Fisheries and Oceans Canada | Pêches et Océans Canada
Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

Pacific Region

Canadian Science Advisory Secretariat
Science Advisory Report 2025/016

SOUTHERN RESIDENT KILLER WHALE PREY SELECTIVITY IN RELATION TO CHINOOK SALMON STOCK AND SIZE COMPOSITION WITHIN CANADIAN CRITICAL HABITAT

Southern Resident Killer Whales off Swiftsure Bank. Photo credit: Dylan Smyth, DFO.

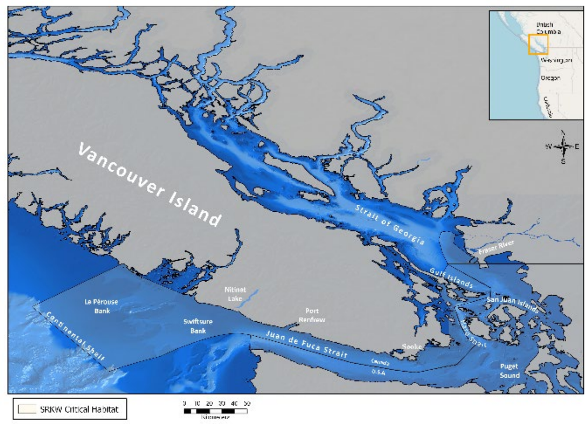

Figure 1. Study area including portions of Canadian southern resident killer whale critical habitat.

CONTEXT

Fisheries and Oceans Canada (DFO) Salmonid Enhancement Program and Fisheries Management have requested that Science Branch provide advice on Chinook salmon stock composition at monthly or seasonal temporal scales to support SRKW survival and recovery. This Science Advisory Report is from the regional peer review of November 20-21, 2024 on Distribution, Biological Characteristics, and Relative Abundance Information of Chinook Salmon Stocks within Southern Resident Killer Whale Critical Habitat. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Chinook salmon are a key prey of Southern Resident Killer Whales (SRKW) and variability in individual traits (e.g., body size, lipid content) affects their nutritional value to SRKW.
- Spatiotemporal distribution, local abundance, and fish behavior may influence the accessibility and availability of Chinook salmon to SRKW.
- Using recreational fisheries data (2014-2023), a geostatistical model was developed to estimate the stock composition and the size composition of Chinook salmon within SRKW critical habitat in Canadian waters, during May-September, when SRKW diets are dominated by Chinook salmon.

- To investigate SRKW prey selectivity, a co-occurrence approach was taken to compare the size and stock composition of SRKW prey remains in relation to model estimates from recreational fishery samples, in the western portion of SRKW critical habitat from June to September (2017-2023).
- All Chinook salmon stocks observed in the recreational fisheries data occurred in SRKW prey remains. Fraser River Spring 5_2, Summer 5_2, and Summer 4_1 stocks were more common, while Puget Sound, West Coast Vancouver Island (WCVI), Columbia River Summer/Fall, and "Other" stocks were less common, in prey remains than predicted by the recreational fishery model.
- Chinook salmon estimated to be smaller than 75 cm fork length were rarely observed in SRKW prey remains. Chinook salmon greater than 75 cm fork length were more common, while fish between 55 and 75 cm fork length were less common than predicted by the recreational fishery model.
- While total terminal abundance summed across all stocks considered here has remained relatively stable since 1982, Fraser River Spring 5_2 and Summer 5_2 Chinook salmon populations have declined in abundance, while the Fraser River Summer 4_1 and WCVI stocks have increased in abundance. Puget Sound and Columbia River Summer/Fall abundance has varied cyclically.
- SRKW have poor body condition in the spring. In the current study, SRKW showed selectivity towards Chinook salmon stocks with high lipid content and Chinook salmon individuals with large body size. Therefore, improvements to the SRKW prey field in Canadian critical habitat may occur via increasing the abundance of Chinook salmon with early migration timing, high lipid content, and large body size.
- Independent of abundance, SRKW may also benefit from increases in prey quality as represented by the body size and/or lipid content of Chinook salmon stocks.
- Key sources of uncertainty in the SRKW prey remains data include potential sampling bias, as well as low precision due to a relatively small sample size.
- A key source of uncertainty associated with characterizing Chinook salmon available to SRKWs is the extent to which fisheries-dependent samples accurately represent the underlying prey base.
- The importance of Chinook salmon stocks outside of Canadian critical habitat and during other periods of the year was not considered here because prey remains samples were not available. Non Chinook salmon and other species present in SRKW diets were not evaluated and warrant additional research.

