Pacific Fishery Management Council Salmon Fishery Management Plan Impacts to Southern Resident Killer Whales

FINAL DRAFT Risk Assessment

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Ad-Hoc Southern Resident Killer Whale Workgroup

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1 INTRODUCTION

This report is a product of the Pacific Fishery Management Council's (PFMC or Council) ad-hoc Southern Resident Killer Whale (SRKW) Workgroup which was tasked with reassessing the effects of Council-area ocean salmon fisheries on SRKW. We first provide a brief overview of the background context, workshop process, and the role of the SRKW Workgroup. Then we assess the current status of the SRKWs, followed by describing the interactions known to occur between SRKW and salmon fisheries, leading to a general description of the Pacific Coast Salmon Fishery Management Plan (FMP). Lastly, we attempt to assess how reductions in prey through implementing the FMP may affect SRKW demographics.

1.1 Background

SRKW are listed as endangered under the Endangered Species Act (ESA) (70 FR 69903). Multiple actions along the west coast are active in conserving and recovering SRKW, particularly to address three main threats to the whales that were identified in the SRKW Recovery Plan (NMFS 2008): prey limitation, vessel traffic and noise, and chemical contaminants. Fisheries affect the whales primarily through removing prey. The Council uses provisions of the FMP to make recommendations to NMFS for implementing salmon fisheries in Federal waters (3-200 nautical miles) off the coast of Washington, Oregon, and California. The effects on SRKW of implementing the FMP, *i.e.,* prey removal and the potential for interaction between fishing gear and vessels, were last consulted under the ESA per Section 7(a)(2) by NMFS in 2009 (NMFS 2009). That consultation described the effects on the amount of prey available to SRKW and the potential for interactions between fishing gear and vessels. In that opinion, NMFS concluded Council fisheries did not jeopardize the survival and recovery of SRKW.

Since the 2009 consultation was completed, new information is available on SRKW and their relationship to salmon prey species, and in March of 2019, NMFS announced plans to reinitiate consultation on the implementation of the FMP which it did on April 12, 2019. Subsequently, at its April 2019 meeting, the Council formed the ad-hoc SRKW workgroup (Workgroup) to reassess the effects of Council-area ocean salmon fisheries on the Chinook salmon prey base of SRKW, and depending on the results, develop a long-term approach that may include proposed conservation measure(s) or management tool(s) that limit PFMC fishery impacts to prey availability for SRKW relative to implementing the FMP.

The Workgroup met numerous times during the course of 2019 and early 2020 in order to develop the risk assessment approach contained in this report, and all meetings were open to the public. A detailed list of Workgroup meetings and presentations can be found online at: https://www.fisheries.noaa.gov/west-coast/southern-resident-killer-whales-and-fisheries-interaction-workgroup

1.2 Purpose and Need

Chinook salmon, the whales' primary prey, are important to SRKW survival and recovery. Any activities that affect the abundance of Chinook salmon available to SRKW have the potential to impact the survival and population growth of the whales. Fisheries can reduce the prey available to the whales and in some cases can interfere directly with their feeding. Insufficient prey can impact their energetics (causing them to search more for fewer prey), health (decreasing their body condition), and reproduction (reducing fecundity and calf survival).

NMFS consulted on the effects of Council salmon fisheries under the ESA in 2009 and concluded that annual management recommendations developed according to the PFMC's Pacific Coast Salmon FMP and its associated amendments were not likely to jeopardize the continued existence of the SRKW Distinct Population Segment (DPS) or adversely modify its critical habitat. Given new information (since 2009) is available on SRKW and their prey, and potentially the effects of the fisheries on the whales, NMFS has re-initiated ESA consultation on the Council salmon fisheries, and asked for the Council's assistance in assessing the effects of implementing the FMP in 2019 and beyond. In cooperation, the Council appointed a workgroup with membership including representatives from West Coast tribes; the states of California, Oregon, Washington, and Idaho; the PFMC; and NMFS' West Coast Region, Northwest Fisheries Science Center, and Southwest Fisheries Science Center.

The purpose the Council tasked the workgroup with was to reassess the effects of PFMC ocean salmon fisheries on SRKW and if needed, develop a long-term approach that may include proposed conservation measure(s) or management tool(s) that limit PFMC fishery impacts to Chinook salmon prey availability for SRKW relative to implementing the FMP. The need is that the workgroup's findings will inform NMFS' ESA consultation and biological opinion, wherein NMFS will determine whether the fisheries jeopardize the continued existence of SRKWs in light of new information about the whales' dependence on West Coast Chinook salmon stocks.

As background, the Workgroup collected and summarized information related to:

- Overlap between PFMC salmon fisheries and SRKW;
- A Council's Salmon Technical Team (STT) report (see Agenda Item D.8.a, Supplemental STT Report 2 from the Council's 2019 March meeting) regarding which FMP stocks have Council salmon fishery model representation when compared against a priority stock list developed by NMFS and the Washington Department of Fish and Wildlife (NOAA and WDFW 2018) for the purposes of prioritizing salmon restoration work. The STT did not also attempt to assess their priority and excluded the rankings; and
- Analyses for prior salmon fishery/SRKW evaluations.

The Workgroup was also instructed to recommend (if needed based on the risk assessment) conservation measures or management tools to limit PFMC fishery impacts on Chinook salmon prey availability for SRKW.

In trying to quantify effects on SRKW due to Chinook salmon removals in Council-area ocean salmon fisheries, the Workgroup approached the analysis in four steps:

I) Develop annual indices of adult (age-3+) Chinook salmon abundance by ocean area and three seasonal breakpoints

II) Relate these indices of Chinook salmon abundance to measures of SRKW demographic rates

III) Estimate reductions in Chinook salmon abundance by time and area that are attributable to Council-area ocean salmon fisheries

IV) Estimate the changes in predicted vital rates that the statistical relationships fitted in step II predict for the reductions in abundance estimated in step III.

Details for this methodology and criteria are described in Chapter 5.

The workgroup is focused exclusively on addressing the impacts of PFMC-area ocean salmon fisheries through tools or conservation measures that apply to those fisheries. Considerations of other fisheries or other threats to SRKW are outside the scope of the reinitiated consultation, which is limited to the salmon fisheries as implemented under the FMP. NMFS considers other activities in the action area as part of the environmental baseline in the consultation. In addition, the NMFS West Coast Region and its partners are addressing the broader suite of threats separately.

1.3 NMFS Recovery Plan Guidance

Working with its federal, state, tribal, and local partners, NMFS published a recovery plan for SRKW in January 2008 (NMFS 2008). The plan provides a road map to recovery and there is considerable uncertainty about which threats (prey abundance and quality, noise, and contaminants) may be responsible for the decline in the SRKW population, or which is the most important to address for recovery. The plan lays out an adaptive management approach and a recovery strategy that addresses each of the potential threats based on the best available science. The recovery program outlines links from management actions to an active research program to fill data gaps and a monitoring program to assess effectiveness. Feedback from research and monitoring will provide the information necessary to refine ongoing actions and develop and prioritize new actions. For actions that affect prey abundance, (*e.g.*, salmon), NMFS identified near-term priorities of ongoing restoration efforts for depleted salmon populations in order to:

- Rebuild depleted populations of salmon and other prey to ensure an adequate food base for recovery of SRKWs.
- Support salmon restoration efforts in the region.
- Support regional restoration efforts for other prey species.
- Use NMFS authorities under the ESA and the Magnuson Stevens Act (MSA) to protect prey habitat, regulate harvest, and operate hatcheries.

Healthy SRKW populations are dependent on adequate prey levels. Reductions in prey availability may force SRKWs to spend more time foraging and might lead to reduced reproductive rates or higher mortality rates.

2 STATUS OF THE SPECIES

There are three killer whale (*Orcinus orca*) ecotypes recognized off the west coast of North America: residents, transients, and offshore killer whales (Bigg *et al.* 1990, Ford *et al.* 1994). These killer whale ecotypes differ in numerous ways including their morphology, ecology, behavior, and genetics (refer to NMFS 2008). Resident killer whales feed primarily on fish, whereas transient killer whales have diets consisting of primarily marine mammals (NMFS 2008). Less is known about offshore killer whales, however they are thought to primarily consume fish with a specialization in sharks (Herman *et al.* 2005; Krahn *et al.* 2007a; Dahlheim *et al.* 2008; Ford *et al.* 2011a; Ford *et al.* 2014). Given their differences, eight killer whale stocks are recognized in the Pacific EEZ: Alaska Residents, Northern Residents, Southern Residents, West Coast transients, Gulf of Alaska, Aleutian Islands, and Bering Sea transients, AT1 killer whales, offshore killer whales, and the Hawaiian killer whale stock (Carretta *et al.* 2019).

Krahn *et al.* (2004) concluded that all North Pacific resident killer whales should be considered a single subspecies distinct from offshore and transient whales. They also concluded that the SRKWs were discrete from other North Pacific residents and significant with respect to the North Pacific resident taxon, and therefore should be considered a distinct population segment (DPS) (Krahn et al. 2004). The SRKW DPS, composed of J, K, and L pods, was listed as endangered under the ESA on November 18, 2005 (70 FR 69903). A 5-year review under the ESA completed in 2016 concluded that SRKWs should remain listed as endangered and includes recent information on the population, threats, and new research results and publications (NMFS 2016). NMFS considers SRKWs to be currently among eight of the most at-risk species as part of the Species in the Spotlight initiative[1] because the population has relatively high mortality and low reproduction, and unlike other resident killer whale populations that have generally been increasing since the 1970s (Carretta *et al.* 2019), SRKWs are currently well below the recovery goals identified in their ESA Recovery Plan (NMFS 2008).

The limiting factors described in the final recovery plan included reduced prey availability and quality, high levels of contaminants from pollution, and disturbances from vessels and sound (NMFS 2008). This section summarizes the status of SRKWs throughout their range and summarizes information taken largely from the recovery plan (NMFS 2008), recent 5-year review (NMFS 2016), as well as newly available data.

Most of the scientific research conducted on SRKW occurs in inland waters of Washington State and British Columbia. In general, the primary objective of this research is population monitoring or data gathering for behavioral and ecological studies. Research activities are typically conducted between May and October in inland waters and can include aerial surveys, vessel surveys, close approaches, and documentation, and biological sampling.

2.1 Abundance, Productivity, and Trends

Killer whales – including SRKW - are a long-lived species, sexual maturity occurs at age 10 (review in NMFS (2008)). Females produce a small number of surviving calves (n < 10, but generally fewer) over the course of their reproductive life span (Bain 1990; Olesiuk *et al.* 1990).

[1] https://www.fisheries.noaa.gov/resource/document/species-spotlight-priority-actions-2016-2020-southern-resident-killer-whale

Compared to Northern Resident killer whales (NRKWs), which are a resident killer whale population with a sympatric geographic distribution ranging from coastal waters of Washington State and British Columbia north to Southeast Alaska, SRKW females appear to have reduced fecundity (Ward *et al.* 2013; Vélez-Espino *et al.* 2014), and all age classes of SRKW have reduced survival compared to other fish-eating populations of killer whales in the Northeast Pacific (Ward et al. 2013).

Since the early 1970s, annual summer censuses in the Salish Sea using photo-identification techniques have occurred (Bigg *et al.* 1976; Balcomb *et al.* 1980; Center for Whale Research annual photographic identification catalog, 2019). The surveys are typically performed from May to October, when all three pods tend to reside near the San Juan Islands, and are considered complete censuses of the population. The population of SRKW was at its lowest known abundance in the early 1970s following live-captures for aquaria display (n = 68). The highest recorded abundance since the 1970s was in 1995 (98 animals), though the population declined from 1995-2001 (from 98 whales in 1995 to 81 whales in 2001). In 2014 and 2015, the SRKW population increased from 78 to 81 as a result of multiple successful pregnancies (n = 9) that occurred in 2013 and 2014. At present, the SRKW population has declined to near historically low levels (Figure 2.1.a). As of August 2019, the population is 73 whales (2 calves were born and three whales died since the 2018 census).

Figure 2.1.a. Population size and trend of Southern Resident killer whales, 1960-2019. Data from 1960-1973 (open circles, gray line) are number projections from the matrix model of Olesiuk *et al.* (1990). Data from 1974-2019 (diamonds, black line) were obtained through photo-identification surveys of the three pods (J, K, and L) in this community and were provided by the Center for Whale Research (unpublished data) and NMFS (2008). Data for these years represent the number of whales present at the end of each calendar year.

There are several demographic factors of the SRKW population that are cause for concern, namely (1) reduced fecundity, (2) a skewed sex ratio toward male births in recent years, (3) a lack of calf production from certain components of the population (K pod, other groups), (4) a small number of adult males acting as sires (Ford *et al.* 2018) and (5) an overall small number of individuals in the population (review in NMFS 2008). Based on an updated pedigree from new genetic data, many of the offspring in recent years were sired by two fathers, meaning that less than 30 individuals make up the effective reproducing portion of the population. Because a small number of males were identified as the fathers of many offspring, a smaller number may be sufficient to support population growth than was previously thought (Ford *et al.* 2011b; Ford *et al.* 2018). Inbreeding may be common amongst this small population, with a recent study by Ford *et al.* (2018) finding several offspring resulting from matings between parents and their own offspring. The fitness effects of this inbreeding remain unclear and are an effort of ongoing research (Ford *et al.* 2018).

The previously published historical estimated abundance of SRKW is 140 animals (NMFS 2008). This estimate (~140) was generated as the number of whales killed or removed for public display in the 1960s and 1970s (summed over all years) added to the remaining population at the time the captures ended. Because of the summed captures over all years, this estimate is likely an over estimate of the population size prior to removals.

The NWFSC continues to evaluate changes in fecundity and mortality rates, and has updated population viability analyses conducted for the 2004 Status Review for Southern Resident Killer Whales and the 2011 science panel review of the effects of salmon fisheries (Krahn *et al.* 2004; Hilborn *et al.* 2012; Ward *et al.* 2013). Following from that work, the data now suggests a downward trend in population size projected over the next 50 years. As the model projects out over a longer time frame (50 years) there is increased uncertainty around the estimates. The downward trend is in part due to the changing age and sex structure of the population. If the population of SRKW experiences demographic rates that are more similar to 2016 than the recent 5-year average (2011-2016), the population will decline faster as shown in Figure 2.1.b (NMFS 2016).

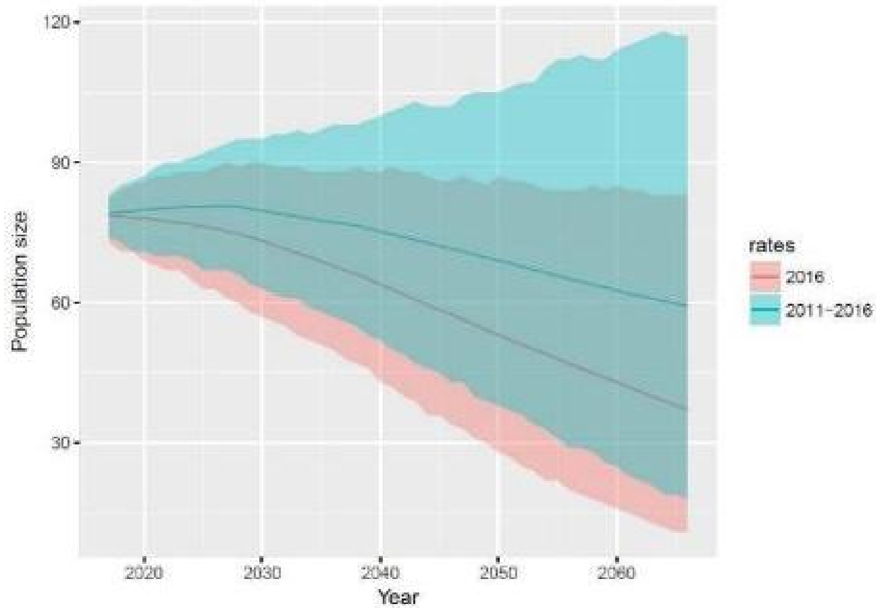

Figure 2.1.b. Southern Resident killer whale population size projections from 2016 to 2066 using two scenarios: (1) projections using demographic rates held at 2016 levels, and (2) projections using demographic rates from 2011 to 2016. The pink line represents the projection assuming future rates are similar to those in 2016, whereas the blue represents the scenario with future rates being similar to 2011 to 2016 (Figure 2, NMFS 2016).

Because of this population's small abundance, it is also susceptible to increased risks of demographic stochasticity – randomness in the pattern of births and deaths among individuals in a population. Several other sources of stochasticity can affect small populations and contribute to variance in a population's growth and increased extinction risk. Other sources include environmental stochasticity, or fluctuations in the environment that drive changes in birth and death rates, and demographic heterogeneity, or variation in birth or death rates of individuals because of differences in their individual fitness (including sexual determinations). In combination, these and other sources of random variation combine to amplify the probability of extinction, known as the extinction vortex (Gilpin and Michael 1986; Fagan and Holmes 2006; Melbourne and Hastings 2008). The larger the population size, the greater the buffer against stochastic events and genetic risks. In light of the current small population size and declining status, these conditions reinforce the need to promote immediate population growth.

Population growth is also important because of the influence of demographic and individual heterogeneity on a population's long-term viability. Population-wide distribution of lifetime reproductive success can be highly variable, such that some individuals produce more offspring than others to subsequent generations, and male variance in reproductive success can be greater than that of females (*e.g.* Clutton-Brock 1988; Hochachka 2006). For long-lived vertebrates such as killer whales, some females in the population might contribute less than the number of offspring required to maintain a constant population size (n = 2), while others might produce more offspring. The smaller the population, the more weight an individual's reproductive success has on the population's growth or decline (Coulson *et al.* 2006). For example, from 2010 through July 2019, only 15 of the 28 reproductive aged females successfully reproduced, resulting in 16 calves. There were an additional 10 documented non-viable calves, and likely more undocumented, born during this period (CWR unpubl. data). A recent study indicated pregnancy hormones (progesterone and testosterone) can be detected in SRKW feces and have indicated several miscarriages, particularly in late pregnancy (Wasser *et al.* 2017). The fecal hormone data have shown that up to 69 percent of the detected pregnancies do not produce a documented calf (Wasser *et al*. 2017). Recent aerial imagery [2] corroborates previous notions that SRKWs are thought to have high rates of reproductive failure. This further illustrates the risk of demographic stochasticity for a small population like SRKWs – the smaller a population, the greater the chance that random variation will result in too few successful individuals to maintain the population.

2.2 Geographic Range and Distribution

SRKWs occur throughout the coastal waters off Washington, Oregon, and Vancouver Island and are known to travel as far south as central California and as far north as Southeast Alaska (NMFS 2008; Carretta *et al.* 2019; Ford et al. 2017) (Figure 2.2.a). SRKW are highly mobile and can travel up to approximately 86 miles in a single day (Erickson 1978; Baird 2000), with seasonal movements likely tied to the migration of their primary prey, salmon. During the spring, summer, and fall months, SRKWs have typically spent a substantial amount of time in the inland waterways of the Strait of Georgia, Strait of Juan de Fuca, and Puget Sound (Bigg 1982; Ford *et al.* 2000; Krahn *et al.* 2002; Hauser *et al.* 2007). During fall and early winter, SRKWs, and J pod in particular, expand their routine movements into Puget Sound, likely to take advantage of chum, coho, and Chinook salmon runs (Osborne 1999; Hanson *et al.* 2010; Ford *et al.* 2016). Although seasonal movements are somewhat predictable, there can be large inter-annual variability in arrival time and days present in inland waters from spring through fall, with late arrivals and fewer days present in recent years (Hanson and Emmons 2010; The Whale Museum unpubl. data).

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[2] Presentation on May 23, 2019, to the SRKW Ad Hoc Workgroup: "Photogrammetry to monitor growth and body condition". This work is a collaboration with NOAA SWFSC and SR3 (a non-profit research and animal welfare group based in Seattle). The time series has also had key contributions from the Center for Whale Research on San Juan Island, and the Vancouver Aquarium.

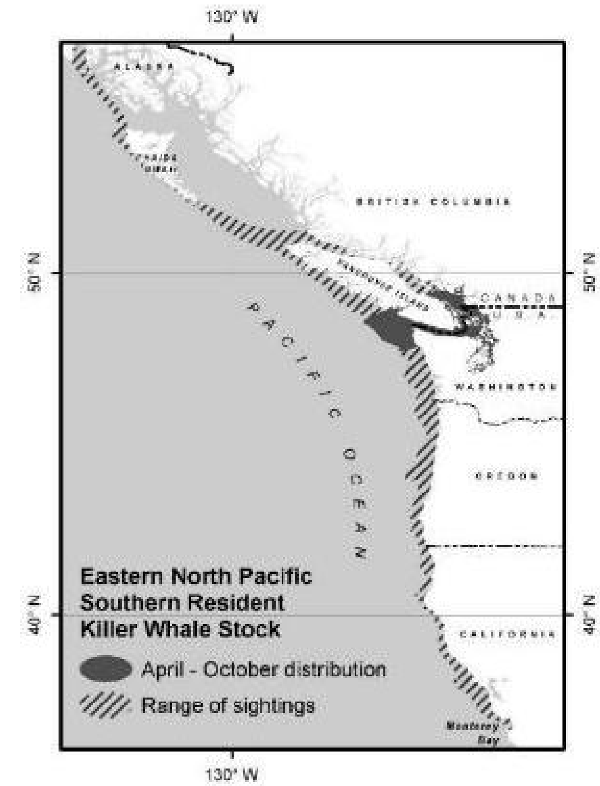

Figure 2.2.a. Approximate April – October distribution of Southern Resident killer whales (shaded area) and range of sightings (diagonal lines) (reprinted from Carretta *et al.* 2019).

In November 2006, NMFS issued a final rule designating approximately 2,560 square miles of inland waters of Washington State as critical habitat for the SRKW DPS. At that time, few data were available on SRKWs distribution and habitat use in coastal waters of the Pacific Ocean (e.g. there were only 28 confirmed and unconfirmed sightings of SRKWs in outer coastal waters that were available (Krahn et al. 2004, NMFS 2006). Since the 2006 designation, additional effort has been made to better understand the geographic range and movements of SRKWs. For example, opportunistic visual sightings, satellite tracking, and passive acoustic research conducted since 2006 have provided an updated estimate of the whales' coastal range that extends from the Monterey Bay area in California, north to Chatham Strait in southeast Alaska (NMFS 2019b).

On September 19, 2019 NMFS proposed to revise the critical habitat designation for the SRKW DPS under the ESA by designating six new areas along the U.S. West Coast (84 FR 49214). Specific new areas proposed along the U.S. West Coast include 15,626.6 square miles (mi^2) (40,472.7 square kilometers (km^2)) of marine waters between the 6.1-meter (m) depth contour and the 200-m depth contour from the U.S. international border with Canada south to Point Sur, California (Figure 2.2.b). In the proposed rule (84 FR 49214), NMFS states that the "proposed areas are occupied and contain physical or biological features that are essential to the conservation of the species and that may require special management considerations or protection." Three physical or biological features essential to conservation in designating critical habitat were identified as: (1) Water quality to support growth of the whale population and development of individual whales, (2) Prey species of sufficient quantity, quality and availability to support individual growth, reproduction and development, as well as overall population growth, and (3) Passage conditions to allow for migration, resting and foraging. In the proposed rule (84 FR 49214), NMFS identified six areas off the U.S. west coast delineated based on SRKW use and the habitat features (see NMFS 2019b for more descriptions on the six areas). NMFS (2019b) describes that each area contains all three essential features but prey is the identified primary feature in Areas 1, 2, 4, and 6 and passage is the identified primary feature in Areas 3 and 5 (see Figure 2.2.b for an illustration of Area).

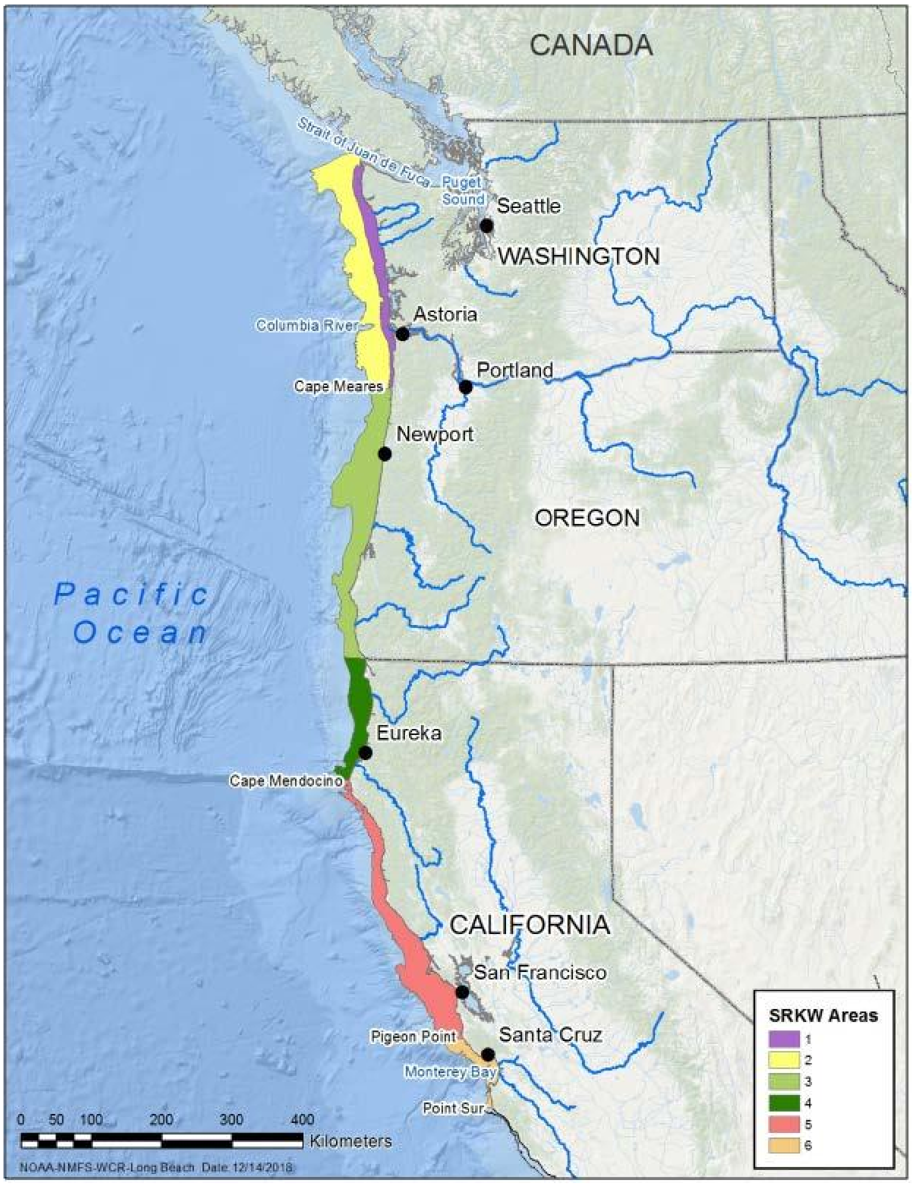

Figure 2.2.b. Specific areas containing essential habitat features (Figure 9 reproduced from NMFS 2019b).

Opportunistic Sightings

Since 1975, confirmed and unconfirmed opportunistic SRKW sightings from the general public or researchers have been collected off British Columbia, Washington, Oregon, and California. Here, we do not discuss unconfirmed sightings and we only discuss confirmed sightings off Washington, Oregon, and California (*i.e.,* proposed critical habitat areas). Between 1986 and 2016, there have been 49 confirmed opportunistic sightings within the proposed critical habitat coastal areas Table 2.2.a). Of these 49 confirmed opportunistic sightings, 26 of them were in Areas 1 and 2, 8 in Area 3, 1 in Area 4, 7 in Area 5, and 7 in Area 6 (Table 2.2.a). Because of the limitations of not having controlled and dedicated sampling efforts, these confirmed opportunistic sightings have provided only general information on the whales' potential geographic range during this period of time (*i.e.,* there are no data to describe the whales' general geographic range prior to 1975). Together, these SRKW sightings have confirmed their presence as far north as Chatham Strait, southeast Alaska (see NMFS 2019b for sightings in Canadian and Alaskan waters) and as far south as Monterey Bay, California.

Table 2.2.a Confirmed opportunistic sightings of SRKW off Washington, Oregon, and California from 1986 – 2016. Unconfirmed sightings are not included in this table. Confirmed sightings that occurred off Canadian and Alaskan waters are not included in this table.

Date	Location	Identification[a]	Source[b]	Critical Habitat Area
4 Apr 1986	Off Westport/Grays Harbor, WA	L pod	1, 2	1 or 2
13 Sep 1989	West of Cape Flattery, WA	L pod	3	1 or 2
17 Mar 1996	3 km off Grays Harbor, WA	L pod	3	1 or 2
20 Sep 1996	Off Sand Point, WA	L pod	4, 5	1 or 2
Apr 1999	Off Depoe Bay, OR	L pod	2	3
29 Jan 2000	Monterey Bay, CA	K and L pods	6, 7	6
21 Mar 2000	Off Yaquina Bay, OR	L pod	1	3
14 Apr 2000	Off Depoe Bay, OR	SRKW	5	3
15 Apr 2002	Long Beach, WA	L60 (stranded)	5, 8	1 or 2
13 Mar 2003	Monterey Bay, CA	L pod	6, 9	6
11 Mar 2004	Off Grays Harbor, WA	L pod	10	1 or 2
13 Mar 2004	Off Cape Flattery, WA	J pod	10	1 or 2
16 Feb 2005	Farallon Islands, CA	L pod	5	5
22 Mar 2005	Fort Canby-North Head, WA	L pod	10	1 or 2
23 Oct 2005	Off Columbia River	K pod	11	1 or 2
29 Oct 2005	Off Columbia River	K and L pods	11	1 or 2
26 Jan 2006	Pt. Reyes, CA	L pod	12	5

Date	Location	Identification[a]	Source[b]	Critical Habitat Area
30 Mar 2006	Off Columbia River	K and L pods	10	2
6 Apr 2006	Off Westport, WA	K and L pods	13	1
24 Jan 2007	Off San Francisco, CA	K pod	5, 6	5
18 Mar 2007	Off Fort Bragg, CA	L pod	5	5
24-25 Mar 2007	Monterey Bay, CA	K and L pods	6	6
30 Oct 2007	Bodega Bay, CA	L pod	13	5
27 Jan 2008	Monterey Bay, Cypress Point, Carmel Bay, CA	L pod	5, 6	6
2 Feb 2008	Monterey Bay, CA	K and L pods	5, 6	6
31 Jul 2008	Between Cape Alava and Cape Flattery, WA	L pod	5, 14	1 or 2
21 Jan 2009	Off Depoe, OR	L pod	5, 15	3
24 Jan 2009	Off Depoe, OR	L pod	5, 15, 16	3
5 Mar 2009	Monterey Bay, CA	L pod	5, 6	6
7 Mar 2009	Farallon Islands, CA	L pod	5	5
26 Mar 2009	Off Westport, WA	L pod	10	1 and 2
27 Mar 2009	Off Columbia River	L pod	10	2
4 June 2009	Off WA coast, west of Lake Ozette	L12 subpod	17	2
24 Jan 2010	Near Florence, OR	K pod	18	3
15 Apr 2010	Off Taholah, WA	L pod	13	2
10 Feb 2011	Monterey Bay, CA	L pod	5, 6	6
14 Feb 2011	Off San Francisco, CA	L pod	19	5
24 Mar 2011	WA coast near Umatilla Reef	K12 subpod	5, 14	1
29 Apr 2012	Off Westport, WA	K and L pods	13	2
21 May 2012	Off Depoe Bay, OR	L pod	10	3
15 Jun 2012	WA coast, 20 nmi offshore of La Push	L pod	13	2
2 Aug 2012	23 nm WNW of Cape Alava, WA	J pod	20	2
2 Feb 2013	25 km southwest of Willapa Bay, WA	L12 subpod	10	2
14 Feb 2013	Off Yaquina Head Lighthouse, OR	L pod	21	3

Date	Location	Identification[a]	Source[b]	Critical Habitat Area
28 Apr 2014	CA coast, 9 km west of Eel River mouth	K and L pods	22	4
17 Feb 2015	Off Cape Flattery, WA	K and L pods	10	1 and 2
23 Feb 2016	Off La Push, WA	L pod	10	1
27 Feb 2016	WA coast just north of Columbia River	K and L pods	10	2
7 Mar 2016	Off Cape Flattery, WA	J pod	10	2

[a] Identification: Pod listings do not imply that the entire pod was present.

[b] Sources: 1, J. K. B. Ford, Pacific Biological Station, Department of Fisheries and Oceans Canada, Nanaimo, B.C.; 2, Bigg et al. (1990); 3; Calambokidis et al. (2004); 4, P. Gearin, National Marine Mammal Laboratory, Alaska Fisheries Science Center, Seattle, WA; 5, D. Ellifrit, K. Balcomb, and M. Malleson, Center for Whale Research, Friday Harbor, WA; 6, N. A. Black, Monterey Bay Whale Watch, Pacific Grove, CA; 7, Black et al. (2001); 8, D. Duffield, Portland State University, Portland, OR; 9, Monterey Bay Whale Watch (2003); 10, Northwest Fisheries Science Center, Seattle, WA; 11, Southwest Fisheries Science Center, La Jolla, CA; 12, S. Allen, National Park Service, Pt. Reyes, CA; 13, Cascadia Research Collective, Olympia, WA; 14, J. Scordino and A. Akmajian, Makah Tribe, Neah Bay, WA; 15, M. Grover and L. Taylor, Whale Watching Center, Depoe Bay, OR; 16, C. Newell, Whale Research EcoExcursions, Depoe Bay, OR; 17, F. Pierson & J Hubbell, S/V Storm Petrel, report to Orca Sightings Network; 18, N. Edwards, Florence, OR, report to Orca Sightings Network; 19, J. Smith, Naked Whale Research, Fort Bragg, CA; 20, R. Fletcher, NOAA Olympic Coast National Marine Sanctuary, Port Angeles, WA; 21, B. Lagerquist and B. Mate, Oregon State University, Newport, OR; 22, Bio-Waves, Inc., Encinitas, CA.

Satellite Tagging Efforts

As part of a collaborative effort between NWFSC, Cascadia Research Collective and the University of Alaska, satellite-linked tags were deployed on eight male SRKW (three tags on J pod members, two on K pod, and three on L pod) from 2012 to 2016 in Puget Sound or in the coastal waters of Washington and Oregon (Table 2.2.b). The tags transmitted multiple locations per day to assess winter movements and occurrences of SRKW (Hanson *et al.* 2017).

Over the course of the study, the satellite tagging resulted in data range of duration days, from 3 days to 96 days depending on the tag, of monitoring with deployment durations from late December to mid-May (Table 2.2.b). The winter locations of the tagged whales included inland and coastal waters. The inland waters range occurs across the entire Salish Sea, from the northern end of the Strait of Georgia and Puget Sound, and coastal waters from central west coast of Vancouver Island, British Columbia to northern California (Hanson *et al.* 2017). J pod had high use areas (defined as 1 to 3 standard deviations) in the northern Strait of Georgia and the west entrance to the Strait of Juan de Fuca where they spent approximately 30 percent of their time there (Figure 2.2.c). K/L pods occurred almost exclusively on the continental shelf during December to mid-May, primarily on the Washington coast, with a continuous high use area between Grays Harbor and the Columbia River and off Westport and spending approximately 53 percent of their time there (Figure 2.2.d); Hanson *et al.* 2017, 2018). The tagged animals did not travel as far north or south as the confirmed opportunistic sightings discussed above; however, the tagging data provide general information on the home range and overlap of each pod from 2012 to 2016.

Satellite tagging can also provide details on preferred depths and distances from shore. Approximately 95 percent of the SRKW locations were within 34 km of the shore and 50 percent of these were within 10 km of the coast (Hanson *et al.* 2017). Only 5 percent of locations were greater than 34 km away from the coast, but no locations exceeded 75 km. Most locations were in waters less than 100m in depth.

Table 2.2.b. Satellite-linked tags deployed on Southern resident killer whales 2012-2016. (Hanson et al. 2018. This was part of a collaborative effort between NWFSC, Cascadia Research Collective, and the University of Alaska.

