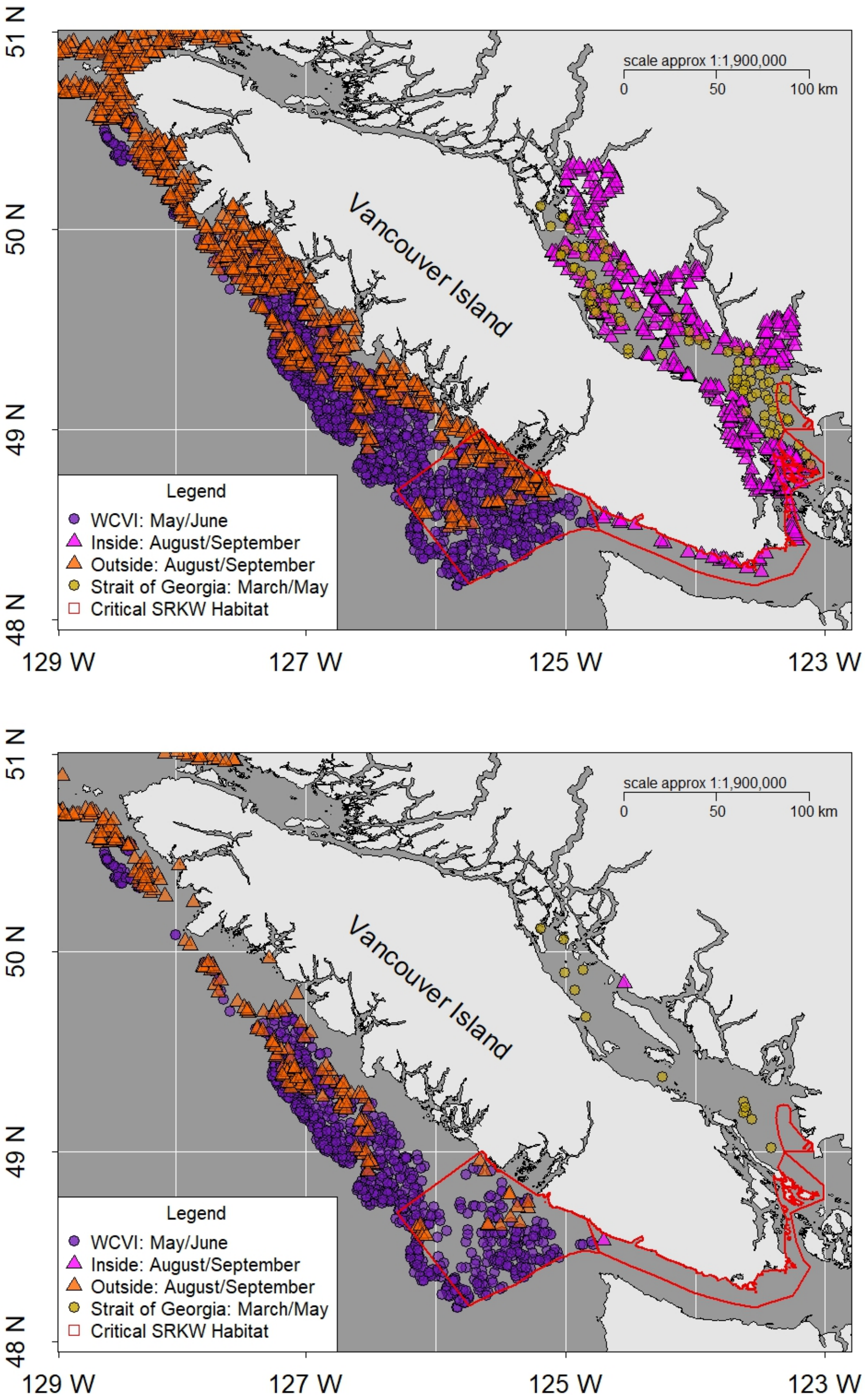

Figure 3 **Total survey effort and sablefish distribution along the west coast of Vancouver Island and within the Salish Sea. The top map shows the total effort for the four surveys, while the bottom map depicts the location of survey sets where sablefish were caught. Circular points represent bottom trawl surveys, while triangles represent longline surveys.**

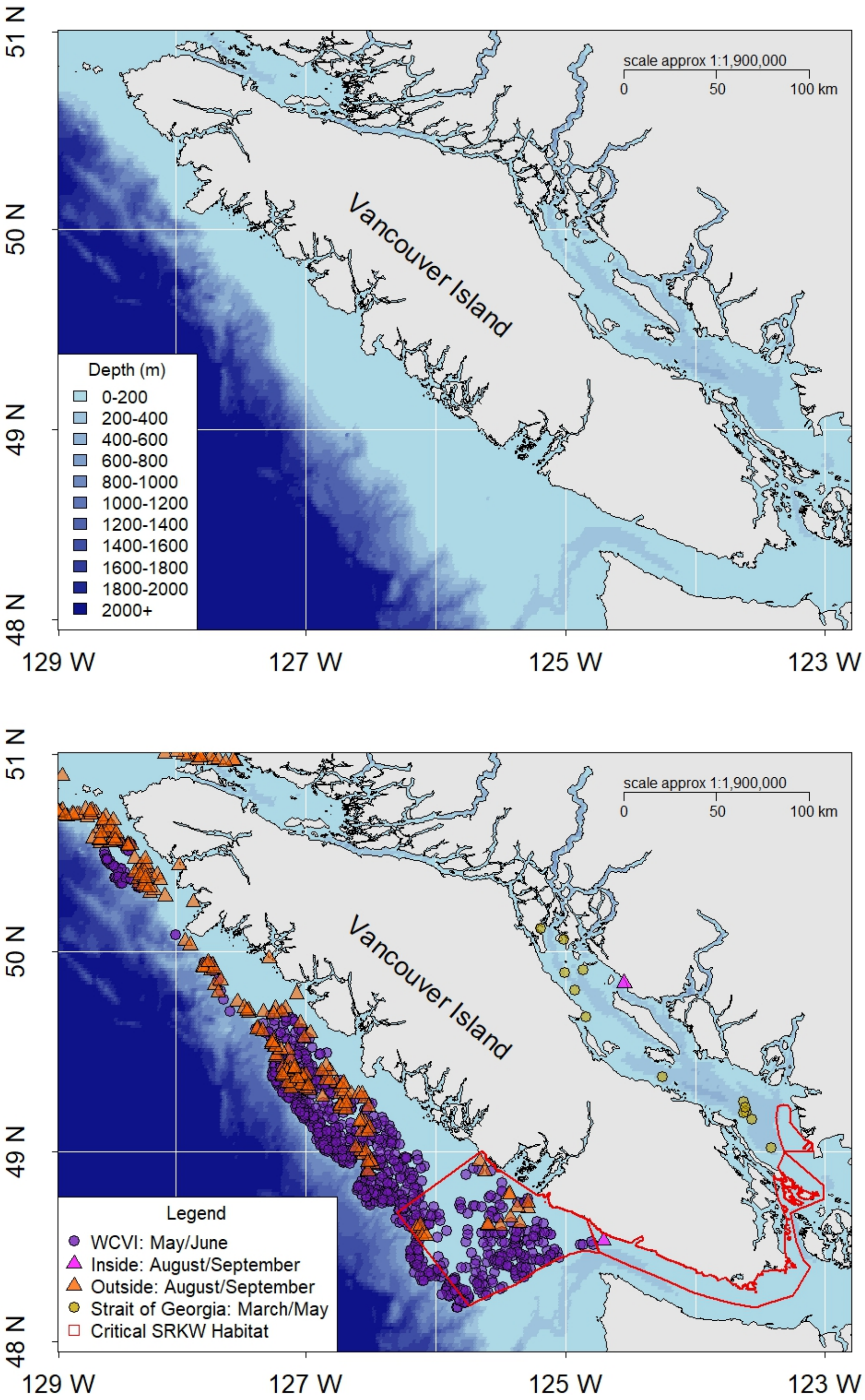

Figure 4 Sablefish distribution along the west coast of Vancouver Island and inside the Salish Sea. The top map shows the bathymetry of the area, while the bottom map shows all survey sets where sablefish were encountered layered over the bathymetric data. These figures show that sablefish are most often encountered along the continental slope off of western Vancouver Island.

3.2. SRKW Bioenergetics Model

3.2.1. SRKW Energetic Requirements

BMR, FMR, and DPER are all a function of SRKW body mass, therefore they all increase as the SRKWs grow older and larger (Figure 5, Table A2). Energy requirements follow a logarithmic growth pattern, with an initially steep slope that levels off over time. SRKWs reach their maximum body size at approximately 20 years old, after which their energy requirements will remain relatively constant.

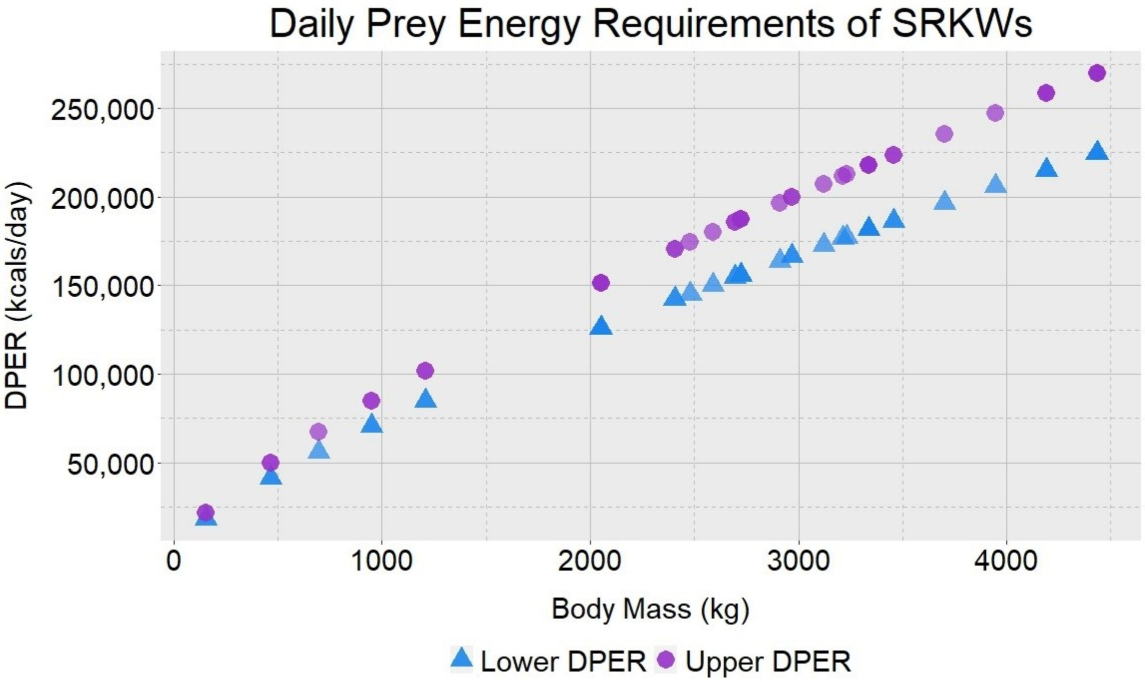

Figure 5 **Daily prey energy requirements (DPER) of the current SRKW population. Lower DPER estimates are shown in blue and upper DPER estimates are shown in purple.**

Swimming speed has the greatest influence on an SRKWs COT (Figure 6). SRKWs have higher COTs in low-speed activity states like socializing or resting, while high-speed activities like travelling and foraging burn fewer kilocalories per meter. SRKWs who spend the highest percentage of their day travelling will exert the least amount of energy. SRKWs with a greater body mass have a higher COT than smaller SRKWs when travelling at the same speed.