INTRODUCTION

Limited prey availability is one of several factors that may prevent the SRKW population from rebuilding. From May to October, SRKW predominantly forage in critical habitat in Canadian waters (the Salish Sea and waters west of Juan de Fuca Strait, Fig.1; Thornton et al. 2022) and their diets are dominated by Chinook salmon (Ford and Ellis 2006, Hanson et al. 2021). Within this relatively small spatial domain, diversity among and within Chinook salmon stocks may impact their availability as prey to SRKW. Some Chinook salmon stocks are actively migrating through SRKW critical habitat and are only available for brief periods in any given year, while others remain resident in coastal waters overwinter. Chinook salmon stocks also vary in migration timing, migration routes, and habitat use, which likely impact their vulnerability to

SRKW. In addition to spatiotemporal variability, Chinook salmon differ in physical traits such as size-at-maturity and lipid content that influence their quality as prey. Finally, Chinook salmon stocks have divergent population trajectories, suggesting that availability of preferred prey for SRKW may not be driven by total Chinook salmon abundance, but rather trends in specific stocks. Identifying the Chinook salmon stocks and size classes that are most common in SRKW diets and critical habitat, during specific periods, may provide an opportunity to increase the efficacy of management interventions to improve SRKW prey availability.

ASSESSMENT

The relative contribution of different Chinook salmon stocks and size classes to SRKW diets in Canadian critical habitat between May and October was evaluated using SRKW prey remains and recreational fishery data. Patterns in SRKW diets were examined directly using samples from prey remains collected during two sampling periods (2003-2013 and 2017-2023). Samples collected from recreational Chinook salmon fisheries (2014-2023) were used to evaluate size and stock composition within Canadian critical habitat, as well as the relative abundance of hatchery origin fish. Geostatistical models were fit to fisheries-dependent data to quantify seasonal, spatial, and interannual variability in composition. Prey remains and geostatistical model outputs were compared to test for stock- and size-selective foraging by SRKWs relative to the recreational fishery. Terminal abundance (i.e., abundance of mature fish in relative proximity to the freshwater entry locations) data were collated to identify trends in aggregate (i.e., abundance summed among stocks) and stock-specific Chinook salmon abundance in Canadian SRKW critical habitat since 1982.

SRKW prey remains (n = 236) included all stocks that were present in the recreational fishery; however, Fraser River Summer 4_1 (both periods) and Spring 5_2 (early period) were the largest proportion of the diet samples (Fig. 2). Ocean age-3 and age-4 fish were the most common age classes with ocean age-2 fish rarely observed. Ocean age refers to the number of winters spent at sea (e.g., a fish with a yearling life history and total age of four years (i.e., 4_2) is ocean age-2, while a subyearling with the same total age (i.e., 4_1) is ocean age-3). Stock- and season-specific size-at-age relationships indicate that the majority of prey remains were from fish larger than 75 cm fork length. A small number of Canadian hatchery origin fish were identified in the prey remains; however, this estimate is likely biased low due to incomplete parentage based tagging during the study period. It was not possible to quantify interannual, seasonal, or spatial patterns in stock, age, or size composition in SRKW prey remains due to low sample sizes.