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

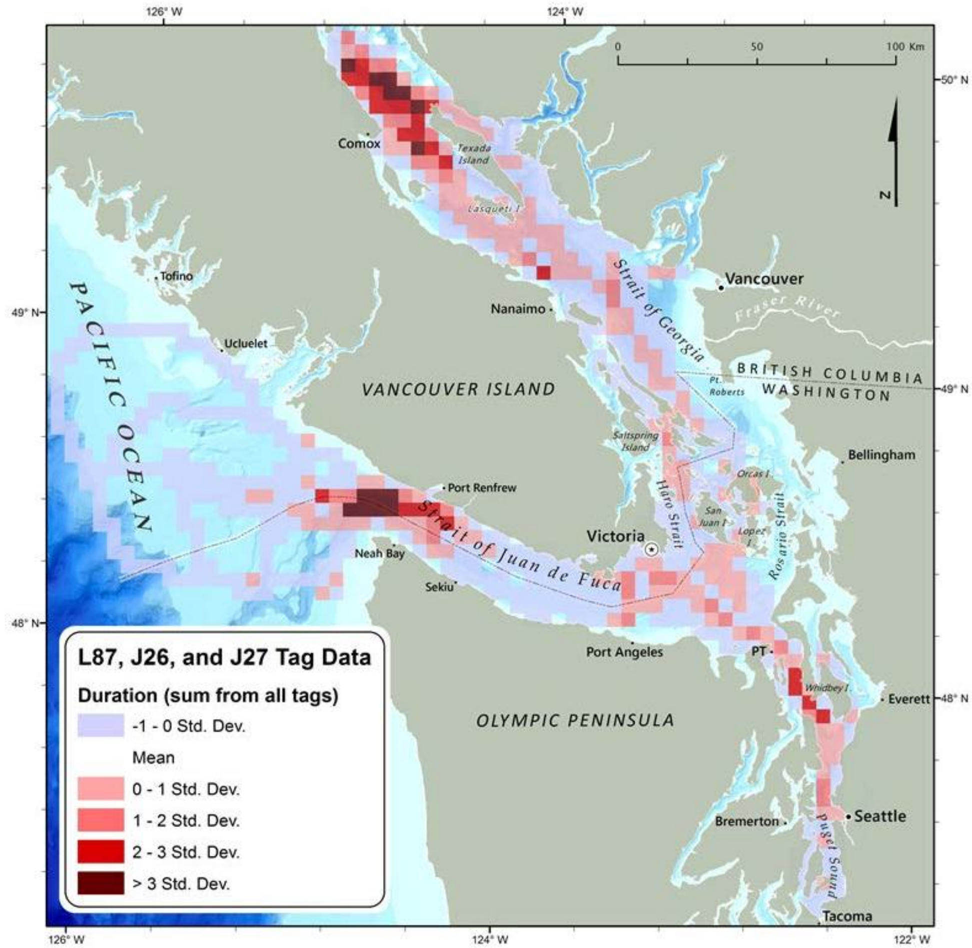

Figure 2.2.c Duration of occurrence model output for J pod tag deployments (Hanson *et al.* 2017). "High use areas" are illustrated by the 0 – 3 standard deviation pixels.

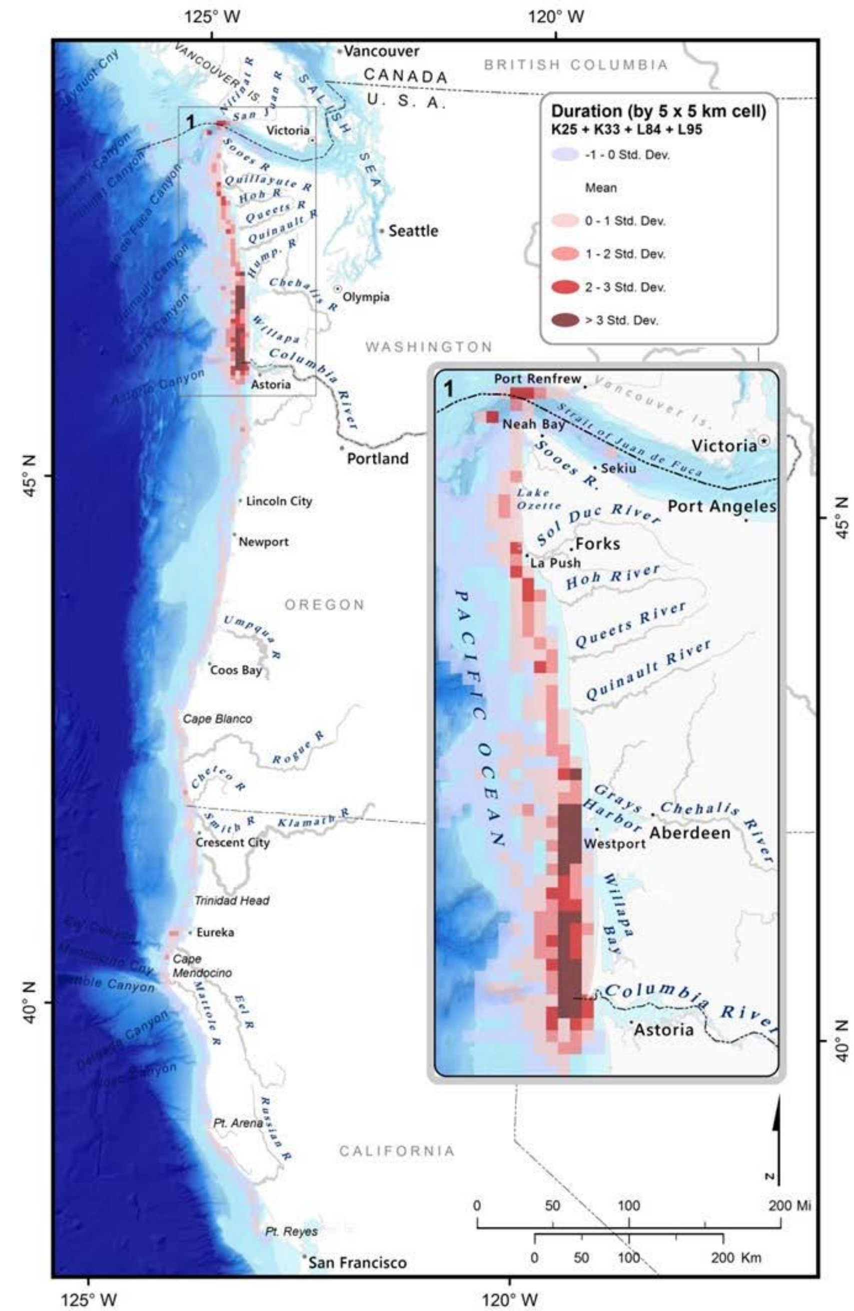

Figure 2.2.d Duration of occurrence model for all unique K and L pod tag deployments (Hanson *et al.* 2017). "High use areas" are illustrated by the 0 – 3 standard deviation pixels.

Passive Acoustic Monitoring

Passive acoustic recorders were deployed off the coasts of California, Oregon and Washington in most years since 2006 to assess their seasonal uses of these areas via the recording of stereotypic calls of the SRKW (Hanson *et al.* 2013; Emmons *et al.* 2019; Table 2.2.c). Passive aquatic listeners

(PALs) were originally deployed from 2006 – 2008. Since 2008, four to seventeen Ecological Acoustic Recorders (EARs) have been deployed. From 2006 – 2011, passive acoustic listeners and recorders were deployed in areas thought to be of frequent use by SRKWs based on previous sightings, where enhanced productivity was expected to be concentrated, and in areas with a reduced likelihood of fisheries interactions (Figure 2.2.e; Hanson *et al.* 2013). The number of recorder sites off the Washington coast increased from 7 to 17 in the fall of 2014 and locations were selected based on "high use areas" identified in the duration of an occurrence model (Figure 2.2.f), and sites within the U.S. Navy's Northwest Training Range Complex (NWTRC) in order to determine if SRKWs used these areas in other seasons when satellite-linked tags were not deployed (Hanson *et al.* 2017; Emmons *et al.* 2019). "High use areas" for the SRKW in winter were determined to be primarily located in three areas 1) the Washington coast, particularly between Grays Harbor and the mouth of the Columbia River (primarily for K/L pods); 2) the west entrance to the Strait of Juan de Fuca (primarily for J pod); and 3) the northern Strait of Georgia (primarily for J pod). It is important to note that recorders deployed within the NWTRC were designed to assess spatial use off Washington coast and thus the effort was higher in this area (*i.e.* the number of recorders increased in this area) compared to off Oregon and California.

There were acoustic detections off Washington coast in all months of the year (Figure 2.2.g; Table 2.2.d), with greater than 2.4 detections per month from January through June and a peak of 4.7 detections per month in both March and April, indicating that the SRKW may be present in Washington coastal waters at nearly any time of year, and in other coastal waters more often than previously believed (Hanson *et al.* 2017). Acoustic recorders were deployed off Newport, Fort Bragg, and Port Reyes between 2008 through 2013 and SRKW were detected 28 times (Table 2.2.d).

Table 2.2.c Recorder locations and recording dates (Emmons *et al.* 2019).

Location	Latitude/ Longitude	Dates of Recording	Total recording time (Days)
Juan de Fuca (JF)	48.49167, -124.7833	Nov 2013- Jul 2014	264
		Oct 2014- Jul 2015	293
		Sep 2015- May 2016	268
Cape Flattery Inshore	48.3338, -124.8264	Jan 2006-June 2006* Jan 2007-June 2007* Oct 2008- Feb 2009	159 158 145
(CFI)		Sep 2010- Apr 2011	216
		Oct 2011- Mar 2012	187
		Aug 2012- Nov 2013	99
Cape Flattery Mid Shelf	48.2078, -125.3480	Sep 2015- Jun 2016	281
(CFM)		Feb 2017- Jul 2017	160
Cape Flattery Offshore	48.17166, -125.6269	Jan 2006-June 2006* Jan 2007-June 2007* Jan 2008-June 2008* Oct 2008- Mar 2009	154
(CFO)		Sep 2010- Jul 2011	334
		Oct 2011- Aug 2012	336

Location	Latitude/ Longitude	Dates of Recording	Total recording time (Days)
		Sep 2012- Sep 2013	371
		Nov 2013- Sep 2014	336
		Oct 2014- Aug 2015	317
		Sep 2015- May 2016	259
		Feb 2017- Jul 2017	176
Cape Flattery Deep (CFD)	48.1000, -125.7833	Feb 2017- Jul 2017	161
Sand Point (SP)	48.1015, -124.7941	Nov 2013- Jul 2014	259
		Oct 2014- Aug 2015	317
La Push (LP)	47.8803, -124.6809	Oct 2014- Jul 2015	297
		Sep 2015- Jul 2016	317
Quinault Deep (QD)	47.4640, -125.1964	Nov 2014- Jul 2015	265
		Mar 2016- Apr 2016	45
		Feb 2017- Jul 2017	159
Quinault Mid Shelf (QM)	47.3000, -124.7500	Feb 2017- Apr 2017	69
Quinault Inshore (QI)	47.3172, -124.4158	Nov 2014- Jul 2015	265
		Sep 2015- Jul 2016	319
		Feb 2017- Jul 2017	160
Westport (WP)	46.9794, -124.4281	Oct 2008- Feb 2009	145
		Nov 2010- Aug 2011	308
		Oct 2011- Aug 2012	328
		Oct 2012- Jun 2013	222
		Oct 2013- Jan 2014	77
		Nov 2014- Nov 2014	15
		Sep 2015- Aug 2016	339
Westport Mid Shelf	46.9615, -124.4878	Nov 2014- Jul 2015	265
(WM)		Jan 2016- Sep 2016	243
		Sep 2016- Jun 2017	276
Westport Deep (WD)	46.8333, -125.0998	Mar 2016- Sep 2016	172
		Sep 2016- Jul 2017	328
Willapa (WI)	46.6515, -124.2608	Nov 2014- Jan 2015	72
		Sep 2016- Apr 2017	230
Columbia River (CR)	46.3388, -124.4170	Mar 2008- Jul 2008	71
		Dec 2008- Apr 2009	150
		Oct 2010- Sep 2011	336
		Oct 2011- Nov 2011	53
		Nov 2012- Nov 2012	10
		Oct 2013- Sep 2014	344
		Nov 2014- Sep 2015	310
		Jan 2016- Sep 2016	244

Location	Latitude/ Longitude	Dates of Recording	Total recording time (Days)
		Sep 2016- Jul 2017	315
Columbia River South	46.1617, -124.2658	Oct 2013- Oct 2014	374
(CRS)		Nov 2014- Jun 2015	215
Newport (NP)	44.7434, -124.2466	Feb 2011- Jul 2011	155
		Sep 2011- Sep 2012	367
		Sep 2012- Mar 2013	172
Fort Bragg (FB)	39.3482, -123.8843	Feb 2008- May 2008	100
		Dec 2010- Jul 2011	209
		Nov 2011- Sep 2012	321
		Sep 2012- Aug 2013	342
Point Reyes (PR)	37.9175, -123.0723	Dec 2010- Oct 2011	315
		Oct 2011- Sep 2012	324
		Sep 2012- Sep 2013	365

*Indicates a passive aquatic listener (PAL) was deployed.

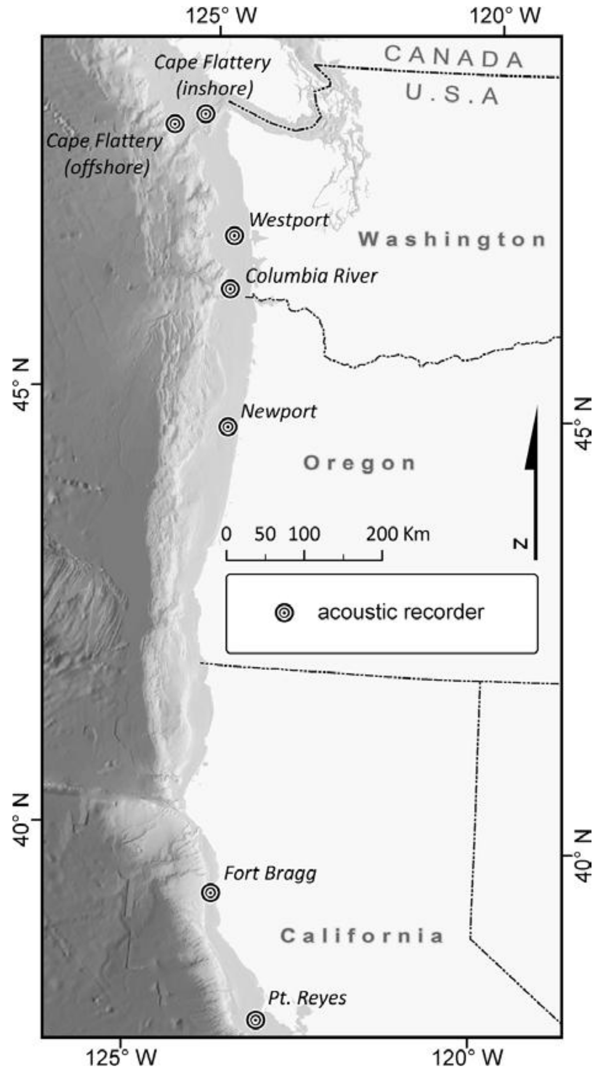

Figure 2.2.e. Deployment locations of acoustic recorders on the U.S. west coast from 2006 to 2011 (Hanson *et al.* 2013).

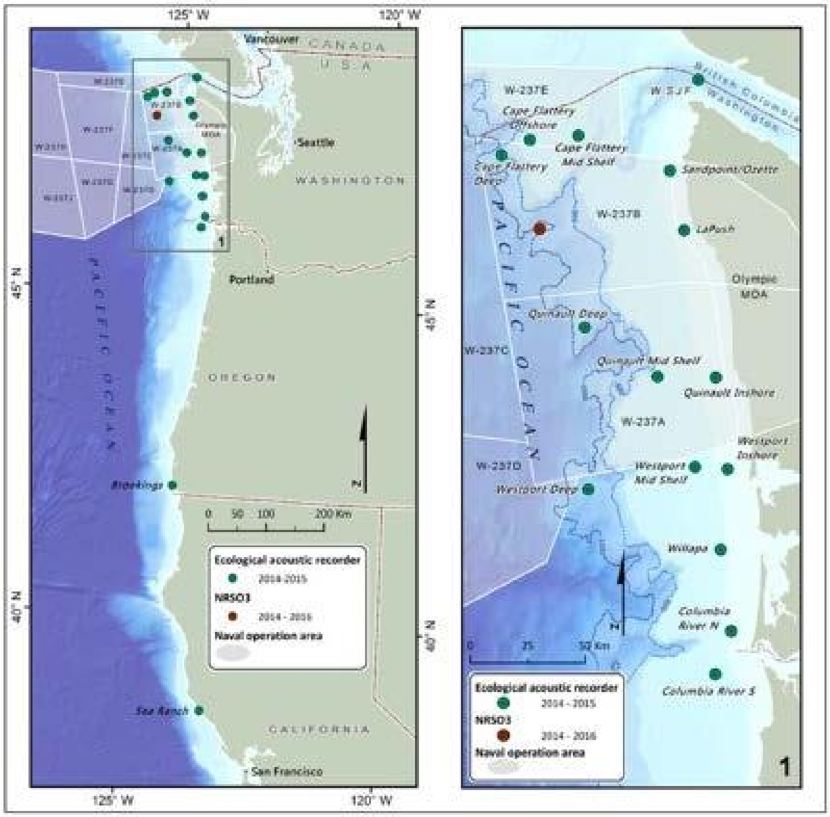

Figure 2.2.f. Locations of passive acoustic recorders deployed beginning in the fall of 2014 (Hanson *et al.* 2017).

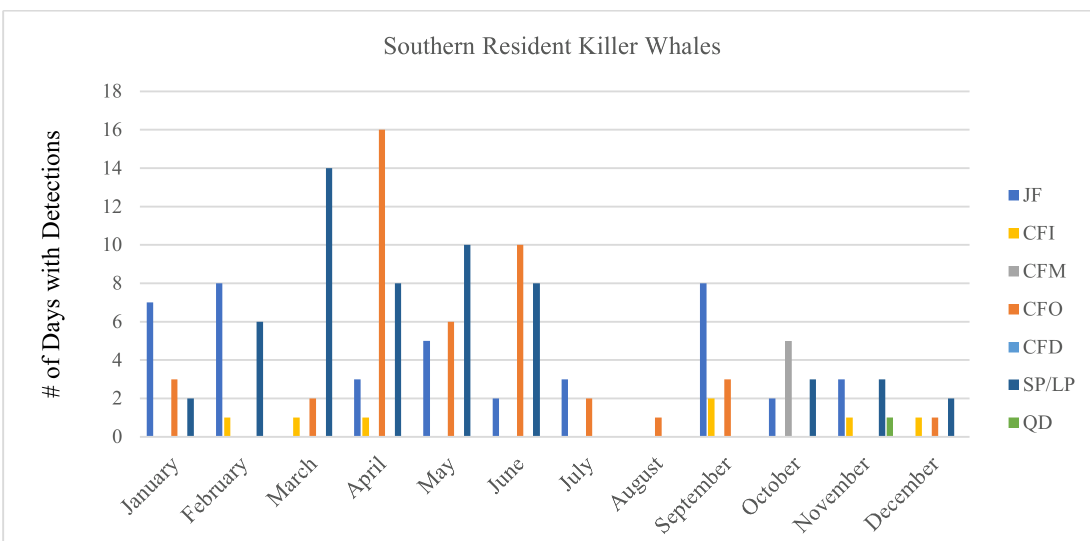

Figure 2.2.g. Counts of detections at each northern recorder site by month from 2014-2017 (Emmons *et al.* 2019). Areas include Juan de Fuca (JF); Cape Flattery Inshore (CFI); Cape Flattery Mid Shelf (CFM); Cape Flattery Offshelf (CFO); Cape Flattery Deep(CFD); Sand Point and La Push (SP/LP); and Quinault Deep (QD).

Table 2.2.d. Detection days by month and year at each recorder location. Effort days of recording are indicated in parentheses (NWFSC unpubl. data). Months with no recorder effort or data are shaded in grey.

2006	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Cape Flattery Inshore	0 (9)	1 (28)	3 (31)	0 (30)	0 (31)	1 (30)	0 (31)	0 (12)				
Cape Flattery Offshore	0 (9)	0 (28)	0 (31)	1 (30)	1 (31)	0 (30)	0 (31)	0 (31)	0 (26)			
Westport	0 (8)	0 (28)	4 (31)	2 (30)	3 (31)	1 (30)	0 (31)	0 (31)	0 (15)			
2007	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Cape Flattery Inshore	1 (8)	2 (28)	1 (31)	0 (30)	0 (31)	0 (30)	0 (25)					
Cape Flattery Offshore	0 (8)	0 (28)	0 (31)	1 (30)	1 (31)	0 (30)	0 (25)	0 (15)	0 (30)	2 (17)		
Westport	0 (5)	2 (28)	0 (31)	0 (30)	0 (31)	0 (30)	0 (31)	0 (31)	0 (30)	0 (31)	0 (30)	0 (31)
2008	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Cape Flattery Inshore										0 (30)	2 (30)	0 (31)
Cape Flattery Offshore	0 (15)	0 (29)	0 (31)	1 (30)	0 (31)	2 (30)	0 (31)	0 (1)		6 (30)	3 (30)	0 (31)
Westport	0 (31)	0 (29)	3 (31)	1 (30)	1 (31)	0 (17)				0 (30)	0 (30)	0 (31)
Columbia River			1 (13)	3 (30)	4 (31)	0 (30)	0 (10)					0 (29)
Fort Bragg		0 (10)	0 (31)	0 (30)	0 (17)							
2009	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Cape Flattery Inshore	5 (31)	5 (23)						0 (1)				
Cape Flattery Offshore	2 (31)	2 (28)	0 (4)									
Westport	1 (23)											
Columbia River	2 (31)	5 (28)	4 (31)	6 (30)	0 (1)							
Newport				0 (23)	1 (31)	0 (30)	0 (31)	0 (11)				
2010	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Cape Flattery Inshore									0 (30)	1 (31)	0 (30)	0 (31)
Cape Flattery Offshore									1 (30)	0 (31)	1 (30)	0 (31)
Westport											0 (10)	0 (31)

Columbia River											0 (8)	0 (31)
Newport									0 (17)	0 (31)	0 (30)	0 (31)
Fort Bragg										0 (4)	0 (30)	0 (31)
Point Reyes												0 (16)
2011	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Cape Flattery Inshore	0 (31)	2 (28)	2 (31)	1 (4)						3 (31)	1 (30)	2 (31)
Cape Flattery Offshore	3 (31)	0 (28)	2 (31)	2 (30)	2 (31)	5 (30)	0 (31)			0 (31)	0 (30)	0 (31)
Westport	4 (31)	1 (28)	6 (31)	3 (30)	3 (31)	2 (30)	0 (31)	0 (4)		0 (31)	1 (30)	0 (31)
Columbia River	4 (31)	1 (28)	3 (31)	2 (30)	3 (31)	0 (30)	1 (31)	0 (31)	0 (30)	1 (31)	0 (22)	
Newport		1 (11)	0 (31)	0 (30)	1 (31)	0 (30)	0 (22)		0 (17)	0 (31)	0 (30)	0 (31)
Fort Bragg	0 (31)	1 (28)	0 (31)	0 (30)	0 (31)	0 (30)	0 (13)			0 (4)	0 (30)	0 (31)
Point Reyes	0 (31)	3 (28)	0 (31)	0 (30)	0 (31)	0 (30)	0 (31)	0 (31)	0 (30)	0 (31)	0 (30)	0 (31)
2012	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Cape Flattery Inshore	0 (31)	0 (29)	0 (31)	0 (4)				0 (8)	2 (30)	1 (31)	0 (30)	
Cape Flattery Offshore	0 (31)	0 (29)	1 (31)	0 (30)	2 (31)	0 (30)	1 (31)	1 (31)	1 (30)	0 (31)	0 (30)	0 (31)
Westport	0 (31)	1 (29)	7 (31)	7 (30)	5 (31)	1 (30)	0 (31)	0 (23)		0 (4)	0 (30)	1 (31)
Newport	0 (31)	2 (29)	2 (31)	0 (30)	1 (31)	0 (30)	0 (31)	0 (31)	0 (30)	0 (31)	0 (30)	0 (31)
Fort Bragg	2 (31)	0 (29)	0 (31)	0 (30)	0 (31)	0 (30)	0 (31)	0 (31)	0 (12)			
Point Reyes	2 (31)	0 (29)	0 (31)	0 (30)	1 (31)	0 (30)	0 (31)	0 (31)	0 (12)	0 (31)	0 (30)	1 (31)
2013	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Cape Flattery Offshore	0 (31)	1 (28)	0 (31)	4 (30)	0 (31)	1 (30)	0 (31)	1 (31)	0 (6)	0 (1)	0 (30)	0 (31)
Westport	2 (31)	3 (28)	9 (31)	7 (30)	1 (31)	0 (6)				0 (8)	2 (30)	0 (31)
Newport	2 (31)	3 (28)	1 (13)									
Fort Bragg	1 (31)	3 (28)	0 (31)	0 (30)	0 (31)	0 (30)	0 (31)	0 (20)				
Point Reyes	0 (31)	0 (28)	0 (31)	0 (30)	0 (31)	0 (30)	0 (31)	0 (31)	0 (12)			
Columbia River South										3 (9)	1 (30)	0 (31)
Juan de Fuca										0 (1)	1 (30)	0 (31)
2014	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Cape Flattery Offshore	0 (31)	0 (28)	0 (31)	2 (30)	0 (31)	0 (30)	0 (31)	0 (31)	1 (30)	0 (31)	0 (30)	0 (31)
Westport	1 (31)	5 (28)	3 (31)	2 (30)	6 (31)	3 (30)	1 (31)	0 (31)	0 (30)	0 (31)	1 (15)	

Juan de Fuca	1 (31)	0 (28)	0 (31)	0 (30)	1 (31)	0 (30)	1 (31)	0 (31)	0 (30)	0 (31)	0 (30)	0 (31)
Sand Point/Ozette	0 (31)	0 (28)	0 (31)	0 (30)	4 (31)	5 (30)	0 (31)	0 (31)	0 (30)	1 (31)	3 (30)	0 (31)
Columbia River North	0 (31)	1 (28)	3 (31)	3 (30)	1 (31)	2 (30)	1 (31)	0 (31)	0 (30)	0 (31)	1 (30)	0 (31)
Columbia River South	1 (31)	2 (28)	1 (31)	1 (30)	2 (31)	0 (30)	0 (31)	0 (31)	0 (30)	0 (31)	0 (30)	0 (31)
Brookings	3 (27)	0 (24)	0 (31)	0 (30)	0 (31)	0 (30)	0 (31)	0 (31)	0 (30)	0 (31)	0 (30)	1 (31)
Sea Ranch	0 (31)	0 (28)	0 (31)	0 (30)	0 (31)	0 (30)	0 (31)	0 (31)	0 (30)	0 (20)	0 (10)	0 (31)
La Push										1 (29)	1 (30)	2 (31)
Willapa										0 (1)	0 (30)	0 (31)
Quinault Inshore										0 (1)	0 (30)	0 (31)
Westort Mid Shelf										0 (1)	0 (30)	0 (31)
Quinault Deep										0 (1)	0 (30)	0 (31)
2015	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Cape Flattery Offshore	0 (31)	0 (28)	0 (31)	0 (30)	0 (31)	1 (30)	0 (30)	0 (15)	0 (24)	0 (31)	0 (30)	0 (31)
Westport									0 (15)	0 (31)	0 (30)	0 (31)
Juan de Fuca	2 (31)	3 (28)	0 (31)	1 (30)	1 (31)	2 (30)	2 (23)		8 (25)	2 (31)	2 (30)	0 (31)
Sand Point/Ozette	0 (31)	3 (28)	2 (31	1 (30)	0 (31)	1 (30)	0 (30)	0 (15)	0 (5)			
Columbia River North	3 (31)	3 (28)	4 (31)	9 (30)	7 (31)	1 (30)	0 (30)	0 (31)	0 (7)			
Columbia River South	1 (31)	2 (28)	0 (31)	0 (30)	0 (31)	0 (4)						
Brookings	0 (31)	0 (28)	1 (31)	0 (30)	0 (31)	0 (1)						
Sea Ranch	0 (31)	0 (28)	0 (31)	0 (30)	0 (31)	0 (30)	0 (30)	0 (31)	0 (30)	0 (13)		
La Push	1 (31)	1 (28)	4 (31)	5 (30)	4 (31)	1 (30)	0 (26)		0 (25)	1 (31)	0 (30)	0 (31)
Willapa	0 (11)											
Quinault Inshore	1 (31)	2 (28)	0 (31)	0 (30)	1 (31)	0 (30)	0 (23)		0 (25)	0 (31)	0 (30)	0 (31)
Westort Mid Shelf	0 (31)	0 (28)	2 (31)	0 (30)	1 (31)	0 (30)	0 (23)					
Quinault Deep	0 (31)	0 (28)	0 (31)	0 (30)	0 (31)	0 (30)	0 (24)					
2016	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Cape Flattery Offshore	0 (31)	0 (29)	0 (31)	2 (30)	1 (19)							
Westport	0 (31)	4 (29)	1 (31)	5 (30)	1 (19)	0 (30)	0 (31)	0 (31)	0 (7)			
Juan de Fuca	4 (31)	5 (29)	0 (31)	2 (30)	3 (28)							
Sand Point/Ozette												
Columbia River North	0 (21)	5 (29)	3 (31)	6 (30)	6 (31)	0 (30)	0 (31)	0 (31)	0 (7)	2 (0)	1 (0)	0 (0)

La Push	1 (31)	1 (29)	8 (31)	1 (30)	1 (31)	0 (30)	0 (16)					
Willapa									0 (22)	1 (31)	1 (30)	0 (31)
Quinault Inshore	0 (31)	1 (29)	0 (31)	0 (30)	0 (31)	0 (30)	0 (31)	0 (31)				
Westort Mid Shelf	0 (22)	4 (29)	1 (31)	1 (30)	0 (31)	0 (30)	0 (28)		0 (23)	0 (31)	2 (30)	1 (31)
Quinault Deep			0 (22)	0 (22)								
2017	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Cape Flattery Offshore		0 (21)	0 (31)	2 (30)	1 (31)	0 (30)	1 (31)	0 (2)				
Columbia River North	1 (31)	1 (28)	5 (31)	3 (30)	5 (31)	0 (30)	0 (19)					
Willapa	3 (31)	3 (28)	6 (31)	1 (26)								
Quinault Inshore		0 (20)	1 (31)	0 (30)	0 (31)	0 (30)	0 (18)					
Westort Mid Shelf	4 (31)	4 (28)	1 (31)	0 (30)	4 (31)	1 (10)						
Quinault Deep		0 (19)	0 (31)	0 (30)	0 (31)	0 (30)	0 (18)					

In a recent study, researchers collected data using an autonomous acoustic recorder deployed at Swiftsure Bank from August 2009 to July 2011 to assess how this area is used by Northern Resident and Southern Resident killer whales as shown in Figure 2.2.h (Riera *et al.* 2019).

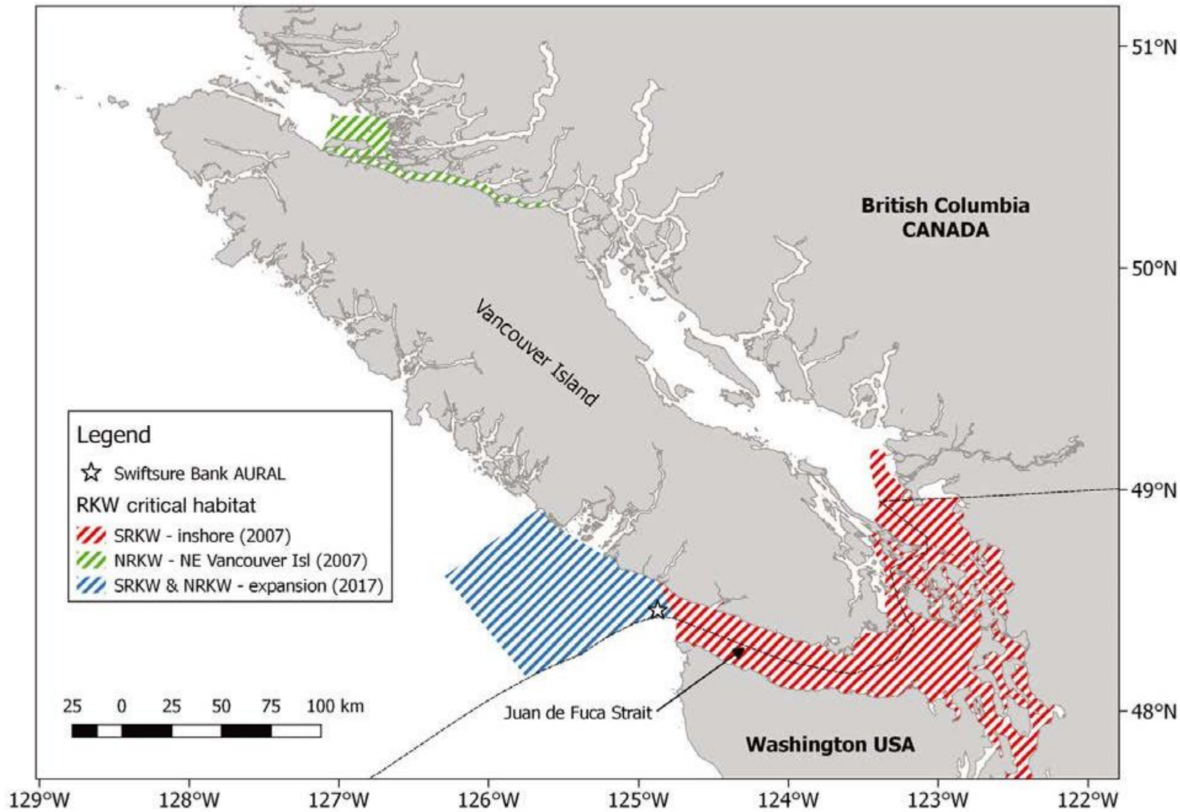

Figure 2.2.h. Swiftsure Bank study site off the coast of British Columbia, Canada in relation to the 2007 Northern Resident critical habitat (NE Vancouver Island) and 2007 Southern Resident killer whale critical habitat (inshore waters) and the 2017 Northern Resident and Southern Resident expansion of critical habitat (Riera *et al.* 2019).

SRKW were detected on 163 days with 175 encounters (see Figure 2.2.i for number of days of acoustic detections for each month). All three pods were detected at least once per month except for J pod in January and November and L pod in March. K and L pods were heard more often (87 percent of calls and 89 percent of calls, respectively), between May and September. J pod was heard most often during winter and spring (76 percent of calls during December and February through May; Riera *et al.* 2019). K pod had the longest encounters in June, with 87 percent of encounters longer than 2 hours occurring between June and September. L pod had the longest encounters in May, with 79 percent of encounters longer than two hours occurring during the summer (May through September). The longest J pod encounters were during winter, with 72 percent of encounters longer than 2 hours occurring between December and May (Riera *et al.* 2019).

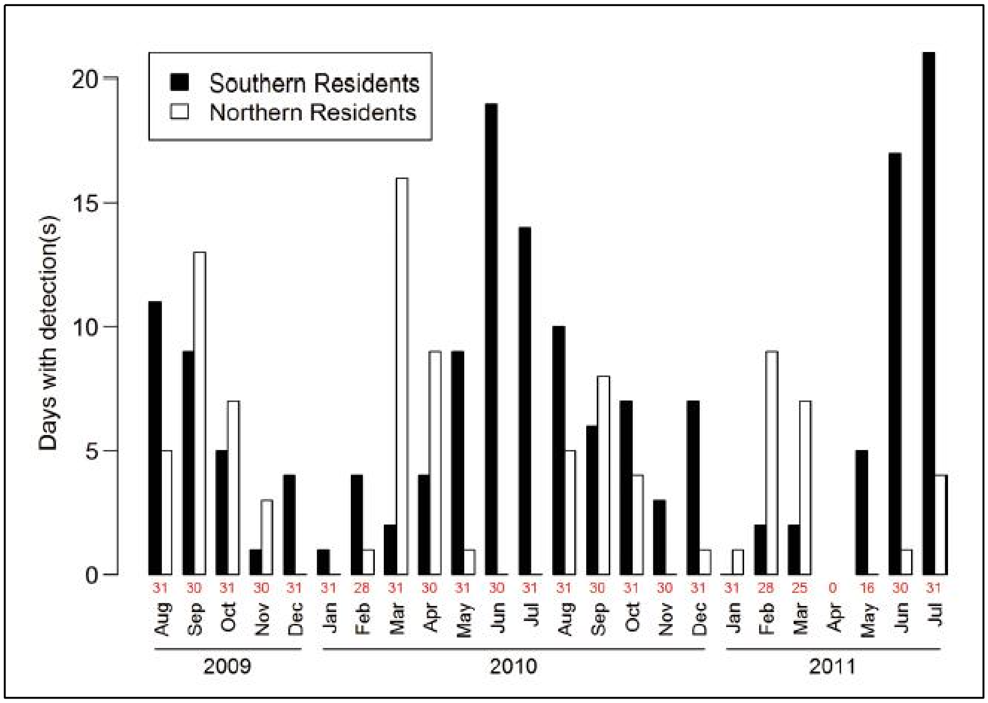

Figure 2.2.i. Number of days with acoustic detections of SRKWs at Swiftsure Bank from August 2009 – July 2011. Red numbers indicate days of effort. (Riera *et al.* 2019).

2.3 Limiting Factors and Threats

Several factors – including the demographic and behavioral issues (Section 2.1) and those identified in the recovery plan for SRKW may be limiting recovery. The recovery plan identified three major threats including (1) the quantity and quality of prey, (2) toxic chemicals that accumulate in top predators, and (3) impacts from sound and vessels. Oil spills and disease are also risk factors. It is likely that multiple threats are acting together to impact SRKWs. Modeling exercises have attempted to identify which threats are most significant to survival and recovery (*e.g.* Lacy *et al.* 2017) and available data suggest that all of the threats are potential limiting factors (NMFS 2008).