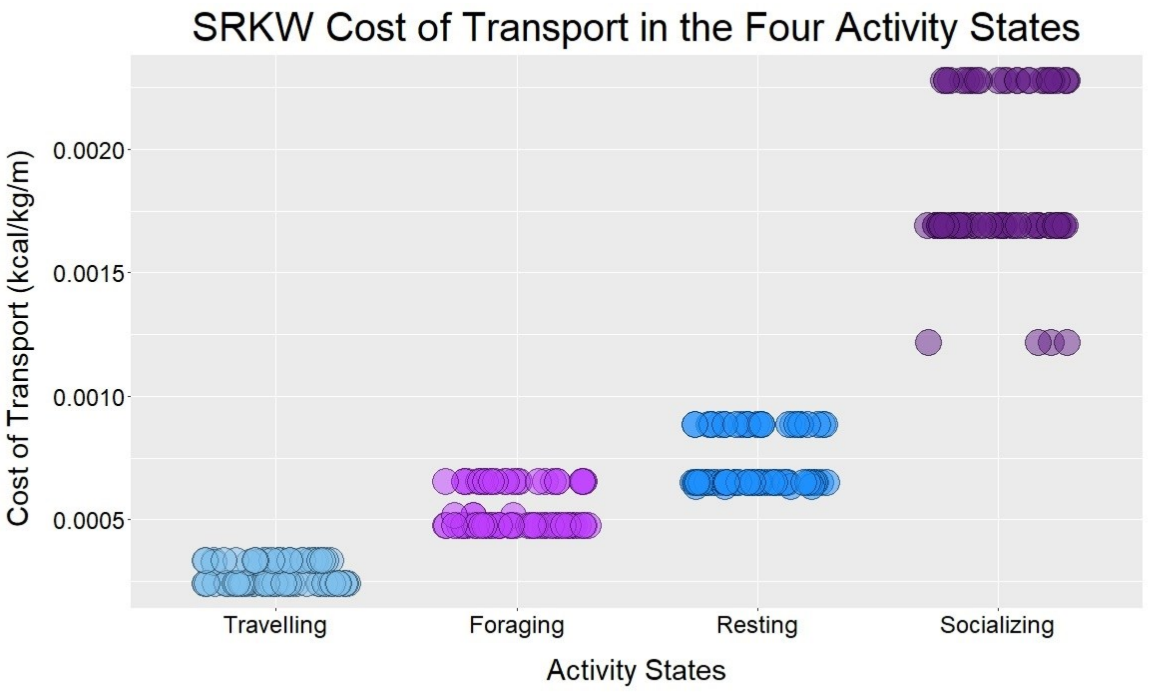

Figure 6 **SRKW cost of transport across the four activity states. Each dot represents an SRKW's COT in each state. Adult males have the highest COT in each activity state, while females with calves have the lowest. High-speed activities like travelling have significantly lower COTs than activities with a lower average speed.**

3.2.2. Prey Availability and Nutrient Content

Sablefish caught across the four surveys were substantially larger than Chinook salmon. Only 29% of surveyed Chinook weighed over 1000 g, while 80% of all surveyed sablefish were over 1000 g (Table 5, Figure 8). As sablefish have a higher caloric density than Chinook salmon, this means that most of the sablefish caught in these surveys had a greater energy content than any of the Chinook.

As SRKWs increase in body mass, the variation between the number of Chinook and the number of sablefish required to meet their DPERs increases (Figure 7). Conversely, the youngest and smallest SRKWs have little difference between their required intake of Chinook and sablefish as their estimated DPERs are much smaller.

Table 5 **Weight ranges for Chinook salmon and sablefish, rounded to the nearest gram.**

Species	Minimum (g)	Median (g)	Mean (g)	Maximum (g)	95% Confidence Interval
Chinook	250	583	1408	5278	661-1878
Sablefish	225	1366	1601	10550	1575-1627

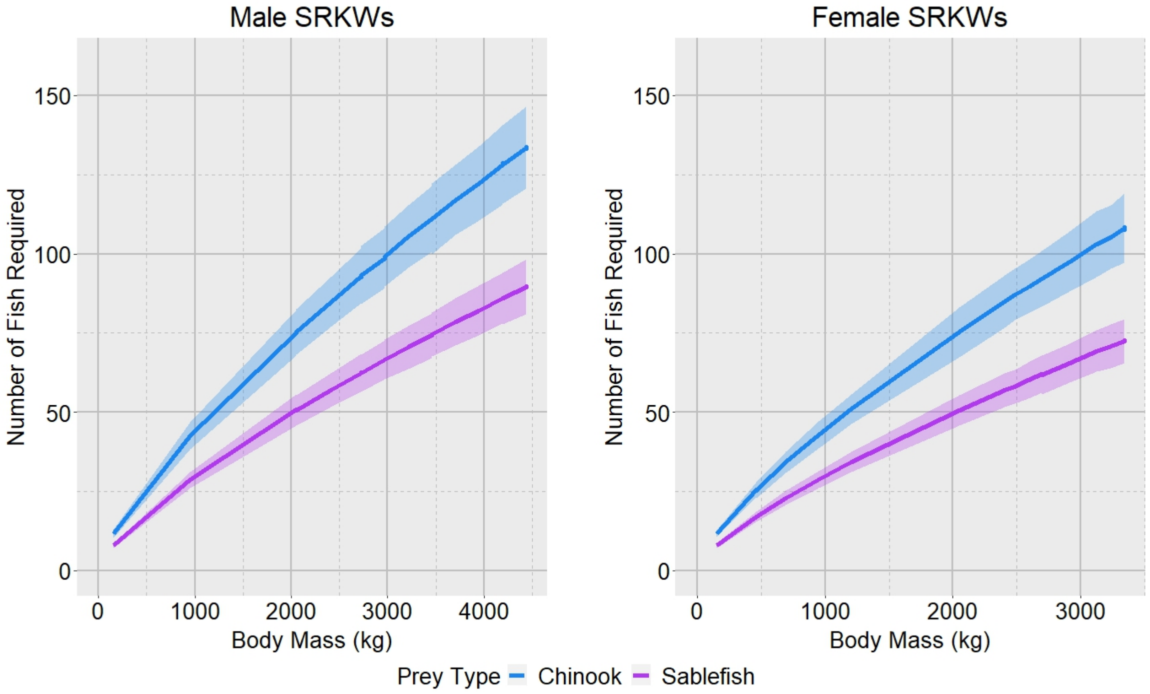

Figure 7 **The number of fish an SRKW would need to catch to meet their DPER, based on their sex and body mass. The darker blue and purple lines indicate the average number of fish required, while the lighter ribbons show the range of values that fall within a 95% confidence interval.**

3.2.3. SRKW Foraging Efforts

Chinook salmon and sablefish were both found in waters less than 250 m deep, with sablefish displaying a greater range of depths than Chinook (Table 6, Figure 8). Sablefish depths were estimated using only longline data to increase the accuracy of depth measurements. If bottom trawl survey data had been included, sablefish depths would have increased to 803 m.

Table 6 **Depth ranges in meters for Chinook salmon and sablefish, rounded to the nearest meter.**

Species	Minimum (m)	Median (m)	Mean (m)	Maximum (m)	95% Confidence Interval
Chinook	43	112	115	200	105-124
Sablefish	31	151	157	256	154-162

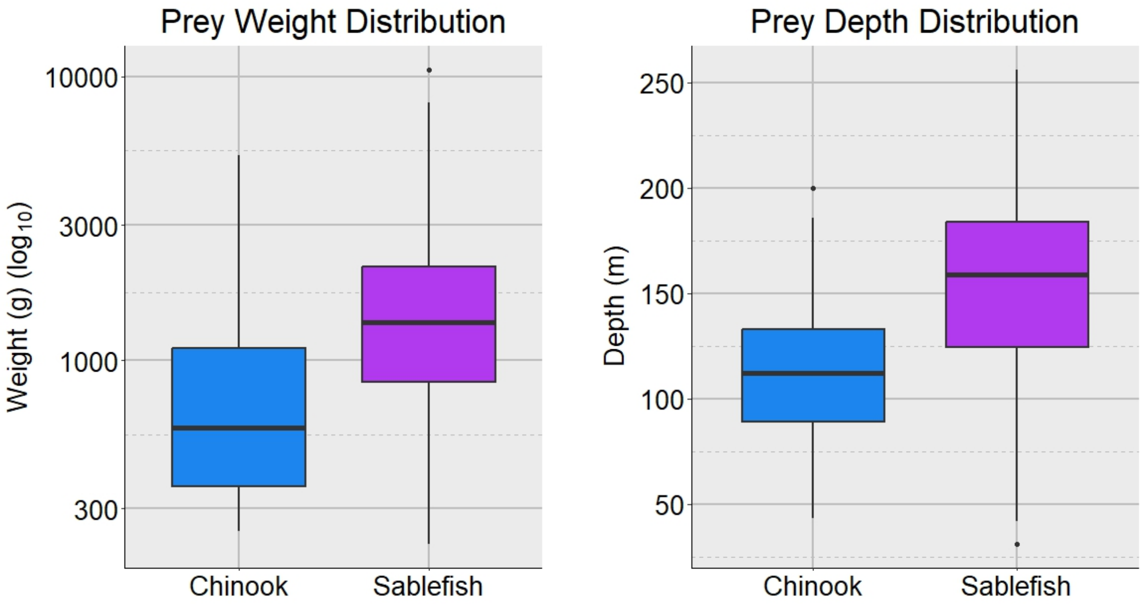

Figure 8 **Weight and depth distribution of Chinook and sablefish within the Salish Sea and along the west coast of Vancouver Island. Sablefish depths were estimated using data from only the longline surveys, while Chinook depths were estimated from bottom trawl and longline surveys.**

The maximum depths of Chinook and sablefish were 200 m and 256 m, respectively. Using Equation 19 I determined that the maximum dive duration would be 6.10 minutes when foraging for Chinook salmon and 7.46 minutes when foraging for sablefish. SRKW cADLs ranged from 5.14 minutes for the calves to 11.92 minutes for the largest mature males (Table A3). Only four SRKWs were found to exceed their cADL while foraging. Calves L-126 and L-127 would exceed their cADL if they dove to the maximum Chinook depth of 200 m or the maximum sablefish depth of 256 m. Juveniles J-59 and K-45 would exceed their cADL if they dove to the maximum sablefish depth of 256 m.