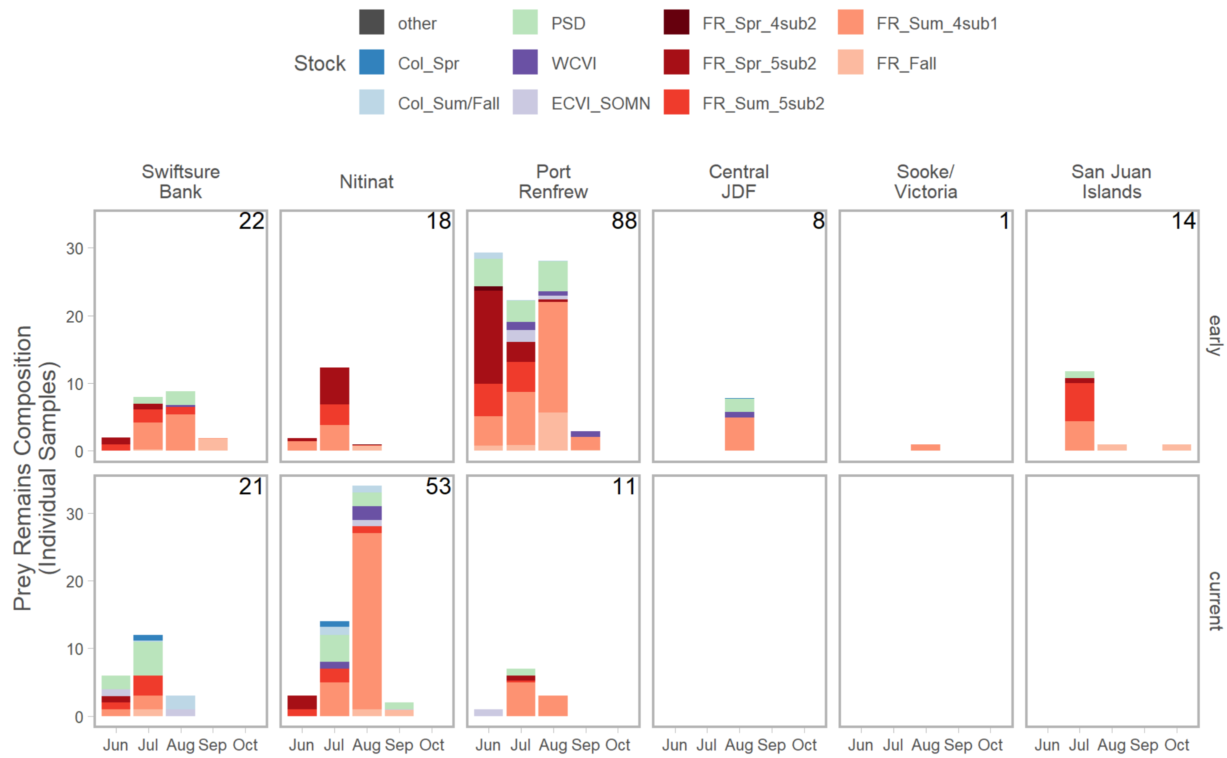

Figure 2. Monthly stock composition of SRKW prey remain samples across spatial strata. Y-axis represents the number of samples collected in a given month-strata-sampling period. Numerals in upper right corner of each panel represent the total sample size in each strata and period. Stock group codes are: Col_Spr – Columbia Spring; Col_Sum/Fall – Columbia Summer/Fall; PSD – Puget Sound; WCVI – West Coast Vancouver Island Chinook; ECVI_SOMN – East Coast Vancouver Island and Southern Mainland; FR_Spr – Fraser Spring; FR_Sum – Fraser Summer; FR_Fall – Fraser Fall.

Sampling of Chinook salmon catch from recreational fisheries started in 2014 (n = 8000) with greater seasonal coverage than the prey remains data; however, no recreational fisheries sampling occurred during the early prey remains sampling period (2003-13). Recreational fisheries showed both spatial and seasonal variability in stock and size composition. The Puget Sound stock was abundant early in the year in most strata, while the West Coast Vancouver Island (WCVI) and Fraser River Summer 4_1 stocks were abundant in specific strata late in the year (Fig. 3). Chinook salmon larger than 75 cm were most common in Nitinat and Renfrew during July and August, while smaller size classes were common early in the year and in the remaining strata. Canadian and American hatchery-origin Chinook salmon were a major component of recreational fishery samples except in periods and locations where the Fraser River Summer 4_1 stock was common.

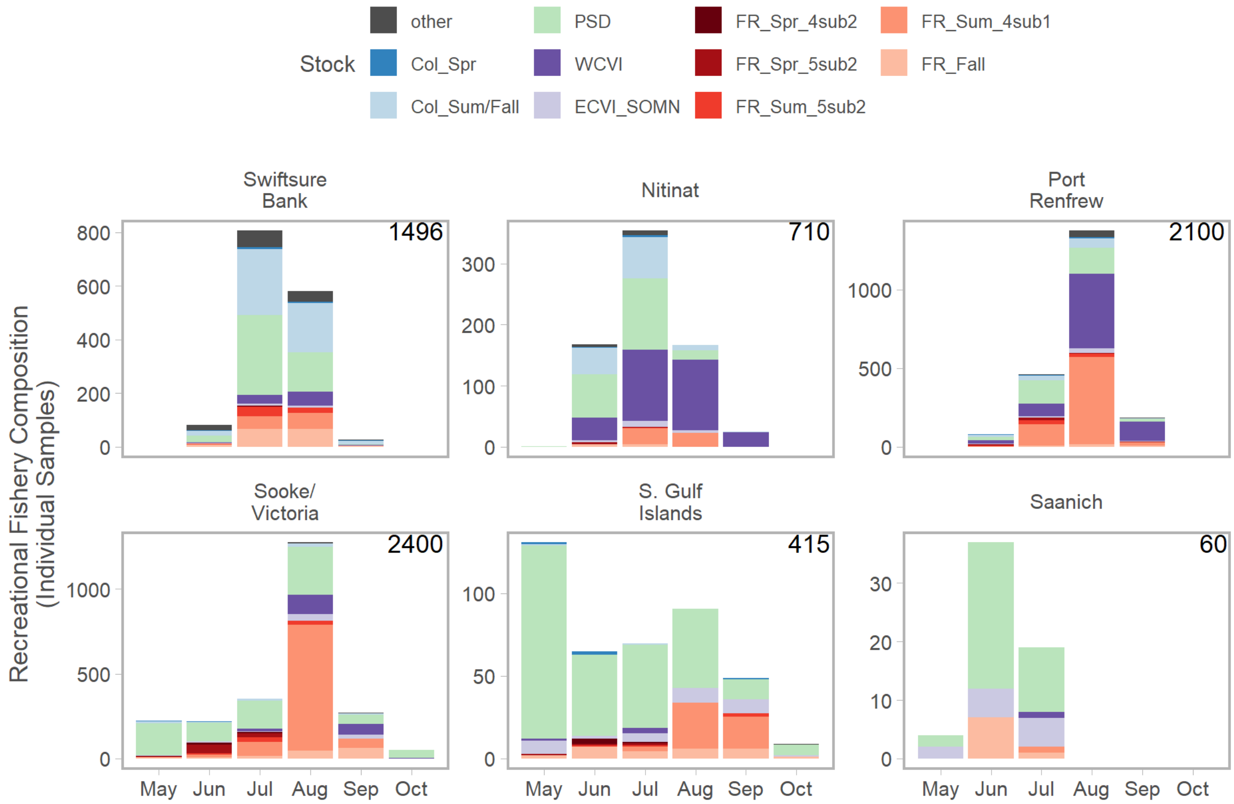

Figure 3. Monthly stock composition of recreational Chinook salmon fishery samples across spatial strata. Y-axis represents the number of samples collected in a given month and strata. Numerals in upper right corner of each panel represent the total sample size in each strata.