2.3.1 Quantity and Quality of Prey

SRKWs have been documented to consume a variety of fish species (22 species) and one species of squid (Ford *et al.* 1998; Ford *et al.* 2000; Ford and Ellis 2006; Hanson *et al.* 2010; Ford *et al.* 2016), but salmon are identified as their primary prey. SRKWs are the subject of ongoing research, the majority of which has occurred in inland waters of Washington State and British Columbia, Canada during summer months and includes direct observation, scale and tissue sampling of prey remains, and fecal sampling. The diet data suggest that SRKWs are consuming mostly larger (*i.e.,* generally age 3 and up) Chinook salmon (Ford and Ellis 2006). Chinook salmon is their primary prey despite the much lower abundance in comparison to other salmonids in some areas and during certain time periods (Ford and Ellis 2006). Factors of potential importance include the species' large size, high fat and energy content, and year-round occurrence in the SRKWs' geographic range. Chinook salmon have the highest value of total energy content compared to other salmonids because of their larger body size and higher energy density (kilocalorie/kilogram (kcal/kg)) (O'Neill *et al.* 2014). For example, in order for a SRKW to obtain the total energy value of one adult Chinook salmon, they would need to consume approximately 2.7 coho, 3.1 chum, 3.1 sockeye, or 6.4 pink salmon (O'Neill *et al.* 2014). Research suggests that SRKWs are capable of detecting, localizing, and recognizing Chinook salmon through their ability to distinguish Chinook echo structure as different from other salmon (Au *et al.* 2010).

Over the last forty years, predation on Chinook salmon off the West Coast of North America by marine mammals has been estimated to have more than doubled (Chasco et al. 2017). In particular, southern Chinook salmon stocks ranging south from the Columbia River have been subject to the largest increases in predation, and Chasco et al. (2017) suggested that Southern Residents may be the most disadvantaged compared to other more northern resident killer whale populations given the northern migrations of Chinook salmon stocks in the ocean and this competition may be limiting the growth of the Southern Resident population.

May - September

Scale and tissue sampling from May to September in inland waters of Washington and British Columbia, Canada indicate that the SRKW's diet consists of a high percentage of Chinook salmon (monthly proportions as high as >90 percent) (Hanson *et al.* 2010; Ford *et al.* 2016). Genetic analysis of the Hanson *et al.* (2010) samples from 2006-2010 indicate that when SRKW are in inland waters from May to September, they primarily consume Chinook stocks that originate from the Fraser River (80–90 percent of the diet in the Strait of Juan de Fuca and San Juan Islands; including Upper Fraser, Mid Fraser, Lower Fraser, North Thompson, South Thompson and Lower Thompson), and to a lesser extent consume stocks from Puget Sound (North and South Puget Sound) and Central British Columbia Coast and West and East Vancouver Island. This is not unexpected as all of these stocks are returning to streams proximal to these inland waters during this timeframe. Few diet samples have been collected in summer months outside of the Salish Sea.

DNA quantification methods are also used to estimate the proportion of different prey species in the diet from fecal samples (Deagle *et al.* 2005). Recently, Ford *et al.* (2016) confirmed the importance of Chinook salmon to SRKWs in the early to mid-summer months (May-August) using DNA sequencing from SRKW feces collected in inland waters of Washington and British Columbia. Salmon and steelhead made up greater than 98 percent of the inferred diet, of which almost 80 percent were Chinook salmon. Coho salmon and steelhead are also found in the diet in inland waters of Washington and British Columbia in spring and fall months when Chinook salmon are less abundant. Specifically, coho salmon contribute to over 40 percent of the diet in September in inland waters, which is evidence of prey shifting at the end of summer towards coho salmon (Ford *et al.* 1998; Ford and Ellis 2006; Hanson *et al.* 2010; Ford *et al.* 2016). Less than 3 percent each of chum salmon, sockeye salmon, and steelhead were observed in fecal DNA samples collected in the summer months (May through September) in inland waters.

October - December

Prey remains and fecal samples collected in U.S. inland waters during October through December indicate Chinook and chum salmon are primary contributors of the whale's diet during this time (NWFSC unpublished data; Figure 2.3.a). Diet data for the Strait of Georgia and coastal waters is limited.

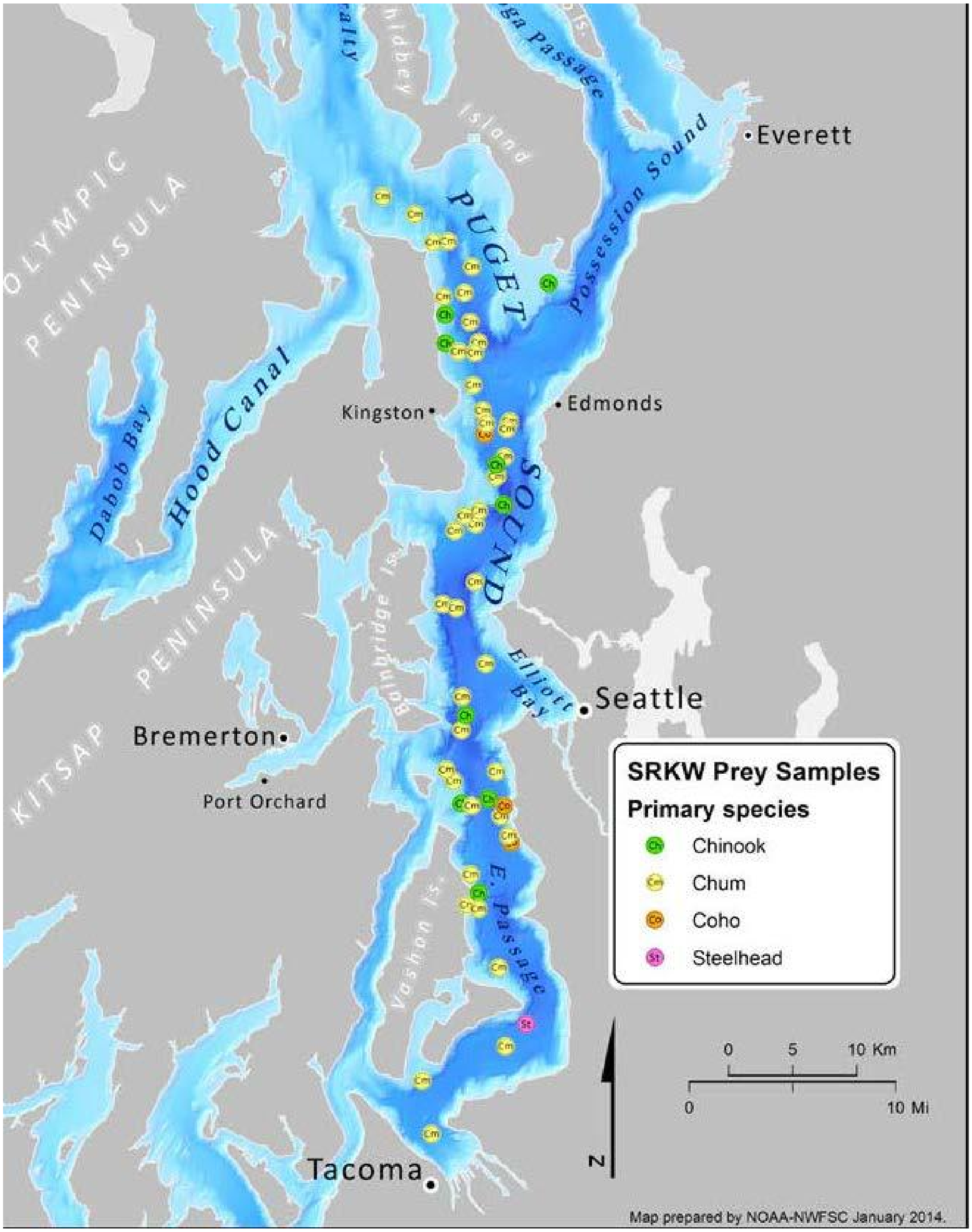

Figure 2.3.a Map of locations of SRKW predation events by prey species in Puget Sound between October and December (NWFSC unpubl. data).

January – April

Observations of SRKWs overlapping with salmon runs (Wiles 2004; Zamon *et al.* 2007) and collection of prey and fecal samples have also occurred in coastal waters in the winter and spring months. Although fewer predation events have been observed and less fecal samples collected in coastal waters, recent data indicate that salmon, and Chinook salmon in particular, remains an important dietary component when the SRKWs occur in outer coastal waters during these timeframes. Prior to 2013, only three prey samples for SRKW on the U.S. outer coast had been collected (Hanson *et al.* in prep). From 2013 to 2016, satellite tags were used to locate and follow the whales to obtain predation and fecal samples. A total of 55 samples were collected from northern California to northern Washington (Figure 2.3.b). Results of the 55 available prey samples indicate that, as is the case in inland waters, Chinook are the primary species detected in diet samples on the outer coast, although steelhead, chum, lingcod, and halibut were also detected in samples. Despite J pod utilizing much of the Salish Sea – including the Strait of Georgia – in winter months (Hanson *et al*. 2018), few diet samples have been collected in this region in winter.

The occurrence of K and L pods off the Columbia River in March suggests the importance of Columbia River spring runs of Chinook salmon in their diet (Hanson *et al.* 2013). Chinook genetic stock identification from samples collected in winter and spring in coastal waters from California through Washington included 12 U.S. west coast stocks, and showed that over half the Chinook salmon consumed originated in the Columbia River (Ward, May 23, 2019; Workgroup Agenda Item B.3; Figure 2.3.b). Columbia River, Central Valley, Puget Sound, and Fraser River Chinook salmon collectively comprised over 90 percent of the 55 diet samples collected for SRKW's in coastal areas (Ward, May 23, 2019; Workgroup Agenda Item B.3).

As noted, most of the Chinook prey samples opportunistically collected in coastal waters were determined to have originated from the Columbia River basin, including Lower Columbia Spring, Middle Columbia Tule, and Upper Columbia Summer/Fall. In general, we would expect to find these stocks given the diet sample locations (Figure 2.3.b) However, the Chinook stocks included fish from as far north as the Taku River (Alaska and British Columbia stocks) and as far south as the Central Valley California (Ward, May 23, 2019; Workgroup Agenda Item B.3).

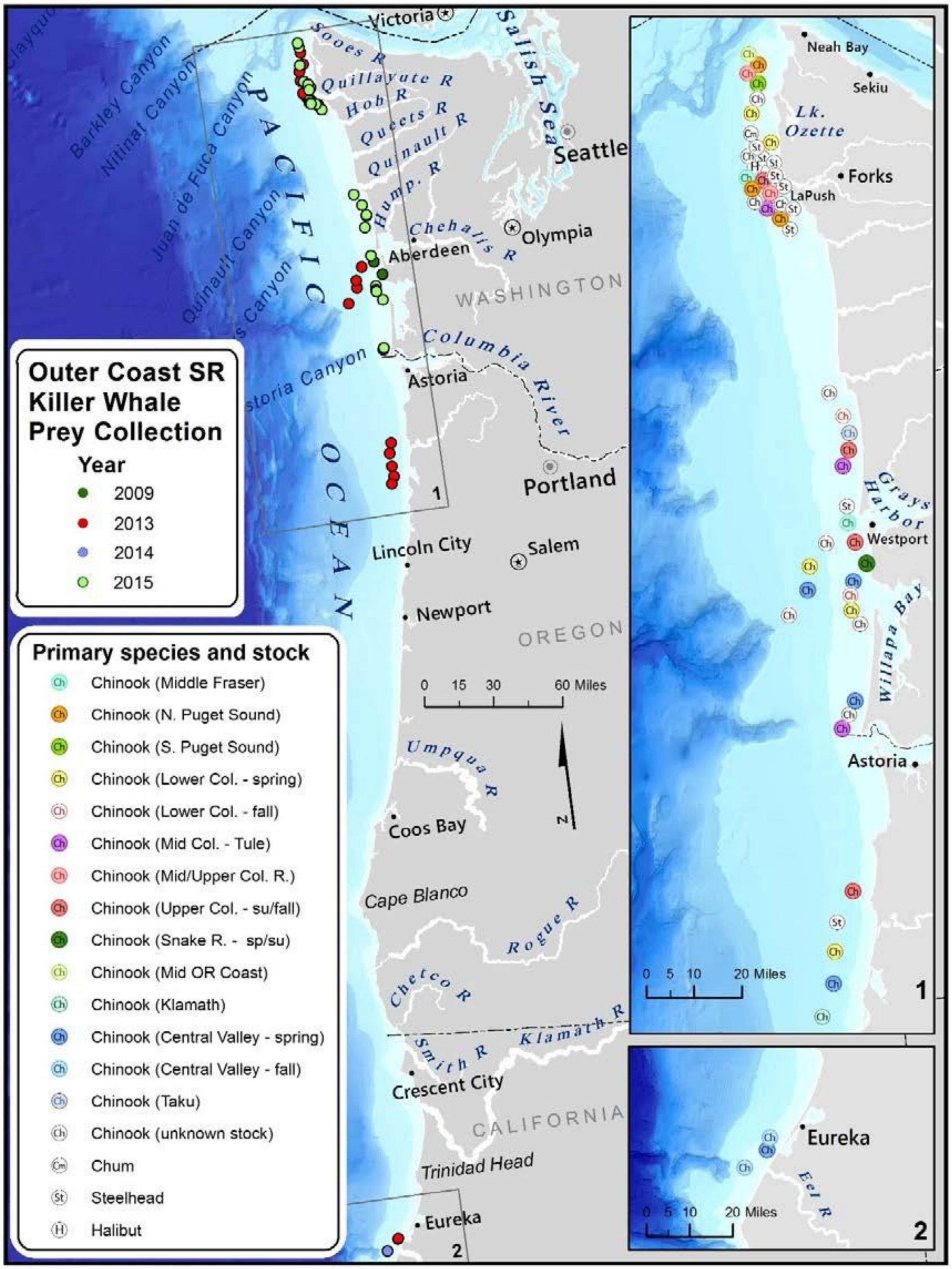

Figure 2.3.b. Location and species for scale/tissue samples collected from Southern Resident killer whale predation events in outer coastal waters[3]

[3] Ward presentation to the Workgroup on May 23, 2019; Agenda Item B.3

In general, over the past decade, some Chinook salmon stocks within the range of the SRKWs have had relatively high abundance (*e.g.* Washington (WA)/Oregon (OR) coastal stocks, some Columbia River stocks) compared to the previous decade, whereas other stocks originating in the more northern and southern ends of the whales' range (*e.g.* most Fraser stocks, Northern and Central British Columbia (B.C.) stocks, Georgia Strait, Puget Sound, and Central Valley) have declined. There are many factors that affect the abundance, productivity, spatial structure, and diversity of Chinook salmon and thus affect prey availability for the whales. Human impacts and limiting factors come from multiple sources, including dams, water management and diversion, habitat degradation, hatchery effects, fishery management decisions, and ecological factors, including predation and environmental variability. Changing ocean and freshwater conditions driven by climate change have influenced freshwater and ocean survival and distribution of Chinook and other Pacific salmon, affecting the prey available to SRKWs.

In an effort to prioritize local recovery efforts concentrated in the Salish Sea to increase the whales' prey base, NMFS and WDFW developed a report identifying Chinook salmon stocks thought to be of high importance to SRKW along the West Coast (NOAA and WDFW 2018)[4]. Scientists and managers from the U.S. and Canada reviewed the model at a workshop sponsored by the National Fish and Wildlife Foundation (NFWF), where the focus was on assisting NFWF in prioritizing funding for salmon related projects (many of these were geographically constrained to the Salish Sea, because of limitations by NFWF funders). The priority stock report was created using observations of Chinook salmon stocks found in scat and prey scale/tissue samples, and by estimating the spatial and temporal overlap with Chinook salmon stocks ranging from Southeast Alaska (SEAK) to California (CA). At the March 2019 Council meeting, the Council asked the Salmon Technical Team (STT) to examine this list and identify the stocks that are represented in models used annually in the ocean salmon fishery management process. In response, the STT created a table with the rankings removed, that aligned NMFS' list of prioritized Chinook salmon prey stocks for SRKW (NOAA and WDFW 2018) with PFMC Chinook salmon stocks with model representation, as well as identified Chinook salmon stocks from NMF' list without model representation. The STT presented the table to the Council on March 12, 2019 (Agenda Item D.8.a, Supplemental STT Report 2, reproduced in Appendix G). The Workgroup examined these reports, and members of the Workgroup suggested some modifications to the distribution scores for some stocks as well as some error checking. Because the list was developed to help prioritize salmon recovery actions and not to describe or assess prey availability along the coast, and the full workgroup was unable to endorse the methodology used to develop it, the Workgroup decided to not use the list. Instead, we developed a quantitative method to assess area-specific abundances of Chinook stocks, described in Section 5.1 of this document.

Hatchery production is a significant component of the salmon prey base returning to watersheds within the range of SRKWs (Barnett-Johnson *et al.* 2007; NMFS 2008). The release of hatchery fish has not been identified as a threat to the survival or persistence of SRKWs. It is likely that hatchery produced fish benefit this endangered population of whales by enhancing prey availability to SRKWs and hatchery fish often contribute significantly to the salmon stocks consumed (Hanson *et al.* 2010). Currently, hatchery fish play a mitigation role of helping sustain

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[4]https://www.westcoast.fisheries.noaa.gov/publications/protected_species/marine_mammals/killer_whales/recovery/srkw_priority_chinook_stocks_conceptual_model_report___list_22june2018.pdf

Chinook salmon numbers while other, longer term, recovery actions for natural fish are underway (For large scale examples please see NMFS 2014 or NMFS 2017).

2.3.2 Nutritional Limitation and Body Condition

When prey is scarce or in low density, SRKWs likely spend more time foraging than when prey is plentiful or in high density. Increased energy expenditure and prey limitation can cause poor body condition and nutritional stress. Nutritional stress is the condition of being unable to acquire adequate energy and nutrients from prey resources and as a chronic condition, can lead to reduced body size of individuals and to lower reproductive or survival rates in a population (Trites and Donnelly 2003). During periods of nutritional stress and poor body condition, cetaceans lose adipose tissue behind the cranium, displaying a condition known as "peanut-head" in extreme cases (Pettis *et al.* 2004; Bradford *et al.* 2012; Joblon *et al.* 2014). Between 1994 and 2008, 13 SRKWs were observed from boats to have a pronounced "peanut-head"; and all but two subsequently died (Durban *et al.* 2009; Center for Whale Research unpublished data). None of the whales that died were subsequently recovered, and therefore definitive cause of death could not be identified. Both females and males across a range of ages were found in poor body condition.

Since 2008, NOAA's Southwest Fishery Science Center (SWFSC) and SR[3], a response rehabilitation and research center, have used aerial photogrammetry to assess the body condition and health of SRKWs, initially in collaboration with the Center for Whale Research and the Vancouver Aquarium. Aerial photogrammetry studies have provided finer resolution for detecting poor condition, even before it manifests in "peanut-head" that is observable from boats. Annual aerial surveys of the population from 2013-2017 (with exception of 2014) have detected declines in condition before the death of seven SRKWs (L52 and J8 as reported in Fearnbach *et al.* (2018); J14, J2, J28, J54, and J52 as reported in Durban *et al.* (2017)), including five of the six most recent mortalities (Trites and Rosen 2018). These data have provided evidence of a general decline in SRKW body condition since 2008, and documented members of J pod being in poorer body condition in May compared to September of the previous year (at least in 2016 and 2017) (Trites and Rosen 2018). Other pods could not be reliably photographed in both seasonal periods.

Previous scientific review investigating nutritional stress as a cause of poor body condition for SRKWs concluded "Unless a large fraction of the population experienced poor condition in a particular year, and there was ancillary information suggesting a shortage of prey in that same year, malnutrition remains only one of several possible causes of poor condition" (Hilborn *et al.* 2012). Body condition in whales can be influenced by a number of factors, including prey availability or limitation, increased energy demands, disease, physiological or life history status, and variability over seasons or across years. Body condition data collected to date has documented declines in condition for some animals in some pods and these occurrences have been scattered across demographic and social groups (Fearnbach *et al.* 2018).

It is possible that poor nutrition could contribute to mortality through a variety of mechanisms. To exhibit how this is possible, we reference studies that have demonstrated the effects of energetic stress (caused by incremental increases in energy expenditures or incremental reductions in available energy) on adult females and juveniles, which have been studied extensively (*e.g.*, adult females: Gamel *et al.* (2005), Schaefer (1996), Daan *et al.* (1996), juveniles: Trites and Donnelly (2003)). Small, incremental increases in energy demands should have the same effect on an animal's energy budget as small, incremental reductions in available energy, such as one would expect from reductions in prey. Malnutrition and persistent or chronic stress can induce changes in immune function in mammals and may be associated with increased bacterial and viral infections, lymphoid depletion, (Neale et al. 2005, Mongillo et al. 2016, Maggini et al. 2018). Ford and Ellis (2006) report that SRKWs engage in prey sharing about 76 percent of the time. Prey sharing presumably would distribute more evenly the effects of prey limitation across individuals of the population than would otherwise be the case (*i.e.,* if the most successful foragers did not share with other individuals).

2.3.3 Toxic Chemicals

Because the PFMC has little to no control over toxic chemicals, we only briefly describe this threat (see NMFS 2008 for more information). Various adverse health effects in humans, laboratory animals, and wildlife have been associated with exposures to persistent pollutants. These pollutants have the ability to cause endocrine disruption, reproductive disruption or failure, immunotoxicity, neurotoxicity, neurobehavioral disruption, and cancer (Reijnders 1986; Subramanian *et al.* 1987; de Swart *et al.* 1996; Bonefeld-Jørgensen *et al.* 2001; Reddy *et al.* 2001; Schwacke *et al.* 2002; Darnerud 2003; Legler and Brouwer 2003; Viberg *et al.* 2003; Ylitalo *et al.* 2005; Fonnum *et al.* 2006; Darnerud 2008; Legler 2008). SRKWs are exposed to a mixture of pollutants, some of which may interact synergistically and enhance toxicity, influencing their health, and reproductive success. Relatively high levels of these pollutants have been measured in blubber biopsy samples from SRKWs compared to other resident killer whales in the North Pacific (Ross *et al.* 2000; Krahn *et al.* 2007b; Krahn *et al.* 2009; Lawson *et al.* in prep), and more recently, these pollutants were measured in fecal samples collected from SRKWs providing another potential opportunity to evaluate exposure to these pollutants (Lundin *et al.* 2016a; Lundin *et al.* 2016b).

SRKWs are exposed to persistent pollutants primarily through their diet. For example, Chinook salmon contain higher levels of some persistent pollutants than other salmon species, but only limited information is available for pollutant levels in Chinook salmon (Krahn *et al.* 2007b; O'Neill and West 2009; Veldhoen *et al.* 2010; Mongillo *et al.* 2016). These harmful pollutants, through consumption of prey species that contain these pollutants, are stored in the SRKW's blubber and can later be released; when the pollutants are released, they are redistributed to other tissues when the SRKWs metabolize the blubber in response to food shortages or reduced acquisition of food energy that could occur for a variety of other reasons. The release of pollutants can also occur during gestation or lactation. Once the pollutants mobilize in to circulation, they have the potential to cause a toxic response. Therefore, nutritional stress from reduced Chinook salmon populations may act synergistically with high pollutant levels in SRKWs and result in adverse health effects.

2.3.4 Disturbance from Vessels and Sound

Because the Council only tasked the Workgroup to assess impacts from the PFMC ocean salmon fisheries on prey availability, we did not assess the impacts of fishing vessels in PFMC fisheries on the whales. However, here we provide a general description of this threat. Vessels have the potential to affect SRKWs through the physical presence and activity of the vessel, increased underwater sound levels generated by boat engines, or a combination of these factors. Vessel strikes are rare, but do occur and can result in injury or mortality (Gaydos and Raverty 2007). In addition to vessels, underwater sound can be generated by a variety of other human activities, such as dredging, drilling, construction, seismic testing, and sonar (Richardson *et al.* 1995; Gordon and Moscrop 1996; National Research Council 2003). Impacts from these sources can range from serious injury and mortality to changes in behavior. In other cetaceans, hormonal changes indicative of stress have been recorded in response to intense sound exposure (Romano *et al.* 2003). Chronic stress is known to induce harmful physiological conditions including lowered immune function, in terrestrial mammals and likely does so in cetaceans (Gordon and Moscrop 1996).

Killer whales rely on their highly developed acoustic sensory system for navigating, locating prey, and communicating with other individuals. While in inland waters of Washington and British Columbia, SRKWs are the principal target species for the commercial whale watch industry (Hoyt 2001; O'Connor *et al.* 2009) and encounter a variety of other vessels in their urban environment (*e.g*., recreational, fishing, ferries, military, shipping). Several main threats from vessels include direct vessel strikes, the masking of echolocation and communication signals by anthropogenic sound, and behavioral changes (NMFS 2008). There is a growing body of evidence documenting effects from vessels on small cetaceans and other marine mammals. Research has shown that SRKWs spend more time traveling and performing surface active behaviors and less time foraging in the presence of all vessel types, including kayaks, and that noise from motoring vessels up to 400 meters away has the potential to affect the echolocation abilities of foraging whales (Holt 2008; Lusseau *et al.* 2009; Noren *et al.* 2009; Williams *et al.* 2010). Individual energy balance may be impacted when vessels are present because of the combined increase in energetic costs resulting from changes in whale activity with the decrease in prey consumption resulting from reduced foraging opportunities (Williams *et al.* 2006; Lusseau *et al.* 2009; Noren *et al.* 2009; Noren *et al.* 2012).

At the time of the SRKWs' listing under the ESA, NMFS reviewed existing protections for the whales and developed recovery actions, including vessel regulations, to address the threat of vessels to SRKWs. NMFS concluded it was necessary and advisable to adopt regulations to protect SRKWs from disturbance and sound associated with vessels, to support recovery of SRKWs. Federal vessel regulations were established in 2011 to prohibit vessels from approaching SRKWs within 200 yards and from parking in the path of SRKWs within 400 yards. These regulations apply to all vessels in inland waters of Washington State with exemptions to maintain safe navigation and for government vessels in the course of official duties, ships in the shipping lanes, research vessels under permit, and vessels lawfully engaged in commercial or treaty Indian fishing that are actively setting, retrieving, or closely tending fishing gear (76 FR 20870, April, 14, 2011).

In the final rule, NMFS committed to reviewing the vessel regulations to evaluate effectiveness, and also to study the impact of the regulations on the viability of the local whale watch industry. In December 2017, NMFS completed a technical memorandum evaluating the effectiveness of regulations adopted in 2011 to help protect endangered SRKWs from the impacts of vessel traffic and noise (Ferrara *et al.* 2017). In the assessment, Ferrara *et al.* (2017) used five measures: education and outreach efforts, enforcement, vessel compliance, biological effectiveness, and economic impacts. For each measure, the trends and observations in the five years leading up to the regulations (2006-2010) were compared to the trends and observations in the five years following the regulations (2011-2015). The memo finds that some indicators suggested the regulations have benefited SRKWs by reducing impacts without causing economic harm to the commercial whale-watching industry or local communities, whereas some indicators suggested that vessel impacts continue and that some risks may have increased. The authors also find room for improvement in terms of increasing awareness and enforcement of the regulations, which would help improve compliance and further reduce biological impacts to the whales.

2.3.5 Oil Spills

Because PFMC activities have little to no bearing on the risk of large oil spills due to the PFMC salmon fisheries, we only briefly describe this threat (see NMFS 2008 for more information). In the Northwest, SRKWs are the most vulnerable marine mammal population to the risks imposed by an oil spill due to their small population size, strong site fidelity to areas with high oil spill risk, large group size, late reproductive maturity, low reproductive rate, and specialized diet, among other attributes (Jarvela Rosenberger *et al.* 2017). Oil spills have occurred in the range of SRKWs in the past, and there is potential for spills in the future. Oil can be discharged into the marine environment in any number of ways, including shipping accidents, refineries and associated production facilities, and pipelines. Despite many improvements in spill prevention since the late 1980s, much of the region inhabited by SRKWs remains at risk from serious spills because of the heavy volume of shipping traffic and proximity to petroleum refining centers.

Repeated ingestion of petroleum hydrocarbons by killer whales likely causes adverse effects; however, long-term consequences are poorly understood. In marine mammals, acute exposure to petroleum products can cause changes in behavior and reduced activity, inflammation of the mucous membranes, lung congestion and disease, pneumonia, liver disorders, neurological damage, adrenal toxicity, reduced reproductive rates, and changes in immune function (Schwacke *et al.* 2013; Venn-Watson *et al.* 2015; de Guise *et al.* 2017; Kellar *et al.* 2017), potentially death and long-term effects on population viability (Matkin *et al.* 2008; Ziccardi *et al.* 2015). For example, 122 cetaceans stranded or were reported dead within 5 months following the Deepwater Horizon spill in the Gulf of Mexico (Ziccardi *et al.* 2015). An additional 785 cetaceans were found stranded from November 2010 to June 2013, which was declared an Unusual Mortality Event (Ziccardi *et al.* 2015). In addition, oil spills have the potential to adversely impact habitat and prey populations, and, therefore, may adversely affect SRKWs by reducing food availability.

3 SRKWS AND CHINOOK SALMON FISHERIES

Here we provide a basic description of the relationship between SRKWs and Chinook salmon and a summary of the history of fisheries impacts analyses on SRKWs.

3.1 Relationship between SRKWs and Chinook salmon

As summarized in Section 2.3.1, Chinook salmon have been identified as the SRKWs' primary prey. Several studies in the past have found correlations between Chinook salmon abundance indices and SRKW demographic rates at a coarse coastwide scale (Ford *et al.* 2005; Ford *et al.* 2009; Ward *et al.* 2009; Ward *et al.* 2013). Although these studies examined different demographic responses related to different Chinook salmon aggregate abundance indices, they all found significant positive relationships (high Chinook salmon abundance coupled with high SRKW fecundity or survival). However, these correlations have weakened with the addition of data from recent years. There are several challenges to quantitatively characterizing the relationship between SRKWs and Chinook salmon and uncertainty remains. The results of statistical models relating indices of Chinook salmon abundance to measures of SRKW demographic rates are sensitive to which animals and which years are used (*e.g.* only data after 1976 versus only data after 1980), whether Chinook salmon abundance is included as a covariate on specific SRKW demographic metrics like survival or fecundity (and which lag time is used), or the specific Chinook abundance indices used in a given analysis (*e.g.* the Pacific Salmon Commission Chinook Technical Committee's dataset, the Council's FRAM model, etc.). Attempts to date to compare the relative importance of any specific Chinook salmon stocks or stock groups using the strengths of statistical relationships have not produced clear distinctions as to which are most influential, and most Chinook salmon abundance indices are highly correlated with each other. Different Chinook salmon populations are likely more important in different years. Large aggregations of modeled Chinook salmon stocks that reflect abundance on a more coastwide scale appear to be equally or better correlated with SRKW vital rates than smaller aggregations of Chinook salmon stocks, or specific stocks such as Chinook salmon originating from the Fraser River that have been positively identified in diet samples as key sources of prey for SRKWs during certain times of the year in specific areas (see Hilborn *et al.* 2012; Ward *et al.* 2013).

There are numerous challenges to identifying statistically robust relationships in natural systems. Demographic stochasticity can create year-to-year variation in measured SRKW demographic rates that mask underlying probabilities or rates. Effects of demographic stochasticity are particularly pronounced because SRKWs have a small population size (*e.g*., not many births or deaths per year to correlate with annual salmon abundance). These whales are long-lived, thus changes in mortality rates across years are relatively small, making it more challenging to detect statistically-significant changes in mortality rates. Demographic performance across years is also affected by changes in other primary threats (disturbance from vessels and sound and high levels of toxic pollutants) and these effects can confound analysis of the effects of prey abundance. There are substantial uncertainties in the annual Chinook salmon abundance estimates being used to predict SRKW performance, and there is currently no widely-accepted single metric for prey abundance and accessibility to the whales. These challenges make it more difficult to accurately predict the relationship between SRKW demographic rates and Chinook salmon abundance. Nonlinear or threshold responses, if present, would not be captured well by relatively simple statistical models.

3.2 History of salmon fisheries impacts analyses

3.2.1 Summary description of the 2009 NMFS biological opinion on PFMC salmon fisheries

In the 2009 biological opinion on PFMC salmon fisheries (NMFS 2009), NMFS compared prey potentially available to SRKWs with and without the action and found that the fisheries will reduce prey available in some locations during some time periods. The analysis considered whether effects of that prey reduction may reduce the reproduction, numbers, or distribution of SRKWs, pursuant to NMFS' jeopardy standard. NMFS evaluated the potential effects of the FMP on SRKWs based on the reductions in prey resulting from a range of harvest scenarios that have been previously authorized, and considered likely in the future, under the FMP.

NMFS evaluated the potential short-term or annual effects as well as the long-term effects of prey reduction from the FMP. Short-term or annual effects of the FMP on prey availability were evaluated as: 1) the percent reduction in Chinook salmon available with the action, and 2) the remaining prey base of Chinook salmon with the action compared to the metabolic needs of the SRKWs. NMFS evaluated the potential for long-term effects on prey availability based on NMFS' most recent conclusions for effects of the FMP on salmon and review of conservation objectives for individual Chinook salmon stock groups affected by the action. The prey reduction was evaluated by time and area, among other factors, based on the information available to stratify the analysis.

Information on Chinook salmon availability was based on FRAM runs. FRAM provides year-specific ocean abundance estimates based on fishery data, escapement estimates, and assumptions about incidental and natural mortality from central California to Southeast Alaska. All Chinook stocks modeled in FRAM travel through the range of SRKWs. FRAM includes most listed and non-listed Chinook stocks within the whales' range, with notable exceptions including Alaska stocks, Upper Columbia River spring, Snake River summer/spring, Klamath River Chinook, Rogue River Chinook, San Joaquin fall, Central Valley late-fall, winter, and spring runs, and fish from other rivers along the Southern Oregon and Northern California coasts. FRAM is a single-pool model that does not provide abundance estimates of Chinook within sub-regions. However, by using catch distribution patterns from the FRAM base period (for the 2009 biological opinion the base period was 1979-1982) when fisheries were broadly distributed across time and area, NMFS developed a method to estimate abundance for inland waters (Strait of Juan de Fuca, east to Georgia Strait in the north, and Puget Sound in the south), and coastal waters (all FRAM fishery regions except inland waters).

Regional abundance estimates were derived for two retrospective years that represented a range of high (2002) and low (2008) Chinook abundance and respective harvest levels. For both years, the estimates were specific to time periods in the FRAM for an annual cycle: October to April, May to June, and July to September. The range of high and low years analyzed was expected to represent a reasonable range of abundance and harvest under the FMP in future years. In general, the percent reduction in Chinook abundance from fisheries is greater in high Chinook abundance years than in low abundance years, because more fish can be caught in high abundance years while still meeting management objectives.

The PFMC salmon fisheries were found to cause minimal or no prey reduction during the October to April time period, regardless of year or region and caused incrementally larger prey reductions during May to June and July to September when the majority of FMP fisheries occur. NMFS' opinions on effects of FMP fisheries on salmon also consider the effects of environmental variability on sustainability of salmon stocks (*i.e.*, from ocean conditions or climate effects) and aim to maintain stocks at or above conservation objectives. Although in specific cases, for some years and stocks the conservation objectives are not met, overall NMFS determined that effects to the ESU still meet ESA compliance standards. When necessary to ensure that the FMP fisheries do not exceed ESA jeopardy standards, regulations for those fisheries have been adjusted to incorporate conservation measures. For example, in 2008 and 2009, poor performance of Chinook salmon stocks in Central Valley, California were the impetus behind fisheries closures south of Cape Falcon, Oregon. As a result of the fishery closures the proposed action would not affect escapements of these stocks. However, while the salmon harvest is managed to meet objectives to promote recovery of salmon, NMFS was not able to evaluate if recovery levels identified for salmon ESUs are consistent with the prey needs and recovery objectives for SRKWs.

NMFS concluded in the 2009 biological opinion that the extent of take was not anticipated to appreciably reduce the survival and recovery of SRKWs. The amount of anticipated take would not increase the risk of mortality (*i.e*., and therefore would not rise to the level of serious injury or mortality), or hinder the reproductive success of any individual SRKW (NMFS 2009).

3.2.2 Summary description of the 2012 Independent Science Panel review

Following the 2010 Puget Sound Chinook harvest Biological Opinion (NMFS 2011), an independent Science Panel (Panel) reviewed the best available scientific information on the effects that salmon fisheries may have on SRKWs by reducing their prey (Hilborn *et al.* 2012). The Panel and workshop participants reviewed the ecology of the SRKWs, their feeding preferences, and their energy requirements. The participants examined the extent to which various salmon fisheries may reduce prey available to SRKWs, and the potential consequences to their survival and recovery. Following the independent science panel approach on the effects of salmon fisheries on SRKWs, NMFS and partners have actively engaged in research and analyses to fill gaps and reduce uncertainties raised by the Panel in their report.

For reference, below are the key points and conclusions from the Panel report (Hilborn *et al.* 2012), The Workgroup has included some updates based on scientific information that have become available since the Panel report.