My bioenergetics model found that each life stage of SRKW would spend a greater percentage of their day foraging for Chinook salmon than they would for sablefish (Figure 9). All juvenile SRKWs showed very low foraging percentage estimates, while SRKWs in other life stages had values that remained close to the original estimate of 21%. Adult male SRKWs showed the greatest increase in foraging effort, with old mature males increasing their foraging percentage above 21% in all four scenarios. Adult females were at or below the 21% foraging effort estimate for all scenarios except the Upper Chinook Foraging Percentage.

Using Equation 16, I calculated the new lower and upper DPER estimates for each SRKW on a diet of all-Chinook or all-sablefish (Figure 10). Male SRKWs have a greater variation in DPER between whales of a similar mass while female SRKWs display an almost linear increase in DPER with body size. Each SRKW had higher DPER values when foraging for Chinook salmon rather than sablefish.

I used a Shapiro-Wilk test to determine whether the lower and upper DPER distributions were normal for either Chinook or sablefish diets. I tested the lower and upper DPERs for the original estimates, the estimates with an all-Chinook diet, and the estimates with an all-sablefish diet. All six Shapiro-Wilk tests had a p-value less than 0.05, indicating none of the values were normally distributed. I ran a Wilcoxon Rank Sum Test to see if there was a significant difference between any of the DPER estimates. The test determined that there was no significant difference between any of the lower or upper DPER values calculated in the bioenergetics model (Table 7).

Table 7 Results of the Wilcoxon Rank Sum Test on the different DPER estimates for SRKWs. No test results had p values < 0.05, indicating there was no significant difference in DPERs between the new estimates and the original DPERs, or the DPERs associated with an all-Chinook salmon diet and an all-sablefish diet.

DPER 1	DPER 2	P-value	Significant Difference?
Original Lower DPER	Chinook Lower DPER	0.38	No
Original Lower DPER	Sablefish Lower DPER	0.36	No
Chinook Lower DPER	Sablefish Lower DPER	0.31	No
Original Upper DPER	Chinook Upper DPER	0.24	No
Original Upper DPER	Sablefish Upper DPER	0.79	No
Chinook Upper DPER	Sablefish Upper DPER	0.30	No

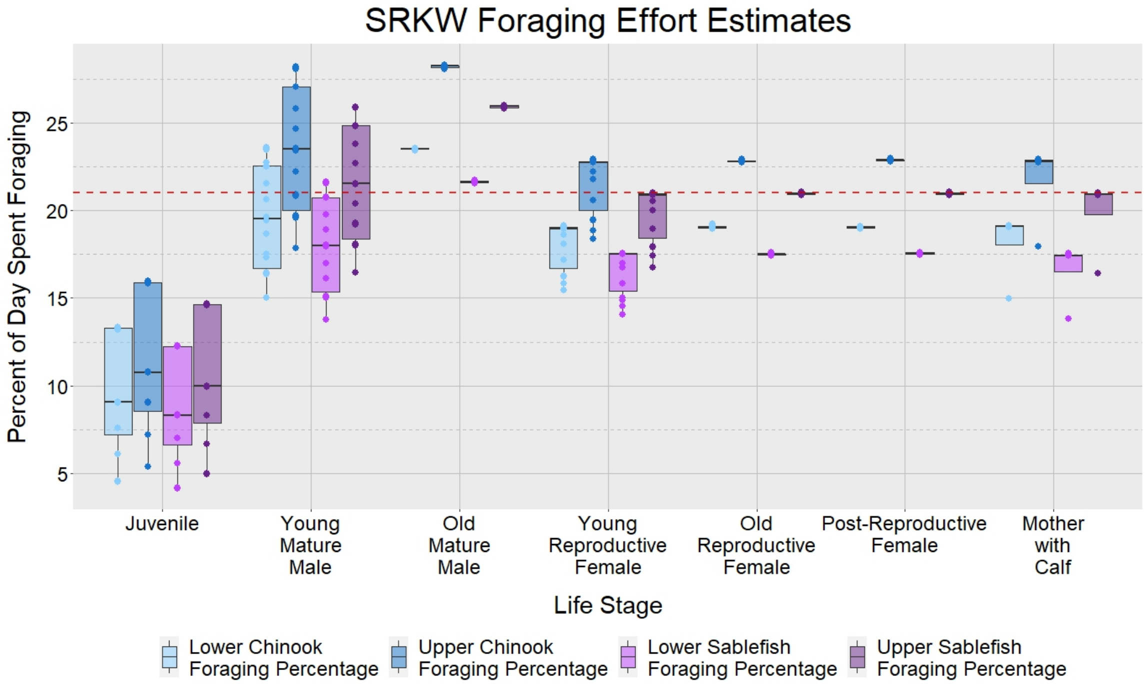

Figure 9 Differences in SRKW foraging percentages between diets of all-Chinook salmon and all-sablefish. The dots represent the lower and upper foraging percentages for each SRKW on a diet of Chinook (blue) or sablefish (purple). The red dashed line indicates the 21% foraging effort estimated by Noren (2011).

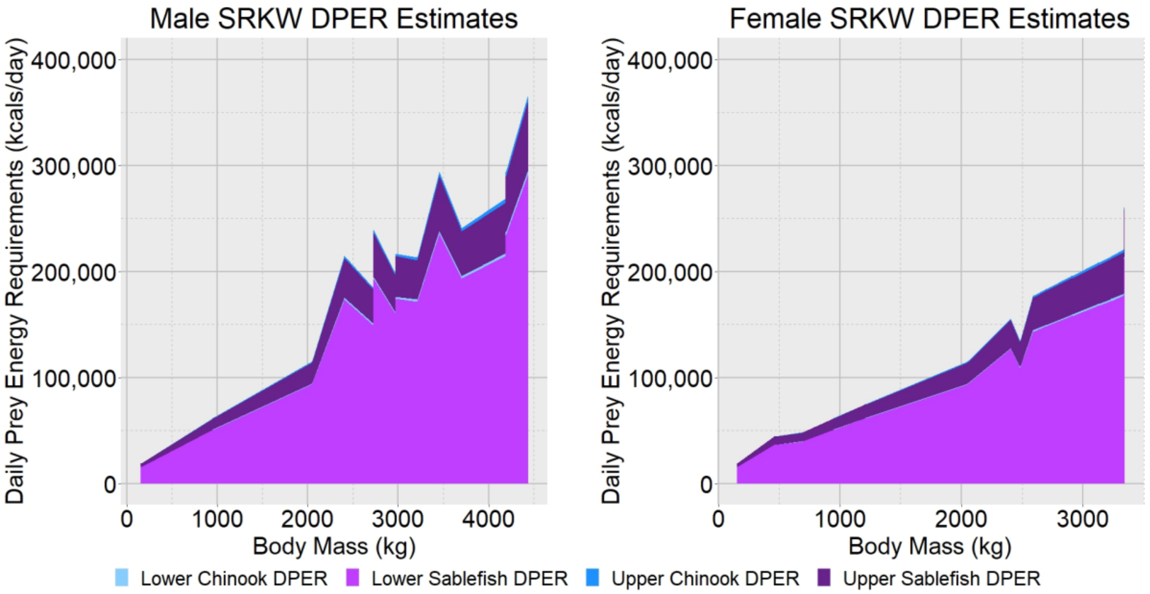

Figure 10 The lower and upper range of daily prey energy requirements for male and female SRKWs on a diet of all-Chinook (blue) or all-sablefish (purple). There is no significant difference between the two.

Chapter 4. Discussion

4.1. Sablefish Distribution

Sablefish were found within the limits of SRKW habitat, though the highest density of sablefish surveyed appeared elsewhere. While the boundaries of the SRKW habitat are not absolute, this finding indicates that SRKWs may have to travel outside of their typical range to forage for sablefish.

There was a substantial number of sablefish caught within the shallow waters at Swiftsure Bank, a known SRKW foraging spot (Thornton, et al. 2022). These sablefish were caught in water less than 200 m deep, meaning all but two SRKWs could forage for them without exceeding their cADL (Table A4). 40% of sablefish caught along the west coast of Vancouver Island were bigger than the legal catch limit of 55 cm. The large body size and resulting caloric density of these sablefish would provide any SRKWs in the area with a high energy prey source.

Despite extensive survey efforts, only 15 sablefish were encountered within the Salish Sea, with 14 of these fish found outside of SRKW habitat. The two inshore surveys took place over the summer months when adult sablefish are most likely to be on the continental shelf, therefore it is unlikely that the timing of these surveys affected the distribution results. Most sablefish found within inshore waters were juveniles or sublegal adults, with only one sablefish surveyed that was larger than 55 cm. These results indicate that adult sablefish do not return to the Salish Sea after they leave the protected inshore waters at maturity. No sablefish were caught in the deep, sheltered waters around the Southern Gulf Islands.

The West Coast of Vancouver Island Bottom Trawl Survey encountered many sablefish along the continental slope. Though these fish were included in distribution maps, they were not included in the bioenergetics model as bottom trawl surveys do not provide an accurate depth measurement. Sablefish caught in this survey were found up to 803 m below the surface. All SRKWs would need to exceed their cADL to reach this depth, and as 803 m is significantly deeper than the maximum recorded SRKW dive of 350 m, this depth may be beyond the physiological limits of the SRKW population (Tennessen et al. 2019b, 2019a).

4.2. SRKW Bioenergetics Model

4.2.1. SRKW Energetic Requirements

BMR, FMR, and DPER all increased with SRKW body mass. As killer whales are highly sexually dimorphic, this increase is more pronounced in male SRKWs. The oldest male SRKW is in his early thirties, while the eldest female is 95. The substantial size difference, and therefore DPER, between a mature male and female SRKW makes it progressively difficult for mature males to catch enough prey to sustain themselves.

Across all ages, sexes, and life stages, SRKWs would need to catch more Chinook salmon than sablefish to meet their daily energy requirements. A mature male SRKW may need to catch 30 additional Chinook salmon when compared to a mature female of a similar age, a feat that will be increasingly difficult as Chinook populations continue to decline. Sablefish may be a boon to these males, who will need to make far fewer dives if they can supplement their diet with these high-fat fish.