Geostatistical models predicted seasonal and spatial patterns in stock and size composition, while accounting for variable sampling effort. These models highlighted variability in composition at small spatial (less than 10 km) and temporal (between weeks) scales. Specific stocks and size classes were found in SRKW prey remains out of proportion to their abundance in the recreational fishery samples. SRKW prey remains showed evidence of positive selection for Fraser River Spring 5_2, Summer 5_2, and Summer 4_1 Chinook salmon, but negative selection for WCVI, Puget Sound, Columbia River Summer/Fall, and Other stocks (Fig. 4). Chinook salmon with fork lengths greater than 75 cm were more common while Chinook salmon with 55-75 cm fork lengths were less common in SRKW prey remains than in the recreational fishery (Fig. 5). This evidence of stock selectivity persisted after accounting for size selectivity.

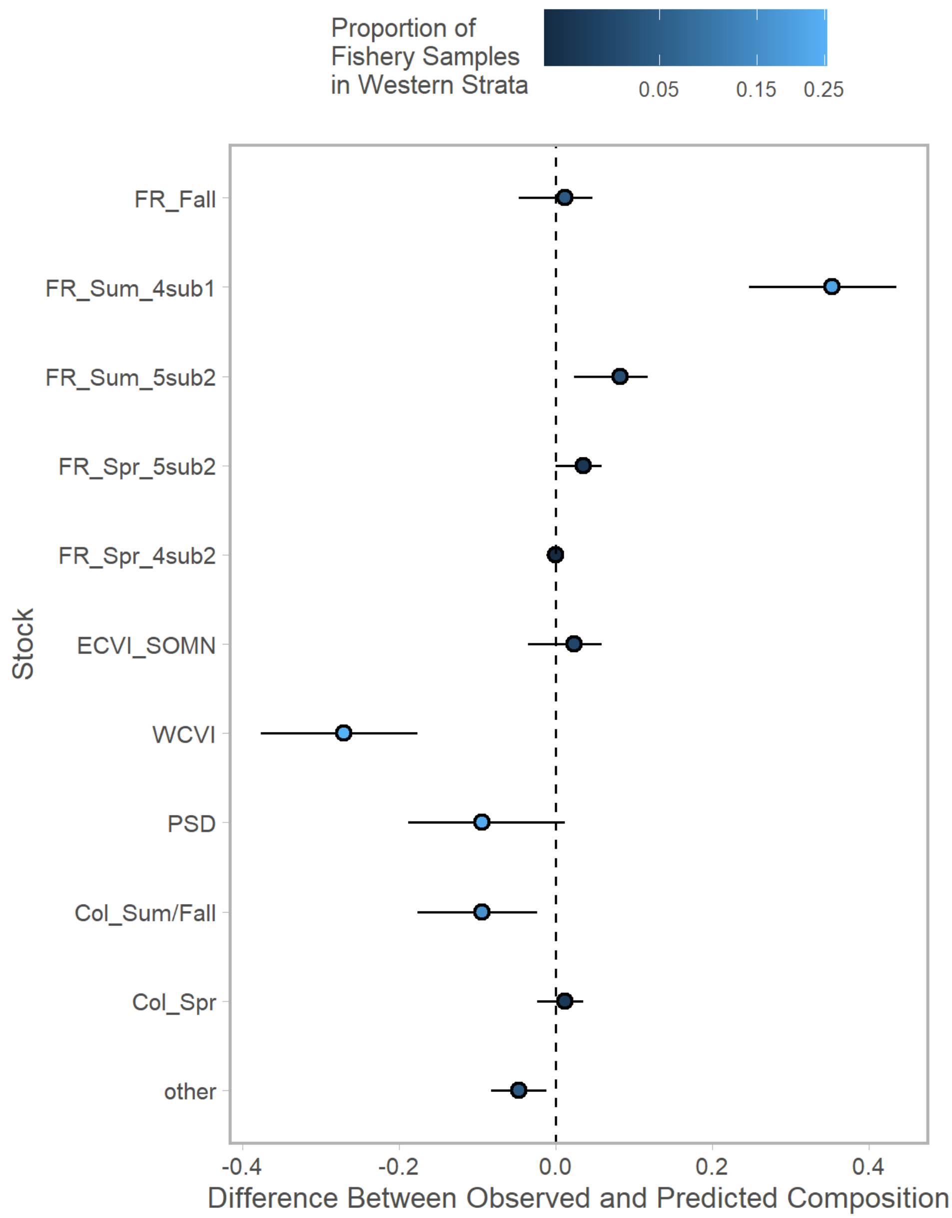

Figure 4. Differences between the observed and model predicted contribution of each stock to SRKW prey remains. Positive (negative) values indicate a given size class was observed more (less) frequently in SRKW prey remains than predicted by the fishery-dependent model. Points represent medians and whiskers represent 95th percentile intervals among 500 Monte Carlo simulations. Brighter (darker) points represent stocks that were more (less) common in recreational fishery samples from times and strata coincident with SRKW prey remains.