Status of Southern Resident Killer Whales

Panel Key Point: The SRKW population has been observed to increase at an average rate of 0.71 percent per year, and would be expected to increase at about one percent per year in the long term if sex ratio at birth were 50:50.

Panel Key Point: The Panel believed that the existing delisting criterion of 2.3 percent growth rate is unlikely to be achieved given current (2012) circumstances or by reducing Chinook salmon fisheries. But if the total abundance continued to increase, a point will be reached where a reappraisal of their status would be likely.

The Panel examined the then-current knowledge of the SRKW population size, growth rates, and demography to: 1) assess current trends relative to historical trends in abundance; and 2) to evaluate the understanding of the current status of the population relative to recovery goals. The Panel examined the time period from 1974 to 2011 and found the population experienced a realized growth rate of 0.71 percent, from 67 individuals to 87 individuals. However, since 2011, the population has declined to 73 individuals and updated status information and population projections are summarized in the December 2016 ESA 5-year status review (NMFS 2016). As described in the Status of the Species and illustrated in Figure 3.2.a, the population is now expected to decline over the next 50 years. However, we note there is increasing uncertainty as the projection extends beyond the first 10 years and with the small population size and number of births the model output can change substantially with the birth of a small number of calves, particularly female calves.

During the workshop, the Vélez-Espino *et al.* (2014) demographic analysis was preliminary and had not yet been published. More recently, Vélez-Espino *et al.* (2014) used data from 1987 to 2011 and estimated expected SRKW population growth rates at a 0.91 percent annual decline for SRKWs (Figure 3.2.a). Furthermore, the estimated SRKW population size was predicted to decline to 75 individuals in a generation (which is considered 25 years), with an extinction risk of 49 percent and an expected minimum abundance of 15 during a 100-year period. The largest contributor to the variance and uncertainty in population growth rate was the survival of young reproductive females. Therefore, Vélez-Espino *et al.* (2014) suggest survival of young reproductive females has the largest influence on population growth and population growth variance.

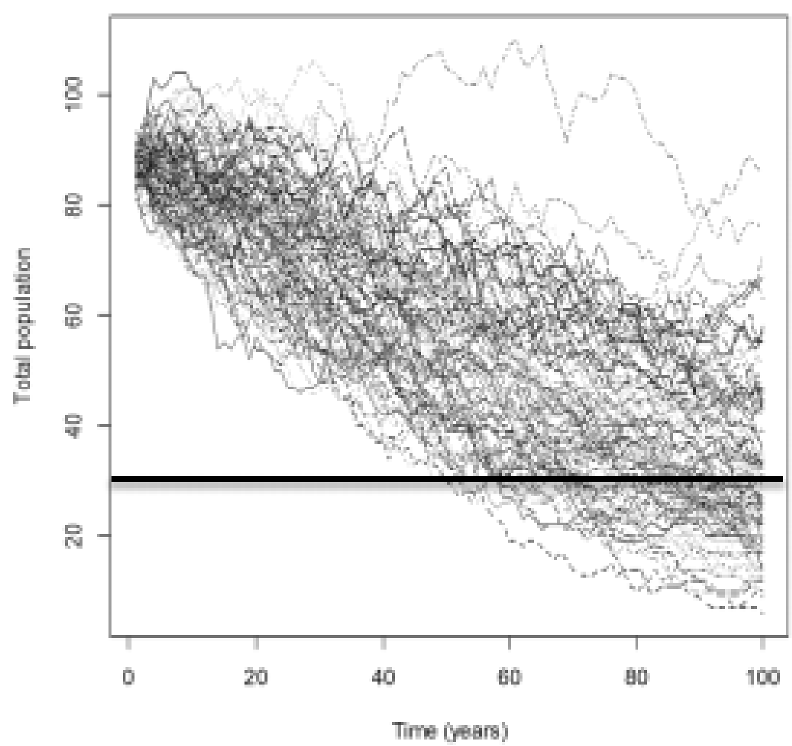

Figure 3.2.a. Projections of SRKW population size under demographic stochasticity and status quo conditions. Horizontal line shows a 30 individual quasi extinction threshold (Vélez-Espino *et al.* 2014).

SRKW Dependency on Chinook Salmon

Panel Key Point: The evidence for strong reliance on Chinook salmon in the summer is convincing, but it is also clear that SRKWs will switch to alternative, more abundant chum salmon when Chinook salmon of suitable size and quality are not readily available in the fall.

Panel Key Point: Photographic evidence supports the assertion that poor condition, which is linked to mortality, and by implication to fecundity, may reflect nutritional stress. However, unless a large fraction of the population experienced poor condition in a particular year, and there was ancillary information suggesting a shortage of prey in that same year, malnutrition remains only one of several possible causes of poor condition.

The Panel report recognized SRKWs have a specialized diet of Chinook salmon from May to September which "means that it is biologically plausible for reduced Chinook salmon abundance to cause nutritional stress and impede recovery of the SRKW population." The report provides context with information on SRKW distribution, diet (species and size selectivity), daily prey requirements, and nutritional stress (Hilborn *et al.* 2012). Despite logistical challenges, the Panel concluded that the diet data collected provide a reasonable indication of what SRKWs are eating in the summer in inland waters; however, winter diet was a major uncertainty. They concluded that Chinook salmon appears to dominate SRKW summer diet and diet is skewed in general towards larger Chinook salmon (4 and 5 year olds). Prey sampling relies on collecting prey remains at or near the surface following a predation event; however, smaller Chinook salmon may not be readily shared with other individuals at the surface and thus could bias detecting their presence. Also fish swallowed at depth could go undetected at the surface and thus not be observed or collected. As discussed in the Status of the Species section above, Ford *et al.* (2016) used fecal DNA analysis to confirm the results of previous studies conducted using other prey identification methods. These fecal samples are thought to be less biased than prey samples recovered from foraging events at the surface because the samples would include information about prey consumed throughout the water column and may also provide information on multiple feeding events.

The Panel considered the bioenergetic modeling approach (Noren 2011) and believed it is a reasonable way to estimate the energy needs of the whales. In contrast, forage ratios (the whales' bioenergetics needs compared to prey available) provide little insight into prey limitations and would require knowing the whale fitness/vital rates as a function of the supply and demand in order for the ratios to be useful. The Panel summarized that of 13 members of the population documented to be in poor condition at that time, all but two died, suggesting some SRKW have been nutritionally limited at certain times of the year. They suggested changes in social behavior may be a sensitive indicator of nutritional limitation.

Fisheries and Prey Availability

Panel Key Point: The maximum long-term increases in abundance of Chinook salmon that might theoretically be available to SRKW would be achieved by eliminating all ocean fishing (typically at least 20 percent increase in ocean abundance of age-4 and age-5 hatchery and wild fish due to elimination of ocean fishery interception of immature fish) and by maximizing recruitment through manipulation of freshwater exploitation rates to maximize recruitment (6 – 9 percent increase in recruitments of wild fish; no impact on hatchery fish).

The best potential for increased Chinook salmon abundance is restoration of freshwater habitat, reducing downstream migration mortality and a change in ocean conditions.

Panel Key Point: The panel sees many potential reasons why not all foregone Chinook salmon catch would be available to SRKW, and is therefore skeptical that reduced Chinook salmon harvesting would have a large impact on the abundance of Chinook salmon available to SRKW.

Projected Future Status and Recovery

Panel Key Point: The statistical analysis by NMFS and DFO scientists are excellent, but the Panel believed considerable caution is warranted in interpreting the correlative results as confirming a linear causal relationship between Chinook salmon abundance and SRKW vital rates.

The Panel described a big picture of the historical vs. current abundances and marine distributions of Chinook salmon; recent trends in Chinook abundance and fisheries; and a description of the probable overlap of SRKW distribution with the distribution of salmon stocks. The Panel considered the results from the correlative approaches that linked Chinook salmon abundance and SRKW vital rates to be consistent with expected dynamics between a predator and its primary prey. The Panel response varied when asked about the strength of evidence that changes in Chinook salmon abundance cause or do not cause changes in SRKW vital rates from being in favor of a cause/effect relationship, rejecting except for one Chinook abundance index, or were unconvinced. The Panel suggested that the regression analyses conducted at the time seemed consistent with a conclusion that SRKW vital rates are more highly correlated with broad scale aggregated abundances of Chinook salmon that overlap with SRKW distribution in spring and late fall periods and potentially winter. However, they concluded a positive relationship between indices of Chinook salmon abundance and killer whale vital rates are probably more complicated than the simple linear relationships assumed. Given the regression results, and the likely higher density of salmon in the inland waters compared to coastal waters, the panel suggested the Chinook salmon that pass through the Salish Sea during the summer period do not directly limit the population growth. Instead, the panel suggested that coastal abundance of Chinook during non-summer months is probably more important for survival and reproduction.

Estimating the Impact of Reducing Chinook Salmon Fisheries on SRKW

Panel Key Point: The Panel was not confident that understanding of the interaction between Chinook salmon fisheries, other predators and SRKW vital rates, is sufficient to expect the model predictions of increased SRKWs to be accurate. The Panel expects the model predictions to overestimate the impact of reductions in Chinook salmon catch on SRKW.

The Panel agreed the methods presented at the workshop seemed appropriate for assessing short-term impacts reduced fishing might have on ocean and terminal abundances of Chinook salmon stocks. Using the Fisheries Regulation Assessment Model (FRAM), if ocean fishery exploitation rates were reduced to zero, there would be an expected increase in abundance (both ocean and terminal) of 18 – 25 percent. They emphasized this was assuming no competing risks of death[5],

[5] The Panel had concerns how natural mortality (and predation on Chinook salmon by SRKW and NRKW) in the FRAM model structure was treated and suggested that a ‘competing risks of death’ framework that modeled the

implying that this would not be the actual percent increase in abundance of Chinook salmon due to other mortality, such as predation by other species. The Panel noted a 20 percent increase from cessation of all ocean fishing is likely the upper limit of abundance increase and that when Chinook salmon are at lower abundance levels or competing predators are at higher abundance levels, this percent increase would be smaller.

When asked what is the strength of evidence that changes in fisheries in the future would cause or would not cause changes in Chinook salmon abundance sufficient to affect SRKW vital rates, a couple of panelists suggested that any causal effect would be weak, another suggested that changes in fisheries harvest should only be considered for those salmon stocks for which a causal relationship has not been rejected. Lastly several Panel members suggested the impacts on SRKWs from changes to Chinook salmon fisheries would need to consider how this might increase availability of salmon to other predators (*e.g.* NRKWs and pinnipeds).

The Conclusions of the Panel

The Panel believed that the estimated benefits of reducing Chinook salmon harvest in NMFS's analyses provided a maximum estimate of the benefits to SRKWs — and that the realized benefits would likely be lower and insufficient to increase SRKW growth rates to a level that meets existing delisting criteria in the foreseeable future. The Panel concluded that there is good evidence that Chinook salmon are a very important part of the diet of SRKWs and that there is good evidence, collected since 1994, that some SRKWs have been in poor condition and poor condition is associated with higher mortality rates. There is a statistical correlation between SRKW survival rates and some indices of Chinook salmon abundance. Based on those correlations, increases in Chinook salmon abundance would lead to higher survival rates, and therefore higher population growth rates of SRKWs. However, the effect is not linear as improvements in SRKW survival would be expected to diminish at Chinook salmon abundance levels above the historical average. Using the statistical correlations, consistently positive SRKW growth rates can occur if Chinook salmon abundances remain above the low levels observed in the 1970-80s and late-1990s.

Elimination of all ocean fisheries for Chinook salmon would impact Chinook salmon abundance far less than the inter-annual Chinook salmon abundance variations that have been seen since the 1970s. The Panel cautioned against overreliance on the correlative studies, and noted that the level of correlation is highly dependent on the choice of Chinook salmon abundance indicators, concluding that the impact of reduced Chinook salmon harvest on future availability of Chinook salmon to SRKWs is not clear.

3.2.3 Summary description of the 2019 NMFS pre-season assessment of fisheries impacts on SRKW

NMFS reinitiated consultation on the 2009 opinion in April 2019. Pending completion of the reinitiated consultation and before adoption of final management measures for 2019, NMFS assessed the impact of 2019 PFMC salmon fisheries on SRKWs. NMFS considered all the information currently available to assess these impacts including:

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effects of fisheries and competing marine mammals on potential consumption of Chinook salmon by killer whales would be more informative.

- Estimated percent reductions in overall Chinook salmon prey availability from the March 2019 Council's three fishery alternatives compared to past percent reductions;
- Estimates of 2019 Chinook salmon abundance in coastal waters and inland waters derived using the Chinook FRAM as well as forecasts of Klamath River Fall Chinook and Sacramento River Fall Chinook;
- Supplemental Salmon Technical Team Report 2 from the March 2019 Council meeting (see Appendix G);
- 2019 pre-season forecasts of abundance for each Chinook salmon prey stock that contributes to the Council salmon fisheries, when available, translated into priority prey stock groups; and the contribution rates of these translated modeled Chinook salmon prey stocks to total catch (both current predicted contribution and historical contribution) in the Council salmon fisheries.

For 2019, NMFS assessed the effects of the percent reductions to available Chinook salmon prey expected to result from the three fishery alternatives at the March Council meeting under consideration and considered this together with pre-season Chinook salmon abundance estimates for 2019 using FRAM and the two California stock-specific models mentioned above (Agenda Item F.1.e, Supplemental NMFS Report 1, April 2019). To put the reductions in context, the analysis involved comparing percent reductions in Chinook salmon prey availability from the fisheries and Chinook salmon abundance anticipated in 2019 to percent reductions and abundance for a retrospective time period (NMFS used 1992-2016 as the retrospective time period).

Overall, total percent reductions in prey availability in coastal waters anticipated from each fishing alternative considered by the Council for 2019 ranged from 7.1 percent in Alternative 3 to 9.9 percent in Alternative 1, which fall within the middle range (the range between the lower and upper quartile boundaries) of what was observed during the retrospective time period (1992 – 2016).

Pre-season coastal Chinook salmon abundance and inland Chinook salmon abundance were estimated to fall within a middle range of abundances estimated during the retrospective time period. Therefore, coastal and inland Chinook salmon abundances projected for 2019 were not in the low nor high quartiles for abundances compared to previous years. NMFS also assessed the forecasted pre-season abundances of the modeled Chinook salmon prey stocks relative to past abundances during the same retrospective time period (1992 to 2016). Four priority stocks were anticipated to have relatively high Chinook salmon abundances (above the upper quartile boundaries) and ten stocks were anticipated to be within a middle range of abundances (*i.e.*, neither substantially low nor high). Therefore, 2019 abundance estimates for all but two of the modeled stocks contributing to Council-area salmon fisheries were expected to be in the middle or upper quartiles of abundance when compared with the retrospective time period. Two Chinook salmon prey stocks, the lower Columbia River spring and the upper Willamette spring, had abundance estimates in the lowest quartile compared to the retrospective time period.

NMFS focused on these two stocks to help assess if the impacts of the 2019 Council area fisheries on these stocks would result in a level it deemed as unacceptable risk by increasing mortality or reducing fecundity of SRKWs because of the stocks' relatively low 2019 abundance compared to their abundances over the retrospective time period. The lower Columbia River spring stock is a low abundance stock but considered relatively high priority because of its spatial and temporal overlap with the whales and because it has been observed in the whales' diet during the winter period when the whales may have a higher likelihood of reduced body condition. However, the stock is a minor contributor to the catch composition of Council area salmon fisheries. Over the retrospective time period, this stock contributed to approximately 0.5 percent of the annual catch on average in Council Area fisheries (Figure 3.2.b). Of note, Figure 3.2.b reflects proportional catches in fisheries as they occurred in a given year, and as a result it includes effects of changes in fisheries management as they may have occurred. For example, in 2009-2010, PFMC fisheries in areas South of Cape Falcon were either highly constrained or closed; as a result of that, the proportion of Central Valley and other more southerly stocks in the overall PFMC catch was very low, and proportions of stocks occurring in fishery areas that remained open were higher. In 2019, the percent contribution to the annual catch of the lower Columbia River spring Chinook stock under each alternative is estimated as 0.1 percent (Figure 3.2.b).

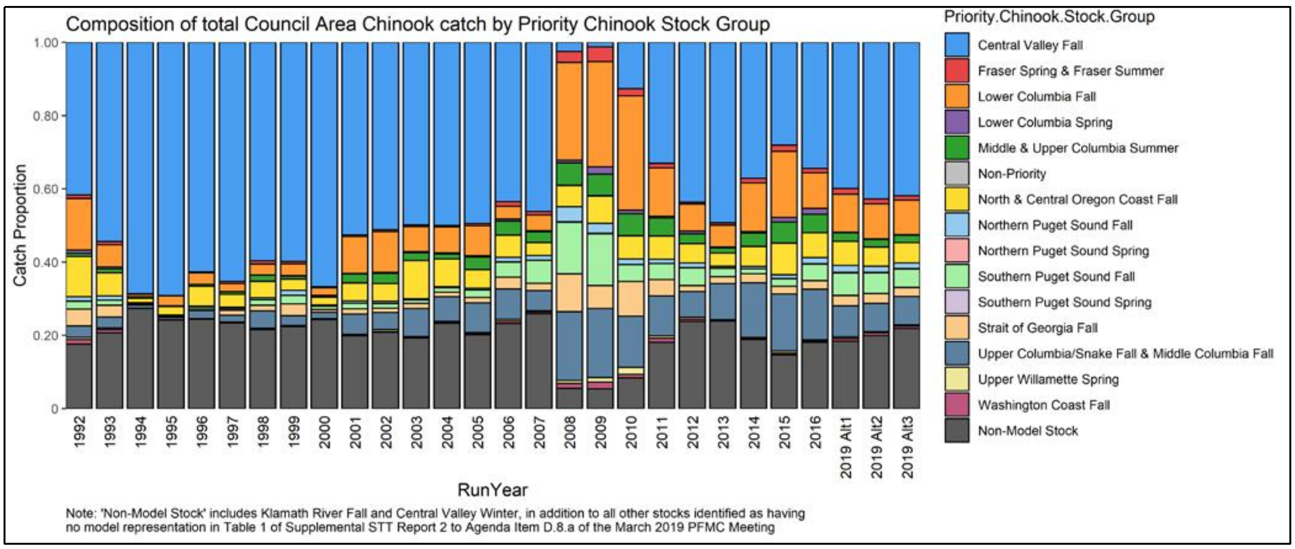

Figure 3.2.b. Composition of total Council Area Chinook salmon catch by Chinook salmon stock group (PFMC Agenda Item F.1.e Supplemental NMFS Presentation 1, April 2019).

The upper Willamette spring Chinook salmon stock has not been observed in the diet of SRKWs, and thus is considered lower priority, but the stock has the same overlap in space and time with the whales as the lower Columbia River spring stock. This stock is more abundant than the lower Columbia River spring Chinook salmon stock, but still considered relatively less abundant when compared to other higher priority Chinook salmon prey stocks, such as Southern Puget Sound fall, Lower Columbia River fall, and Strait of Georgia fall, among others. The expected contribution of the upper Willamette spring Chinook stock to the catch in 2019 is similar to the historical contribution of this stock to the Council salmon fisheries catch, which averaged less than 0.5 percent during the retrospective time period. Thus, although two modeled stocks were anticipated to have low abundance relative to previous years, because of their low occurrence in Council fisheries, NMFS did not anticipate the Council fisheries would substantially reduce the availability of those Chinook salmon prey stocks to the whales. Furthermore, the overall forecast composition in 2019 contained a higher proportion of Chinook salmon stocks that are considered to be higher priority than the average composition in the retrospective time period.

3.2.4 Summary description of the 2019 NMFS biological opinion on South East Alaskan salmon fisheries

In 2018, Canada and the U.S. reached a new agreement under the bilateral Pacific Salmon Treaty (PST) for 2019 through 2028. ESA authorization of impacts to listed species associated with domestic fishery actions under the previous 2009-2018 PST Agreement expired December 31, 2018. Therefore, a new consultation was required on several U.S. domestic fishery and funding actions associated with the new agreement.

In 2019, NMFS completed a biological opinion on the effects of three proposed U.S. domestic actions associated with the new 2019-2028 PST Agreement on salmon and marine mammal species listed under the ESA. The actions are related to management of Southeast Alaska (SEAK) fisheries and funding actions related to the new Agreement.

The approach to this consultation differed from that of the previous two PST Agreements (1999-2008 and 2009-2018) because of the limited applicability of the language in the implementing statute and changes in policy direction between old and new PST Agreements. The proposed actions included reinitiation of consultation on the continued implementation of an important provision of the North Pacific Fishery Management Council's FMP for the salmon fisheries in the EEZ off Alaska, delegating management authority to the State of Alaska, and the provision of funding for monitoring and conservation programs important to addressing obligations and effects of the new PST Agreement.

Specific to SRKW, the analysis in the biological opinion assumed that funding for a conservation program for SRKW will be forthcoming and the program will be implemented for the duration of the new Chinook salmon regime. In the event the required funding is not forthcoming, this could change the proposed action resulting in effects on SRKW not considered in this opinion (NMFS 2019a). If so the biological opinion could be re-initiated.

Based on the biological information described in the Status and Environmental Baseline sections, NMFS' effects analysis focused on the likely reduction in Chinook salmon prey available to the whales as a result of the SEAK fisheries in the short and long term. To put those reductions in context, NMFS assessed how the proposed SEAK fisheries compared to past fisheries, considered the ratio of Chinook salmon prey available compared to the whales' needs, and evaluated effects of the SEAK fisheries with respect to priority prey stocks. As described in the 2019 biological opinion's Effects Section (NMFS 2019a), NMFS focused its analysis on those periods and locations where the reduction in available prey from the SEAK fisheries would be measurable or the ratio of prey available compared to prey needed appeared to be measureable.

Under the 2019 Agreement, the SEAK fisheries catch will be reduced in most cases by 7.5 percent relative to what was allowed in the prior (2009-2018) Agreement. In the West Coast Vancouver Island (WCVI) fishery, in most cases, catch will be reduced by 12.5 percent relative to what was allowed in the prior (2009-2018) Agreement. Because of these reductions to harvest, NMFS found reduced effects to prey availability under the 2019 Agreement than under the previous regime.

NMFS also estimated the Chinook salmon food energy available to the whales and compared available kilocalories to needs and evaluated the ratio after reductions from the proposed SEAK fisheries. NMFS had low confidence in the ratios, but considered them as an indicator to help focus the analysis on the time and location where prey availability may be lowest and where the action may have the most significant effect on the whales. The analysis used updated information to refine the bioenergetics including metabolic needs of the whales and caloric content of different runs of Chinook salmon (NMFS 2019a).

NMFS also compared the Chinook salmon stocks caught in the SEAK fisheries with the priority stocks identified at the time. The stocks ranked high on the priority list (e.g. North and South Puget Sound Chinook salmon stocks) were anticipated to have limited adverse effects because of increased hatchery production and habitat restoration work associated with the mitigation funding initiative that was the third component of the proposed action.

In summary, although the SEAK fisheries catch will be reduced by up to 7.5 percent relative to what was allowed under the 2009 Agreement, the effects of the action add a measurable adverse effect in addition to the existing conditions. The proposed SEAK fisheries could result in up to 12.9 percent reduction in the prey available to the whales in their coastal range, but this would likely occur rarely (most years the percent reduction is anticipated to be lower than eight percent), during summer months when the whales are more often observed in inland waters, and is spread across a large area where the whales would not have access to all of the Chinook salmon or be expected to experience localized prey depletion (NMFS 2019a). The larger percent reductions in prey (i.e., percent reductions at the higher end of the ranges estimated) in coastal and inland waters would have the biggest impact on the whales if they occur in low abundance years.

Due to the mitigation funding, the loss of prey availability from PST harvest, both Canadian and all U.S. salmon fisheries, including the SEAK fisheries, will be partially offset by increased hatchery production in their designated critical habitat. Although there is a gap between increasing hatchery production and increased prey availability, NMFS anticipated the impacts from multiple consecutive low abundance years coupled with relatively large percent reductions to be spread throughout the course of the decade and not compacted into the first few years of the proposed action (NMFS 2019a). The hatchery production is expected to increase abundance of Chinook salmon in coastal and inland waters, which will reduce impacts from the action during times of low prey availability for the whales. Habitat mitigation will also support increases in prey availability over a longer time frame.

The reductions in harvest levels in SEAK fisheries and other fisheries under the 2019 PST Agreement in addition to hatchery and harvest mitigation as part of this and other recovery actions are intended to improve the overall conditions for the whales' Chinook salmon prey, increase prey abundance available to the whales, and reduce impacts to the whales' survival and reproduction.

NMFS concluded in the 2019 biological opinion that the proposed actions are not likely to appreciably reduce the likelihood of both survival and recovery of Southern Resident killer whales or destroy or adversely modify their designated critical habitat. In addition, the action will not jeopardize the listed salmon that the whales depend on over the long term. NMFS will continue to monitor the abundance of Chinook salmon prey, the condition and health of individual whales, and overall population status to evaluate the effectiveness of the proposed actions, including mitigation, along with other recovery actions, in improving conditions for listed Chinook salmon and Southern Resident killer whales compared to recent years (NMFS 2019a).

4 PFMC SALMON FISHERIES

The Pacific Coast Salmon FMP guides management of salmon fisheries in Federal waters known as the Exclusive Economic Zone (EEZ) 3 to 200 nautical miles off the coast of Washington, Oregon, and California. Salmon of U.S. and Canadian origin are included except in the case of species which are managed in those waters by another management entity with primary jurisdiction (*i.e.,* sockeye and pink salmon by the Fraser River Panel of the Pacific Salmon Commission in the Fraser River Panel Area (U.S.) between 49°N latitude and 48°N latitude). The FMP covers the coastwide aggregate of natural and hatchery salmon encountered in ocean salmon fisheries, but only has management objectives and allocation provisions for Chinook or king salmon (*Oncorhynchus tshawytscha*), coho or silver salmon (*O. kisutch*), and pink salmon (*O. gorbuscha*). Catches of other salmon species are inconsequential (low hundreds of fish or less each year) to very rare (PFMC 2016). In the event this situation should change, management objectives for these species could be developed and incorporated by plan amendment. The incidental harvest of these salmon species can be allowed or restricted under existing federal fishery regulations.

Chinook and coho are the species caught in the greatest numbers in Council-managed ocean salmon fisheries. In odd-numbered years, catches of pink salmon can also be significant, primarily off Washington and Oregon (PFMC 2018a).

The FMP also includes identification of essential fish habitat (EFH) for Chinook, coho, and pink salmon in ocean, estuary, and freshwater, and contains recommendations for measures to avoid or mitigate for impacts to salmon EFH (see PFMC 2016, Appendix A), and a description of the social and economic fishery characteristics (see PFMC 20126, Appendix B).

To the extent practicable, the Council has partitioned the coastwide aggregate of Chinook, coho, and pink salmon into various stock components and complexes with specific conservation objectives. A detailed listing of the individual stocks and stock complexes managed under the plan is provided in Tables 1-1, 1-2, and 1-3 (PMFC 2016). Stocks designated as hatchery stocks rely on artificial production exclusively, while those designated as natural stocks have at least some component of the stock that relies on natural production, although hatchery production and naturally spawning hatchery fish may contribute to abundance and spawning escapement estimates.

The FMP also contains allocation provisions to regulate how salmon resources are shared among user groups and regions. The FMP management framework allows fishing seasons to be set and managed in a fair and efficient manner. The Council's primary means of meeting the requirements of the Magnuson Stevens Act (MSA) to achieve the optimum yield (OY) from the salmon fishery, meaning the amount of fish that will provide the greatest overall benefit to the Nation, is through maximum sustained yield (MSY), which is defined as the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions and fishery technological characteristics (*e.g.*, gear selectivity), and distribution of catch among fleets (50 CFR 600.310). The OY to be achieved for species covered by the FMP is the total salmon catch and mortality (expressed in numbers of fish) resulting from fisheries within the EEZ adjacent to the States of Washington, Oregon, and California, and in the waters of those states (including inland waters), and Idaho, that, to the greatest practical extent within pertinent legal constraints, fulfill the plan's conservation and harvest objectives.

Annually the Council recommends management measures to NMFS that achieve the stock conservation objectives for each stock or stock complex (see PFMC 2016, Chapter 3), while simultaneously seeking to fulfill, to the extent practicable, the harvest and allocation objectives (see PFMC 2016 Chapter 5) that reflect the Council's social and economic considerations. The level of total allowable harvest, the relative harvest levels in various management areas, and the species and stock composition of OY varies annually, depending on the relative abundance and distribution of the various stocks and contingencies in allocation formulas, while also considering ESA guidance from NMFS for ESA-listed species affected by implementation of the FMP.

The Council's annual Review of Ocean Salmon Fisheries (stock assessment and fishery evaluation; SAFE) document and pre-season reports (e.g., PFMC 2019a, 2019b, 2019c, and 2019d) assess and specify the present and historical range of harvests and harvest related mortalities that represent the OY.

4.1 Harvest Controls

Control rules are the metrics used to manage the harvest of stocks to achieve OY and prevent overfishing (as defined under the MSA). Control rules are derived using biological reference points and are used to specify the allowable harvest of stocks based on their abundance and are intended to meet conservation objectives,.

The MSA provides an exception to the requirement for a FMP to specify ACLs and accountability measures for stocks managed under international agreements in which the U.S. participates, and for PFMC this includes the PST, however, it is still necessary to specify MSY reference points for these stocks. Pacific salmon stocks subject to fisheries in both the U.S. and Canada are managed under the provisions of the PST. Natural stocks managed under the provisions of the PST include: (1) Puget Sound pink salmon stocks, (2) most non-ESA-listed Chinook salmon stocks from the mid-Oregon coast to the US/Canada border, and (3) all non-ESA-listed coho stocks except Willapa Bay natural coho. For these stocks, the PST annually places overall limits on fishery impacts and allocates those impacts between the U.S. and Canada. It allows the U.S. and Canada to manage their own fisheries to achieve domestic conservation and allocation priorities, while remaining within the overall limits determined under the PST. Because of these provisions of the PST, and the exception provided by the MSA, it is unnecessary for the FMP to specify ACLs or associated reference points for these stocks. The PST also includes measures of accountability which take effect if annual limits established under the Treaty are exceeded, and further reduce these limits in response to depressed stock status. The recently revised Chinook Chapter of the PST is in effect for the years 2019-2028 and includes reductions in harvest levels for Chinook salmon compared to the preceding agreement.

The ESA requires federal agencies whose actions may adversely affect listed salmon stocks to consult with NMFS. Because NMFS implements ocean harvest regulations, it is both the action agency and the consulting agency for actions taken under the FMP. To ensure there is no jeopardy as a result of this federal action, NMFS conducts ESA consultations with respect to the effects of ocean harvest on ESA-listed salmon stocks. When the biological consultation results in a "no jeopardy" opinion, NMFS issues an incidental take statement which authorizes a limited amount of take of listed species that would otherwise be prohibited under the ESA. In cases where a "jeopardy" opinion is reached, NMFS develops reasonable and prudent alternatives to the proposed action which also authorizes a limited amount of take, but requires modifications or mitigating components to the original action (*i.e.,* the reasonable and prudent alternatives).

The constraints on take authorized under incidental take statements and reasonable and prudent alternatives are collectively referred to as consultation standards in the FMP. These constraints take a variety of forms including FMP conservation objectives, limits on the time and area during which fisheries may be open, ceilings on fishery impact rates, and reductions from base period impact rates. NMFS may periodically revise consultation standards and NMFS annually supplies a guidance letter to PFMC which reflects the most current information.

Because of the need to meet all FMP control rules and ESA consultation standards in each fishing year, Council salmon fisheries are managed under a "weak stock" approach. In order to meet all control rules and consultation standards for the weakest stocks in a given year, Council fisheries forego full use of available harvests for healthier stocks. As a result, it is a very common case for stock-specific harvests for some stocks to be less than allowed under FMP control rules or ESA consultation standards due to the need to protect co-occurring limiting stocks.

4.2 Overall Fishery Objectives

The following FMP objectives guide the Council in establishing fisheries against a framework of ecological, social, and economic considerations.

1. Establish ocean exploitation rates for commercial and recreational salmon fisheries that are consistent with requirements for stock conservation objectives and ACLs within Section 3, specified ESA consultation or recovery standards, or Council adopted rebuilding plans.
2. Fulfill obligations to provide for Indian harvest opportunity as provided in treaties with the U.S., as mandated by applicable decisions of the federal courts, and as specified in the October 4, 1993 opinion of the Solicitor, Department of Interior, with regard to federally recognized Indian fishing rights of Klamath River Tribes.
3. Maintain ocean salmon fishing seasons supporting the continuance of established recreational and commercial fisheries while meeting salmon harvest allocation objectives among ocean and inside recreational and commercial fisheries that are fair and equitable, and in which fishing interests shall equitably share the obligations of fulfilling any treaty or other legal requirements for harvest opportunities.[6]
4. Minimize fishery mortalities for those fish not landed from all ocean salmon fisheries as consistent with achieving OY and the bycatch management specifications of Section 3.5.
5. Manage and regulate fisheries so that the OY encompasses the quantity and value of food produced, the recreational value, and the social and economic values of the fisheries.
6. Develop fair and creative approaches to managing fishing effort and evaluate and apply effort management systems as appropriate to achieve these management objectives.
7. Support the enhancement of salmon stock abundance in conjunction with fishing effort management programs to facilitate economically viable and socially acceptable commercial, recreational, and tribal seasons.

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[6] In its effort to maintain the continuance of established ocean fisheries, the Council includes consideration of maintaining established fishing communities. In addition, a significant factor in the Council's allocation objectives in Section 5.3 is aimed at preserving the economic viability of local ports and/or specific coastal communities (*e.g.,* recreational port allocations north of Cape Falcon). Chapter 6 in Appendix B and the tables it references provides additional specific information on the fishing communities.

8. Achieve long-term coordination with the member states of the Council, Indian tribes with federally recognized fishing rights, Canada, the North Pacific Fishery Management Council, Alaska, and other management entities which are responsible for salmon habitat or production. Manage consistent with the PST and other international treaty obligations.
9. In recommending seasons, to the extent practicable, promote the safety of human life at sea.

Harvest allocations are determined from a total allowable ocean harvest, which is maximized to the largest extent possible but still consistent with PST and treaty-Indian obligations, state fishery needs, and spawning escapement requirements, including consultation standards for stocks listed under the ESA. The Council makes every effort to establish seasons and gear requirements that provide commercial troll and recreational fleets a reasonable opportunity to catch the available harvest. Procedures for determining allowable ocean harvest vary by species, area, fishery complexity, available data, and the state of development of predictive tools. These procedures have and will change over time to incorporate the best available science. A number of management controls are available to manage the ocean fisheries each season, once the allowable ocean harvests and the basis for allocation among user groups have been determined. Stock management considerations also guide the Council for setting seasons within major subareas of the Pacific Coast (Figure 4.2.a).

Controls include management boundaries and seasons, quotas, minimum harvest lengths, fishing gear restrictions, area restrictions, commercial landing limits, and recreational daily bag limits. Natural fluctuations in salmon abundance require that annual fishing periods, quotas, and bag limits be designed for the conditions of each year. Measures that are suitable one year may not be suitable the next. New information on the fisheries and salmon stocks also may require other adjustments to the management measures. The Council assumes these ocean harvest controls also apply to territorial seas or any other areas in state waters specifically designated in the annual regulations. Details to the incorporation and use of these controls are contained in Chapter 6 of the FMP (PFMC 2016).

Successful management of the salmon fisheries requires considerable information on the fish stocks, the amount of effort for each fishery, the harvests by each fishery, the timing of those harvests, and other biological, social, and economic factors. Much of the information must come from the ocean fisheries; other data must come from inside fisheries, hatcheries, dam counts, and spawning grounds. Some of this information needs to be collected and analyzed daily, whereas other types need to be collected and analyzed less frequently, *i.e.*, once a year. In general, the information can be divided into that needed for in-season management and that needed for annual and long-term management. The methods for reporting, collecting, analyzing, and distributing information can be divided similarly. The description of the data needs, methods for obtaining in-season and annual long-term data, reporting requirements, and schedules for the Council's monitoring of the resource and the fisheries harvesting that resource are contained in Chapters 7 and 8 of the FMP (PMFC 2016).