Faster SRKW swimming speeds result in lower COTs than slower speeds, with the optimum killer whale swimming speed estimated to be 3.1 m/s (Kriete 1994, Williams and Noren 2009). As the travelling activity state has a mean swimming speed of 2.2 m/s it has a lower COT than the foraging activity state, which has an average swimming speed of 1.1 m/s. SRKWs who spend a greater percentage of their day foraging will need to consume additional prey to meet their increasing energy requirements. Though foraging for sablefish may require slightly longer dives than foraging for Chinook, the reduced number of dives makes them the more energetically efficient prey option for SRKWs.

4.2.2. Prey Availability and Nutrient Content

Sablefish have a greater lipid content and therefore caloric density than Chinook. Each individual sablefish contained more energy than a Chinook of a similar size. Sablefish sampled in the four surveys had a much greater size range than Chinook salmon, with the largest sablefish being twice the size of the largest Chinook. This combination of larger size and higher caloric density resulted in SRKWs having to consume fewer sablefish than Chinook to meet their DPERs.

Both Chinook and sablefish exhibited a positively skewed distribution, with most of the fish surveyed being of a smaller size and weight. Adult sablefish move further down the continental slope as they age, with the largest fish found in the deepest water (Cox et al. 2023). This vertical movement may have impacted survey results, as survey equipment limited to a certain depth range could have prevented researchers from catching and recording larger sablefish. However, it is likely that any sablefish that live at these great depths are well beyond the dive limits of SRKWs.

Chinook salmon were not sampled extensively in any of the surveys as all four were targeting groundfish. With only 28 Chinook weight and depth values to choose from, each fish had a significant impact on the model outcome. Survey results may be biased towards bottom-dwelling fish, resulting in Chinook being underrepresented in the data. Previous studies have shown that SRKWs will seek out Chinook over more prevalent prey options, therefore a better understanding of Chinook size and abundance in SRKW habitat should be included in future iterations of this model (Ford and Ellis 2006).

4.2.3. SRKW Foraging Efforts

Four SRKWs exceeded their aerobic dive limit when foraging for Chinook salmon or sablefish: J-59, K-45, L-126, and L-127 (Table A4). It is unlikely that the two calves, L-126 and L-127, will be actively foraging as SRKWs receive all their required energy through nursing for the first year of their lives. However, I chose to include their cADL values as a previous study of Bigg's killer whales found that juveniles often exceeded their aerobic dive limits on their longest dives (Miller et al. 2010). Adult Bigg's killer whales never exceeded their aerobic dive limits, seemingly reducing their dive time to alleviate aerobic stress on the younger whales in their group (Miller et al. 2010). SRKWs may employ a similar strategy when foraging, which may impact the four young whales identified in my model.

4.3. Limitations and Assumptions

This bioenergetics model relied on many assumptions that may have impacted the results. Bioenergetics are difficult to study with any cetacean species, and as the SRKWs are an endangered population they pose additional challenges. Due to necessary federal protection in Canada and the United States, SRKW metabolic rates cannot be measured directly in the field. Research on captive killer whales may provide a close approximation of BMRs, but as captive killer whales are inherently less active than whales in the wild these values would likely be underestimated. The FMRs and DPERs used in this model were calculated based on existing metabolic rate equations such as Kleiber's Law and Gompertz functions, and by estimating SRKW values based on the known parameters of killer whales from other populations.

Another assumption made in this model is that SRKWs have a 100% success rate with their foraging dives. A whale may make many dives and pursue multiple fish before it is able to catch and consume one. Furthermore, this model assumes that each SRKW dives straight down until it catches its prey, then turns around and immediately returns to the surface. Foraging dives are much more complex and multidimensional, with the whales frequently changing speed, direction, and depth throughout the dive (Tennessen et al. 2019b, 2019a). Additionally, this model did not account for the different speeds of the two prey species, which would significantly alter the foraging efforts of the SRKWs.

This model did not take prey sharing into account, as it assumed each whale must forage for their own food. Furthermore, the model did not add any additional energy requirements to mothers with calves to compensate for the energetic demands of nursing. Previous studies on delphinids and otariids have stated that gestation and lactation do not have a significant impact on the energy requirements of mothers compared to other females, but more work should be done on killer whales before this assumption is accepted (Winship et al. 2002, Noren 2011).

Finally, the model did not account for seasonal changes in the SRKW diets. Noren (2011) recommended that prey consumption rates should be estimated for the SRKWs, but that changes in prey distribution, lipid content, and population density can all impact these values, along with the seasonal movement of the SRKWs. More information on the annual movement of sablefish would need to be confirmed before this could be input into the model.

Chapter 5. Conclusion

Sablefish are a viable prey alternative for SRKWs. They are found within critical SRKW habitat at depths that are accessible to all whales in the population, and their larger size and high lipid content make them an energy rich source of food. SRKWs who choose to prey on sablefish will need to catch fewer fish than if they were foraging for Chinook of an equivalent size.

Further research needs to be conducted on SRKW sablefish foraging strategies. Are sablefish only preyed upon when Chinook are not abundant? Have SRKWs historically foraged for sablefish in this area, or is this a result of recent sablefish population growth? Did the recent change in matriarchs with the loss of J-2 result in this prey switching behaviour?

A key stressor on any endangered species is not having enough resources to sustain a healthy population. If the SRKWs are unable to meet their DPERs they will not have additional energy to put towards reproduction, and future pregnancies or births will be unsustainable and unsuccessful. Chinook salmon are the preferred prey of SRKWs, but if Chinook populations continue to decline, they must seek out other prey options. If prey and fecal samples continue to show that SRKWs are turning to sablefish as a prey alternative, additional strategies and protections should be established to ensure that this critical energy source is available when they need it.

References

Argue, A. W. and D. E. Marshal. 1966. *Size and Age of Chinook and Coho Salmon for Subdivisions of the Strait of Georgia Troll Fishery, 1966*.

Beamish, R. J., C. Houle, C. Wood, and R. Scarsbrook. 1979. *A Summary of Sablefish Tagging and Exploratory Trapping Studies Conducted During 1978 by the Pacific Biological Station*. Nanaimo.

Bigg, M. A. and A. A. Wolman. 1975. Live-Capture Killer Whale (Orcinus orca) Fishery, British Columbia and Washington, 1962–73. *Journal of the Fisheries Research Board of Canada* 32:1213–1221.

Booth, C. G., M. Guilpin, A.-K. Darias-O'Hara, J. M. Ransijn, M. Ryder, D. Rosen, E. Pirotta, S. Smout, E. A. McHuron, J. Nabe-Nielsen, and D. P. Costa. 2023. Estimating energetic intake for marine mammal bioenergetic models. *Conservation Physiology* DOI 10.1093/conphys/coac083.

Bowen, W. D. and S. J. Iverson. 2013. Methods of estimating marine mammal diets: A review of validation experiments and sources of bias and uncertainty. *Marine Mammal Science* 29:719–754.

Chasco, B. E., I. C. Kaplan, A. C. Thomas, A. Acevedo-Gutiérrez, D. P. Noren, M. J. Ford, M. B. Hanson, J. J. Scordino, S. J. Jeffries, K. N. Marshall, A. O. Shelton, C. Matkin, B. J. Burke, and E. J. Ward. 2017a. Competing tradeoffs between increasing marine mammal predation and fisheries harvest of Chinook salmon. *Scientific reports* 7:15439–14.

Chasco, B., I. C. Kaplan, A. Thomas, A. Acevedo-Gutiérrez, D. Noren, M. J. Ford, M. B. Hanson, J. Scordino, S. Jeffries, S. Pearson, K. N. Marshall, and E. J. Ward. 2017b. Estimates of Chinook salmon consumption in Washington State inland waters by four marine mammal predators from 1970 to 2015. *Canadian journal of fisheries and aquatic sciences* 74:1173–1194.

Clark, S. T., D. K. Odell, and C. T. Lacinak. 2000. Aspects of growth in captive killer whales (Orcinus orca). *Marine Mammal Science* 16:110–123.

COSEWIC. 2008. *COSEWIC assessment and update status report on the killer whale, Orcinus orca : Southern resident population, Northern resident population, West Coast transient population, Offshore population, Northwest Atlantic/Eastern Arctic population in Canada.* Ottawa: Committee on the Status of Endangered Wildlife in Canada.

Costa, D. P. and J. L. Maresh. 2018. Energetics. Pages 329–335 in B. Würsig, J. G. M. Thewissen, and K. M. Kit M. Kovacs (eds), *Encyclopedia of Marine Mammals*. Third. : Academic Press.

Cox, S. P., A. R. Kronlund, L. Lacko, M. Jones, and O. Canada. 2023. A Revised Operating Model for Sablefish in British Columbia, Canada in 2016.

Fisheries and Oceans Canada. 2005. *Stock Assessment Report on Sablefish (Anoplopoma fimbria)*. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2005/040.

Fisheries and Oceans Canada. 2013. *A review of sablefish population structure in the Northeast Pacific Ocean and implications for Canadian seamount fisheries*.

Fisheries and Oceans Canada. 2016, January 18. Sablefishhttps://www.dfo-mpo.gc.ca/fisheries-peches/sustainable-durable/fisheries-peches/sablefish-morue_charbonniere-eng.html (accessed March 5 2024).

Fisheries and Oceans Canada. 2018a. *Recovery strategy for the Northern and Southern Resident Killer Whales (Orcinus orca) in Canada [Proposed].* Ottawa.

Fisheries and Oceans Canada. 2018b, July 13. Strait of Georgia Synoptic Bottom Trawl Surveyhttps://open.canada.ca/data/en/dataset/d880ba18-8790-41a2-bf73-e9247380759b (accessed February 23 2024).

Fisheries and Oceans Canada. 2018c, July 13. West Coast Vancouver Island Synoptic Bottom Trawl Surveyhttps://open.canada.ca/data/en/dataset/557e42ae-06fe-426d-8242-c3107670b1de (accessed 14 September 2023).

Fisheries and Oceans Canada. 2020a, April 30. Outside South Hard Bottom Longline Surveyshttps://open.canada.ca/data/en/dataset/3cdc1ad5-70e5-4fac-865d-e583e54d15df (accessed January 3 2024).

Fisheries and Oceans Canada. 2020b, April 30. Inside South Hard Bottom Longline Surveyshttps://open.canada.ca/data/en/dataset/ad921d10-363f-45fb-b0ce-05304fb91386 (accessed January 1 2024).

Fisheries and Oceans Canada. 2022. *British Columbia Groundfish Fisheries and Their Investigations in 2021*. Nanaimo.

Ford, J. K. B. and G. M. Ellis. 2006. Selective foraging by fish-eating killer whales Orcinus orca in British Columbia. *Marine Ecology Progress Series* 316:185–199.