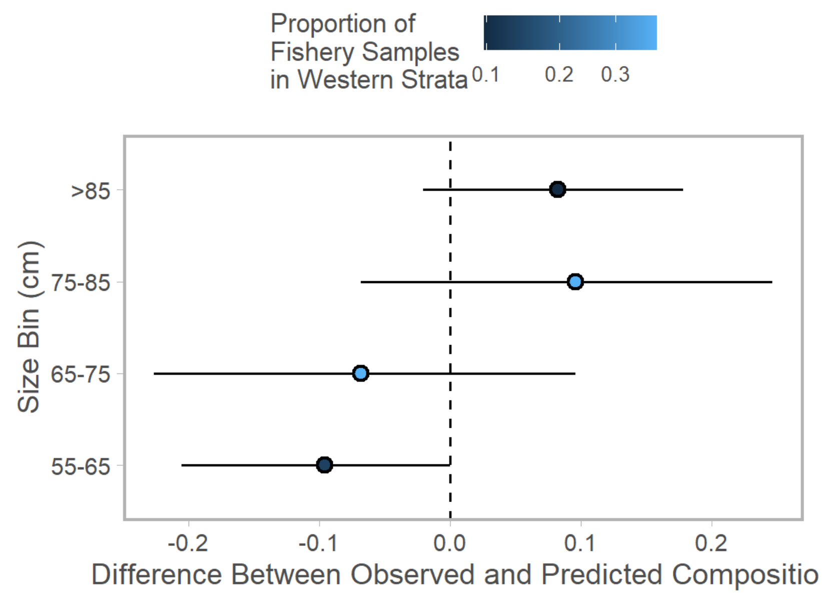

Figure 5. Differences between the observed and model predicted contribution of each size class (cm fork length) to SRKW prey remains. Positive (negative) values indicate a given size class was observed more (less) frequently in SRKW prey remains than predicted by the fishery-dependent model. Points represent medians and whiskers represent 95th percentile intervals among 500 Monte Carlo simulations. Brighter (darker) points represent size classes that were more (less) common in recreational fishery samples from times and strata coincident with SRKW prey remains.

Aggregate terminal Chinook salmon abundance has not declined since 1982; however, stocks show divergent patterns. In particular, Washington and Oregon Coastal, Fraser River Spring 4_2, Fraser River Spring 5_2, and Fraser River Summer 5_2 stocks have declined in abundance in recent decades, while Fraser River Summer 4_1, WCVI, and East Coast Vancouver Island/Southern Mainland Inlet stocks have increased in abundance (Figure 6).