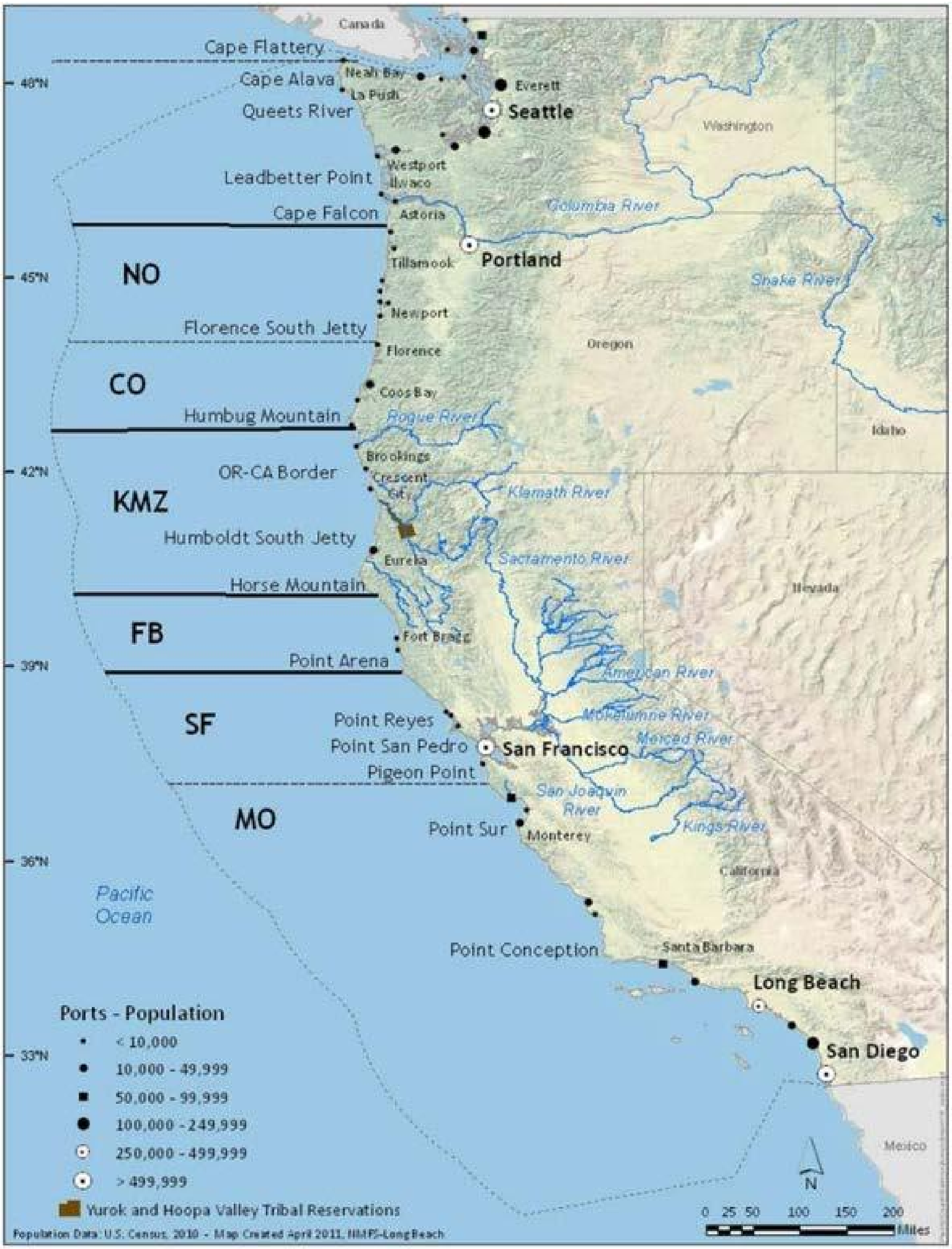

Figure 4.2.a. Map of major management boundaries in common use since 2000.

4.3 Schedule and Procedures for establishing annual management measures

The process for establishing annual or pre-season management measures under the FMP contains a considerable amount of analysis, public input, and review. This is detailed in Chapter 9 (PFMC 2016). The actions by the Secretary of Commerce after receiving the pre-season regulatory modification recommendations from the Council are limited to accepting or rejecting, in total, the Council's recommendations. If the Secretary rejects such recommendations he or she will so advise the Council as soon as possible of such action along with the basis for rejection, so that the Council can reconsider. Until such time as the Council and the Secretary can agree on modifications to be made for the upcoming season, the previous year's regulations remain in effect. This procedure does not prevent the Secretary from exercising his or her authority under Sections 304(c) or 305(c) of the MSA and issuing emergency regulations, as appropriate, for the upcoming season. In-season modifications of the regulations may be necessary under certain conditions to fulfill the Council's objectives and the process and procedures for doing so are detailed in Chapter 10 (PFMC 2016). Modifications not covered within the framework will require either an FMP amendment, rulemaking, or emergency Secretarial action. Depending on the required environmental analyses, the amendment process generally requires at least a year from the date of the initial development of the draft amendment by the Council. Emergency regulations may be promulgated without an FMP amendment. Details for both an FMP Amendment process and Emergency Regulations are detailed in Chapter 11 (PFMC 2016).

4.4 Season structure

4.4.1 North of Falcon

The North of Cape Falcon (NOF) management area encompasses the Washington coast and northern Oregon. Harvest allocation and seasons may vary among the four ocean subareas, which include Marine Area 1 (Columbia River subarea - Leadbetter Point to Cape Falcon, OR), Marine Area 2 (Westport subarea - Queets River to Leadbetter Point, WA), Marine Area 3 (La Push subarea - Cape Alava to Queets River, WA) and Marine Area 4 (Neah Bay subarea - U.S./Canada Border to Cape Alava, WA) (refer to Figure 4.2.a).

Stocks that constrain NOF fisheries vary annually depending on relative stock abundance and sharing of the conservation responsibility between ocean and inside fisheries. In recent years, fisheries have been structured to limit impacts on ESA-listed Chinook salmon stocks from the Columbia River and Puget Sound, on ESA-listed coho salmon from the Columbia River, as well as on non-listed coho salmon stocks from the Washington Coast and Puget.

North of Falcon Coastal Non-Tribal Commercial and Recreational Ocean Fisheries

Fisheries are planned based on allocations between recreational and commercial sectors and between subareas as established in the FMP. In recent years (2016-2018), emergency deviations were made from FMP-specified allocations due to the poor status of coho, and the relative importance of coho fisheries to each fleet and port.

In-season management focuses on extending quotas throughout the season to avoid early closures. To achieve this goal, occasionally quota is transferred between subareas, sectors and/or species on an impact-neutral basis. Impact neutrality is assessed for limiting stocks (identified annually at the end of the preseason process) and requires that modeled total fishery impacts specific to these stocks resulting from an in-season action are equal to or less than originally planned for in that specific year. Control zone closures are enacted within the subareas to protect stocks of concern.

The commercial non-tribal troll fishery NOF is typically open for a Chinook-only season between May 1 and June 30 and an all-species season between July 1-September 30. Effort controls, such as days open per week and vessel landing limits, are used to prolong the season and to ensure quotas are not exceeded. In recent years with poor coho salmon abundance, the planned closure date of the all-species fishery has been moved earlier as a coho salmon conservation measure. The fishery has been mark-selective for coho salmon since around the year 2000, although mark-selective quotas have been converted to non-selective equivalents on an impact neutral basis during the fishing season in some years.

For the recreational fishery NOF, season opening dates, closing dates and daily retention limits vary by year and by subarea. The FMP goal is to provide coho salmon for an all-species recreational fishery from late June through early September, and if possible a minimal Chinook-only fishery prior to the all-species season. Recreational fisheries did include small early-season Chinook-only mark-selective fisheries in May-June from 2010 through 2015. More recent fisheries have only had an all-species fishery from late June or early July through early September, and were limited primarily by poor coho salmon forecasts in most years. Recreational fisheries have been mark-selective for coho salmon since 1999, although mark-selective quotas have been converted to non-selective equivalents on an impact neutral basis during the fishing season in some years. Fishery structure is often modified in-season to maintain season length and to ensure quotas and sub-area quotas and guidelines are not exceeded.

Because the July-September season operates with a quota for Chinook salmon and another quota for coho salmon, reaching one quota before the fishery catches the other would result in closure for the season. Accordingly, catch is carefully managed to not exceed either of the two quotas. In some years, weekly landing limits are used for one species or the other, to ensure that the fishery can remain open long enough to take both quotas. The actual combined catch in the Washington coastal troll and sport fisheries combined has not exceeded the quotas since before the year 2000.

Washington Coast Treaty Ocean Troll Fishery

The Makah, Quileute, Hoh, and Quinault tribes may exercise their treaty rights to harvest salmon in their respective usual and accustomed fishing areas in Washington Marine Areas 2, 3 and 4 . In addition, Makah, Lower Elwha Klallam, Jamestown S'Klallam, and Port Gamble S'Klallam tribes may exercise their treaty rights to harvest salmon in their respective usual and accustomed fishing areas in Marine Area 4B, the entrance to the Strait of Juan de Fuca. During the May through September time period tribal salmon harvest in Area 4B is attributed to the treaty troll quotas. Treaty Indian tribes have a legal entitlement to take up to 50 percent of the harvestable surplus of stocks which pass through their usual and accustomed fishing areas.

Similar to the non-tribal commercial fishery, the treaty troll fishery consists of a Chinook-only season between May 1 and June 30 and an all-species season between July 1-September 30. Chinook remaining from the May through June treaty troll quota may be transferred to the July through September quota on an impact-neutral basis for limiting stocks. Treaty tribes may apply inseason effort controls, such as days open per week, vessel landing limits, fishery closures, etc., when necessary to ensure tribal harvest does not exceed the Chinook or coho treaty troll quotas.

The annual treaty troll ocean quotas proposed by the tribes represent maximum allowable catch. For the most recent ten-year period (2009-2018) the ocean quota in the treaty troll fishery ranged from 37,500 to 62,500 Chinook. Harvest during this time period ranged from 12,200 to 61,700 Chinook. On average, 70 percent of the harvest occurred in Marine Area 4 (Neah Bay). Since 2016, the Chinook tribal ocean quota has been set at or below 40,000 fish, however, catch has not exceeded 25,000 fish due to fish availability and fisher effort. For example, the treaty troll Chinook fishery harvested 58 percent, 61 percent, 60 percent and 52 percent of the allowable tribal Chinook ocean catch in 2016, 2017, 2018 and 2019 respectively.

Overlap of SRKW with North of Falcon salmon fisheries

The whales are observed in the NOF area in all seasons and likely have some direct overlap with the fisheries every year. As described in Section 2.2, there have been 49 confirmed opportunistic sightings between 1986- 2016 off the coastal areas of Washington, Oregon, and California. Twenty six of these 49 confirmed sightings occurred off Washington coast and six of the 26 occurred from May to September (Table 2.2.a). Satellite tagging efforts that were deployed from 2012-2016 between the months of December to May provide less information on the overlap between whales and fisheries. However, the tagging effort showed K/L pods occurred almost exclusively on the continental shelf, primarily on the Washington coast, with a continuous high use area between Grays Harbor and the Columbia River and off Westport (Figure 2.2.d); Hanson *et al.* 2017, 2018), whereas J pod remained primarily in the Salish Sea. Lastly, there were acoustic detections of SRKW off Washington coast in all months of the year (Figure 2.2.g; Table 2.2.d), and results suggest SRKW may be present in Washington coastal waters at nearly any time of year, and in other coastal waters more often than previously believed (Hanson *et al.* 2017) indicating overlap with PFMC fisheries could occur each month of open season.

4.4.2 South of Falcon to California Border

Oregon Coast

This area includes the major management areas of Oregon (Cape Falcon to Humbug Mt.) and the Oregon portion of the Klamath Management Zone (KMZ; Humbug Mt. to the OR/CA border).

In the Cape Falcon to Humbug Mt. area, the commercial season is typically open from mid-March/early-April through October, with various mid-season closures to reduce impacts on limiting stocks. The Oregon KMZ typically opens in mid-March/early-April, with monthly quotas beginning in June. These quotas may run through September in some years, but late-summer/fall fisheries do not occur every year. Weekly landing limits may be used in all areas to constrain catch to meet management objectives. The minimum size limit for Chinook salmon is generally 28 inches in Oregon fishing areas. Constraining Chinook salmon stocks for commercial fisheries in the Oregon areas are most often those originating in California rivers. These include Klamath River fall Chinook and Sacramento basin fall Chinook salmon, which are managed for escapement goals as specified in the Council's FMP. Ocean impact limitations on Age 4 Klamath River Fall Chinook as part of the consultation standard for ESA-listed Coastal California Chinook salmon also constrain fisheries. In any given year, any of these may be the principal limitation for commercial fishing opportunity in this area. Commercial troll fisheries have been closed to coho retention south of Cape Falcon (SOF) since 1993 with the exception of limited fisheries in 2007, 2009, and 2014.

In the Cape Falcon to OR/CA border area, the large majority of the catch and effort in the recreational salmon fishery is directed at coho salmon. Various coho salmon quota fisheries occur from June through the summer (depending on quota) and into September, overlapping with the ongoing Chinook salmon season. While effort directed at Chinook and catch of Chinook salmon are typically low, retention of Chinook salmon is usually open from mid-March through October. The KMZ is usually open for Chinook salmon (with some years of limited summer coho salmon fishing in the Oregon KMZ), early-May through early-September, although mid-season closures are common. Due to low catch of Chinook salmon, ESA-listed coho salmon stocks are the principal limitation for recreational opportunity in this area. Depending on year, limitations on either Lower Columbia wild coho or Oregon coast wild coho salmon (both ESA-listed) will be the limiting stock for this fishery, and these limitations are more restrictive than coho salmon provisions of the Council's FMP. Oregon recreational anglers are generally restricted to no more than two salmon per day, with minimum size limits of 24 inches for Chinook salmon and 16 inches for coho salmon. From 1994 through 1998, coho retention was prohibited in Oregon recreational fisheries SOF.

For the recent ten-year period (2009-2018), which included the second year of a complete Chinook closure (2009), Oregon's commercial season typically ranged from 107 to 209 open days (Cape Falcon-Humbug Mt.) and 0 (2017) to 163 open days in the Oregon KMZ (Humbug Mt. to OR/CA border), excluding 2009. During openings, the troll fleet landed 602,348 Chinook salmon and expended 48,510 vessel days between Cape Falcon and the Oregon/California border. When converted to annual averages, this represents, levels that are roughly a third of what they were in the 1970s to 1990s (see also section 4.5 below). The majority of effort and catch occurred in the Cape Falcon to Humbug Mt. area, 92 and 93 percent, respectively. The Oregon KMZ area, effort and catch was 8 percent and 7 percent, respectively, of Oregon's total. The commercial fishery is managed with a 28 inch minimum length restriction and vessel limits in the fall fisheries as well the June through August quota fisheries in the Oregon KMZ area.

During the same ten-year period, recreational anglers experienced mostly complete seasons for Chinook salmon because catches of Chinook salmon in Oregon ocean recreational fisheries are generally very low. For the Cape Falcon to Humbug Mt. area the fishery generally opened mid-May and continued through October. For the Oregon KMZ area the fishery opened in early to late May and generally continued through early September, with the exception of 2017 when the area from Florence South Jetty to the OR/CA border was closed for salmon angling. During this period, the Oregon south of Cape Falcon recreational salmon fleet landed 85,612 Chinook salmon and expended 589,641 angler trips. When converted to annual averages, this represents approximately 42 and 33 percent, respectively, of what they averaged historically (1970s to 1990s). On average, 62 percent of the catch and 84 percent of the effort occurs in the Cape Falcon to Humbug Mt. area. The recreational fishery is managed with a bag limit of two salmon per angler and a 24 inch minimum length restriction for Chinook salmon.

Overlap of SRKW with salmon fisheries South of Falcon to California border

The whales are observed off the Oregon coast and likely have some direct overlap with the fisheries,. As described in Section 2.2, of the 49 confirmed opportunistic sightings between 1986 and 2016, 8 were off the Oregon coast (south of Falcon to the California border). Of these 8 sightings, 4 occurred in March and April and 4 occurred in January and February (Table 2.2.a). Satellite tagging efforts that were deployed from 2012-2016 between the months of December to May provide less information on the overlap between whales and fisheries. However, the tagging effort showed K/L pods occurred off Oregon coast, but to a lesser extent than off the Washington coast (Figure 2.2.d; Hanson *et al.* 2017, 2018). Lastly, there were acoustic detections of SRKW off Oregon coast on the Newport hydrophone (Figure 2.2.e). Results suggest SRKW were detected off the Newport recorder in January, February, March, and May. This suggests overlap may be more likely to occur from March through May when fisheries are open. However, their predictive use is uncertain and the limited data seems to suggest that distribution off the Oregon coast has a seasonal component, but there is considerable year-to-year variation.

4.4.3 California Coast

Commercial and recreational fisheries targeting Chinook salmon along the California coast are managed within four major catch/port areas (north to south, Figure 4.2.a): (1) the California portion of the Klamath Management Zone (CA-KMZ), which extends from the OR-CA border to Horse Mountain, (2) Fort Bragg (Horse Mountain to Point Arena), (3) San Francisco (Point Arena to Pigeon Point), and (4) Monterey (Pigeon Point to the US-Mexico border). Within each area, fisheries are shaped annually to provide harvest opportunity and to achieve, in expectation, stock conservation objectives defined in the salmon FMP and/or through ESA consultation. Retention of coho has been prohibited off California since 1996.

Because the impact of fisheries on sensitive Chinook salmon stocks varies between port areas and seasonally, both commercial and recreational opportunity tend to be greatest in Fort Bragg and San Francisco areas. To the south and north, protracted early (Monterey) or late (CA-KMZ) seasons or quotas [CA-KMZ troll] are often adopted to reduce impacts on ESA-listed Sacramento River Winter Run Chinook salmon and California Coastal Chinook (CCC). Management objectives for SRFC and KRFC stocks also often play a role in limiting opportunity coast wide, however fishing in the Fort Bragg and CA-KMZ is most constrained by objectives for KRFC, or by CCC in years with high KRFC abundance. In a largely unconstrained fishing season, commercial opportunity exists from May 1 through the middle of October, with earlier or later seasons precluded by winter run ESA consultation standards south of Point Arena. Recreational fisheries are available from the first Saturday in April through the second Sunday in November, again with earlier or later seasons precluded by winter run ESA consultation standards south of Point Arena. Commercial and recreational seasons in the Monterey management area are typically further restricted beyond these end dates due to limits on the projected impact rate allowable under winter run ESA consultation standards. These consultation standard related constraints always exist, even when target stocks are not constraining.

For the most recent ten-year period (2009-2018), which included the second year of a coast-wide closure (2009), California's commercial season typically ranged anywhere from a few weeks (i.e., CA-KMZ) to 4+ months (San Francisco, Fort Bragg) in length. During openings, the troll fleet logged 8,962 vessel days and landed 105,312Chinook salmon across the four areas, on average, levels that are roughly a quarter of what they were in the 1970s to 1990s (see also section 4.5 below). The majority of effort and catch occurred in San Francisco (51 / 47 percent [effort/catch]), followed by Fort Bragg (26 / 35 percent), and Monterey (21 /15 percent). Less than five percent of California's total commercial catch and effort typically occurs in the northern-most port area (CA-KMZ), which is also the only commercial area that is routinely managed on a quota basis (usually confined to September).

During the same ten-year period (barring 2009), recreational anglers experienced longer and (in some areas and years) more stable seasons, encompassing much of the spring (April/May) to early fall (October/November) time period. However, recreational fisheries are also routinely managed with intermittent mid-season closures (CA-KMZ, Fort Bragg, San Francisco) or early season endings (Monterey) aimed at lessening impacts on weak stocks. During the last decade, the California recreational salmon fleet landed 60,487 Chinook salmon over 88,359 angler trips for the entire coast, on average, levels that are approximately half of what they averaged historically (1970s to 1990s). In a typical year, 50-60 percent of the coast-wide catch and effort total occurs in the San Francisco area, with 10-20 percent occurring in each of the other port areas. Note that the recreational fishery is managed with bag limit (two fish per angler) and minimum length (20-24 inch [total length], depending on time/area) restrictions; commercial trollers are also subject to minimum length restrictions (26-28 inch, depending on time/area) and, on occasion, vessel limits.

Overlap of SRKW with salmon fisheries off the California coast

The whales are observed off the California coast and likely have some direct overlap with the fisheries. As described in Section 2.2, of the 49 confirmed opportunistic sightings between 1986 and 2016, 15 were off the California coast (from the Oregon-California border to Point Sur, CA). Of these 15 sightings, 13 occurred in January, February, and March, and 2 occurred in April and October (Table 2.2.a). Satellite tagging efforts that were deployed from 2012-2016 between the months of December to May provide less information on the overlap between whales and fisheries. However, the tagging effort showed K/L pods occurred off California coast, but to a lesser extent than off the Washington coast (Figure 2.2.d; Hanson *et al.* 2017, 2018). Lastly, there were acoustic detections of SRKW off California coast on the Fort Bragg and Point Reyes hydrophones (Figure 2.2.e). Results suggest SRKW were detected off these recorders in January, February, May, and December (Table 2.2.d). These results suggest there may be overlap in some years with the PFMC fisheries from April, May, and October when the harvest is relatively low.

4.5 Chinook salmon harvest

The Annual post-season review of the Council's recommended management measures is documented by the Salmon Technical Team (STT) and Council staff in the stock assessment and fishery evaluation (SAFE) document (for an example refer to PFMC 2019a). The SAFE document reviews the prior year's ocean salmon fisheries off the coasts of Washington, Oregon, and California to assess Council salmon fishery management performance, the status of Council-area salmon stocks, and the socioeconomic impacts of salmon fisheries. The SAFE document compares post-season fishery performance against achieving stock specific conservation objectives and reference points governing harvest control rules and status determination criteria for salmon stocks and stock complexes in the Pacific Coast salmon FMP (for current objectives see Table 3-1, PFMC 2016). Over the course of implementing the FMP many of these objectives have been modified, often as a result of ESA consultations for specific species of salmon. Therefore trying to depict long-term adherence to a single standard or contemporary reference point for many stocks will not capture the changes that may have occurred over several decades, or the changes that have taken place in just the last decade. Similarly, due to the weak stock management approach, evaluation of the effects of FMP control rules and ESA guidance on past fisheries management is a very complex exercise necessitating consideration of the status of all managed stocks in any given year. Nevertheless, an examination of catch and stock status information can be used to describe general trends in PFMC salmon fisheries over time.

This exercise did not make use of the area-specific landed harvest data described earlier, because those numbers reflect only landed catch (i.e. do not include release or dropoff mortality), do not distinguish jacks from adults, do not account for natural mortality affecting foregone harvest from earlier seasons, and do not account for the possibility that fish harvested in one area might have moved to another area if they were still alive. The modeling exercise instead compared projected abundances with and without the impacts of Council-area directed salmon fisheries. This was done by calculating stock-specific reductions in ocean-wide abundance (from all PFMC ocean salmon fishing) using the usual fishery management models, calculating alternative abundances that would be projected if those fisheries had not occurred, and then apportioning the modeled changes in abundance across areas using the Shelton et al. (2019) spatial distribution model.

Figure 4.5.a through Figure 4.5.d show Chinook salmon adult (age 3 and older) abundance and reductions in adult abundance attributable to Council-area directed salmon fisheries for the major management areas the Workgroup aggregated: North of Cape Falcon, Oregon coast (Cape Falcon south to Horse Mountain, California) and California coast (south of Horse Mountain). However, it should be noted that reductions in specific areas may be partially driven by fisheries occurring in other areas of the EEZ, and cannot be interpreted as the direct effect of fishing in that particular area. Note that although only Council-area directed salmon fisheries were considered, the model estimated that these fisheries would lead to some reduction in abundances outside the EEZ, due to how the model was implemented (see Chapter 5) and to account for movement of fish within and between time steps.

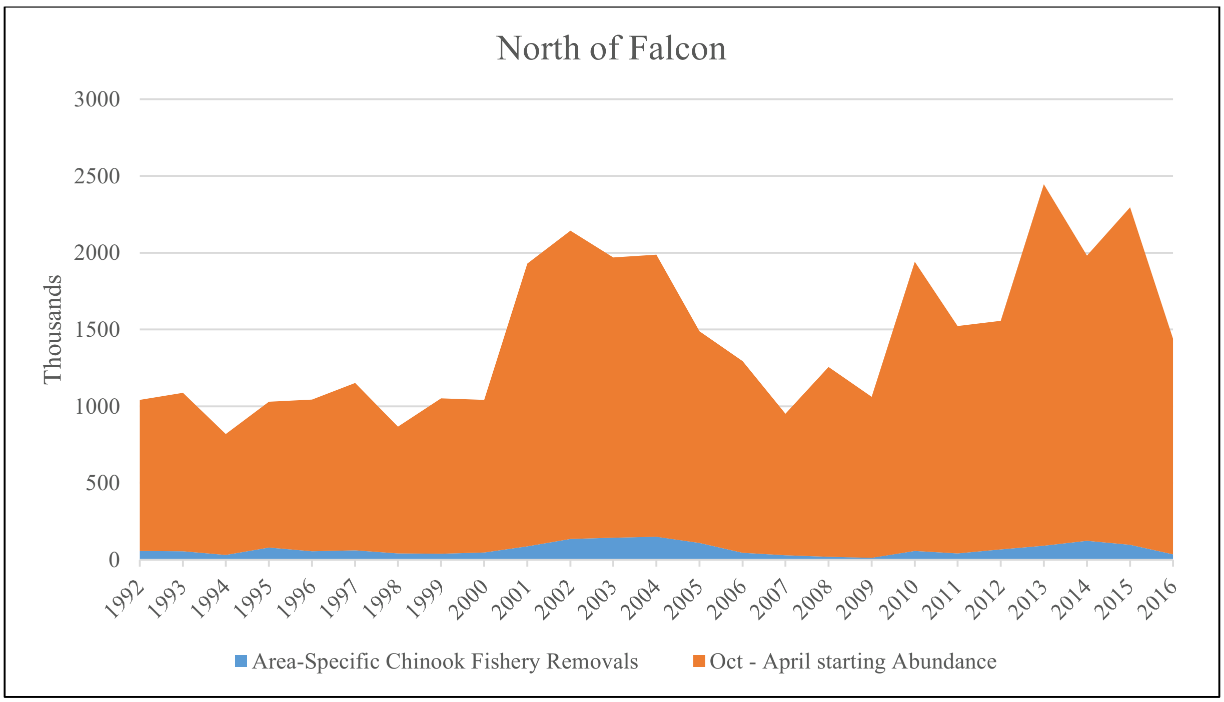

Figure 4.5.a. North of Cape Falcon 1992-2016 trends in annual adult abundance (estimated annually to be present on October 1) and area-specific reduction in adult abundance modeled to result from all PFMC salmon fisheries (from October through the following September).

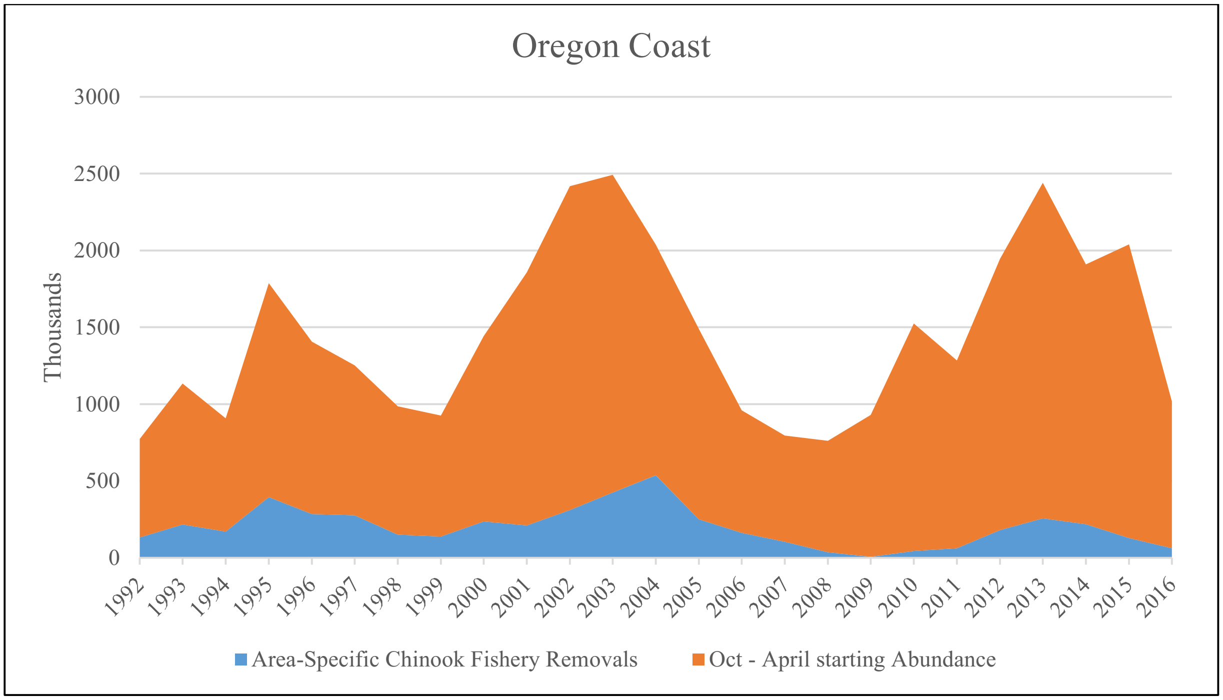

Figure 4.5.b. Oregon coast (Cape Falcon south to Horse Mountain, California) coastal 1992-2016 trends in annual adult abundance (estimated annually to be present on October 1) and area specific reduction in adult abundance modeled to result from all PFMC salmon fisheries (from October through the following September).

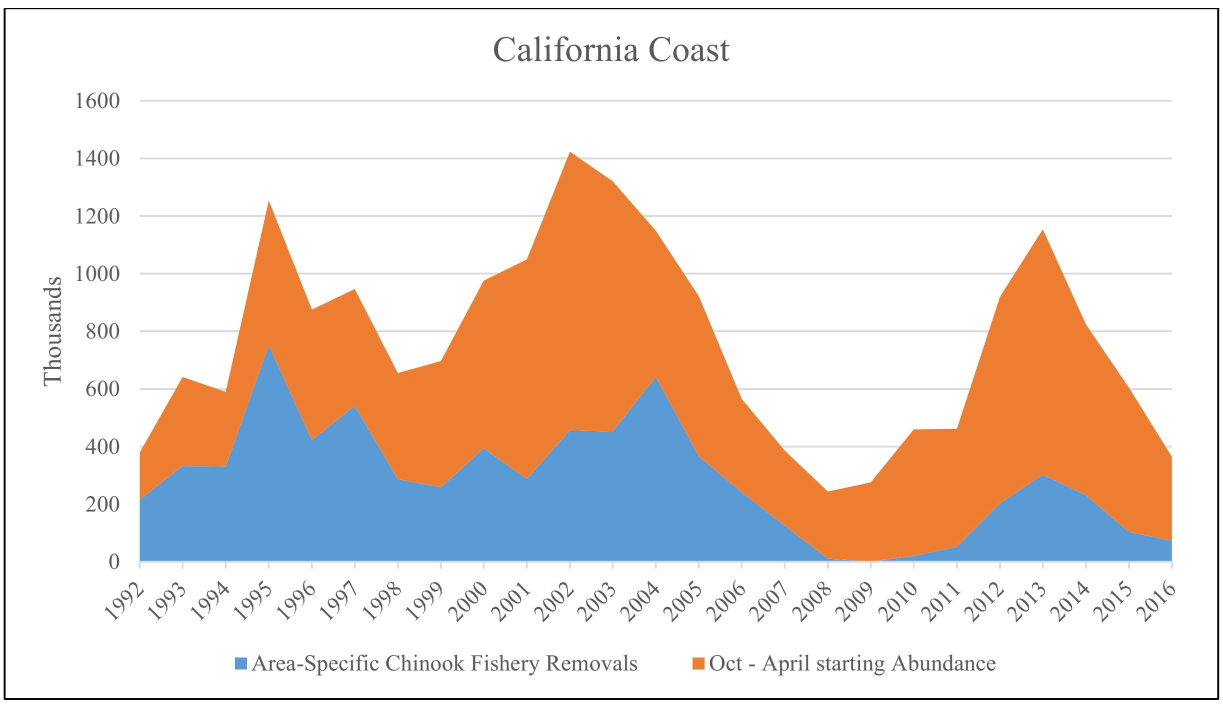

Figure 4.5.c. California coast, south of Horse Mountain coastal 1992-2016 trends in annual adult abundance (estimated annually to be present on October 1) and area specific reduction in adult

abundance modeled to result from all PFMC salmon fisheries (from October through the following September).

At a coastwide level Figure 4.5.d. depicts Chinook salmon abundance, and the area-specific reductions in adult abundance attributable to PFMC salmon fisheries, aggregated across all areas of the EEZ. As described above, the level of fishery mortality has changed, and has generally been reduced, over time relative to implementing changes to harvest control rules and ESA limitations on the fisheries. By dividing the estimated end of year abundance without fishery by the estimated end of year abundance with the fishery, we calculate the percent of potential ending abundance that remains after PFMC fisheries have occurred. When plotted by year for coastwide abundance, the percent of potential abundance that is remaining after ocean fisheries occur is increasing over time – meaning fisheries have been taking a lower proportion of the available abundance over time (Figure 4.5.e). The trend line depicted in Figure 4.5.e. is not intended to reflect any particular level of significance, but is simply to demonstrate the trend.

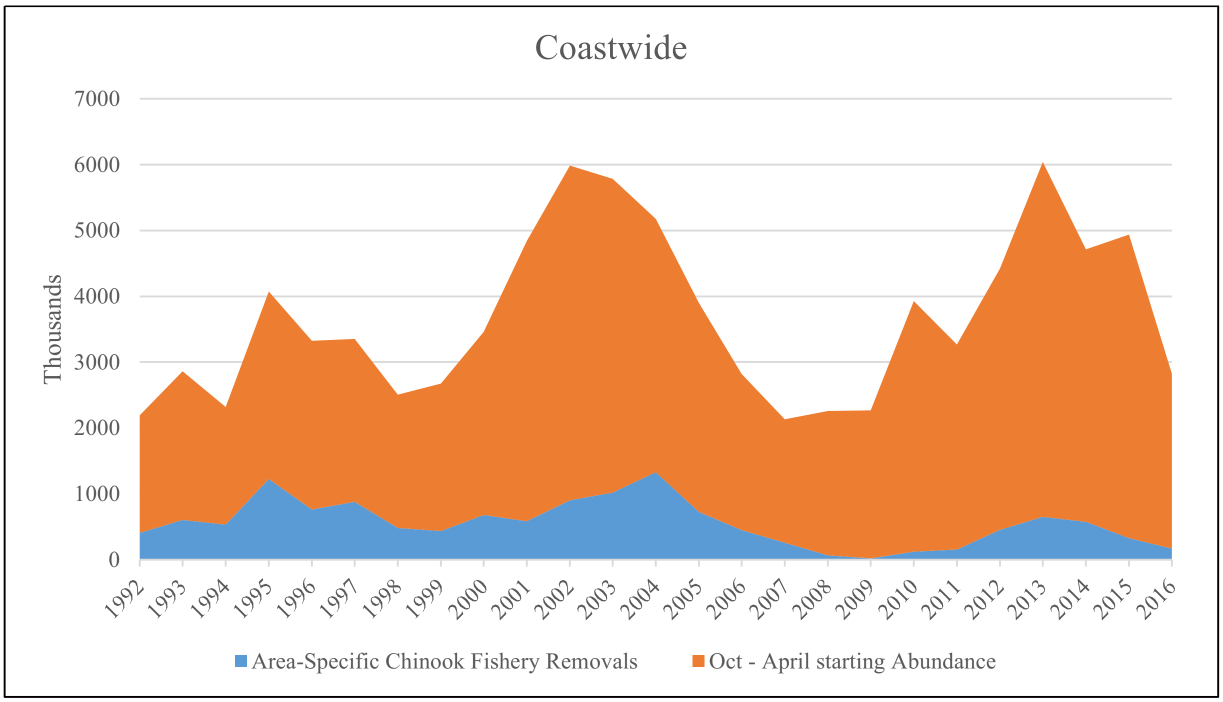

Figure 4.5.d. Coastwide (EEZ) 1992-2016 trends in annual abundance (estimated annually to be present on October 1) and reductions in abundance attributable to PFMC ocean salmon fisheries (from October through the following September). Note that this does not include abundance outside the EEZ, nor the modeled reduction in abundance outside the EEZ owing to PFMC fisheries within the EEZ impacting fish that would have moved between areas.

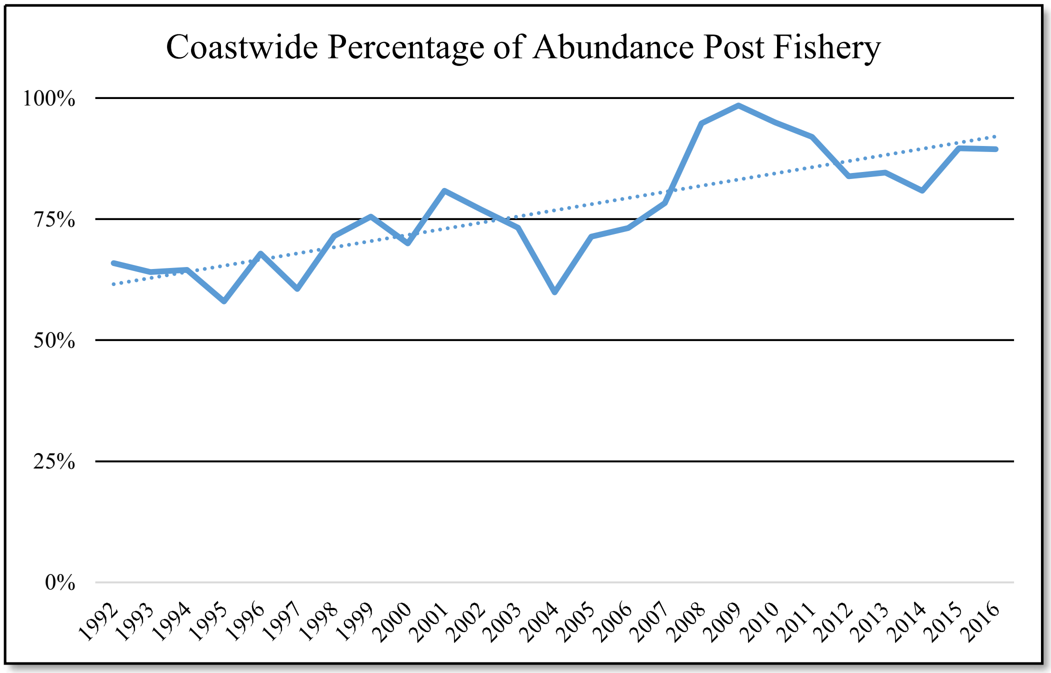

Figure 4.5.e. Coastwide (EEZ) 1992-2016 trend in percent of Chinook adult abundance remaining after PMFC ocean salmon fisheries (from October through the following September).