Ford, M. J., J. Hempelmann, M. B. Hanson, K. L. Ayres, R. W. Baird, C. K. Emmons, J. I. Lundin, G. S. Schorr, S. K. Wasser, and L. K. Park. 2016. Estimation of a killer whale (Orcinus orca) population's diet using sequencing analysis of DNA from feces. *PLoS ONE* DOI 10.1371/journal.pone.0144956.

Gallagher, C. A., S. J. Stern, and E. Hines. 2018. The metabolic cost of swimming and reproduction in harbor porpoises (Phocoena phocoena) as predicted by a bioenergetic model. *Marine mammal science* 34:875–900.

Gibson, G. A., W. T. Stockhausen, K. O. Coyle, S. Hinckley, C. Parada, A. J. Hermann, M. Doyle, and C. Ladd. 2019. An individual-based model for sablefish: Exploring the connectivity between potential spawning and nursery grounds in the Gulf of Alaska. *Deep-Sea Research Part II: Topical Studies in Oceanography* 165:89–112.

Hanson, M. B., C. K. Emmons, M. J. Ford, M. Everett, K. Parsons, L. K. Park, J. Hempelmann, D. M. Van Doornik, G. S. Schorr, J. K. Jacobsen, M. F. Sears, M. S. Sears, J. G. Sneva, R. W. Baird, and L. Barre. 2021. Endangered predators and endangered prey: Seasonal diet of Southern Resident killer whales. *PLoS ONE* DOI 10.1371/journal.pone.0247031.

Herman, D. P., D. G. Burrows, P. R. Wade, J. W. Durban, C. O. Matkin, R. G. LeDuc, L. G. Barrett-Lennard, and M. M. Krahn. 2005. Feeding ecology of eastern North Pacific killer whales Orcinus orca from fatty acid, stable isotope, and organochlorine analyses of blubber biopsies. *Marine Ecology Progress Series* 203:275–291.

Jeffrey, K. M., I. M. Côté, J. R. Irvine, and J. D. Reynolds. 2017. Changes in body size of Canadian Pacific salmon over six decades. *Canadian Journal of Fisheries and Aquatic Sciences* 74:191–201.

Kleiber, M. 1975. *The fire of life: An introduction to animal energetics*. 2nd edition. New York: Robert E. Kreiger Publishing.

Kriete, B. 1994. Bioenergetics in the killer whale, orcinus orca. Doctor of Philosophy, : University of British Columbia.

Lacy, R. C., R. Williams, E. Ashe, K. C. B. Iii, L. J. N. Brent, C. W. Clark, D. P. Croft, D. A. Giles, M. Macduffee, and P. C. Paquet. 2017. Evaluating anthropogenic threats to endangered killer whales to inform effective recovery plans OPEN. *Scientific Reports* DOI 10.1038/s41598-017-14471-0.

Mason, J. C., R. J. Beamish, and G. A. McFarlane. 1983. *Sexual Maturity, Fecundity, Spawning, and Early Life History of Sablefish (Anoglopoma fimbria) off the Pacific Coast of Canada*.

McSheffrey, E. 2023, December 7. B.C. scientists scooping killer whale poop to search for DNAGlobal News.

Miller, P. J. O., A. D. Shapiro, and V. B. Deecke. 2010. The diving behaviour of mammal-eating killer whales (Orcinus orca): variations with ecological not physiological factors. *Canadian journal of zoology* 88:1103–1112.

Molnár, P. K., T. Klanjscek, A. E. Derocher, M. E. Obbard, and M. A. Lewis. 2009. A body composition model to estimate mammalian energy stores and metabolic rates from body mass and body length, with application to polar bears. *Journal of Experimental Biology* 212:2313–2323.

Murray, C. C., L. C. Hannah, T. Doniol-Valcroze, B. Wright, E. Stredulinsky, A. Locke, and R. Lacy. 2019. *Cumulative Effects Assessment for Northern and Southern Resident Killer Whale Populations in the Northeast Pacific*.

Noren, D. P. 2011. Estimated field metabolic rates and prey requirements of resident killer whales. *Marine Mammal Science* 27:60–77.

Noren, S. R. and D. A. S. Rosen. 2023. What are the Metabolic Rates of Marine Mammals and What Factors Impact this Value: A review. *Conservation Physiology* DOI 10.1093/conphys/coad077.

Noren, S. R., M. S. Udevitz, and C. V. Jay. 2012. Bioenergetics model for estimating food requirements of female Pacific walruses Odobenus rosmarus divergens. *Marine Ecology Progress Series* 460:261–275.

Pirotta, E. 2022. A review of bioenergetic modelling for marine mammal populationsConservation Physiology. : Oxford University Press.

Shedd, T. 2018, June 1. Characterization of Surface Foraging Behaviors of Southern Resident Killer Whales from Aerial Photographs. Capstone Paper, : UC San Diego.

Smil, V. 2000. Laying down the law. *Nature* 403:597.

Sogard, S. M. and S. A. Berkeley. 2017. Patterns of movement, growth, and survival of adult sablefish (Anoplopoma fimbria) at contrasting depths in slope waters off oregon. *Fishery Bulletin* 115:233–251.

Tennessen, J. B., M. M. Holt, M. B. Hanson, C. K. Emmons, D. A. Giles, and J. T. Hogan. 2019a. Kinematic signatures of prey capture from archival tags reveal sex differences in killer whale foraging activity. *Journal of Experimental Biology* DOI 10.1242/jeb.191874.

Tennessen, J. B., M. M. Holt, E. J. Ward, M. B. Hanson, C. K. Emmons, D. A. Giles, and J. T. Hogan. 2019b. Hidden Markov models reveal temporal patterns and sex differences in killer whale behavior. *Scientific reports* 9:14951–12.

Tennessen, J. B., M. M. Holt, B. M. Wright, M. B. Hanson, C. K. Emmons, D. A. Giles, J. T. Hogan, S. J. Thornton, and V. B. Deecke. 2023. Divergent foraging strategies between populations of sympatric matrilineal killer whales. *Behavioral ecology* 34:373–386.

The Whale Museum. 2023. Meet the Whaleshttps://whalemuseum.org/collections/meet-the-whales (accessed 20 May 2023).

Thornton, S. J., S. Toews, R. Burnham, C. M. Konrad, E. Stredulinsky, K. Gavrilchuk, P. Thupaki, and S. Vagle. 2022a. *Areas of elevated risk for vessel-related physical and acoustic impacts in southern resident killer whale (Orcinus orca) critical habitat*. West Vancouver.

Thornton, S. J., S. Toews, E. Stredulinksy, K. Gavrilchuk, C. Konrad, R. Burnham, D. Noren, M. Holt, and S. Vagle. 2022b. *Southern resident killer whale (Orcinus orca) summer distribution and habitat use in the southern Salish Sea and the Swiftsure Bank area (2009 to 2020)*.

Tollit, D. J., M. Wong, A. J. Winship, D. A. S. Rosen, and A. W. Trites. 2003. Quantifying errors associated with using prey skeletal structures from fecal samples to determine diet of Stellar sea lion (Eumetopias jubatus). *Marine Mammal Science* 19:724–744.

U.S. Department of Agriculture. 2019, April 1. FoodData Centralhttps://fdc.nal.usda.gov/fdc-app.html#/food-details/175134/nutrients (accessed 27 May 2023).

Vélez-Espino, L. A., J. K. B. Ford, H. A. Araujo, G. Ellis, C. K. Parken, and K. C. Balcomb. 2014. *Comparative Demography and Viability of Northeastern Pacific Resident Killer Whale Populations at Risk. Canadian Technical Report of Fisheries and Aquatic Sciences 3084*. Page *Canadian Technical Report of Fisheries and Aquatic Sciences*. Nanaimo.

Vincenzi, S., D. Jesensek, and A. J. Crivelli. 2020. Biological and statistical interpretation of size-at-age, mixed-effects models of growth DOI 10.1098/rsos.192146.

Williams, R., M. Krkošek, E. Ashe, T. A. Branch, S. Clark, P. S. Hammond, E. Hoyt, D. P. Noren, D. Rosen, and A. Winship. 2011. Competing conservation objectives for predators and prey: Estimating killer whale prey requirements for Chinook salmon. *PLoS ONE* DOI 10.1371/journal.pone.0026738.

Williams, R. and D. P. Noren. 2009. Swimming speed, respiration rate, and estimated cost of transport in adult killer whales. *Marine mammal science* 25:327–350.

Williams, T. M., J. A. Estes, D. F. Doak, and A. M. Springer. 2004. Killer Appetites: Assessing the Role of Predators in Ecological Communities. *Ecology* 85:3373–3384.

Williams, T. M., W. A. Friedl, and J. E. Haun. 1993. *The physiology of bottlenose dolphins (Tursiops truncatus): heart rate, metabolic rate and plasma lactate concentration during exercise*. Page *J. exp. Biol*.

Winship, A. J., A. W. Trites, and D. A. Rosen. 2002. A bioenergetic model for estimating the food requirements of Steller sea lions Eumetopias jubatus in Alaska, USA. *Marine Ecology Progress Series* 229:291–312.

Worthy, G. A. J., T. A. M. Worthy, P. K. Yochem, and C. Dold. 2014. Basal metabolism of an adult male killer whale (Orcinus orca). *Marine Mammal Science* 30:1229–1237.

Appendix A. Tables

Table A1 Equations used in the SRKW bioenergetics model.