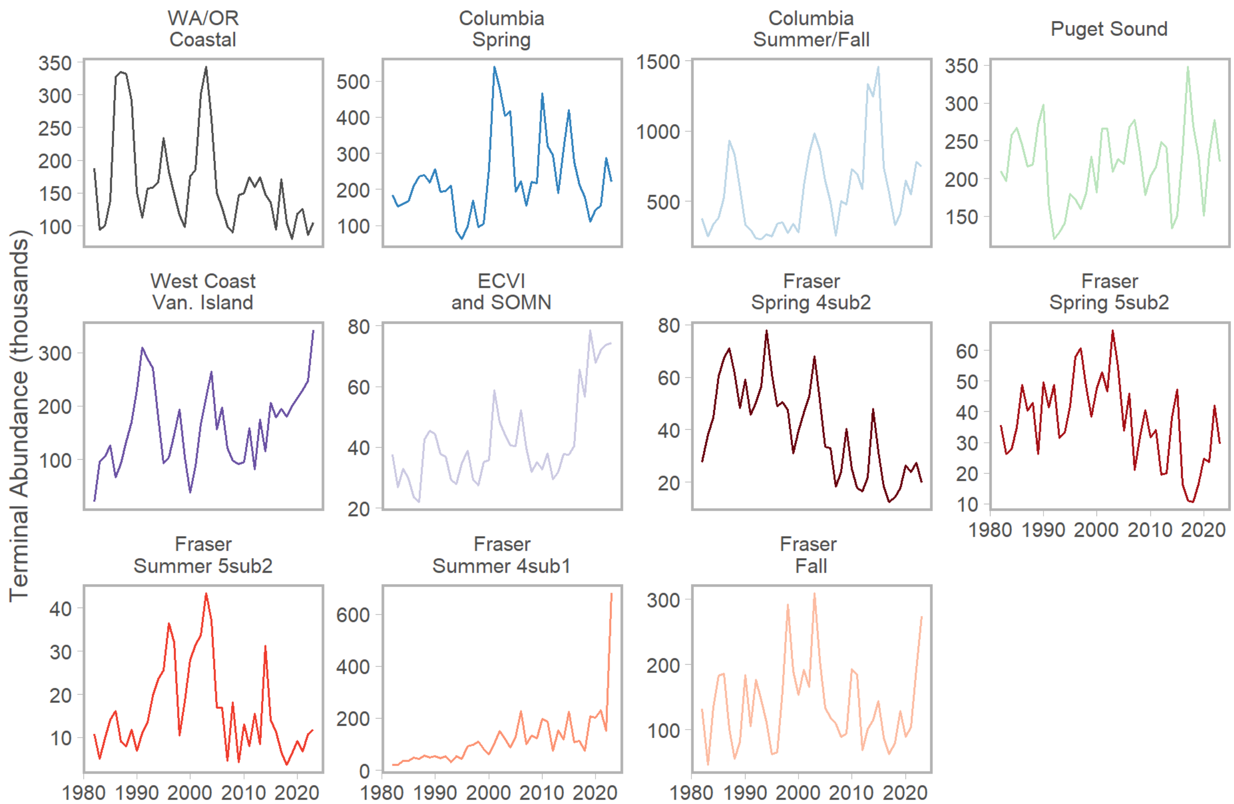

Figure 6. Terminal abundance of Chinook salmon stocks. Washington and Oregon (WA/OR) Coastal populations are included in the `Other` stock throughout the manuscript. 2023 data were unavailable for WA/OR Coastal and Puget Sound stocks and were imputed based on 2019-2022 averages. Y-axis scales differ among stocks.

Sources of Uncertainty

The results reported here have multiple dimensions of uncertainty due to data limitations that constrained the analysis or required assumptions. First, selectivity analyses were limited to a portion of the SRKW range only during summer months (June—August) when Chinook salmon prey remains were available. The stock and size composition of the Chinook salmon prey field and SRKW diets, as well as selectivity, may differ in other locations (e.g., coastal Washington) or later in the year (e.g., fall and winter). Similarly, several other prey species are important in the fall and winter (Hanson et al. 2021), and warrant further investigation.

Second, the prey remains and fisheries-dependent data may be biased. Prey remains were collected from the surface after foraging events. Estimates of SRKW diet indexed from fecal samples show greater species diversity than estimates from prey remains due to differences among species in the probability that physical debris is available for sampling (Hanson et al. 2021); however, these effects are assumed to be negligible here given the focus on Chinook salmon. While samples collected at the surface are thought to provide an accurate estimate of SRKW foraging events on Chinook salmon given that prey captured at depth are commonly brought to the surface for consumption (Wright et al. 2021), this assumption could not be evaluated. Fisheries-dependent data were used as an index of the Chinook salmon prey field available to SRKW because there is no fisheries-independent abundance data in SRKW critical habitat. Fisheries-dependent estimates may be biased relative to the underlying prey field if the fishery is selective for particular stocks or size classes. This is most likely to occur in times and locations where management interventions (e.g., non-retention areas, size limits, mark selective fisheries) are in place. Within the study area management interventions have varied seasonally, spatially, and interannually. It was not possible to account for these effects statistically and biases will influence predictions of size and stock composition with the magnitude of these impacts varying among strata and seasons. However, a sensitivity analysis demonstrated that management interventions were unlikely to have impacted the selectivity results because few prey remains were collected when fisheries were restricted. Three sources of fisheries-dependent samples (i.e., fleets) were used in this analysis and assumed to have identical selectivity because it was not possible to estimate fleet-specific parameters. Ultimately, these limitations introduce uncertainty in the extent to which differences between SRKW prey remains and recreational fishery samples are driven by the selectivity of whales, of recreational fishers, or both, relative to the true unobserved prey field.

Third, too few data were collected to statistically evaluate changes in SRKW prey stock and size composition among years, sampling periods, or spatial strata. The analysis does not directly account for changes in SRKW habitat use over time because the majority of prey remains were collected west of Juan de Fuca Strait (Ettinger et al. 2022). Changes in terminal abundance provide an index of changes in stock-specific abundance and are consistent with other sources (Atlas et al. 2023, CTC 2024). Yet terminal abundance data do not reflect historical abundances prior to 1982 and do not account for landed catch in marine fisheries or immature individuals that would also be available to SRKW as prey.