Estimates of reductions in abundance attributable to PFMC salmon fisheries for each geographic area aggregated for evaluation in this report using the methodology described in Section 5 are contained in Appendix E. They are available annually, also by the time steps described in further detail in Section 5.1. PFMC salmon fisheries also cause some reduction in modeled abundances outside of the EEZ (notably, the Salish Sea and West Coast Vancouver Island) which are not reflected in the "coastwide" total in Figure 4.5.e above.

5 RISK ASSESSMENT

The analyses developed to support the risk assessment use correlative analyses of relationships between Chinook abundance and SRKW demography similar to those included in the Panel Report (Hilborn *et al.* 2012) and described by Ward *et al.* (2013). These new analyses include more recent data and include a broader range of SRKW demographic indices. While previous documents have referred to such relationships as "correlations" we note that strictly speaking we are estimating coefficients in generalized linear models with non-Gaussian distributions rather than calculating correlation coefficients. In contrast with earlier correlative studies, abundances were defined not on the basis of individual stocks or sets of stocks, but on the basis of composite abundances in specific ocean areas based on distributions inferred from recent modeling efforts (Shelton *et al.* 2019). This analysis related past SRKW demographic performance with retrospective estimates of time- and area-specific Chinook salmon abundance. For the first part of the analysis, only the estimated Chinook salmon abundance present in a particular time and area was of interest; no attempt was made to separate out the effects of production, natural mortality, or harvest in generating the realized abundances. We then estimated time- and area-specific reductions in abundance due to the fishery and used the fitted relationships between Chinook salmon abundance and demographic rates to calculate the change in predicted demographic rates corresponding to abundances with and without PFMC fisheries occurring.

As a coarser approach, we also performed clustering analyses attempting to identify sets of years of similar SRKW demographic performance, and then examined whether years of good or bad demographic performance were consistently associated with high or low Chinook abundance. The clustering analyses are described in Appendix D.

5.1 Model Description

The models analyzed the statistical relationship between demographic indices of SRKW performance (see Section 5.2) and retrospective estimates of adult (age 3 and older) ocean Chinook abundance at three time steps (October 1-April 30, May 1-June 30, and July 1-September 30) aggregated at various spatial scales and for fishery management years 1992-2016 (the fishery management year starts in the fall of the preceding year, so the first time step considered was October 1, 1991 – April 30, 1992). When biologically appropriate, we considered temporal lags between Chinook abundance and observed SRKW performance based on plausible physiological mechanisms linking food supply to future performance. For example, because killer whales have a gestation period of approximately 17 to 18 months, it may be important to consider Chinook salmon indices in earlier years as predictors of fecundity (Hilborn *et al.* 2012, Ward *et al.* 2009, Ward *et al.* 2013). While discussed as a potential evaluation consideration, the workgroup decided not to consider moving averages of abundance across multiple years.

Coastwide adult abundance (hereafter the "adult" qualifier is generally dropped, but still applies) estimates for most Chinook salmon stocks were generated using Chinook FRAM (MEW 2008) post-season runs (Round 6.2 of base period calibration; 10.29.2018). Abundance estimates for FRAM stocks are calculated using stock-specific terminal run size estimates by age and mark status provided by regional technical staff. Stock-specific terminal run sizes are then expanded by maturation rates, fishing mortality, and natural mortality estimates to derive a starting abundance. For additional details related to calculations of FRAM starting abundances, please refer to the Backwards FRAM documentation, available at https://github.com/dappdrd/PFMC_SRKW/blob/master/BkFRAM-May-2-2018.docx.

However, there are several Chinook salmon stocks that are not modeled in FRAM. These stocks include those north of Vancouver Island, Hupp Springs, Washington Coastal Springs, Tsoo-Yess Falls, Upper Columbia Spring/Snake River spring-summer, and all Chinook salmon stocks originating south of Elk River, Oregon, with the exception of Sacramento River Fall Chinook (SRFC) (see Appendix A and B). Many of these stocks were relatively small in magnitude (*e.g.,* Hupp Springs, Coastal Springs, and Tsoo-Yess) or were primarily outside of the core SRKW assessment area (*e.g.,* stocks north of Vancouver Island). However, the SRKW workgroup determined that it was necessary to account for Sacramento Fall, Klamath Fall, and Rogue Fall stocks along with Upper Columbia Spring/Snake River spring-summer using methods external to FRAM due to the likely spatial-temporal overlap of these stocks with SRKW and relatively large abundances of these stocks. SRFC tends to dominate ocean abundances in much of California (Satterthwaite *et al.* 2015), and Sacramento Fall, Klamath Fall, and Rogue Fall can make up a large proportion of the ocean abundance off northern California and southern/central Oregon (Bellinger *et al*. 2015).

For Upper Columbia Spring/Snake River spring-summer, terminal run size estimates were expanded to account for assumed ocean natural mortality (using the same natural mortality assumptions as Chinook FRAM) to represent starting abundances. See below:

$$Starting\ Abundance = \frac{Terminal\ Run\ Size}{(1 - natural\ mortality)}$$

Where the natural mortality is age specific to time step 1 ("Oct. through Apr.") and the terminal run size represents the return of Upriver Columbia Springs in time step 1. Starting abundance of Upriver Columbia Springs is only available for time step 1, with starting abundances in time steps 2 and 3 for this stock being set to 0.

The Upriver Columbia Spring aggregate typically experiences an exploitation rate less than one percent in all marine fisheries (the Workgroup estimated this value using a coded wire tag analysis applied to data from 2000–2016). Given the very low rates of ocean exploitation, it is presumed that this stock aggregate either has a far north or offshore distribution, resulting in low encounter rates in fisheries. Therefore, Upper Columbia Spring/Snake River spring-summer are most likely to be available to SRKW near the mouth of the Columbia River as they return to spawn and unavailable outside of the winter season.

For Chinook salmon stocks originating south of the Elk River, we used abundance estimates for SRFC, Klamath River Fall Chinook (KRFC), and Rogue River Fall Chinook (RRFC) derived outside of FRAM. Although SRFC are included in FRAM as Sacramento Falls, we chose to use an alternative model that more closely aligns with South of Falcon fisheries management conventions and models. For SRFC we used a modification of the Sacramento Index (O'Farrell *et al.* 2013) incorporating natural mortality and catch apportioned by month, for KRFC we used the same cohort reconstructions that inform the Klamath Ocean Harvest Model (KOHM; Mohr 2006), and for RRFC we adjusted the September 1 age-specific Rogue Ocean Production Index (ROPI) values (PFMC 2019) according to monthly ratios in age-specific KRFC abundance determined from cohort reconstructions. The KRFC and RRFC abundances are age-specific but although the SRFC index excludes jacks (age 2), it does not distinguish among different adult age classes. Age 3 Chinook typically make up a large but variable proportion of hatchery-origin SRFC adults (Kormos et al. 2012, Palmer-Zwahlen and Kormos 2013, 2015, Palmer-Zwahlen et al. 2018, 2019a, 2019b, Satterthwaite et al. 2017), and the majority of SRFC are of hatchery-origin (Barnett-Johnson et al. 2007, Kormos et al. 2012, Palmer-Zwahlen and Kormos 2013, 2015, Palmer-Zwahlen et al. 2018, 2019a, 2019b). Additional details are available in Appendix B, and Appendix A discusses stocks for which abundance estimates are not available.

At each time step, rangewide ocean abundances were distributed among spatial boxes based on estimates of the proportion of each stock found in each area each season. For fall run stocks, proportional abundance in each management area was based on the results of Shelton *et al.* (2019). This is a state-space model that infers time- and area-specific ocean abundances of tagged fish from representative coded-wire tagged release groups using information on release size, time- and area-specific fishery catch and effort, and age structure of returning spawners. Individual FRAM stocks were matched up to units of analysis in the Shelton *et al.* model as described in Table 5.1.a. Figures Figure 5.1.a and Figure 5.1.b present the geographical delineations and proportional spatial distributions by season estimates from the Shelton *et al.* model. SRFC corresponds with Shelton *et al.*'s SFB stock and KRFC corresponds with NCA. Although the Rogue River is in Southern Oregon, the "SOR" results in Shelton *et al.* are for Chetco River fish. Spatial patterns in recoveries of Rogue River Chinook coded-wire tags (Weitkamp 2010) and genetically-identified fish (Bellinger *et al.* 2015, Satterthwaite *et al.* 2015) are more similar to Klamath River Chinook than to other Southern Oregon Chinook, so we apportioned RRFC spatially using NCA results. For spring run stocks, which lacked distribution estimates from Shelton *et al.*, we followed the logic described in https://www.fisheries.noaa.gov/webdam/download/93036440, using point values of 0.02 to represent ranges of 0-0.05, 0.15 to represent ranges of 0.05-0.25, and 0.5 for areas directly adjacent to the river of origin. Note that, as per the logic above, Upriver Columbia Spring Chinook were considered unavailable to SRKW in all areas during the "May–June" and "July–September" time steps.

Table 5.1.a. Mapping Chinook stocks used within the Shelton *et al.* model to the FRAM model stocks.

Stock (Shelton)	Stocks (FRAM)
Central Oregon	Mid Oregon Coast
Lower Columbia	Columbia River Oregon Hatchery Tule, Columbia River Washington Hatchery Tule, Lower Columbia River Wilds, Lower Columbia Naturals, Columbia River Bonneville Pool Hatchery
Upper Columbia	Columbia River Upriver Summer, Columbia River Upriver Bright, and Snake River Fall
Northern Oregon	Oregon North Coast
Puget Sound	Nooksack/Samish, Skagit, Snohomish, Stillaguamish, Tulalip, Mid Puget Sound, University of Washington Accelerated, South Puget Sound, Hood Canal, Juan de Fuca Tributaries, Hoko
Southern Georgia Strait	Fraser Lates, Fraser Earlies, Lower Georgia Strait
Washington Coastal	Willapa Bay, Washington North Coast
West Coast Vancouver Island	West Coast Vancouver Island

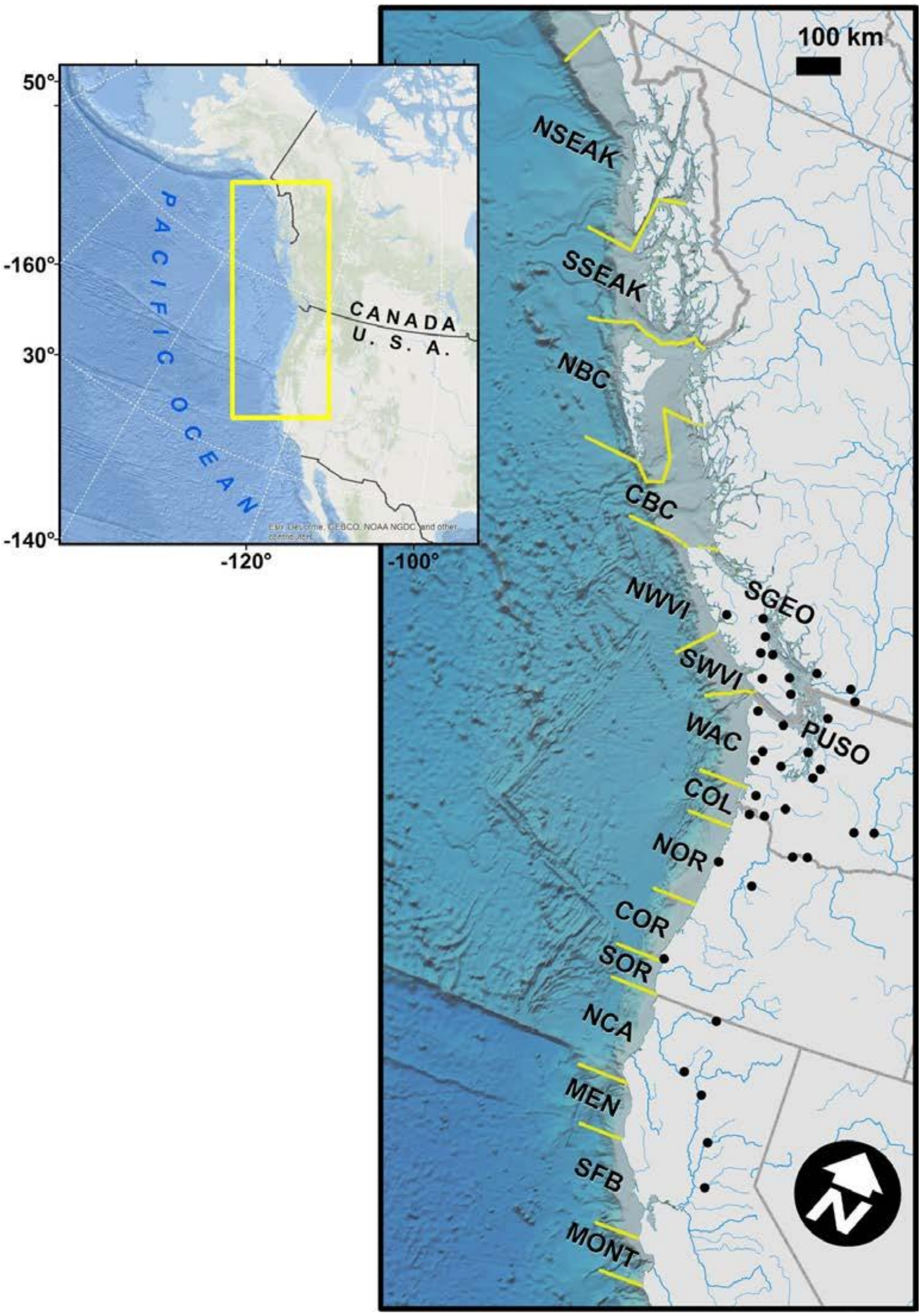

Figure 5.1.a Map of the 17 ocean regions Shelton *et al.* (2018) [7] delineated to estimate seasonal abundance and distribution of fall Chinook salmon (Figure 1 reprinted from Shelton *et al.*2018) (black dots are hatchery locations).

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[7] Acronyms from Shelton *et al.*2018: NSEAK or SSEAK= southeast Alaska regions; NBC or CBC = British Columbia Coastal regions; NWVI or SWVI = West Coast Vancouver Island regions; SGEO or PUSO = Salish Sea regions, WAC = Washington coast region, COL = mouth of the Columbia River region; NOR or COR or SOR= Oregon coast regions; NCA or MEN or SFB or MON= California coast regions

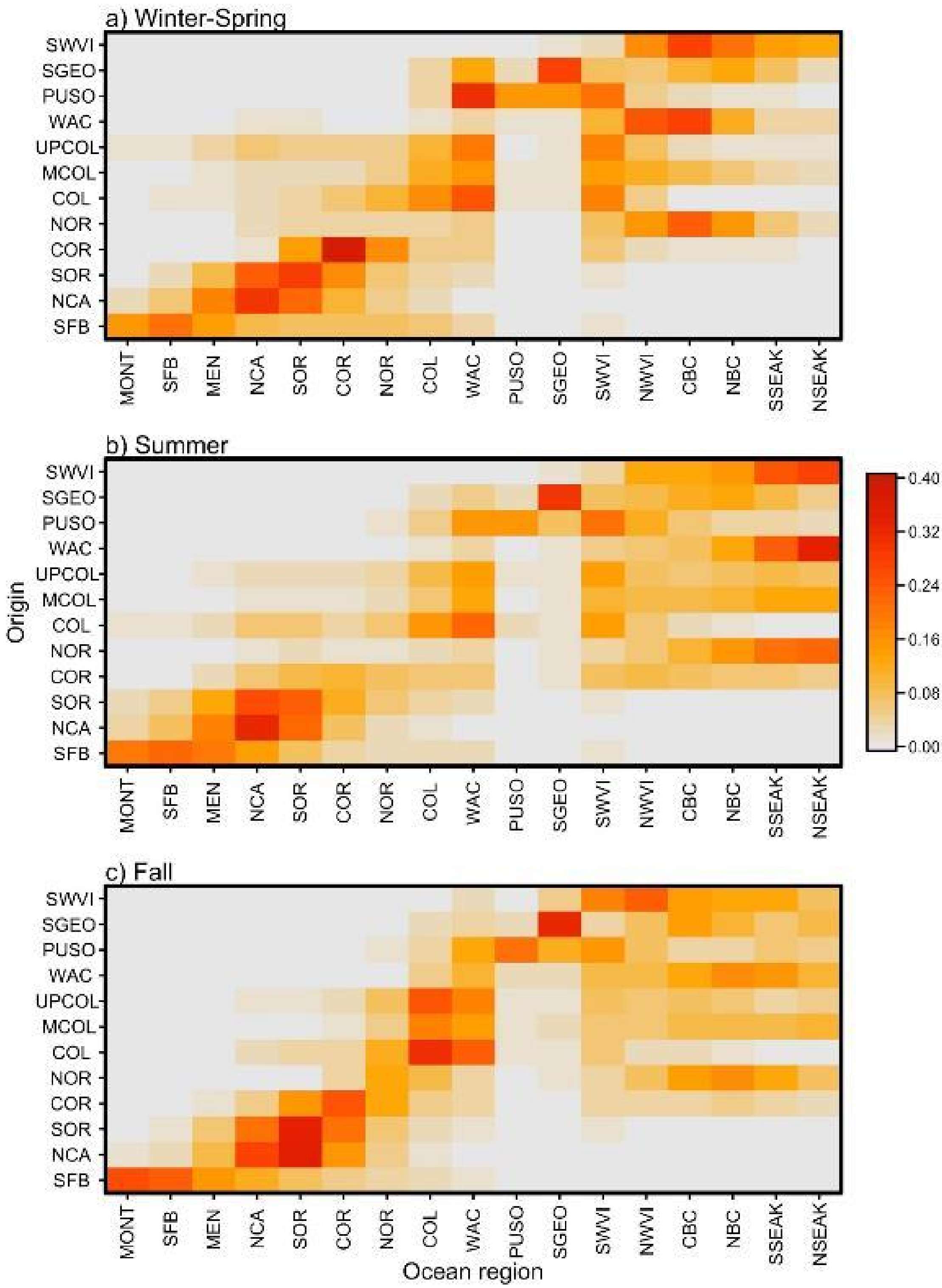

Figure 5.1.b. Estimated proportional spatial distribution by season of fall Chinook salmon originating from 11 different regions (Figure 3 reproduced reprinted from Shelton *et al.*2018, see footnote to Figure 5.1.a for acronym list). Each row represents the proportion of fish from a region present in each ocean region (rows sum to 1).

We then aggregated individual spatial boxes and their corresponding abundances at three levels:

1. the entire U.S. West Coast EEZ as a single unit ("Coastwide");
2. the West Coast EEZ split into two boxes north versus south of Cape Falcon ("NOF" and "SOF"), and
3. the West Coast EEZ split into three boxes at Cape Falcon and at Horse Mountain, which are among the management area lines used in ocean fisheries management by the PFMC (north of Cape Falcon "NOF", between Cape Falcon and Horse Mountain "Oregon coast", and south of Horse Mountain "California coast"). We also calculated separate abundances for the Salish Sea ("Salish"; sum of PUSO and SGEO from Shelton *et al.* 2019) and Southwest West Coast Vancouver Island ("SWCVI"). Note that "Coastwide" does not include the Salish Sea nor SWCVI.

5.2 Demographic Indices Considered

The workgroup considered the following demographic indices: 1) SRKW annual survival rates, 2) SRKW annual fecundity (birth) rates, and 3) frequency of occurrence of "peanut-head" whales (a metric previously used as an index of extremely poor condition, Matkin *et al.* 2017). The birth and death data were filtered to remove individual-year combinations that were associated with known non-prey related deaths (*e.g.* vessel strike). A number of additional metrics were also discussed, but not ultimately included for a variety of reasons (questionable utility as indicators, few years of data, etc.). The list of these latter metrics included social cohesion (Parsons *et al.* 2009), occupancy of the Salish Sea (Olson *et al.* 2018), changes in body condition other than the occurrence of peanut-head whales (Fearnbach *et al.* 2018), hormone indicators of nutritional status (Wasser *et al.* 2017), indicators based on stable isotope data (Warlick *et al.* in review), diet diversity (Ford *et al.* 2016), and demographic parameters of Northern Resident killer whales (Olesiuk *et al.* 2005; Ford *et al.* 2009).

SRKW survival varies with age or stage of the whale (Olesiuk *et al.* 1990). Because some ages were uncertain (particularly older animals at the start of the survey), we modeled an effect of stage on survival so that we could compare survival standardized to a common stage across years (Hilborn *et al.* 2012; Ward *et al.* 2013). Similarly, fecundity varies with age so we modeled an effect of age on fecundity so that we could compare fecundity at a common age (set to age 20 because fecundity is thought to peak in the early 20s [Ward *et al.* 2009]).

Similar to previous analyses attempting to link killer whale demography with metrics of Chinook salmon abundance (Ford *et al.* 2009, Hilborn *et al.* 2012), the Workgroup considered temporal lags between Chinook salmon abundance and observed SRKW performance based on plausible physiological mechanisms linking food supply to future performance, and to allow for uncertain timing in the death of SRKW experiencing mortality events. We considered Chinook salmon abundance estimates during the corresponding management year (no time lag) for all three vital rates. We also considered abundance estimates at lags of one year for both survival and fecundity for several reasons including to allow time for plausible biological mechanisms to operate (*i.e.* food stress could lead to reduced body condition and health leading to increased disease susceptibility leading to eventual death).

Additionally, we also considered a lag of one year because exact birth and especially death dates are uncertain, such that births or deaths assigned to a particular calendar may have already taken place before the corresponding management year is complete, and it would not be sensible to relate demographic rates to Chinook salmon abundance measured after the demographic event of interest has already taken place. Because killer whales have a gestation period of approximately 17 to 18 months, it may be important to consider Chinook salmon indices in year t-2 as predictors of fecundity (Hilborn *et al.* 2012, Ward *et al.* 2009, Ward *et al.* 2013) to allow for a lagged response to food supply in the initiation of pregnancy, followed by the extensive gestation period.

Though seasonal metrics of salmon abundance were available, the killer whale response variables have been recorded on an annual basis. As a result, we modeled relationships between annual demographic rates and Chinook salmon abundance indices measuring different seasonal time steps within the year, not demographic rates within the specific seasonal time steps.

5.3 Model Structure

Fecundity of Age 20 female whales was modeled using logistic regression as a function of time-area specific Chinook salmon abundance along with a quadratic function of age, allowing for fecundity peaking at an intermediate age. Whales that gave birth in the previous year were excluded due to the approximate 17 to 18 month gestation period meaning they could not possibly give birth again the following year (Ward *et al.* 2013). Females younger than 10 or older than 42 were excluded from the fecundity analysis (Ward *et al.* 2013). We separately considered abundance in the current year, in the prior year, and two years prior to account for lagged effects.

Survival of individual whales was modeled using logistic regression as a function of time-area specific Chinook abundance and a categorical variable describing stage/sex (juvenile, young female, young male, old female, old male). For consistency, we used delineations that have been used previously (Ward *et al.* 2013). As discussed in previous workshops (Hilborn *et al.* 2012), to avoid introducing biases, we removed the deaths of a handful of whales whose cause of death was thought to be associated with infection from satellite tags (L95), ship strikes (e.g. J34, L112), or several deaths of juveniles that disappeared with their mothers (and thus thought to not be independent). In all cases, we included survival of these whales up to the year of death, just not the death itself.

The occurrence of whales with peanut-head each year as a function of area-specific Chinook abundance was modeled using Poisson GLM (Poisson family with log-link). Alternative approaches could include logistic regression, for example, but the number of whales with this condition is extremely small such that sample size precludes inclusion of covariates (age, sex) that might explain variation.

All statistical analyses were performed in R (R Core Team 2019). The code and statistical methodology used by the SRKW workgroup to perform all analyses is publicly available and can be accessed at: https://github.com/dappdrd/PFMC_SRKW.

5.4 Model Run Descriptions

Complete results can be obtained from https://dappdrd.shinyapps.io/SRKW_Chinook_Analysis/

To use the application and produce outputs:

1.) Go to it via website: https://dappdrd.shinyapps.io/SRKW_Chinook_Analysis/

2.) Input your email address.

3.) Send the input file to your email via the associated button (this may take a moment).

4.) Save the input file to your computer and then use the browse button on the application to select the input file.

5.) Press the "Begin Processing/Email Outputs" button to send an output file to your email (this may take a few minutes).

Interpreting the results:

1.) Each area-time step can be found as a tab in the output file. Time step 1 corresponds to October-April, time step 2 corresponds to May-June, time step 3 corresponds to July-September.

2.) Each graphic depicts the relationship between Chinook abundance and a SRKW population parameter. Each analysis was conducted as a logistic regression (or Poisson regression in the case of peanut-head). For fecundity analyses, age was included as a covariate and modeled as a quadratic. For the survival analysis, stage was included as a covariate. In order, the analyses are Chinook abundance versus fecundity (no lag; row 2), survival rates (row 28), peanut head (row 54), fecundity (1 year lag; row 80), fecundity (2 year lag; row 106), and survival (1 year lag; row 158).

3.) The model summaries are available to the left of each graphic. To determine if there is a statistically significant relationship between Chinook abundance on each population parameter, refer to the p-value for abundance in these sections.

Only one of the fitted regressions met the typical criterion of $p \leq 0.05$ that is often associated with "statistical significance" (Table 5.4.a through Table 5.4.g summarize the regression statistics; Appendix C depicts all regression model outputs). However, several regressions had $p \leq 0.10$, and this occurred for times and areas where whale presence is understood to be most likely (Table 5.4.b, Table 5.4.d, Table 5.4.e). Although $p \leq 0.05$ is the typical criterion for "statistical significance", there is precedent for using other values. Fields such as genomics that generate large amounts of data have a precedent for using smaller values (e.g. Concato and Hartigan 2016), and some statisticians have proposed using values smaller than 0.05 to avoid 'p-hacking' (Benjamin et al. 2018). In the opposite direction, some fields have conventionally used slightly larger values, or interpreted larger p-values as 'marginally significant' (Pritschet et al. 2016). Larger significance thresholds may be considered more appropriate in the face of noisy data, small sample sizes, and/or cases where the consequences of erroneously rejecting an effect are considered more severe than the converse. In addition, mechanistic hypotheses may justify a 1-tailed test (testing the probability under the null hypothesis of a coefficient greater than zero by at least certain amount, rather than the probability of a coefficient at least a certain distance from zero in either direction, resulting in a smaller p value given the same data and model). Similarly, because of multiple statistical tests being conducted with correlated Chinook salmon abundance estimates (abundance in adjoining spatial boxes being generated from the same cohorts and FRAM modeled output) an argument could be made for applying a correction factor (e.g., Bonferroni) that would lead to a higher critical p-value. However, best practices call for making such adjustments before seeing the results, but the workgroup did not do so.

A p-value of 0.05 means that given the level of variability in the data and the model assumptions, there is a five percent probability of seeing a relationship at least as strong as the one observed purely by chance under a null hypothesis of no effect (in this case a parameter value of zero for the coefficient describing the change in demographic SRKW rate with changes in Chinook abundance, again conditional on the assumed form of the statistical model). It should not be interpreted as the probability that there is or is not an effect in any particular case (Wasserstein and Lazar 2016). Rather, a small p-value means that it is unlikely that a pattern in the data at least as strong as the one seen would arise by chance, whereas a large p-value means that a pattern as strong as the one observed could easily arise by chance. It is still possible to occasionally get an apparently strong, but spurious relationship with a small p-value in the absence of a real effect, especially when conducting multiple tests. Conversely, especially when the data are noisy or confounding variables are not accounted for, it is possible for a real effect to be present despite the data having a pattern no more extreme than one that could be explained by chance alone (large p-value).

In Table 5.4.a through Table 5.4.g, the reported regression coefficients are based on z-score transformed abundances. This transformation scales each annual abundance estimates' deviation from the mean relative to typical variation around the mean abundance for the time-area combination under consideration. The regression coefficient gives the model predicted change in the demographic rate changes on the logit (fecundity, survival) or log (peanut-head) scale in response to an abundance change equal to one standard deviation in the annual abundance estimates for that time-area combination. This was intended to facilitate comparisons across regions that varied in both their mean abundance and typical degree of variability.

Table 5.4.a. Regression statistical summaries for the Council Coastwide EEZ aggregate area. The independent variable in each case is Chinook abundance after z-score transformation (*i.e.*, scaled so that 0 = mean and ±1 means 1 SD above or below the mean), and the "coefficient" gives the modeled effect on the log odds scale of a 1 SD change in abundance. Dependent variables are labeled under the column “Regression”. Lag effects described indicate the abundance variable used was either 1 (lag 1) or 2 (lag 2) years prior to the observed dependent variable.

Geographic Area	Timestep	Regression	Coefficient	Standard Error	p_Value
Coastwide (EEZ) aggregate	1 (October 1 – April 30)	Fecundity	0.1203	0.1208	0.3191
		Survival	0.0307	0.1200	0.7983
		Peanut	-0.3035	0.2816	0.2811
		Fecundity Lag 1	-0.0345	0.1244	0.7815
		Fecundity Lag 2	0.0367	0.1270	0.7727
		Survival Lag 1	0.2088	0.1267	0.0993
	2 (May 1 – June 30)	Fecundity	0.0866	0.1212	0.4749
		Survival	-0.0215	0.1184	0.8558
		Peanut	-0.1994	0.2700	0.4601
		Fecundity Lag 1	-0.0480	0.1245	0.7001
		Fecundity Lag 2	0.0282	0.1272	0.8243
		Survival Lag 1	0.1649	0.1248	0.1864
	3	Fecundity	0.0990	0.1205	0.4113
		Survival	0.0200	0.1198	0.8672

Geographic Area	Timestep	Regression	Coefficient	Standard Error	p_Value
	(July 1 – September 30)	Peanut	-0.3238	0.2906	0.2652
		Fecundity Lag 1	-0.0388	0.1250	0.7565
		Fecundity Lag 2	0.0686	0.1258	0.5854
		Survival Lag 1	0.1896	0.1276	0.1374

Table 5.4.b. Regression statistical summaries for the North of Cape Falcon aggregate area.

Geographic Area	Timestep	Regression	Coefficient	Standard Error	p_Value
North of Falcon	1 (October 1 – April 30)	Fecundity	0.1327	0.1207	0.2717
		Survival	0.1474	0.1245	0.2364
		Peanut	-0.4789	0.3070	0.1188
		Fecundity Lag 1	0.0083	0.1237	0.9465
		Fecundity Lag 2	0.1077	0.1257	0.3917
		Survival Lag 1	0.2547	0.1296	0.0494
	2 (May 1 – June 30)	Fecundity	0.1167	0.1197	0.3296
		Survival	0.1152	0.1249	0.3566
		Peanut	-0.4403	0.3182	0.1664
		Fecundity Lag 1	-0.0021	0.1243	0.9863
		Fecundity Lag 2	0.1154	0.1235	0.3504
		Survival Lag 1	0.2121	0.1310	0.1054
	3 (July 1 – September 30)	Fecundity	0.0963	0.1198	0.4215
		Survival	0.1114	0.1257	0.3754
		Peanut	-0.4736	0.3331	0.1550
		Fecundity Lag 1	0.0000	0.1245	1.0000
		Fecundity Lag 2	0.1355	0.1215	0.2645
		Survival Lag 1	0.1966	0.1319	0.1360

Table 5.4.c. Regression statistical summaries for the South of Cape Falcon aggregate area

Geographic Area	Timestep	Regression	Coefficient	Standard Error	p_Value
South of Falcon aggregate	1 (October 1 – April 30)	Fecundity	0.1003	0.1212	0.4082
		Survival	-0.0374	0.1182	0.7514
		Peanut	-0.1785	0.2662	0.5025
		Fecundity Lag 1	-0.0557	0.1243	0.6541
		Fecundity Lag 2	-0.0073	0.1279	0.9544
		Survival Lag 1	0.1582	0.1239	0.2016
	2 (May 1 – June 30)	Fecundity	0.0600	0.1216	0.6215
		Survival	-0.0759	0.1175	0.5184
		Peanut	-0.0887	0.2595	0.7324
		Fecundity Lag 1	-0.0617	0.1242	0.6192
		Fecundity Lag 2	-0.0133	0.1279	0.9174
		Survival Lag 1	0.1229	0.1228	0.3170
	3 (July 1 – September 30)	Fecundity	0.0812	0.1209	0.5021
		Survival	-0.0509	0.1178	0.6659
		Peanut	-0.1742	0.2681	0.5158
		Fecundity Lag 1	-0.0617	0.1248	0.6210
		Fecundity Lag 2	0.0046	0.1277	0.9715
		Survival Lag 1	0.1489	0.1248	0.2327

Table 5.4.d. Regression statistical summaries for the Salish Sea aggregate area.

Geographic Area	Timestep	Regression	Coefficient	Standard Error	p_Value
Salish Sea aggregate	1 (October 1 – April 30)	Fecundity	0.0287	0.1221	0.8139
		Survival	0.1324	0.1197	0.2688
		Peanut	-0.2905	0.2574	0.2589
		Fecundity Lag 1	-0.0522	0.1230	0.6714
		Fecundity Lag 2	0.1053	0.1280	0.4106
		Survival Lag 1	0.2195	0.1214	0.0707
	2 (May 1 – June 30)	Fecundity	0.0471	0.1223	0.7003
		Survival	0.1299	0.1205	0.2812
		Peanut	-0.3457	0.2637	0.1899
		Fecundity Lag 1	-0.0367	0.1233	0.7659
		Fecundity Lag 2	0.1002	0.1276	0.4326
		Survival Lag 1	0.2211	0.1228	0.0717
	3 (July 1 – September 30)	Fecundity	0.0320	0.1222	0.7933
		Survival	0.1208	0.1207	0.3170
		Peanut	-0.3034	0.2626	0.2479
		Fecundity Lag 1	-0.0438	0.1233	0.7225
		Fecundity Lag 2	0.0814	0.1275	0.5231
		Survival Lag 1	0.2100	0.1227	0.0872

Table 5.4.e. Regression statistical summaries for the South West / West Coast of Vancouver Island aggregate area.

Geographic Area	Timestep	Regression	Coefficient	Standard Error	p_Value
S.W. West Coast Vancouver Island coast	1 (October 1 – April 30)	Fecundity	0.1040	0.1202	0.3870
		Survival	0.1445	0.1260	0.2515
		Peanut	-0.4626	0.3157	0.1427
		Fecundity Lag 1	-0.0131	0.1247	0.9165
		Fecundity Lag 2	0.1293	0.1234	0.2947
		Survival Lag 1	0.2237	0.1312	0.0881
	2 (May 1 – June 30)	Fecundity	0.0998	0.1203	0.4066
		Survival	0.1356	0.1255	0.2800
		Peanut	-0.4586	0.3156	0.1462
		Fecundity Lag 1	-0.0178	0.1248	0.8867
		Fecundity Lag 2	0.1312	0.1232	0.2870
		Survival Lag 1	0.2106	0.1306	0.1067
	3 (July 1 – September 30)	Fecundity	0.0925	0.1208	0.4440
		Survival	0.2413	0.1290	0.0613
		Peanut	-0.4443	0.2982	0.1362
		Fecundity Lag 1	-0.0403	0.1252	0.7476
		Fecundity Lag 2	0.1513	0.1236	0.2208
		Survival Lag 1	0.2118	0.1288	0.1001

Table 5.4.f. Regression statistical summaries for the California Coast, south of Horse Mountain.

Geographic Area	Timestep	Regression	Coefficient	Standard Error	p_Value
California Coast	1 (October 1 – April 30)	Fecundity	0.0063	0.1221	0.9591
		Survival	-0.1001	0.1177	0.3950
		Peanut	-0.0075	0.2554	0.9767
		Fecundity Lag 1	-0.0633	0.1239	0.6093
		Fecundity Lag 2	-0.0218	0.1279	0.8647
		Survival Lag 1	0.0914	0.1218	0.4531
	2 (May 1 – June 30)	Fecundity	-0.0096	0.1222	0.9372
		Survival	-0.1145	0.1176	0.3305
		Peanut	0.0497	0.2538	0.8446
		Fecundity Lag 1	-0.0618	0.1238	0.6174
		Fecundity Lag 2	-0.0285	0.1279	0.8235
		Survival Lag 1	0.0676	0.1213	0.5776
	3 (July 1 – September 30)	Fecundity	-0.0362	0.1225	0.7678
		Survival	-0.0902	0.1178	0.4441
		Peanut	-0.0160	0.2559	0.9501
		Fecundity Lag 1	-0.0579	0.1243	0.6410
		Fecundity Lag 2	0.0148	0.1278	0.9080
		Survival Lag 1	0.0846	0.1226	0.4901

Table 5.4.g. Regression summaries for the Oregon coast south of Cape Falcon, including the California portion of the KMZ (CA-OR border through Horse Mountain).