Number	Description (units)	Equation / Value	Reference
1	Basal Metabolic Rate (kcal/day)	$70M_{kw}^{0.75}$	Noren 2011
2	Lower Field Metabolic Rates (kcal/day)	$350M_{kw}^{0.75}$	Noren 2011
3	Upper Field Metabolic Rates (kcal/day)	$420M_{kw}^{0.75}$	Noren 2011
4	Lower Daily Prey Energy Required (kcal/day)	$413.2M_{kw}^{0.75}$	Noren 2011
5	Upper Daily Prey Energy Required (kcal/day)	$495.9M_{kw}^{0.75}$	Noren 2011
6	Cost of Transport for males (J/kg/m)	$3S^{-0.96}$	Williams & Noren 2009
7	Cost of Transport for females without calves (J/kg/m)	$2.2S^{-0.97}$	Williams & Noren 2009
8	Cost of Transport for females with calves (J/kg/m)	$2.3S^{-0.66}$	Williams & Noren 2009
9	Cost of Transport for juvenile ($COT_{juvenile}$) (kcal/kg/m)	$2.2 * (S_{Activity}^{-0.97}) / 4184$	Williams & Noren 2009
10	Cost of Transport for young mature male ($COT_{young\ mature\ male}$) (kcal/kg/m)	$3 * (S_{Activity}^{-0.96}) / 4184$	Williams & Noren 2009
11	Cost of Transport for old mature male ($COT_{old\ mature\ male}$) (kcal/kg/m)	$3 * (S_{Activity}^{-0.96}) / 4184$	Williams & Noren 2009
12	Cost of Transport for young reproductive female ($COT_{young\ reproductive\ female}$) (kcal/kg/m)	$2.2 * (S_{Activity}^{-0.97}) / 4184$	Williams & Noren 2009
13	Cost of Transport for old reproductive female ($COT_{old\ reproductive\ female}$) (kcal/kg/m)	$2.2 * (S_{Activity}^{-0.97}) / 4184$	Williams & Noren 2009
14	Cost of Transport for post reproductive female ($COT_{post\ reproductive\ female}$) (kcal/kg/m)	$2.2 * (S_{Activity}^{-0.97}) / 4184$	Williams & Noren 2009
15	Cost of Transport for mother with calf ($COT_{mother\ with\ calf}$) (kcal/kg/m)	$2.3 * (S_{Activity}^{-0.66}) / 4184$	Williams & Noren 2009

Number	Description (units)	Equation / Value	Reference
16	DPER using COT and activity budget (kcal)	$[(COT_T * P_T + COT_F * P_F + COT_R * P_R + COT_S * P_S) * X * 70M_{kw}^{0.75}] / 0.847$	Noren et al. 2012
17	Chinook mass (g) to kcal	$M_c * 1.79$	U.S. Department of Agriculture 2019
18	Sablefish mass (g) to kcal	$M_s * 1.95$	U.S. Department of Agriculture 2019
19	Dive duration (s) from dive depth (m)	1.45 * dive depth + 76.11	Tennessen et al. 2019b
20	Aerobic dive limit (minutes)	$cADL_{kw} = ADL_{bnd} * (M_{kw} / M_{bnd})^{-0.25}$	Miller et al. 2010
21	Percent of Day Spent Foraging	$[(\Sigma \text{ dive duration}) / 86400] * 100$	

Table A2 **Energetic requirements and COT values for SRKWs in the current population. COT values have been multiplied by the SRKW's body mass to demonstrate how size affects COT.**

Alphanumeric Identifier	Age	Life Stage	Body Mass (kg)	BMR (kcal/day)	Lower FMR (kcal/day)	Upper FMR (kcal/day)	Lower DPER (kcal/day)	Upper DPER (kcal/day)	COT Travelling (kcal/m)	COT Foraging (kcal/m)	COT Resting (kcal/m)	COT Socializing (kcal/m)
L-126	0	Calf	154	3,057.14	15,285.70	18,342.84	18,045.86	21,657.65	0.03	0.02	0.01	3.99E-07
L-127	0	Calf	154	3,057.14	15,285.70	18,342.84	18,045.86	21,657.65	0.03	0.02	0.01	3.99E-07
J-59	1	Juvenile	465	7,009.51	35,047.56	42,057.07	41,376.15	49,657.38	0.08	0.05	0.01	3.99E-07
K-45	1	Juvenile	465	7,009.51	35,047.56	42,057.07	41,376.15	49,657.38	0.08	0.05	0.01	3.99E-07
L-125	2	Juvenile	695	9,475.16	47,375.81	56,850.97	55,930.53	67,124.75	0.12	0.07	0.01	3.99E-07
J-57	3	Juvenile	949	11,968.72	59,843.60	71,812.32	70,649.64	84,789.83	0.16	0.10	0.01	3.99E-07
J-58	3	Juvenile	949	11,968.72	59,843.60	71,812.32	70,649.64	84,789.83	0.16	0.10	0.01	3.99E-07
J-56	4	Juvenile	1,208	14,343.27	71,716.36	86,059.63	84,666.29	101,611.84	0.21	0.12	0.01	3.99E-07
L-124	4	Juvenile	1,208	14,343.27	71,716.36	86,059.63	84,666.29	101,611.84	0.21	0.12	0.01	3.99E-07
J-51	8	Juvenile	2,051	21,334.00	106,670.00	128,004.00	125,931.55	151,136.15	0.35	0.21	0.01	3.99E-07
J-53	8	Juvenile	2,051	21,334.00	106,670.00	128,004.00	125,931.55	151,136.15	0.35	0.21	0.01	3.99E-07
L-121	8	Juvenile	2,051	21,334.00	106,670.00	128,004.00	125,931.55	151,136.15	0.35	0.21	0.01	3.99E-07
L-122	8	Juvenile	2,051	21,334.00	106,670.00	128,004.00	125,931.55	151,136.15	0.35	0.21	0.01	3.99E-07
L-123	8	Juvenile	2,051	21,334.00	106,670.00	128,004.00	125,931.55	151,136.15	0.35	0.21	0.01	3.99E-07
J-49	11	Young Mature Male	2,406	24,047.49	120,237.45	144,284.94	141,948.90	170,359.29	0.57	0.33	0.01	5.92E-07
L-119	11	Mother with Calf	2,406	24,047.49	120,237.45	144,284.94	141,948.90	170,359.29	0.55	0.26	0.01	5.74E-06

Alphanumeric Identifier	Age	Life Stage	Body Mass (kg)	BMR (kcal/day)	Lower FMR (kcal/day)	Upper FMR (kcal/day)	Lower DPER (kcal/day)	Upper DPER (kcal/day)	COT Travelling (kcal/m)	COT Foraging (kcal/m)	COT Resting (kcal/m)	COT Socializing (kcal/m)
L-118	12	Young Reproductive Female	2,482	24,614.97	123,074.87	147,689.84	145,298.67	174,379.51	0.43	0.25	0.01	3.99E-07
J-47	13	Young Mature Male	2,726	26,408.42	132,042.10	158,450.52	155,885.13	187,084.80	0.65	0.37	0.01	5.92E-07
K-43	13	Young Reproductive Female	2,589	25,406.63	127,033.15	152,439.79	149,971.71	179,987.83	0.45	0.26	0.01	3.99E-07
L-115	13	Young Mature Male	2,726	26,408.42	132,042.10	158,450.52	155,885.13	187,084.80	0.65	0.37	0.01	5.92E-07
L-116	13	Young Mature Male	2,726	26,408.42	132,042.10	158,450.52	155,885.13	187,084.80	0.65	0.37	0.01	5.92E-07
L-117	13	Young Mature Male	2,726	26,408.42	132,042.10	158,450.52	155,885.13	187,084.80	0.65	0.37	0.01	5.92E-07
J-44	14	Young Mature Male	2,970	28,162.12	140,810.61	168,972.73	166,236.98	199,508.52	0.70	0.41	0.01	5.92E-07
J-45	14	Young Mature Male	2,970	28,162.12	140,810.61	168,972.73	166,236.98	199,508.52	0.70	0.41	0.01	5.92E-07
J-46	14	Young Reproductive Female	2,696	26,190.15	130,950.74	157,140.89	154,596.70	185,538.49	0.46	0.27	0.01	3.99E-07
L-113	14	Young Reproductive Female	2,696	26,190.15	130,950.74	157,140.89	154,596.70	185,538.49	0.46	0.27	0.01	3.99E-07

Alphanumeric Identifier	Age	Life Stage	Body Mass (kg)	BMR (kcal/day)	Lower FMR (kcal/day)	Upper FMR (kcal/day)	Lower DPER (kcal/day)	Upper DPER (kcal/day)	COT Travelling (kcal/m)	COT Foraging (kcal/m)	COT Resting (kcal/m)	COT Socializing (kcal/m)
K-42	15	Young Mature Male	3,214	29,880.13	149,400.64	179,280.76	176,378.12	211,679.36	0.76	0.44	0.01	5.92E-07
J-42	16	Young Reproductive Female	2,910	27,734.34	138,671.68	166,406.02	163,711.83	196,477.96	0.50	0.29	0.01	3.99E-07
L-109	16	Young Mature Male	3,458	31,565.80	157,828.99	189,394.79	186,328.40	223,621.14	0.82	0.48	0.01	5.92E-07
L-110	16	Young Mature Male	3,458	31,565.80	157,828.99	189,394.79	186,328.40	223,621.14	0.82	0.48	0.01	5.92E-07
L-108	17	Young Mature Male	3,702	33,221.97	166,109.84	199,331.81	196,104.53	235,353.91	0.88	0.51	0.01	5.92E-07
J-41	18	Young Reproductive Female	3,124	29,250.37	146,251.83	175,502.20	172,660.73	207,217.95	0.54	0.31	0.01	3.99E-07
L-106	18	Young Mature Male	3,946	34,851.05	174,255.24	209,106.29	205,720.76	246,894.79	0.93	0.54	0.01	5.92E-07
J-40	19	Young Reproductive Female	3,231	29,998.58	149,992.92	179,991.51	177,077.36	212,518.54	0.56	0.33	0.01	3.99E-07
K-37	19	Young Mature Male	4,190	36,455.12	182,275.61	218,730.73	215,189.38	258,258.50	0.99	0.58	0.01	5.92E-07
K-38	19	Young Mature Male	4,190	36,455.12	182,275.61	218,730.73	215,189.38	258,258.50	0.99	0.58	0.01	5.92E-07

Alphanumeric Identifier	Age	Life Stage	Body Mass (kg)	BMR (kcal/day)	Lower FMR (kcal/day)	Upper FMR (kcal/day)	Lower DPER (kcal/day)	Upper DPER (kcal/day)	COT Travelling (kcal/m)	COT Foraging (kcal/m)	COT Resting (kcal/m)	COT Socializing (kcal/m)
L-105	19	Young Mature Male	4,190	36,455.12	182,275.61	218,730.73	215,189.38	258,258.50	0.99	0.58	0.01	5.92E-07
J-38	20	Young Mature Male	4,434	38,036.00	190,179.99	228,215.98	224,521.06	269,457.87	1.05	0.61	0.01	5.92E-07
J-39	20	Young Mature Male	4,434	38,036.00	190,179.99	228,215.98	224,521.06	269,457.87	1.05	0.61	0.01	5.92E-07
K-36	20	Young Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07
L-103	20	Young Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07
K-35	21	Young Mature Male	4,434	38,036.00	190,179.99	228,215.98	224,521.06	269,457.87	1.05	0.61	0.01	5.92E-07
J-37	22	Mother with Calf	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.77	0.36	0.01	5.74E-06
K-33	22	Old Mature Male	4,434	38,036.00	190,179.99	228,215.98	224,521.06	269,457.87	1.05	0.61	0.01	5.92E-07
K-34	22	Old Mature Male	4,434	38,036.00	190,179.99	228,215.98	224,521.06	269,457.87	1.05	0.61	0.01	5.92E-07
J-36	24	Young Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07