CONCLUSIONS AND ADVICE

The stock and size composition of Chinook salmon available to SRKWs varies at fine spatial and seasonal scales. Although SRKWs prey upon a range of Chinook salmon stocks and size classes, diets consistently diverged from the prey field, as indexed by the recreational fishery. The relatively low proportion of younger, smaller Chinook salmon in SRKW diets is consistent with evidence that SRKW prefer larger prey (Ford and Ellis 2006). The factors driving SRKW stock selectivity are less clear, but could be influenced by two interacting hypotheses. First, SRKW may select Chinook salmon that have higher mean lipid content. Three stocks that were positively selected for (Fraser River Spring 5_2, Summer 5_2, and Summer 4_1) have above average lipid content. Conversely, several stocks that were negatively selected for (WCVI, Puget Sound, and Columbia River Fall populations) have below average lipid content (Freshwater and King 2024). Second, Chinook salmon may show stock-specific behaviours that make them more or less vulnerable to predation. Specifically, stocks that were negatively selected for include resident stocks (Puget Sound, Columbia River Fall) and one stock (WCVI) that has effectively completed its marine migration. Resident stocks are likely to forage in SRKW critical habitat until late summer, while WCVI fish are oriented towards bathymetric structure once they are near freshwater entry points. Conversely, the Fraser River Spring 5_2, Summer 5_2, and Summer 4_1 stocks are actively migrating towards freshwater. Stocks that are migrating, rather than primarily foraging or holding prior to freshwater entry, may be relatively more accessible to SRKWs due to their position in the water column or other behavioural differences.

SRKW may benefit from increased prey availability in Canadian critical habitat during the spring because this is a period when whales show evidence of relatively poor body condition (Fearnbach et al. 2020; J. Durban. pers. comm.). Large, mature Chinook salmon are relatively rare in coastal Washington and the Salish Sea during this period, which occurs after Columbia River spring run fish have entered freshwater and before abundant late summer and fall run mature fish are present. One strategy for increasing prey availability in spring and early summer is via continued rebuilding of Fraser River Spring 5_2 and Summer 5_2 stocks. These stocks migrate through critical habitat early in the year, have declined in abundance, have high lipid content and large body size, and appeared in SRKW diets more frequently than their abundance in the prey field. While Fraser Summer 4_1 fish were also positively selected in SRKW diets, their migration timing is somewhat later and their abundance has been very high in recent years, making additional increases unlikely. In the short term the options for increasing Fraser River Spring 5_2 and Summer 5_2 abundance are limited—Canadian exploitation rates, particularly in marine areas, have already been substantially reduced (DFO 2023) and there is minimal hatchery capacity to enhance these stocks.

Increases in the body size or energy density of currently abundant Chinook salmon stocks may also improve prey availability. The average size of many Chinook salmon populations has declined due to changes in age-at-maturity and size-at-age (Ohlberger et al. 2018, Freshwater et al. 2022). Though the causes of declines in body size are uncertain and likely multifaceted, it may be possible to increase the availability of larger, older Chinook salmon via fishery regulations (e.g., maximum size limits), changes to hatchery practices, or reductions in natural mortality. Each of these interventions is uncertain in outcome, and has considerable socio-economic or ecological trade-offs that must be evaluated carefully prior to implementation.

OTHER CONSIDERATIONS

Tests for SRKW stock and size selectivity were limited to summer months and a relatively small spatial domain. Equivalent analyses conducted in other seasons or locations would provide a more nuanced understanding of which Chinook salmon stocks are key prey for SRKWs. Additional data are also necessary to determine whether selectivity is shaped by variation in Chinook salmon lipid content, behavior, or both. A better understanding of the factors driving declines in the abundance of Fraser River Spring 4_2, Spring 5_2, and Summer 5_2 stocks, even as other Chinook salmon have increased in abundance, may be necessary to increase the availability of these stocks as SRKW prey. Estimates of the availability of other prey species (e.g., coho salmon *O. kisutch*, chum salmon *O. keta*, and sablefish (*Anoplopoma fimbria*)) during periods where they are present in the diets may provide information on when and where SRKW are most prey limited. Finally, research to better understand how prey quality could be improved via management interventions would help support ecosystem-based management objectives.

LIST OF MEETING PARTICIPANTS

Last Name	First Name	Affiliation
O	Miriam	DFO Centre for Science Advice Pacific
Agbayani	Selina	DFO Centre for Science Advice Pacific
Ahern	Pat	Sport Fishing Advisory Board
Anderson	Erika	DFO Science
Churchland	Carolyn	DFO Salmonid Enhancement Program
Connors	Brendan	DFO Science
Dennert	Alison	Raincoast Conservation Foundation
Fredrickson	Nicole	Island Marine Aquatic Working Group
Freshwater	Cameron	DFO Science

Last Name	First Name	Affiliation
Galbraith	Ryan	DFO Salmonid Enhancement Program
Hawkshaw	Mike	DFO Fisheries Management
Hendriks	Brian	University of British Columbia
Horning	Carilia	Nuu-chah-nulth
Ladell	Jason	DFO Science (National Capital Region)
Lagasse	Cory	DFO Science
Luedke	Wilf	DFO Science
MacConnachie	Sean	DFO Science
Matwichuk	Kiana	Ka:'yu:'k't'h'/Che:k'tles7et'h' First Nations
McDuffee	Misty	Raincoast Conservation Foundation
O'Brien	Michael	DFO Science
Parken	Chuck	DFO Fraser and Interior Area
Picco	Candace	Ha'oom Fisheries Society
Porter	Aswea	DFO Science
Prior	Jasmine	DFO Fisheries Management
Stredulinsky	Eva	DFO Science
Thornton	Sheila	DFO Science
Toews	Scott	DFO Science
Tollit	Dominic John	SMRU Consulting
Trites	Andrew	University of British Columbia
Ward	Eric	National Oceanic and Atmospheric Administration
Wor	Catarina	DFO Science