Geographic Area	Timestep	Regression	Coefficient	Standard Error	p_Value
Oregon Coast	1 (October 1 – April 30)	Fecundity	0.1478	0.1208	0.2211
		Survival	0.0033	0.1191	0.9780
		Peanut	-0.2776	0.2768	0.3160
		Fecundity Lag 1	-0.0472	0.1245	0.7046
		Fecundity Lag 2	0.0018	0.1277	0.9890
		Survival Lag 1	0.1870	0.1250	0.1347
	2 (May 1 – June 30)	Fecundity	0.1171	0.1210	0.3333
		Survival	-0.0337	0.1181	0.7754
		Peanut	-0.2171	0.2704	0.4220
		Fecundity Lag 1	-0.0560	0.1246	0.6529
		Fecundity Lag 2	0.0016	0.1277	0.9903
		Survival Lag 1	0.1629	0.1242	0.1895
	3 (July 1 – September 30)	Fecundity	0.1446	0.1205	0.2303
		Survival	-0.0209	0.1185	0.8599
		Peanut	-0.2626	0.2764	0.3422
		Fecundity Lag 1	-0.0573	0.1248	0.6465
		Fecundity Lag 2	-0.0022	0.1278	0.9863
		Survival Lag 1	0.1720	0.1249	0.1685

These results should be interpreted with caution. Nevertheless, in the majority of cases (71 percent; 90 of 126) the point estimates for the fitted relationships were of the expected sign (*i.e.* survival and fecundity increased with increasing Chinook salmon abundance while occurrence of peanut-head decreased with increasing Chinook salmon abundance). We use the term 'expected' here because our *a priori* expectation based on principles of ecology and physiology, and knowledge about the importance of Chinook salmon as prey, is for an increase in prey to have a neutral or positive effect on killer whale demography, and not a negative one. This was always the case for SRKW survival at a lag of one year, for SRKW survival based on current-year abundance estimates that excluded waters south of Cape Falcon, and for SRKW fecundity based on current-year abundances excluding waters south of Cape Falcon.

5.5 Effects of Fisheries

We estimated area-specific PFMC fishery removals in a two-step process. First, stock-specific reductions in abundance attributable to Council-area directed salmon fisheries were calculated across all fisheries for each modeled stock and each time step. This was to determine total stock abundance changes resulting from fishery removals. Then these reductions in abundance were apportioned across space based on the assumed distribution of each stock (based on the spatial model and assumptions described in Section 5.1), rather than attempting to account for where fishery removals actually occurred and subsequent movement of fish within and across time steps. This is an important clarification for understanding the analyses; the estimates specified for geographic areas represent the effects of all Council-area directed salmon fisheries as they affect the modeled abundance in each geographic area, not just those fisheries that are directly occurring in the area, and similarly some of the modeled reduction in abundance is apportioned to areas outside the PFMC's jurisdiction.

For FRAM stocks (excluding SRFC), we estimated reductions in area specific abundance attributable to PFMC removals by comparing the post-fishery abundances calculated for each timestep by the FRAM "Validation" run (with fisheries as they occurred) with the post-fishery abundances calculated for the start of each timestep in a "Zero PFMC" FRAM run where all PFMC area ocean salmon fisheries were zeroed out, but other salmon fisheries outside PFMC jurisdiction were modeled as before. PFMC removals were calculated based on the difference between the corresponding "Zero PFMC" and "Validation" abundances.

For Upriver Columbia Springs, we assumed no removals in PFMC area ocean salmon fisheries, based on the extremely low rates of recovery of CWTs for this stock.

For RRFC, KRFC, and SRFC we calculated September 1 abundances each year as described in Section 5.1, and then calculated "Zero PFMC" October 1 abundances for each year by adding back September ocean harvest (assumed to all occur within PFMC areas, which is likely appropriate because these stocks are very rarely encountered further north) and discounting for one month of assumed natural mortality. "Zero PFMC" abundances for later timesteps were calculated by discounting the "Zero PFMC" October 1 abundances by assumed natural mortality over the corresponding months elapsed. PFMC removals were calculated based on the differences between corresponding starting abundances calculated in Section 5.4 and the "Zero PFMC" abundances described here.

The metric of abundance used to estimate area-specific effects of PFMC fishery removals differs from the abundance metric used to quantify the relationship between Chinook salmon abundance and SRKW demographic metrics. The Workgroup agreed that the most appropriate abundance metric to use to examine relationships between Chinook salmon abundance and SRKW population metrics was starting abundance in each time step analyzed (pre-natural mortality, pre-fishery removals, pre-maturation in an individual time step). However, to estimate reductions in area-specific abundance attributable to Council-area directed salmon fishery removals, the Workgroup agreed that the most appropriate abundance metric to use was a starting abundance, with fishery mortalities from the season removed (hereafter referred to as a “post-fishery abundance”; this is distinct from abundance at the end of a time step, which would be further reduced by maturation and/or natural mortality). Note however that the starting abundance for time step 2 in the unfished scenario will reflect natural mortality applied to the foregone harvest from time step 1, and the starting abundance for time step 3 in the unfished scenario will reflect natural mortality applied to the foregone harvest from time steps 1 and 2. This decision was made because, while a starting cohort may be the best estimate of abundance at the start of a season, SRKW do not exclusively feed at the beginning of the season but feed throughout the time period examined. By examining a post-fishery abundance in the analysis, the group examined a maximum reduction estimate reflecting removals summed across the entire season. This likely overestimated the effect of within-season fishery removals in reducing prey available to SRKW. In part this is because removals are spread over the course of the season, so abundance will be higher earlier in the season before all of the removals have taken place. In addition, some unknown fraction of foregone removals early in the season would be expected to die of natural mortality (via causes other than SRKW predation) before the end of the season and thus not be available to SRKW. On the other hand, these calculations do not reflect cumulative effects of removals in earlier years.

Estimated Changes in Predicted Vital Rates Due to Effects of Removals on Chinook Abundance

Due to the different abundance metrics used in this analysis, the starting abundance regressions could not be directly applied to post-fishery abundance data calculated to assess the effects on prey availability from the fisheries. In order to estimate mean changes in the predicted demographic metrics due to the removal of Chinook salmon from the PFMC fisheries, all regressions performed in regression analysis were rerun, using the same methodology as described in Section 5.4, but using post-fishery abundance data (post-season runs) rather than starting abundance data.

Post-season and "zero PFMC" abundances for each year and spatio-temporal box were used in conjunction with regressions rerun using post-fishery abundance data to create point estimates of SRKW survival (lag 0 years, 1 year), fecundity (lag 0 years, 1 year, 2 years), and the occurrence of peanut head. Differences in SRKW population metrics derived from point estimates in the post-season and "zero PFMC" runs were used to assess yearly changes in SRKW population metrics that would be predicted to have occurred due to fishing mortality. For lag effect estimates, SRKW population parameter changes were not available for 1992 (lag 1 and lag 2 effects) or 1993 (lag 2 effects) because Chinook post-fishing abundance estimates were not available prior to 1992.

Table 5.5.a. Mean estimates of change in survival (lag 1) and fecundity (lag 0) across the series of years available in the analysis. Time steps 1, 2, and 3 represent "October through April", "May through June", and "July through September", respectively. Annual changes used in the mean represent predicted SRKW metrics from the post-season runs subtracted from the "zero PFMC" run. Survival is expressed as an annual change in survival rate (positive values indicate increase in the absence of fishing) for young females. Fecundity is expressed as an annual change fecundity rate (positive values indicate increase in the absence of fishing) for age 20 females. Note that each table cell represents an annual demography change predicted in a scenario where all PFMC salmon fisheries are closed in a calendar year. Therefore, it is inappropriate to add effects across time steps or across areas. The full set of demographic metrics analyzed is available in Appendix F.

Area	Time Step	Fecundity	Survival L1
CALI	1	0.0%	0.0%
CALI	2	0.0%	0.2%
CALI	3	-0.5%	0.4%
COASTWIDE	1	0.2%	0.0%
COASTWIDE	2	0.6%	0.2%
COASTWIDE	3	1.2%	0.3%
NOF	1	0.1%	0.0%

Area	Time Step	Fecundity	Survival L1
NOF	2	0.2%	0.1%
NOF	3	0.2%	0.1%
OR	1	0.2%	0.0%
OR	2	0.6%	0.1%
OR	3	1.6%	0.2%
SALISH	1	0.0%	0.0%
SALISH	2	0.0%	0.0%
SALISH	3	0.1%	0.0%
SOF	1	0.2%	0.0%
SOF	2	0.6%	0.2%
SOF	3	1.8%	0.3%
SWWCVI	1	0.0%	0.0%
SWWCVI	2	0.1%	0.0%
SWWCVI	3	0.2%	0.1%

The code used for the analysis is publicly available here:
https://github.com/dappdrd/PFMC_SRKW/blob/master/Harvest_analysis.R

5.6 Key Uncertainties

The analyses undertaken for evaluating effects of PFMC fisheries on the prey base of killer whales are largely similar to those reviewed by Hilborn *et al.* (2012), with additional details in Ward *et al.* (2013). Thus, most of the same caveats and uncertainties about these models that have been described in Hilborn *et al.* (2012) also apply here. Among the conclusions by Hilborn *et al.* (2012) were that "considerable caution is warranted in interpreting the correlative results as confirming a linear causal relationship between Chinook salmon abundance and SRKW vital rates". These relationships are likely non-linear, the relationships may be influenced by small sample sizes of killer whale births and deaths, and the relationships may arise from uncertainties in the indices of Chinook abundance used for fisheries management. Additionally, the Hilborn *et al.* (2012) panel cautioned that there are "many potential reasons why all foregone Chinook salmon catch would not be available to SRKW". Thus, even if all ocean fisheries were closed, only a fraction of those removals would be made available to killer whales. These assumptions and limitations identified by Hilborn *et al.* (2013), as well as additional limitations and uncertainties, are addressed in more detail below.

<u>Statistical model assumptions</u>

The models assume that the effect of Chinook salmon abundance in a particular season and area is the same every year (*i.e.* assume stationarity), and the same for all pods, regardless of where SRKW actually spent the most time that year, and do not account for any variation at finer spatial or temporal scales than those defined by the model. The logistic regressions used for survival and fecundity assume that all whales of the same age (fecundity) or sex/stage (survival) have identical probabilities of giving birth or dying in a given year, ignoring individual variability (aside from excluding whales who gave birth the prior year from the fecundity analysis). The logistic regression model assumes that survival or fecundity on the logit scale is a linear function of Chinook abundance. The Poisson GLM used for incidence of peanut-head assumes that all whales have the same probability of displaying peanut-head in a given year. The Poisson model further assumes that the variance in the number of SRKW displaying peanut head in a given year is equal to the expectation for the number of SRKW displaying peanut-head that year. Both the logistic regressions and the Poisson GLM assume that time/area-specific Chinook abundance is measured without error. Unaccounted-for measurement error with constant variance in the independent (putative "driver") variable in a simple linear regression is known to bias estimated coefficients toward zero ("attenuation bias" or "regression dilution"), but the effects are harder to characterize for more complicated models (Chesher 1991).

<u>Uncertainty in Chinook salmon stock abundances</u>

The uncertainty associated with Chinook salmon abundance forecasts in general is relatively well appreciated, but there is also substantial uncertainty in retrospective abundance estimates. Harvest and escapement estimates are themselves uncertain, but ocean abundance estimates depend further on unverified assumptions about natural mortality, constant adult natural mortality rates across years, mortality associated with fish caught but released, drop-off mortality, and bycatch mortality in other fisheries that are not accounted for in the management models.

Additionally the FRAM uses a "base period" to estimate fishing mortalities by stock, age, fishery, and time step. The current Chinook FRAM base period is represented by coded wire tag recoveries from fishing years 2007–2013. If stock distributions differ considerably from the 2007–2013 base period, stock-specific or if tagged fish are not representative of untagged fish (*e.g.,* hatchery versus wild differences), fishery mortality estimates from the model reflect reality less well.

The effects of fishery removals on the availability of Chinook as potential SRKW prey depends on patterns in natural mortality, and how many fish from potentially foregone harvest would die from natural causes (other than SRKW predation) rather than remain available as prey. As Hilborn *et al.* (2012) note, natural mortality likely varies across years, due in part to the relative abundance of Chinook salmon and their multiple predators. However, nearly all models used in Chinook management, including the ones used here, assume constant adult natural mortality (but see Allen *et al.* 2017). Assumptions about natural mortality and when it is applied will change estimates of "foregone removals" that are actually available to SRKW as food. If natural mortality is higher than assumed, the models will overestimate the ability of foregone harvest to increase Chinook abundance. On the other hand, the models used did not consider the effects of fishery impacts on age-2 fish, nor did it consider multi-year effects (i.e. fishery removals in prior years can reduce the abundance of older fish in the current year, and fishery removals in the current year can reduce the abundance of older fish in future years).

Limited range of observed Chinook salmon stock abundances

The regression analyses were limited to the observed range of Chinook salmon abundances for the years 1992-2016. Numerous stocks, and especially spring run stocks, were far more abundant historically than they were in any of the years observed. We have no observations of SRKW demography at such high abundance, nor have we observed SRKW demography when Chinook salmon abundances are even lower than any year included in our dataset. Our models were unable to assess the relationship between SRKW demography and Chinook salmon abundance outside the observed range.

Uncertainty in Chinook salmon stock distributions

The Shelton *et al.* (2019) distribution model is subject to uncertainty due to sampling error in harvest data, assumptions about natural mortality, assumptions about how catch per unit effort scales with local abundance (and the consistency of metrics of fishing effort across time and space), the assumption that stocks have the same spatial distribution every year, and the assumption that a subset of marked hatchery releases are representative of all releases from the corresponding stock and also representative of the natural-origin component of those stocks (an assumption made in FRAM and other salmon fishery models as well). The model published by Shelton *et al.* (2019) does not include data through 2016 as we used here, however, estimated distribution from the period used by Shelton *et al.* (brood years 1977 – 1990) may be more precise because of higher sampling rates. Work is in progress to account for inter-annual variability in the Shelton *et al.* model, and to incorporate GSI information from both hatchery- and natural-origin fish, but no results were available in time to inform this analysis.

Additionally, a temporal mismatch exists between the Shelton *et al.* (2019) model and FRAM. FRAM abundances are based on three different time steps, corresponding to Winter (October through April), Early Summer (May through June), and Late Summer (July through September). However, time steps in Shelton *et al.*, 2019 are offset by a month relative to the FRAM model, with Winter designated as November–May, Early Summer designated as June–July, and Late Summer designated as August–October. Although this mismatch causes a disconnect between the two models, the Shelton *et al.*, 2019 model is believed by the workgroup to be the better model to characterize Chinook salmon distribution at the needed scale, and future work will be explored to produce results from the Shelton model that are compatible with FRAM time steps.

Finally, the spatial model ignores changes in Chinook salmon spatial distribution within each timestep, and assumes that the effects on Chinook salmon abundance from fishery removals are distributed across space in proportion to Chinook salmon abundance, rather than based on where fishery removals actually occur and how quickly fish redistribute themselves across space.

Lack of information on Chinook salmon distributions during winter

The model used to apportion Chinook salmon abundance through space (Shelton *et al.* 2019) depends on coded-wire tag recoveries from ocean fisheries directly targeting Chinook salmon. Effort in these fisheries has been very limited or nonexistent in winter and early spring for most years because fisheries do not currently occur at these times (with several exceptions, including the 4B treaty troll fishery in Washington State near Neah Bay). Efforts are underway to include additional data sources (*e.g.*, from salmon bycatch in trawl fisheries) to learn more about Chinook spatial distributions in the winter and early spring, but no results were available in time to inform this analysis.

Limited information on distribution for most spring-run Chinook salmon stocks

Quantitative distribution estimates from Shelton *et al.* (2019) were only available for fall-run stocks. Efforts are underway to extend this model to spring-run stocks, but the generally lower catch rates and resultant smaller sample sizes for these stocks pose a challenge. Ongoing efforts to share information across coded-wire tag, genetic stock identification, and trawl bycatch datasets should increase the statistical power and provide better insights about spring run distributions, although the seemingly more offshore distribution of some spring run stocks will pose an ongoing challenge to models based on fishery-dependent data. These results may have to be modeled at a coarser spatial resolution for instance, compared to fall stocks, because of significantly smaller sample sizes.

Effects of changes in Chinook salmon size and age structure

The utility of Chinook salmon as prey depends on more than their abundance alone. Older Chinook salmon are larger and thus provide more nutrition per fish than younger fish. In addition, Chinook salmon that mature at younger ages spend less time in the ocean and thus spend less time potentially available as prey, possibly meaning less food for SRKW per smolt entering the ocean. At the same time, returning spawners per smolt may be higher for younger fish that experience less cumulative mortality risk, potentially increasing the availability of Chinook salmon prey per smolt for SRKW specifically targeting aggregations of returning spawners near river mouths. It appears that both hatchery- and natural-origin Chinook salmon are becoming smaller and maturing more rapidly throughout most of the Pacific coast (Ohlberger *et al.* 2018). The workgroup did not analyze any impacts of these changes in size at age during modeling exercises. These changes introduce additional uncertainties in quantifying the biomass of prey available to the whales, as well as the relative selectivity across stocks that differ in their energy content (O'Neill *et al.* 2014).

Uncertainty in the distribution of SRKW

Much of the knowledge of SRKW distribution is based on sightings reported in the inland waters of the Salish Sea, especially in summer months (Olson *et al.* 2018; Hauser *et al.* 2006). The distribution of SRKW year to year can be characterized as variable, and possibly subject to short term trends. Over the last several years, for example, many social groups of the SRKW population have not spent much time in inland waters during the summer relative to their historical occurrence (Olson *et al.* 2018). For non-summer months, sighting data is generally limited. As discussed in Section 2, several satellite tags have been deployed on SRKWs in winter months to characterize the winter distribution (Jan - Apr). Data from these deployments suggests that J pod has a distribution in the Salish Sea, concentrated in the northern Strait of Georgia and western entrance to the Strait of Juan de Fuca (Hanson *et al.* 2018). However, J pod tag data is limited to an extremely small sample size (one tag deployed in February 2012 for three days; one tag deployed in December 2013 for 31 days; one tag deployed December 2014 for 49 days; Hanson *et al.* 2018) and additional data on the distribution of J pod during the winter would be beneficial. K and L pods are estimated to have a more frequent coastal distribution, with a winter/spring concentration off the Columbia River, and Washington coast (Hanson *et al.* 2018). Distribution in spring and fall months has been characterized from acoustic recorders (Hanson *et al.* 2013) and additional analyses are being conducted to update these estimates.

Differential responses to changes in Chinook abundance among pods

In the winter, J pod appears to remain much more within the Salish Sea relative to K and L pods that spend more time in coastal waters, thus it is likely that they would have differential responses to changes in the abundance of particular Chinook stocks compared to K and L. However, considerable statistical power is lost when analyzing one pod at a time due to lower sample sizes. As a result the workgroup has opted to continue to examine all three pods together.

Uncertainty in the factors driving changes in the distribution of SRKW

Other than factors related to prey abundance, or phenology, it is unclear what factors may influence SRKW distribution. Some have speculated that changes in the age structure of SRKW (particularly the loss of older animals) may alter future distributions, if historical knowledge is lost. It is unclear to what degree SRKWs or other killer whales actively avoid vessels, or other populations of killer whales, however both of these may also influence distribution.

Uncertainty in the ability of SRKW to switch to alternative prey sources

The degree to which killer whales are able to or willing to switch to non-preferred prey sources (*i.e.*, prey other than Chinook salmon) is also largely unknown, and likely variable depending on the time and location. We do not account for varying abundance and availability of alternative prey sources in these analyses. Previous genetics work has suggested that SRKWs switch from Chinook to other salmon in fall months (particularly coho and chum salmon, Ford *et al.* 2016). Though a small number of samples have been collected, fecal samples collected in winter suggest a diet that is still more than 50% Chinook, but also includes contributions from groundfish (halibut, lingcod) and steelhead (Hanson *et al.* 2018). In addition to small sample sizes, the spatial location of these recent samples is confounded with season (*e.g.* few summer diet samples have been collected outside of the Salish Sea, and few winter diet samples have been collected in the Salish Sea). Diet data reflecting longer integration windows (bulk stable isotopes) have been analyzed recently, and suggest that year to year variability may affect diet variation (*e.g.* Chinook salmon consumption may be higher when they are more abundant, and lower in years when coastwide abundance is low; Warlick *et al.* in review).

Patterns of temporal variation in competing threats

A number of threats unrelated to Chinook abundance have been identified as potential threats to SRKW. These include, but are not limited to: additional anthropogenic threats (contaminants in the food web, increased noise levels around vessels, risks of ship strikes, potential effects of oil spills,), disease, ecosystem effects (competition from other populations of fish-eating killer whales, and other marine mammals including seals and sea lions), inherent risks associated with small populations (inbreeding depression, demographic stochasticity, skewed sex ratios at birth with unknown causes), and behavioral risks (infanticide, Allee effects). To the extent that these factors vary across years, they will confound the effects of changes in Chinook salmon abundance, but they can only be included as model covariates if annual measurements are available, which by and large they are not.

Chinook salmon stocks whose abundances are not included in the modeling

North of Cape Falcon, non-modeled stocks include those north of Vancouver Island, Hupp Springs, Washington Coastal Springs, and Tsoo-Yess Falls. Many of these stocks are relatively small in magnitude (*e.g.,* Hupp Springs, Washington Coastal Springs, Tsoo-Yess) or are present primarily outside of the core SRKW assessment area (*e.g.,* stocks north of Vancouver Island).

South of Cape Falcon, it is likely that the two most abundant non-modeled stocks are Klamath-Trinity spring run (for which 1992-2016 adult river run sizes were on median 21 percent as large as the river run size of Klamath River Fall Chinook salmon) and California Coastal Chinook salmon (for which 0.23 genetically-identified fish were found for every 1 genetically-identified Klamath River Chinook during sampling of California recreational fisheries in 1998-2002 [Satterthwaite *et al.* 2015]). Rogue River Spring and Central Valley Spring Chinook might also be of particular value to SRKW due to their river return timing coincident with presence of SRKW in southern waters, but their run sizes are relatively small, with typical river run sizes less than 10 percent of the typical river run sizes of Klamath River Fall Chinook and Sacramento River Fall Chinook, respectively. See Appendix A for further details on non-modeled stocks.

6 INTEGRATION AND SYNTHESIS

Purpose of the Workgroup

The purpose of the SRKW Ad Hoc workgroup is detailed in Section 1.2, which was to reassess the effects of PFMC ocean salmon fisheries on SRKW and if needed, develop a long-term approach that may include proposed conservation measure(s) or management tool(s) that limit PFMC fishery impacts to Chinook salmon (*i.e.*, the whales' primary prey). This reassessment is intended to help inform NMFS' ESA consultation and biological opinion, wherein NMFS will subsequently determine whether the fisheries jeopardize the continued existence of SRKWs.

Review of Status of the Species

In Section 2, the Workgroup reviewed the current status of the SRKW DPS, which is listed as endangered under the ESA (70 FR 69903). We have high confidence in the annual census and population trends. The population was at its lowest known abundance (68 whales) in the early 1970s following live-captures for aquaria display. Since the annual censuses began, the abundance peaked in 1995 followed by an almost 20 percent decline from 1995-2001 (from 98 whales in 1995 to 81 whales in 2001). In 2014 and 2015, the SRKW population increased from 78 to 81 as a result of multiple successful pregnancies (n = 9) that occurred in 2013 and 2014. At present, the SRKW population has declined to near historically low levels (Figure 2.1.a). As of August 2019, the population is 73 whales (two calves were born and three whales died since the 2018 census).

The NWFSC continues to evaluate changes in fecundity and mortality rates, and have updated SRKW population viability analyses. The data now suggest a downward trend in population size projected over the next 50 years, and as in prior analyses the uncertainty in the projections increases the further out the analysis projects. This downward trend is in part due to the current age and sex structure of this small population, and the rate of future declines is related to assumptions about future demographic rates (for example, if fecundity rates are relatively low as they have been since 2011, the population will decline more rapidly). NMFS considers SRKWs to be among eight of the most at-risk species as part of the Species in the Spotlight initiative[8].

Section 2.2 describes the known extent of SRKW distribution. In November 2006, NMFS issued a final rule designating approximately 2,560 square miles of inland waters of Washington State as critical habitat for the SRKW DPS. On September 19, 2019 NMFS proposed to revise the critical habitat designation for the SRKW DPS under the ESA by designating six new areas along the U.S. West Coast (84 FR 49214) in addition to maintaining critical habitat designation in inland waters. Specific new areas proposed along the U.S. West Coast include 15,626 square miles of marine waters from the U.S. international border with Canada south to Point Sur, California.

Since the whales' ESA-listing, there has been several efforts to assess the impacts of fisheries on SRKWs (*e.g.* NMFS 2009, Hilborn et al. 2012, Ward et al. 2013). We review these in detail in Section 3. In 2009, NMFS finalized its most recent biological opinion on PFMC fisheries (NMFS 2009). The analysis included a comparison of prey potentially available to SRKWs with and without the PFMC fisheries and found that the fisheries will reduce prey available in some locations during some time periods. NMFS concluded that the PFMC fisheries were likely to

[8] https://www.fisheries.noaa.gov/resource/document/species-spotlight-priority-actions-2016-2020-southern-resident-killer-whale

adversely affect SRKWs and take[9] under ESA was likely to occur via removal of prey from the PFMC fisheries but that the extent of take was not anticipated to appreciably reduce the survival and recovery of SRKWs (*i.e*., not jeopardize) (NMFS 2009).

Since the completion of the 2009 biological opinion, there has been a decade of research and analyses conducted to fill gaps and reduce uncertainties on the whales' diet and distribution in coastal waters (refer to Section 2 for updated information since 2009). Most of the scientific research conducted on SRKWs has occurred outside the areas that the PFMC fisheries occur and there is still a large amount of uncertainty as to the whales' distribution and diet in the winter and in coastal waters, as detailed in Section 2.3.

The available prey samples collected in coastal waters indicate Chinook salmon are the primary species detected and consequently an important dietary component. The samples collected opportunistically in winter and spring in coastal waters (n=55) showed that over half the Chinook salmon consumed originated in the Columbia River (Ward, May 23, 2019; Workgroup Agenda Item B.3; Figure 2.3.b). Columbia River, Central Valley, Puget Sound, and Fraser River Chinook salmon collectively comprised over 90 percent of these 55 diet samples collected for SRKW's in coastal waters (Ward, May 23, 2019; Workgroup Agenda Item B.3). However, this is a relatively small sample size and the composition of stocks may be an artifact of the opportunistic sampling location, for which there is no correction factor. The degree to which SRKWs are able to or willing to switch to other prey sources is also largely unknown and likely variable depending on the time and location. Thus far, prey other than Chinook salmon detected in diet samples on the outer coast have included steelhead, chum, lingcod, and halibut (Hanson *et al.* in prep). Based on the linkage to the Council's Salmon FMP, the PFMC assigned the Workgroup to focus the analysis, and associated assumed risk criteria, on relationships between Chinook salmon and SRKW.

As described in Section 2.3, there are multiple factors limiting SRKW recovery including reduced prey availability and quality, high levels of contaminants from pollution, and disturbances from vessels and sound (NMFS 2008). In addition, vessel strikes, oil spills, disease, ecosystem effects, inherent risks associated with small populations, and behavioral risks are also threats to this population. It is likely that these threats are acting together to impact SRKWs and the intensity of these limiting factors are likely time varying (*i.e.,* having non-stationary relationships). There are also many non-fishery related factors that affect the abundance, productivity, spatial structure, and diversity of Chinook salmon and thus affect prey availability for the whales. Because the PFMC has minimal influence over these other factors, we reviewed them, but focused on the assigned task, the evaluation of the PFMC ocean salmon fisheries. Through the fisheries, the PFMC does influence the level of escapement and thus natural spawning. But a complete reexamining of all escapement goals that contribute to the FMP's implementation was determined to be outside the scope of the Workgroup's assignment. Examining the aggregated "weak stock" approach employed by the Council over time and the resulting annually remaining potential Chinook salmon abundance as prey for SRKW was the approach settled on by the Workgroup.

[9] Take as defined under the ESA means "to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct." Incidental take is an unintentional, but not unexpected, taking.

Fishery Effects on Chinook Salmon Abundance

As previously described, PFMC salmon fisheries can affect Chinook salmon abundance throughout the SRKWs' geographic range. Similar to the conclusions described in Hilborn et al. (2012), due to factors such as natural mortality (including predation by other species, e.g. Chasco et al. (2017)) and mature fish leaving the ocean, it is acknowledged that in the absence of the PFMC salmon fisheries, not of all the foregone Chinook salmon catch would be available prey to SRKWs. Therefore, the calculated reductions in Chinook salmon abundance attributable to Council salmon fisheries do not directly translate into actual effects on prey available to SRKW. Only a fraction of the foregone harvest from any particular year would likely be available to SRKW. As part of our assessment, the Workgroup estimated adult Chinook salmon abundance present in particular seasonal time steps (October – April, May – June, July– September) and areas (NOF, SWCVI, Salish Sea, Oregon coast (Cape Falcon, OR to Horse Mountain, CA), and the California coast, south of Horse Mountain). In each seasonal time step and spatial area, we estimated reductions in adult abundance attributable to PFMC ocean salmon fisheries between 1992 and 2016 (Section 5.1). We did not attempt to account for multi-year effects of fishing nor for changes in Chinook size or age structure[10]. The fisheries effects on potential prey abundance have varied highly over this time period, but in general, reductions in abundance attributable to PFMC salmon fisheries has declined substantially between 1992 and 2016 (we review these details in Sections 4.4 and 4.5). These changes in the fisheries over time (*i.e.*, fisheries have been taking less of the available abundance over time) are a combined result of effects of increased salmon restrictions through updates to harvest control rules, updated conservation objectives including those for ESA-listed species, and increasingly restrictive Pacific Salmon Treaty obligations.

We attempted to quantify the relationship between Chinook salmon and whales in order to understand the effects of prey reduction from the fisheries on SRKW demographic rates from 1992 - 2016. Given that multiple interacting factors affect SRKWs survival and recovery, and the strength of individual effects likely vary across years, it seems reasonable to assume that any effects of the ocean salmon fisheries on SRKWs likely vary annually as well. However, we assumed constant linear relationships between time/area-specific Chinook salmon abundance and SRKW demographic rates. At the November 2019 Council meeting the Scientific and Statistical Committee reported they found the data sets used and the analyses performed to be reasonable and appropriate for the questions at hand given the complexity of the problem and the challenges presented by small populations (Supplemental SSC Report 1 November 2019, Agenda Item E.4.a). The SSC also did not find the available information sufficient to quantitatively justify a threshold at which risk may be greater for SRKWs due to the effects of PFMC salmon fisheries. We also attempted to estimate the changes in vital rates that the statistical relationships predict would result from reductions in Chinook salmon abundance from the fisheries. The Workgroup attempted to parse out geographic distributions of Chinook salmon abundance not previously examined at this scale for relationships with SRKW demographic rates. Therefore, we can examine results at an aggregated level spatially and temporally at the stratifications defined in Section 5.

We estimated the pre-fisheries annual EEZ "coastwide" Chinook salmon abundance ranged from 2,131,210 to 6,040,198 during 1992 – 2016 with an estimated average annual abundance of 3.6 million (see Appendix E, Table 1)[10]. Percent reductions in EEZ abundance due to PFMC salmon

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[10] These estimates, and all that follow, must be considered in the context that model-related uncertainty is not quantifiable to provide confidence intervals. In addition, all estimates include only adult (age-3 or older) Chinook.

fisheries harvest ranged from 0.9 percent to 30.1 percent; total abundance reductions from the PFMC salmon fisheries across the EEZ ranged from 20,597 to 1,329,810 fish. Over the last decade (2007 – 2016), we estimated the average pre-fisheries Chinook salmon abundance in the EEZ was similar to the average between 1992 and 2016 (approximately 3.6 million); however, PFMC salmon harvest was reduced between 2007 and 2016. For example, the maximum percent reduction from starting abundances attributable to PFMC salmon fisheries during the most recent 10 year period was 12.2 percent and the maximum PFMC fishery mortalities occurring in the EEZ was 651,732. The average annual fishery reduction in the most recent 10-year period (280,006 fish) was approximately half the average annual reduction in EEZ abundance that was estimated to occur between 1992 and 2016 (552,888 fish) due to PFMC salmon fisheries coastwide.

Pre-fisheries abundance estimates in NOF coastal areas (refer to Section 5.1 for definition of NOF area) ranged from 819,183 to 2,446,093 Chinook salmon (see Appendix E, Table 2). The estimated average annual abundance in NOF over the entire time series was approximately 1.5 million Chinook salmon and the recent 10-year average was approximately 1.6 million Chinook salmon. Reductions in abundance NOF attributable to PFMC salmon fisheries ranged from 1.2 percent to 7.7 percent and from 12,883 to 144,602 fish from 1992 - 2016. The greatest percent reduction in abundance (7.7 percent) occurred in a year (1995) with relatively low abundance (*i.e.,* less than average) and with a reduction in abundance of 79,088 Chinook salmon. The largest total reduction of fish (150,729) occurred in 2004 (a year with relatively high abundance and a similar percent reduction as that in 1995, 7.6 percent). The recent 10-year average annual reduction attributable to PFMC salmon fisheries (57,926 fish) was slightly less than from 1992 – 2016 (69,095 fish).

Pre-fisheries abundance estimates in Oregon's coastal waters (Cape Falcon, OR to Horse Mt., CA) from 1992 – 2016 ranged from 760,853 to 2,492,455 fish. The average abundance in the last 10 years was similar to the average abundance in the overall time period (approximately 1.5 million), however, the annual reduction in abundance attributable to PFMC salmon fisheries in the last 10 years of the time period (109,902 fish) were almost half the average over the full time period (199,783 fish). Between 1992 and 2016, percent reductions in Chinook salmon between Cape Falcon, OR to Horse Mt., CA due to the PFMC salmon fisheries averaged 13.5 percent and ranged from 0.7 percent in 2009 (a reduction of 6,483 fish) to 26.3 percent in 2004 (a reduction of 536,591 fish). The estimated pre-fishery Chinook salmon abundance in 2004 was slightly above average. The age-4 ocean harvest rate in PFMC salmon fisheries for Klamath River Fall Chinook salmon was 35 percent that year, higher than any other value since 1991 by at least 14 percent. In 2006, inputs to the Klamath Ocean Harvest Model were adjusted (limited to more recent data) in response to harvest rates exceeding expectation in the recent years. Errors of this magnitude in the KOHM have not occurred again after this model adjustment. This is a good example of the responsiveness of Council management to correct for changing biological conditions, fishery changes, and model performance over time.

We estimated pre-fishery Chinook salmon abundance from 1992 – 2016 in California coastal waters south of Horse Mountain ranged from 243,719 to 1,423,376. The estimated average annual abundance over the entire time series was approximately 765,369 Chinook salmon, whereas the recent 10-year average was 569,194 Chinook salmon. Reductions in abundance attributable to PFMC salmon fisheries from 1992 – 2016 ranged from 0.4 percent in 2009 (1,203 fish) to 60.0 percent in 1995 (751,725 fish). The average percent reductions have dropped substantially in the recent 10-year average (16.6 percent) compared to the total time series (34.0 percent). Reductions in abundance attributable to PFMC salmon fisheries in the last 10 years (2007 – 2016) ranged from 1,231 fish to 302,216 fish with an average of 112,048 fish.

The PFMC salmon fisheries also reduce Chinook salmon abundance in the Salish Sea and in waters off the SWCVI. Reductions in abundance in the Salish Sea attributable to PFMC salmon fisheries ranged from 0.9 percent to 3.0 percent and from 2,244 to 21,020 fish from 1992 – 2016 (see Appendix E, Table 3). The recent 10-year average annual reduction attributable to PFMC salmon fisheries (11,920 fish) was slightly more than from 1992 – 2016 (11,747 fish). Reductions in abundance in SWCVI attributable to PFMC salmon fisheries ranged from 0.8 percent to 3.4 percent and from 3,277 to 30,919 fish from 1992 – 2016 (see Appendix E, Table 4). The recent 10-year average annual reduction attributable to PFMC salmon fisheries (12,632 fish) was less than from 1992 – 2016 (14,581 fish).