Alphanumeric Identifier	Age	Life Stage	Body Mass (kg)	BMR (kcal/day)	Lower FMR (kcal/day)	Upper FMR (kcal/day)	Lower DPER (kcal/day)	Upper DPER (kcal/day)	COT Travelling (kcal/m)	COT Foraging (kcal/m)	COT Resting (kcal/m)	COT Socializing (kcal/m)
J-35	25	Young Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07
J-31	28	Young Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07
L-91	28	Young Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07
L-94	28	Mother with Calf	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.77	0.36	0.01	5.74E-06
K-27	29	Young Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07
K-26	30	Old Mature Male	4,434	38,036.00	190,179.99	228,215.98	224,521.06	269,457.87	1.05	0.61	0.01	5.92E-07
L-88	30	Old Mature Male	4,434	38,036.00	190,179.99	228,215.98	224,521.06	269,457.87	1.05	0.61	0.01	5.92E-07
L-90	30	Young Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07
L-87	31	Old Mature Male	4,434	38,036.00	190,179.99	228,215.98	224,521.06	269,457.87	1.05	0.61	0.01	5.92E-07

Alphanumeric Identifier	Age	Life Stage	Body Mass (kg)	BMR (kcal/day)	Lower FMR (kcal/day)	Upper FMR (kcal/day)	Lower DPER (kcal/day)	Upper DPER (kcal/day)	COT Travelling (kcal/m)	COT Foraging (kcal/m)	COT Resting (kcal/m)	COT Socializing (kcal/m)
J-26	32	Old Mature Male	4,434	38,036.00	190,179.99	228,215.98	224,521.06	269,457.87	1.05	0.61	0.01	5.92E-07
J-27	32	Old Mature Male	4,434	38,036.00	190,179.99	228,215.98	224,521.06	269,457.87	1.05	0.61	0.01	5.92E-07
L-85	32	Old Mature Male	4,434	38,036.00	190,179.99	228,215.98	224,521.06	269,457.87	1.05	0.61	0.01	5.92E-07
L-86	32	Old Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07
L-82	33	Old Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07
L-83	33	Old Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07
K-22	36	Old Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07
L-77	36	Old Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07
K-20	37	Mother with Calf	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.77	0.36	0.01	5.74E-06

Alphanumeric Identifier	Age	Life Stage	Body Mass (kg)	BMR (kcal/day)	Lower FMR (kcal/day)	Upper FMR (kcal/day)	Lower DPER (kcal/day)	Upper DPER (kcal/day)	COT Travelling (kcal/m)	COT Foraging (kcal/m)	COT Resting (kcal/m)	COT Socializing (kcal/m)
L-72	37	Old Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07
J-22	38	Old Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07
K-16	38	Old Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07
J-19	44	Old Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07
K-14	46	Old Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07
L-54	46	Old Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07
L-55	46	Old Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07
J-16	51	Post Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07

Alphanumeric Identifier	Age	Life Stage	Body Mass (kg)	BMR (kcal/day)	Lower FMR (kcal/day)	Upper FMR (kcal/day)	Lower DPER (kcal/day)	Upper DPER (kcal/day)	COT Travelling (kcal/m)	COT Foraging (kcal/m)	COT Resting (kcal/m)	COT Socializing (kcal/m)
L-22	52	Post Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07
K-12	53	Post Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07
L-25	95	Post Reproductive Female	3,338	30,740.63	153,703.16	184,443.79	181,457.56	217,775.42	0.58	0.34	0.01	3.99E-07

Table A3 **The number of fish required for each SRKW in the population (excluding the calves). The mean and standard deviation are reported for the lower chinook, upper chinook, lower sablefish, and upper sablefish estimates. The number of Chinook required is greater than the number of sablefish required for every SRKW.**

Alphanumeric Identifier	Life Stage	Mean Lower Chinook Required	Mean Lower Chinook St. Dev	Mean Upper Chinook Required	Mean Upper Chinook St. Dev	Mean Lower Sablefish Required	Mean Lower Sablefish St. Dev	Mean Upper Sablefish Required	Mean Upper Sablefish St. Dev
J-59	Juvenile	23.29	4.59	27.52	4.80	15.49	2.45	18.52	2.51
K-45	Juvenile	22.99	4.55	27.55	5.04	15.41	2.34	18.51	2.65
L-125	Juvenile	31.28	5.30	37.06	5.78	20.84	2.86	24.91	2.97
J-57	Juvenile	38.78	5.83	46.33	6.55	26.23	3.16	30.95	3.48
J-58	Juvenile	38.91	6.19	46.58	6.48	26.15	3.13	31.19	3.47
J-56	Juvenile	46.70	6.78	55.26	7.04	31.20	3.51	37.35	3.81
L-124	Juvenile	46.32	6.51	55.57	7.14	31.27	3.44	37.48	3.65
J-51	Juvenile	68.36	8.01	81.75	8.68	46.07	4.13	55.32	4.81
J-53	Juvenile	67.96	7.98	82.48	8.53	45.99	4.13	55.17	4.39
L-121	Juvenile	68.56	7.90	82.22	8.82	46.06	4.26	54.96	4.45
L-122	Juvenile	68.63	8.26	81.68	8.55	46.06	4.24	55.29	4.71
L-123	Juvenile	68.73	8.17	82.02	8.96	46.10	4.14	55.05	4.45
J-49	Young Mature Male	77.33	8.19	92.10	9.06	51.86	4.46	61.90	4.63
L-119	Mother with Calf	77.13	8.50	92.58	9.36	51.80	4.40	61.92	4.73
L-118	Young Reproductive Female	79.63	8.42	94.70	9.64	52.90	4.61	63.08	4.95
J-47	Young Mature Male	84.93	8.95	101.06	9.57	56.63	4.59	68.17	5.11
K-43	Young Reproductive Female	81.63	8.36	97.49	9.27	54.62	4.56	65.56	4.81
L-115	Young Mature Male	84.76	9.32	101.43	9.85	56.59	4.55	67.88	5.03
L-116	Young Mature Male	84.33	8.87	100.90	9.67	56.89	4.75	67.96	5.12

Alphanumeric Identifier	Life Stage	Mean Lower Chinook Required	Mean Lower Chinook St. Dev	Mean Upper Chinook Required	Mean Upper Chinook St. Dev	Mean Lower Sablefish Required	Mean Lower Sablefish St. Dev	Mean Upper Sablefish Required	Mean Upper Sablefish St. Dev
L-117	Young Mature Male	84.62	8.71	101.85	9.51	56.83	4.62	67.75	5.31
J-44	Young Mature Male	89.70	9.34	107.48	9.94	60.80	4.79	72.40	5.24
J-45	Young Mature Male	90.41	9.46	107.92	10.10	60.71	4.70	72.64	5.27
J-46	Young Reproductive Female	83.81	8.78	100.46	9.82	56.42	4.74	67.67	5.05
L-113	Young Reproductive Female	83.88	8.74	100.42	9.65	55.97	4.60	67.55	4.80
K-42	Young Mature Male	96.14	9.40	114.61	10.51	64.01	4.83	76.93	5.38
J-42	Young Reproductive Female	88.64	9.24	106.43	9.66	59.62	4.85	71.36	5.25
L-109	Young Mature Male	101.18	9.38	120.83	10.54	67.52	5.03	80.94	5.69
L-110	Young Mature Male	100.60	9.89	121.57	10.59	67.93	5.10	81.11	5.56
L-108	Young Mature Male	106.64	10.47	127.32	10.94	71.28	5.19	85.57	5.60
J-41	Young Reproductive Female	93.32	9.26	112.77	10.60	63.02	4.89	75.50	5.38
L-106	Young Mature Male	111.13	10.90	133.35	10.93	74.55	5.23	89.63	5.78
J-40	Young Reproductive Female	95.90	9.72	114.68	9.80	64.15	4.81	77.45	5.35
K-37	Young Mature Male	116.25	10.44	139.83	11.60	78.22	5.49	93.65	5.83
K-38	Young Mature Male	117.32	10.68	139.81	11.31	78.23	5.41	93.75	6.14
L-105	Young Mature Male	116.50	10.03	139.85	11.66	78.17	5.59	93.75	6.06
J-38	Young Mature Male	121.45	10.31	145.79	11.27	81.18	5.28	97.69	6.21
J-39	Young Mature Male	121.70	10.00	145.56	11.45	81.75	5.75	97.66	6.07
K-36	Young Reproductive Female	98.14	9.45	118.01	10.23	65.94	5.21	78.83	5.36
L-103	Young Reproductive Female	98.54	9.79	117.76	10.39	66.17	5.08	78.98	5.62
K-35	Young Mature Male	120.99	10.85	145.21	11.73	81.35	5.47	97.69	6.21
J-37	Mother with Calf	98.28	9.77	118.07	10.46	65.70	4.80	79.21	5.58

Alphanumeric Identifier	Life Stage	Mean Lower Chinook Required	Mean Lower Chinook St. Dev	Mean Upper Chinook Required	Mean Upper Chinook St. Dev	Mean Lower Sablefish Required	Mean Lower Sablefish St. Dev	Mean Upper Sablefish Required	Mean Upper Sablefish St. Dev
K-33	Old Mature Male	121.53	10.89	146.08	11.23	81.60	5.56	97.71	5.93
K-34	Old Mature Male	121.53	11.11	146.04	11.59	81.40	5.46	97.85	6.25
J-36	Young Reproductive Female	98.75	9.38	117.41	10.48	66.03	5.03	78.99	5.53
J-35	Young Reproductive Female	98.68	9.24	117.56	10.38	66.20	5.08	79.11	5.41
J-31	Young Reproductive Female	98.20	9.55	117.99	10.82	66.13	4.91	79.06	5.48
L-91	Young Reproductive Female	98.33	9.69	117.62	10.43	66.27	5.25	79.05	5.52
L-94	Mother with Calf	98.64	9.64	118.21	10.73	66.04	5.00	78.75	5.28
K-27	Young Reproductive Female	98.31	9.76	117.67	10.40	66.01	5.10	79.14	5.40
K-26	Old Mature Male	121.49	10.58	146.14	11.58	81.40	5.42	97.84	6.10
L-88	Old Mature Male	121.20	10.61	145.87	11.79	81.72	5.62	97.47	6.25
L-90	Young Reproductive Female	97.84	9.56	118.45	10.48	65.98	4.93	79.04	5.36
L-87	Old Mature Male	121.44	10.55	145.15	11.40	81.35	5.55	98.13	5.96
J-26	Old Mature Male	121.42	10.41	145.71	11.37	81.19	5.65	97.92	6.33
J-27	Old Mature Male	121.22	10.40	146.05	11.57	81.84	5.61	97.39	6.14
L-85	Old Mature Male	121.42	10.21	145.04	11.56	81.70	5.60	97.97	6.22
L-86	Old Reproductive Female	98.63	9.77	117.88	10.56	66.01	5.13	79.29	5.36
L-82	Old Reproductive Female	98.17	9.60	117.70	10.74	65.64	4.79	79.04	5.25
L-83	Old Reproductive Female	97.98	9.10	117.69	10.32	65.90	4.80	79.28	5.32
K-22	Old Reproductive Female	98.57	9.30	117.62	10.08	65.64	5.13	79.05	5.53
L-77	Old Reproductive Female	97.94	9.20	117.48	10.41	65.82	4.90	79.08	5.47
K-20	Mother with Calf	98.67	9.56	117.32	10.82	65.74	5.11	79.03	5.36
L-72	Old Reproductive Female	98.14	9.40	118.22	10.62	66.12	5.17	78.76	5.42