SOURCES OF INFORMATION

Atlas, W.I., Sloat, M.R., Satterthwaite, W.H., Buehrens, T.W., Parken, C.K., Moore, J.W., Mantua, N.J., Hart, J., and Potapova, A. 2023. Trends in Chinook Salmon Spawner Abundance and Total Run Size Highlight Linkages Between Life History, Geography and Decline. Fish and Fisheries, 24:595-617.

Chinook Technical Committee. 2024. Annual Report of Catch and Escapement for 2023. Pacific Salmon Commission, Vancouver, BC.

DFO. 2023. Fraser Chinook Fishery Mortality Index Summary, 2014-2022. 2023. DFO Fisheries Management Technical Memorandum, 34 p.

Ettinger, A.K., Harvey, C.J., Emmons, C., Hanson, M.B., Ward, E.J., Olson, J.K., and Samhouri, J.F. 2022. Shifting Phenology of an Endangered Apex Predator Mirrors Changes in its Favored Prey. Endangered Species Research, 48:211-223.

Fearnbach, H., Durban, J.W., Barrett-Lennard, L.G., Ellifrit, D.K., and K.C. Balcomb. 2020. Evaluating the Power of Photogrammetry for Monitoring Killer Whale Body Condition. Marine Mammal Science, 36:359-364.

Ford, J.K.B. and Ellis, G.M. 2006. Selective Foraging by Fish-Eating Killer Whales *Orcinus orca* in British Columbia. Marine Ecology Progress Series, 316:185-199.

Freshwater, C., Parken, C.K., Tucker, S., Velez-Espino, A., and King, J. 2022. Nonstationary patterns in demographic traits covary with Chinook salmon marine distributions. Canadian Journal of Fisheries and Aquatic Sciences, 79:1860-1878.

Freshwater, C. and King. J. 2024. Seasonal Variability in Condition and Spatial Distribution of Chinook Salmon: Implications for Ecosystem-Based Management. Transactions of the American Fisheries Society, 153:859-877.

Hanson, M.B., Emmons, C.K., Ford, M.J., Everett, M., Parsons, K., Park, L.K., Hempelmann, J., Van Doornik, D.M., Schorr, G.S., Jacobsen, J.K., Sears, M.F., Sears, M.S., Sneva, J.G., Baird, R.W., Barre, L., and Hyrenbach, D. 2021. Endangered Predators and Endangered Prey: Seasonal Diet of Southern Resident Killer Whales. PLoS One, 16:e0247031.

Ohlberger, J., Ward, E.J., Schindler, D.E., and Lewis, B. 2018. Demographic Changes in Chinook Salmon Across the Northeast Pacific Ocean. Fish and Fisheries, 19:533-546.

Thornton, S.J., Toews, S., Stredulinsky, E., Gavrilchuk, K., Konrad, C., Burnham, R., Noren, D.P., Holt, M.M., and Vagle, S. 2022. Southern Resident Killer Whale (*Orcinus orca*) summer distribution and habitat use in the southern Salish Sea and the Swiftsure Bank area (2009 to 2020). DFO Can. Sci. Advis. Sec. Res. Doc. 2022/037. v + 56 p.

Wright, B., Deecke, V.B., Ellis, G.M., Trites, A.M., and Ford, J.K.B. 2021. Behavioral Context of Echolocation and Prey-Handling Sounds Produced by Killer Whales (*Orcinus orca*) During Pursuit and Capture of Pacific Salmon (*Oncorhynchus* spp.). Marine Mammal Science, 37:1428-1453.

THIS REPORT IS AVAILABLE FROM THE:

Centre for Science Advice (CSA)
Pacific Region
Fisheries and Oceans Canada
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7

E-Mail: DFO.PacificCSA-CASPacifique.MPO@dfo-mpo.gc.ca
Adresse Internet : www.dfo-mpo.gc.ca/csas-sccs/

ISSN 1919-5087
ISBN 978-0-660-76829-8 Cat. No. Fs70-6/2025-016E-PDF

Correct Citation for this Publication:

DFO. 2025. Southern Resident Killer Whale Prey Selectivity in Relation to Chinook Salmon Stock and Size Composition within Canadian Critical Habitat. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2025/016.

Aussi disponible en français :

MPO. 2025. Sélectivité des proies de l’épaulard résident du Sud par rapport à la composition par taille et des stocks de saumon chinook dans l’habitat essentiel canadien. Secr. can. des avis sci. du MPO. Avis sci. 2025/016.