Alphanumeric Identifier	Life Stage	Mean Lower Chinook Required	Mean Lower Chinook St. Dev	Mean Upper Chinook Required	Mean Upper Chinook St. Dev	Mean Lower Sablefish Required	Mean Lower Sablefish St. Dev	Mean Upper Sablefish Required	Mean Upper Sablefish St. Dev
J-22	Old Reproductive Female	98.19	9.78	118.10	10.55	65.91	5.30	78.95	5.42
K-16	Old Reproductive Female	98.11	9.35	117.56	10.60	66.09	4.98	79.11	5.61
J-19	Old Reproductive Female	98.28	9.85	118.37	10.40	65.74	5.18	79.30	5.47
K-14	Old Reproductive Female	98.36	9.41	117.52	10.32	65.97	5.07	78.94	5.60
L-54	Old Reproductive Female	99.22	9.58	117.79	10.64	65.83	5.15	78.94	5.47
L-55	Old Reproductive Female	98.74	9.67	117.79	10.56	66.22	4.89	79.31	5.50
J-16	Post Reproductive Female	97.85	9.37	118.47	10.39	65.90	5.19	79.12	5.39
L-22	Post Reproductive Female	98.30	9.69	117.63	10.50	65.96	5.07	79.36	5.42
K-12	Post Reproductive Female	98.45	9.79	118.42	10.74	66.19	5.12	78.94	5.51
L-25	Post Reproductive Female	98.42	9.49	118.16	10.38	66.22	4.92	78.79	5.40

Table A4 **Calculated Aerobic Dive Limit (cADL) of each SRKW. The maximum duration of a Chinook salmon foraging dive is 6.10 minutes, and the maximum duration of a sablefish foraging dive is 7.46 minutes. Only four SRKWs would exceed their cADL while foraging. L-126 and L-127 (cADL shown in bold italics) would exceed their cADL if they dove to the maximum Chinook depth of 200m or the maximum sablefish depth of 256m. J-59 and K-45 (cADL shown in bold) would exceed their cADL if they dove to the maximum sablefish depth of 256m.**

Alphanumeric Identifier	Age	Life Stage	cADL (min)
L-126	0	Calf	***5.14***
L-127	0	Calf	***5.14***
J-59	1	Juvenile	**6.78**
K-45	1	Juvenile	**6.78**
L-125	2	Juvenile	7.50
J-57	3	Juvenile	8.10
J-58	3	Juvenile	8.10
J-56	4	Juvenile	8.61
L-124	4	Juvenile	8.61
J-51	8	Juvenile	9.83
J-53	8	Juvenile	9.83
L-121	8	Juvenile	9.83
L-122	8	Juvenile	9.83
L-123	8	Juvenile	9.83
J-49	11	Young Mature Male	10.23
L-119	11	Mother with Calf	10.23
L-118	12	Young Reproductive Female	10.31
J-47	13	Young Mature Male	10.55
K-43	13	Young Reproductive Female	10.42
L-115	13	Young Mature Male	10.55
L-116	13	Young Mature Male	10.55
L-117	13	Young Mature Male	10.55
J-44	14	Young Mature Male	10.78
J-45	14	Young Mature Male	10.78
J-46	14	Young Reproductive Female	10.52
L-113	14	Young Reproductive Female	10.52
K-42	15	Young Mature Male	10.99
J-42	16	Young Reproductive Female	10.73
L-109	16	Young Mature Male	11.20
L-110	16	Young Mature Male	11.20

Alphanumeric Identifier	Age	Life Stage	cADL (min)
L-108	17	Young Mature Male	11.39
J-41	18	Young Reproductive Female	10.92
L-106	18	Young Mature Male	11.57
J-40	19	Young Reproductive Female	11.01
K-37	19	Young Mature Male	11.75
K-38	19	Young Mature Male	11.75
L-105	19	Young Mature Male	11.75
J-38	20	Young Mature Male	11.92
J-39	20	Young Mature Male	11.92
K-36	20	Young Reproductive Female	11.10
L-103	20	Young Reproductive Female	11.10
K-35	21	Young Mature Male	11.92
J-37	22	Mother with Calf	11.10
K-33	22	Old Mature Male	11.92
K-34	22	Old Mature Male	11.92
J-36	24	Young Reproductive Female	11.10
J-35	25	Young Reproductive Female	11.10
J-31	28	Young Reproductive Female	11.10
L-91	28	Young Reproductive Female	11.10
L-94	28	Mother with Calf	11.10
K-27	29	Young Reproductive Female	11.10
K-26	30	Old Mature Male	11.92
L-88	30	Old Mature Male	11.92
L-90	30	Young Reproductive Female	11.10
L-87	31	Old Mature Male	11.92
J-26	32	Old Mature Male	11.92
J-27	32	Old Mature Male	11.92
L-85	32	Old Mature Male	11.92
L-86	32	Old Reproductive Female	11.10
L-82	33	Old Reproductive Female	11.10
L-83	33	Old Reproductive Female	11.10
K-22	36	Old Reproductive Female	11.10
L-77	36	Old Reproductive Female	11.10
K-20	37	Mother with Calf	11.10
L-72	37	Old Reproductive Female	11.10
J-22	38	Old Reproductive Female	11.10
K-16	38	Old Reproductive Female	11.10

Alphanumeric Identifier	Age	Life Stage	cADL (min)
J-19	44	Old Reproductive Female	11.10
K-14	46	Old Reproductive Female	11.10
L-54	46	Old Reproductive Female	11.10
L-55	46	Old Reproductive Female	11.10
J-16	51	Post Reproductive Female	11.10
L-22	52	Post Reproductive Female	11.10
K-12	53	Post Reproductive Female	11.10
L-25	95	Post Reproductive Female	11.10

Appendix B. Figures

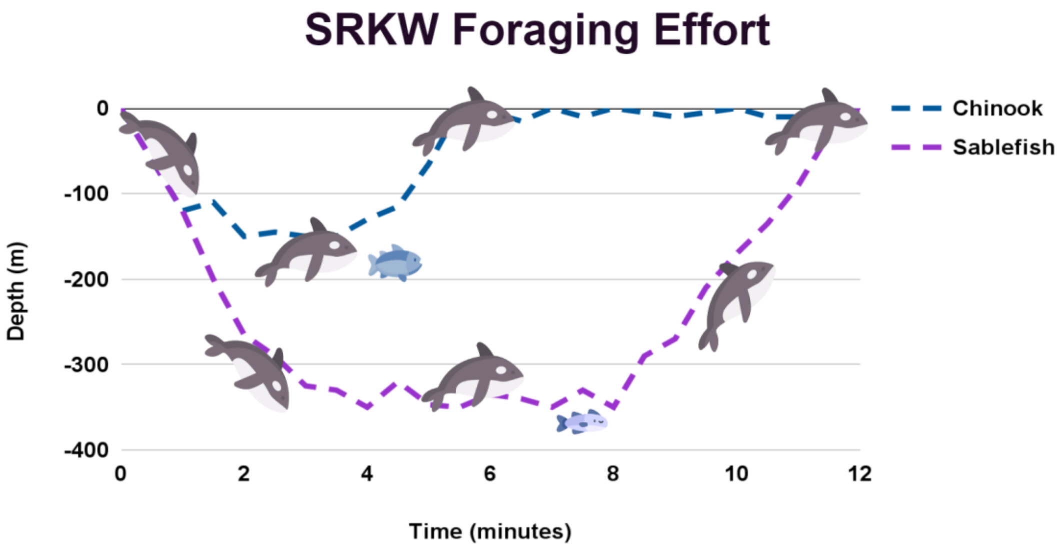

Figure B1 Potential diference in SRKW foraging effort for Chinook salmon vs sablefish. SRKWs may need to spend a longer period of time foraging for sablefish due to their preference for deep water. This may result in SRKWs exceeding their cADL.

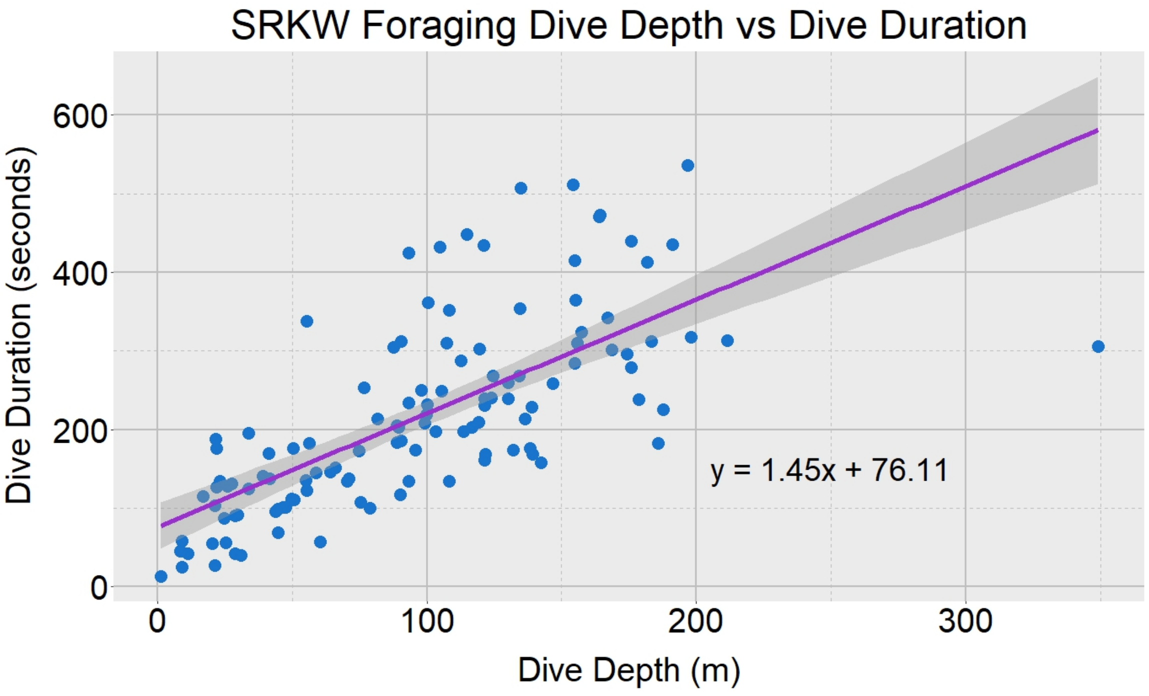

Figure B2 Linear regression between SRKW dive depth (meters) and dive duration (seconds) for successful foraging dives