SRKW Demographic Relationships with Chinook Salmon Abundances

As alluded to in this Section, and described in detail in Section 5, we related past SRKW demographic performance with estimates of these time- and area-specific Chinook salmon abundances. However, while expanding on similar previous attempts, we were unable to develop a robust model that can predict or characterize this relationship. Similar to Hilborn et al. (2012), we believe "considerable caution is warranted in interpreting the correlative results as confirming a linear causal relationship between Chinook salmon abundance and SRKW vital rates". This uncertainty is not at all surprising. There are multiple, interacting factors at play, and the strength of any one effect likely varies through time as different components of the environment (broadly defined here) move into domains where their effects are stronger or weaker, leading to a situation known as "non-stationarity" and limiting our ability to make a binary classification of effect verses no effect, or true verses not true. These multiple threats affect SRKW's demographic performance through time, in addition to random chance, and these effects can confound the analysis of the effects of prey abundance.

SRKW Spatial and Temporal Overlap with PFMC Fisheries

Because the distribution of SRKWs can vary year to year and are only generally predicable at a coarse level, we are restricted to qualitatively assessing the spatial and temporal overlap of the SRKW population and the fisheries. We analyzed the impacts of fisheries on the population as a whole even though there are differences in the pods' distributions and population parameters (J pod appears to remain much more within the Salish Sea relative to K and L pods that spend more time in coastal waters). This means that K and L pods have more overlap with coastal fisheries and may therefore be more affected by reductions in Chinook salmon stocks from harvest in PFMC salmon fisheries than J pod (refer to Section 2.2 for details on SRKW distribution). SRKWs are highly mobile and can be present throughout the coastal waters where the PFMC fisheries occur (Figure 2.2.a). As mentioned above, NMFS is currently proposing modifying its defined critical habitat for SRKW to include areas of the EEZ from the U.S. Canadian border south to Point Sur, California (84 FR 49214).

In most years, SRKW spend summer months in the Salish Sea, NOF, or SWCVI areas. Diet samples from those areas are generally collected in the summer in the Salish Sea and dominated by Chinook salmon. Diet from winter coastal samples appear more diverse compared to summer inland samples, including more non-Chinook salmon, although sample sizes are very limited. The majority of prey samples collected in coastal waters (Figure 2.3.b) have occurred off the Washington coast in winter (to address some of the data gaps outlined by Hilborn et al. 2012), an area with higher prey sampling effort than off Oregon or California (Section 2.2). Prey sampling effort was higher off Washington than off Oregon or California because satellite tags were used to locate and follow the whales to obtain predation and fecal samples. Satellite tagged K/L whales occurred primarily on the Washington coast, with a continuous high use area between Grays Harbor and the Columbia River and off Westport (Hanson *et al.* 2017, 2018).

Acoustic effort was also higher off Washington than off Oregon and California. For example, the number of recorder sites off the Washington coast increased from 7 to 17 in the fall of 2014; however, only one recorder was deployed off Oregon and two recorders were deployed off California. The acoustic detections of SRKW off Washington coast occurred in all months of the year (Figure 2.2.g; Table 2.2.d). As described in Section 2.2, 26 of the 49 confirmed opportunistic sightings between 1986- 2016 were off the coastal areas of Washington. The combined results from the opportunistic sightings, satellite tagging, and acoustic recorders suggest SRKW may be present in Washington coastal waters at nearly any time of year, and in other coastal waters more often than previously believed (Hanson *et al.* 2017, 2018). Occurrence NOF has been primarily K and L pods; however, J pod presence has also occurred in this area (although they primarily occur in the western end of Strait of Juan de Fuca and Salish Sea). Tagged whales travel more slowly in this area than off Oregon or California coasts (Hanson *et al.* 2017) and slower speeds may be indicative of foraging behavior (NMFS 2019b).

Based on the limited and opportunistic data available, SRKW distribution and diet (and to some extent, how diet might vary depending on season and location), we might expect the most consistent importance of Chinook salmon abundance (whatever factors contributed to the realized abundance) to be in the Salish Sea, SWCVI, and NOF coastal areas. While our analysis did not focus on specific Chinook salmon stocks, our regression results for these areas seem consistent with expectations (*e.g.,* several instances of debatably "marginal significance" and a lack (except for lagged fecundity) of relationships with opposite of expected sign). Measures of significance need to be interpreted with caution when model assumptions are violated (Section 5.4). Nonlinearity *(e.g.*, an additional fish may have less value to SRKW when fish are already abundant) when models assume a linear (on the log-odds scale) response is a concern for interpreting all of the model results. Non-stationarity (relationships changing over time) is also a concern, but there might be smaller departures from stationarity in areas that SRKW consistently occupy versus areas they only occasionally occupy. Temporal variation in other factors would likely still introduce some degree of non-stationarity.

Because the whales are observed in the NOF area in all seasons, they likely have some overlap with the fisheries every year and are likely impacted by reduced prey availability resulting from PFMC fisheries to some unknown degree. PFMC ocean fisheries in the NOF coastal area can directly reduce the abundance of Chinook salmon in the NOF coastal area, and can also indirectly reduce abundances in the Salish Sea and (probably to a lesser extent) and SWCVI areas by removing fish that otherwise would have moved into those areas. There is also a potential for lagged effects, by which immature fish in year (t) from some stocks are removed before being available as prey at year (t+1), though the overall impact rates on immature fish are relatively low. Overall PFMC ocean fishery impacts on NOF abundance are relatively small relative to both annual variation in abundance and the total abundance in a given year.

Sightings of SRKW are rarer and seem seasonally restricted SOF. K and L pods have been detected or observed SOF a limited number of times during wintertime and early spring (refer to Section 2.2) but given the limited data their predictive use, especially during the remainder of the year, is uncertain. In summary, the limited data seems to suggest that distribution on the outer coast SOF has a seasonal component, but there is considerable year-to-year variation.

As described in Section 2.2, SRKW occur off Oregon coastal areas (Cape Falcon, OR to Horse Mountain, CA) and likely have some overlap with the fisheries off Oregon coastal waters; however, less frequently than in NOF waters. For example, of the 49 confirmed opportunistic sightings between 1986 and 2016, 8 were off the Oregon coast (south of Falcon to the California border). The satellite tagging effort showed K/L pods occurred off Oregon coast, but to a lesser extent than off the Washington coast (Figure 2.2.d; Hanson *et al.* 2017, 2018). There was one acoustic recorder off Oregon coast (the Newport hydrophone) and SRKW were detected off the Newport recorder in January, February, March, and May. SRKW have not been observed or detected in every month of the year in Oregon coastal waters as they have been NOF.

It is uncertain if SRKW occur off Oregon coastal waters more than off California coastal waters, however SRKW must pass through Oregon coast waters to reach areas that are more southern and to return to areas that are more northern. We might expect an intermediate importance of Chinook salmon abundance in this area compared to NOF and California. The regression results, while not conclusive, somewhat bear this out with generally larger coefficients than California regressions and smaller coefficients than NOF regressions. The mix of stocks off Oregon includes some stocks affected by fishing NOF, but in most years, a substantial fraction of the abundance comes from stocks primarily affected by SOF fisheries (e.g., Sacramento River Fall, Klamath River Fall, and Rogue River Fall). Given the workgroup expects an intermediate importance of Chinook salmon abundance in the Oregon coast, as we define it, at a qualitative level we assume that a given level of reductions in abundance in Oregon coast areas due to the PFMC salmon fisheries will affect the whales less than if that harvest caused similar reduction in abundance in the NOF coastal area.

The most abundant SOF stock, SRFC salmon, has a dominant age-3 maturation rate and so most large adults leave the ocean each fall, leaving predominantly smaller individuals newly recruited to the adult stage over the wintertime. Although three prey samples have been collected from SRKW foraging events in the winter off the California coast (Figure 2.3.b), this suggests that Chinook salmon abundance SOF may be of lower importance overall (assuming whales target age 3-5 year old fish). Our regression results also seem consistent with this - in California areas south of Horse Mountain the smallest p-value associated with any coefficient having the expected sign is 0.45. This does not preclude Chinook salmon abundance in this area of the EEZ as being important because data from the last 20 years suggests the whales have been observed or detected from January – March, May and October south of Horse Mountain along the California coast (Section 2.2). The full period of record (1975 – 2016) shows little or no SRKW presence in this area prior to the early 2000's. However, the data are very limited in this area and it is unknown how much time the whales spend in this area during these months, what they are eating throughout the majority of the California coast (between 2009 and 2015, only three prey samples have been collected off California coastal waters (Figure 2.3.b), or if the whales occur in similar months every year (the satellite-tagged whales did not travel farther south than Area 5 and no acoustic recorders were located in this area). Of the 49 confirmed opportunistic sightings in coastal waters between 1986 and 2016, 15 occurred off the California coast (from the Oregon-California border to Point Sur, CA). Of these 15 sightings, 13 occurred in January, February, and March, and two occurred in April and October (Table 2.2.a). There were acoustic detections of SRKW off California coast on the Fort Bragg and Point Reyes hydrophones (Figure 2.2.e). SRKW were detected off these recorders in January, February, May, and December (Table 2.2.d).

Reductions in Chinook salmon abundance attributable to PFMC ocean salmon fisheries are highest in California coastal areas. If we are correct assuming that SRKW presence in areas south of Horse Mountain California primarily occurs in the wintertime (January – March), the impacts of fisheries (which primarily occur during the summer) may be most relevant in terms of harvest on the subset of salmon that would not have spawned in the fall and therefore remain available the following winter and spring. Opening and closing date restrictions on the fishery in this area preclude most, if not all, fishery overlap with the documented presence of SRKW. In some rare instances, there has been confirmed presence of SRKW in California during the months of April, May, and October when the fishery is just beginning or very near the end and harvest is relatively low. When considering how many adult fish are likely to remain through the fall and winter, it may be relevant to consider that California stocks are generally managed toward an "ocean escapement floor". This ocean escapement floor is the same in most years except those with very low preseason forecasts in which "*de minimis*" fishery provisions apply that allow lower escapement goals. Additionally, constraints imposed by co-occurring and/or ESA stocks or buffering for management error have led to managing toward higher ocean escapements in most years (PFMC 2019e). If age structure were constant, this would imply managing toward a constant carryover abundance of older adults, at least for fall run, with the exceptions described above. SOF ocean salmon fisheries primarily affect abundances of Chinook salmon stocks off California coastal areas, such that cumulative effects considering NOF fisheries would be only very slightly higher. Similarly, fisheries off California coastal areas would have little impact on Chinook salmon abundance for NOF areas and moderate impacts on Chinook salmon abundance off Oregon coastal areas, north of Horse Mountain, California.

While acknowledging above that the greatest percent reductions occur in SOF waters, particularly in California coastal waters, there is less justification overall to conclude that Chinook salmon abundance in SOF areas are consistently important to SRKW. SRKW presence SOF is less frequent and may primarily occur only in a season (winter/spring) during which there is little direct effect of the fishery on Chinook salmon abundance. In addition, as discussed above, the maturation schedule for the primary stock (SRFC) in this area also limits the carryover effect of fisheries in California during times of the year when the whales are present. If, in the future, SRKW are present SOF in the summertime as well, they would directly overlap with the relatively large ocean fishery impacts and the potential effects of this would need to be considered. However, speculating about future changes to SRKW behavior is beyond the scope of the Workgroup.

Conclusion

Over the last decade, the status of SRKWs has substantially declined, raising concern over their status and recovery. The population is currently at 73 whales (as of August 2019), and results from recent population viability analyses suggests a downward trend in population size projected over the next 50 years. There are several demographic factors of the SRKW population that are cause for concern, namely (1) reduced fecundity, (2) a skewed sex ratio toward male births in recent years, (3) a lack of calf production from certain components of the population (K pod, other groups), (4) a small number of adult males acting as sires (Ford *et al.* 2018) and (5) an overall small number of individuals in the population (reviewed in NMFS 2008).

The relationships between modeled Chinook abundance and SRKW demographics examined by the Workgroup appear to be weaker than those from prior analyses (Ford *et al.* 2005; Ford *et al.* 2009; Ward *et al.* 2009; Ward *et al.* 2013), and this is consistent with information provided to the Workgroup by NMFS scientists at the beginning of the Workgroup process. The whales are declining even in recent years when total salmon abundance has been at or above medium term average (although this varies among stocks), and similar to abundances during periods when SRKW were increasing or stable over the 1992-2016 period examined. As reviewed in Section

4.5, this has occurred while fishery exploitation has continued to decrease. However, numerous stocks were far more abundant historically than they were in any of the years observed but the workgroup was unable to assess the relationship between SRKW demography and Chinook salmon abundance outside the observed range. Given the weakening of the estimated relationship between SRKWs and Chinook salmon abundance, it is likely that the relationship has some degree of non-stationarity and multiple factors are negatively impacting the whales.

It is reasonable based on the available information to conclude that Chinook salmon abundance in NOF areas is more consistently important to SRKW than abundance in SOF areas. However, ocean impacts of PFMC fisheries on this abundance are small compared to year-to-year variation in Chinook salmon abundance.

Risk to SRKW from the reduction of prey likely varies based on the effects of other stressors and how healthy individuals are (refer back to Section 2.3 for limiting factors). SRKW experience the cumulative effects of multiple stressors including reduced prey availability, high levels of contaminants, and disturbance from vessels and noise. These stressors may interact and have the potential to be additive or synergistic. For example, individual energy balance may be impacted when vessels are present because of the combined increase in energetic costs resulting from changes in whale activity with the decrease in prey consumption resulting from reduced foraging opportunities (Williams *et al.* 2006; Lusseau *et al.* 2009; Noren *et al.* 2009; Noren *et al.* 2012). Increased energy expenditure and prey limitation from reduced foraging opportunities can cause poor body condition and nutritional stress. Nutritional stress may act synergistically with high pollutant levels in SRKWs and result in adverse health effects. For example, malnutrition and persistent or chronic stress can induce changes in immune function in mammals and may be associated with increased bacterial and viral infections, and lymphoid depletion (Neale et al. 2005, Mongillo et al. 2016, Maggini et al. 2018). As a chronic condition, poor body condition can lead to reduced body size of individuals and to lower reproductive or survival rates in a population (Trites and Donnelly 2003). Populations with healthy individuals may be less affected by changes to prey abundance than SRKW. Because SRKW are already stressed, relatively small changes in Chinook salmon abundance likely have a greater physiological effect, which may have negative implications for SRKW vital rates and population viability (e.g., NAS 2017).

The SRKW population is endangered and their status is predicted to continue to decline, putting the population at a greater level of risk. Since the 2009 opinion was issued, the size of the population has declined over 14 percent, down from 85 animals to a current number of 73 (as of August 2019). Current population projections predict further declines, and, unless circumstances change drastically, NMFS expects this to occur given the current age structure and male/female ratio of the population. This indicates that whale abundance and their current demographics pose a high risk for SRKW. Since Council directed salmon fisheries operate on geographical and temporal stratifications in the EEZ, we hypothesized that abundances in certain areas or certain seasons might have a describable and predictive relationship with SRKW demographic indices. However, our analyses did not clearly identify any specific areas or seasons that were highly correlated to SRKW demographic indices. The available information on SRKW distribution and diet (although collections have focused their effort towards northern areas of the EEZ) support the hypothesis that Chinook salmon abundance in northern areas (NOF coastal, Salish Sea, SWWCVI) would be more important to SRKW than Chinook salmon abundance in southern waters, and while correlations are not particularly strong, the regression results are consistent with this hypothesis. Relationships between Chinook salmon abundance in southern waters and SRKW demographic indices were weaker than those for northern areas. Although the highest reduction in Chinook salmon abundance attributable to PFMC fisheries is SOF, particularly in California south of Horse Mountain, the limited observations of confirmed SRKW presence there may limit the importance of Chinook salmon abundances in these southern areas. The contribution of this abundance to SRKW diet may also be largely confined to during the winter/spring season, after maturing fall run adults that escaped the current year's fishery leave the system. Furthermore, annual presence in the winter/spring season can only be confirmed since the early 2000's despite the long lifetime of these animals and the period of record spanning nearly 40 years. The assessment of relative importance of Chinook salmon abundance in different areas would need revisiting if new data indicates more consistent presence of SRKW in southern waters at other times of year.

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Appendix A

Chinook salmon stocks excluded from the Assessment

The following describes stocks which are known to occur in the EEZ, but for which the Council either does not currently utilize models to account for these stocks, or in the specific case of Sacramento Winter Chinook, a model is available but the stock's contribution to potential SRKW prey base was considered insubstantial. Although their abundance and distribution may affect SRKWs demographics, the Workgroup here provides the rationale for exclusion of these stocks:

· Sacramento Winter Chinook – Sacramento Winter Chinook escapement as a percentage of SRFC escapement had a median value of 1.3 percent for 1992-2016 (for this and the other Central Valley stock comparisons, 1992-2000 escapements were obtained from the CHINOOKPROD data set, obtained from the US Fish and Wildlife Service's Anadromous Fish Restoration Program [http://www.fws.gov/stockton/afrp, downloaded March 2011] and 2001-2016 escapements were obtained from PFMC 2019a). Sacramento Winter Chinook also have small body sizes, a primarily age-3 maturation schedule, and have ocean distributions heavily concentrated south of Point Arena, CA (O'Farrell *et al.* 2012), all of which suggests they are unlikely to make substantial contributions as SRKW prey.

· Central Valley Spring Chinook – Central Valley Spring Chinook escapement as a percentage of SRFC escapement had a median value of 4.6 percent for 1992-2016. Note that the estimated Central Valley Spring Chinook escapement does not include spring run fish spawning in natural areas on the Feather River, which are included in the fall run escapement estimate and thus contribute to the SI modeled in Council fisheries.

·Other components of the Central Valley Fall Chinook Stock Complex (San Joaquin Fall and Sacramento Late-Fall Chinook) – Together escapement of these two as percentage of SRFC escapement had a median value of 6.4 percent for 1992-2016.

· Klamath River Spring Chinook – Adult river run size for Klamath River Spring Chinook as a percentage of adult river run size for KRFC had a median value of 21 percent for 1992-2016 (Klamath River Spring Chinook data from CDFW's "Current – 2017 Spring Chinook Megatable 1-Mar-2019.xlsx", KRFC data from PMFC 2019).

· California Coastal Chinook – Abundance of this stock is not well characterized. Genetic stock identification (GSI) sampling of California recreational ocean fisheries from 1998-2002 (Satterthwaite *et al.* 2015) suggested that 0.23 California Coastal Chinook were caught for each Klamath River Chinook (fall or spring run).

· Smith River Chinook – Abundance of this stock is not well characterized, but a few unpublished estimates suggest annual escapements on the order of 16,000 fish (Shelton *et al.* 2019), less than 20% of the median KRFC adult river run size for 1992-2016.

·Rogue River Spring Chinook – Terminal river returns are under 10,000 fish in most years (C. Kern ODFW pers. comm.), so mostly under 10 percent of the median KRFC adult river run size for 1992-2016.

· Other Southern Oregon Chinook stocks outside the Rogue River – Myers et al (1998) states that Rogue River fish are numerically dominant among these stocks.

Overall, we deemed it unlikely that excluding these less abundant stocks (all of which, with the exception of Sacramento Winter Chinook, lack vetted models for generating ocean abundance estimates, even retrospectively) would substantially affect the conclusions of later analyses relating SRKW performance to aggregate Chinook abundance. Further, again with the exception of Sacramento Winter Chinook, we do not have vetted abundance forecasts available for the excluded southern stocks, so we would have no way of evaluating their expected contribution to the SRKW prey base during pre-season planning. Relative catch rates from genetic stock identification studies might be informative on relative ocean abundance for similarly distributed stocks, but sample sizes and spatio-temporal coverage are currently limited. Relative escapements or river run sizes might provide some indication of relative ocean abundances, but are confounded by differences in age structure, maturation schedules, natural mortality, and ocean fishing mortality.

Appendix A References

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Appendix B

Abundance models for southern stocks

For SRFC, we used a modification of the Sacramento Index (SI, O'Farrell *et al.* 2013) to characterize adult (ages 3 and older combined) ocean abundances through time. The SI is the sum of adult river run size and ocean harvest of SRFC south of Cape Falcon and serves to index abundance on September 1 of each management year (management years south of Cape Falcon run from September 1 to August 31). Note that the SI does not account for natural mortality, nor does it account for unharvested immature fish remaining in the ocean for another year, so it likely underestimates pre-season ocean abundance. While we were not able to account for immature fish remaining in the ocean, we made new calculations that incorporate natural mortality. We assumed monthly adult natural mortality of m=0.0184, equivalent to 20 percent annual mortality. We then calculated August 1 ocean abundance N_8 as $N_8=R/(1-m)+H_8$ where R represents adult river run size and H_8 is adult ocean harvest of SRFC in August. For earlier months, $N_t=N_{t+1}/(1-m)+H_t$ (and for management years, month 12 precedes month 1). Our October 1 abundances do not match the SI values reported in PFMC 2019 Table II-1 both because our calculation reflects removals during September and because we adjust numbers upward throughout the year to account for natural mortality.

For KRFC, we used monthly age-specific (ages 3 and older) ocean abundance estimates produced by cohort reconstructions informing the Klamath Ocean Harvest Model (KOHM, Mohr 2006; September 1 values for ages 3 and 4 are available in PFMC 2019 Table II-3). Ratios between monthly age-specific abundance estimates in the KRFC cohort reconstruction reflect the combined effects of fisheries removals and assumed values of natural mortality.

For RRFC, we characterized age-specific September 1 ocean abundances using the ROPI (ROPI, PFMC 2019 Table II-7). The ROPI is calculated based on age-specific RRFC river run size, scaled up by age-specific ocean harvest rates estimated for KRFC and assumed natural mortality. Therefore, we assumed that age-specific values of RRFC abundance for later months would have the same ratio to the ROPI that monthly age-specific abundances for KRFC have to their corresponding September 1 estimates.

SRKW appear most likely to be present in waters south of Cape Falcon during the winter and early spring (Hanson *et al.* 2018). Thus, fishery removals of Chinook salmon during October could affect prey availability when SRKW are most likely to be present (ocean fisheries are closed during the winter). For SRFC, a maximum of three percent of the SI was harvested during October during the years 1992-2016, with annual median and mean of 0.9 percent and one percent, respectively. For KRFC, total reduction in adult abundance between October 1 and November 1 (reflecting both fisheries and assumed natural mortality) ranged from four to five percent with median five percent. Thus, it appears unlikely that accounting for October fishery removals would substantially change the results of later analyses.

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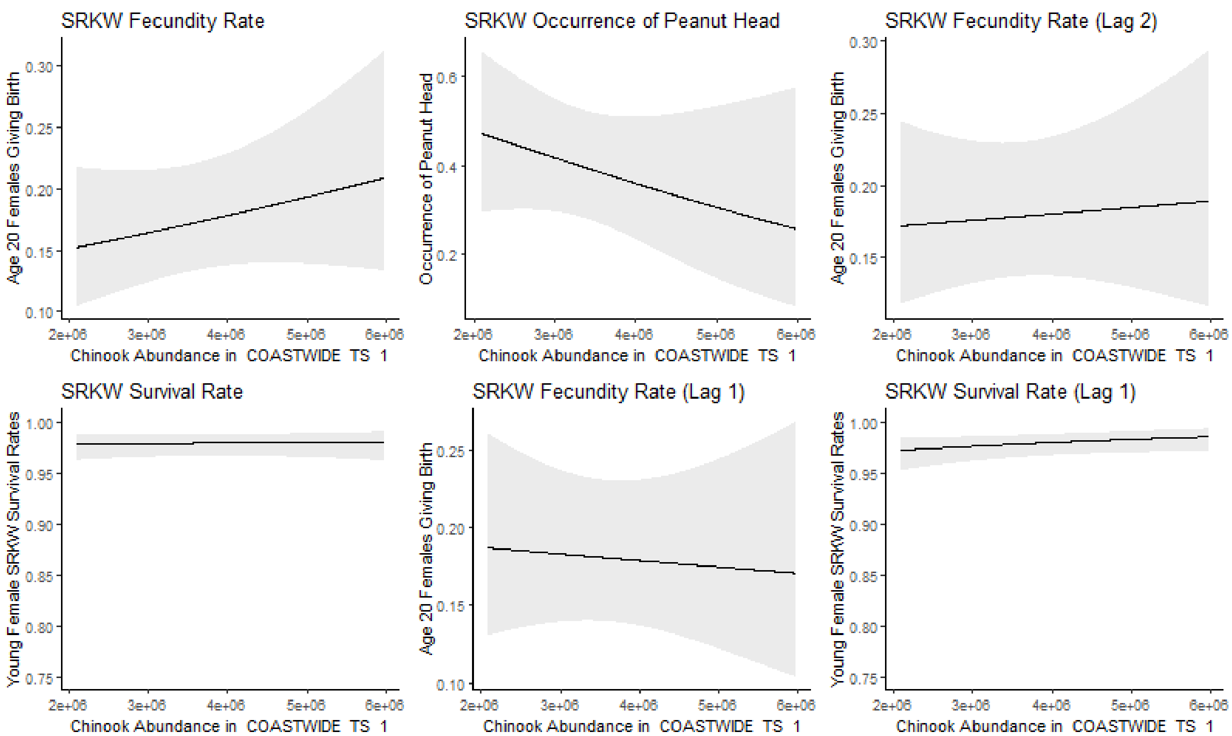
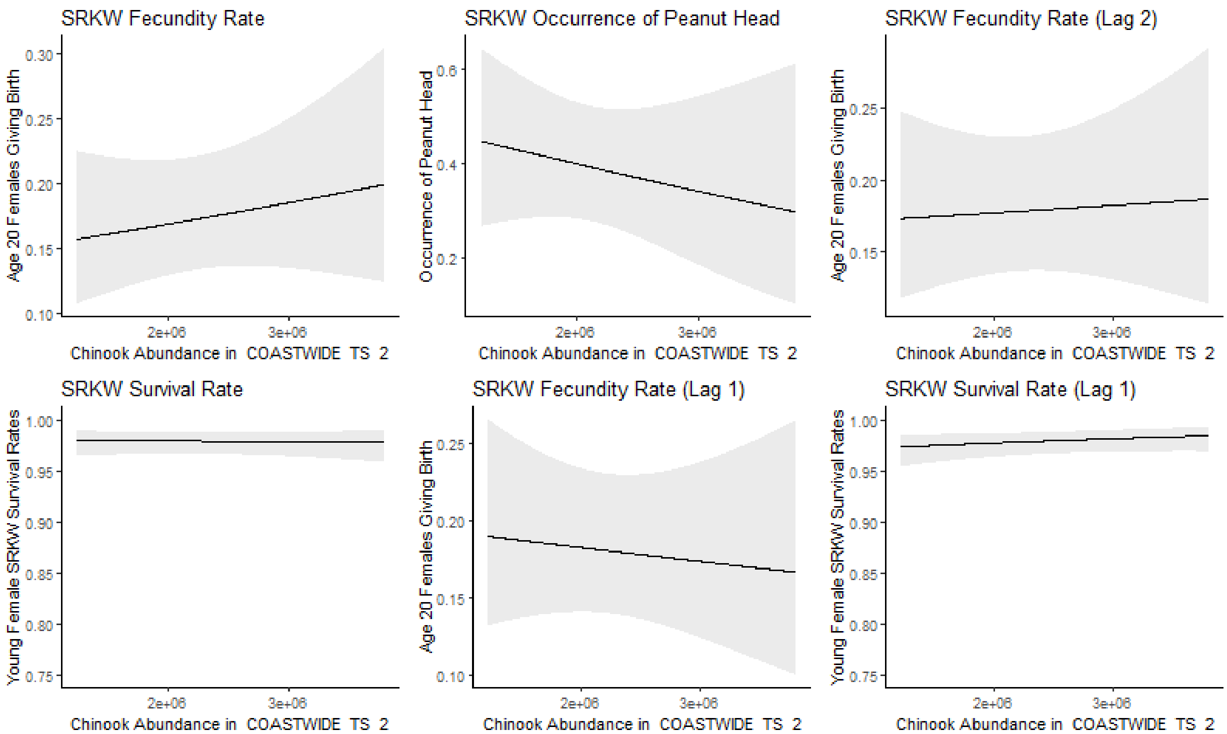
APPENDIX C

Regression model outputs

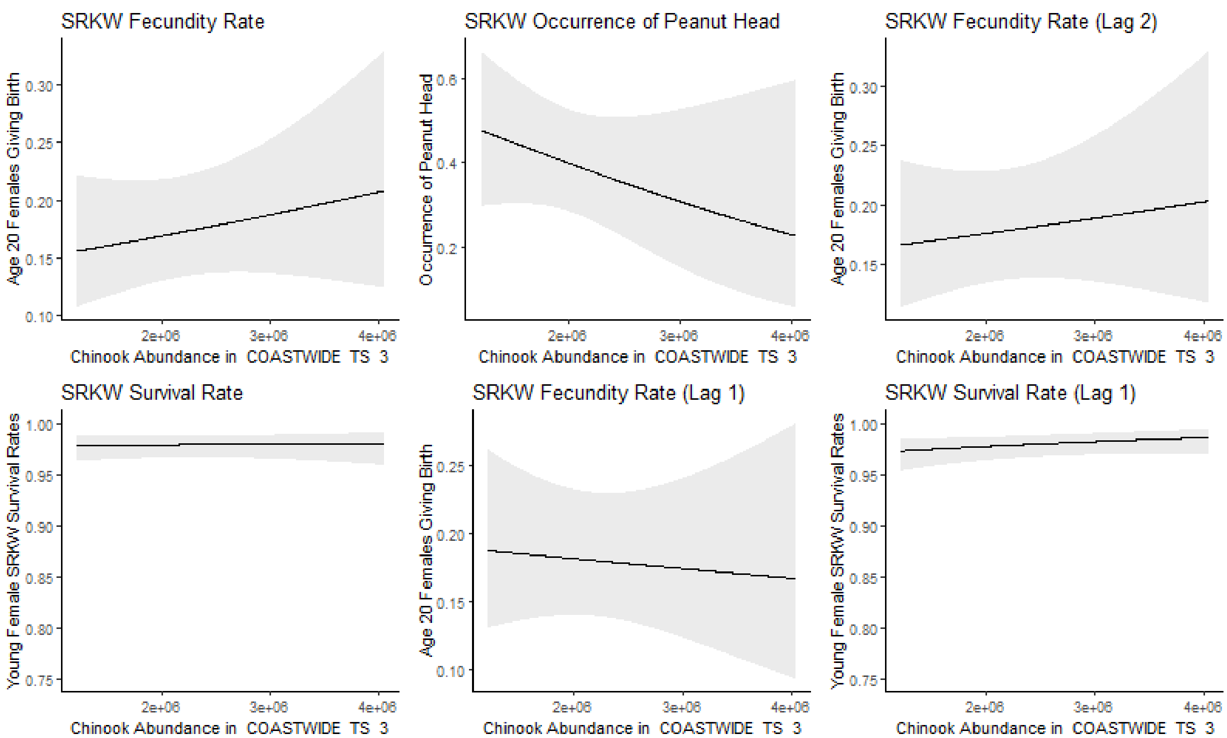
Appendix C Figure 1. Demographic rates modeled as functions of Coastwide (EEZ) aggregate abundance in Timestep 1. Figures illustrate fecundity with no lag (top left), survival with no lag (bottom left), peanut head with no lag (top middle), fecundity with 1 year lag (bottom middle), fecundity with 2 year lag (top right), and survival with 1 year lag (bottom right).



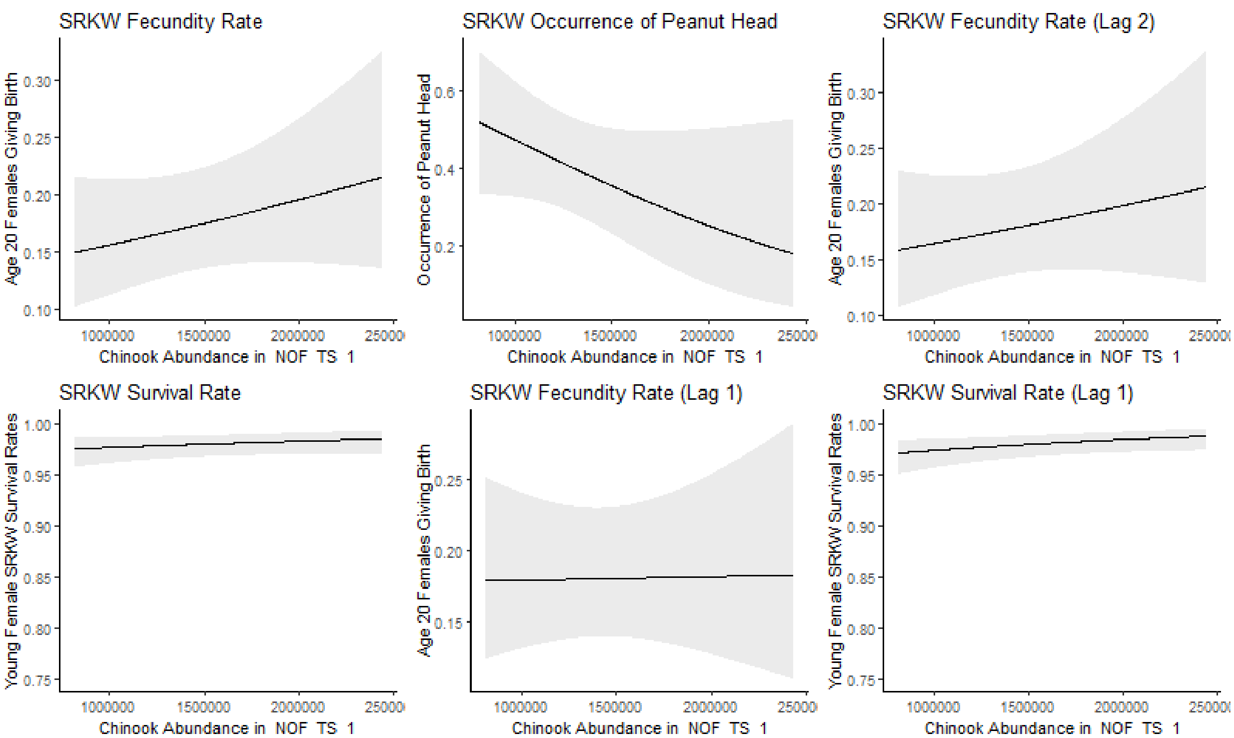
Appendix C Figure 2. Coastwide (EEZ) aggregate Timestep 2



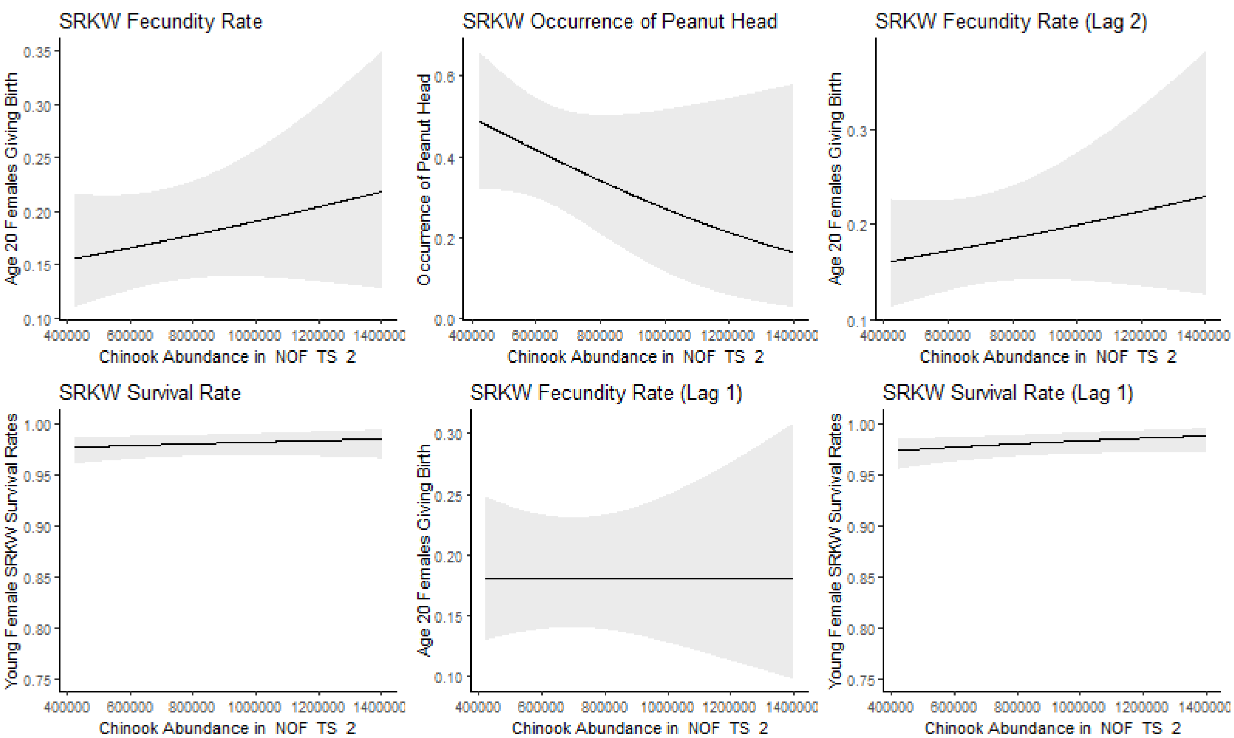
Appendix C Figure 3. Coastwide (EEZ) aggregate Timestep 3



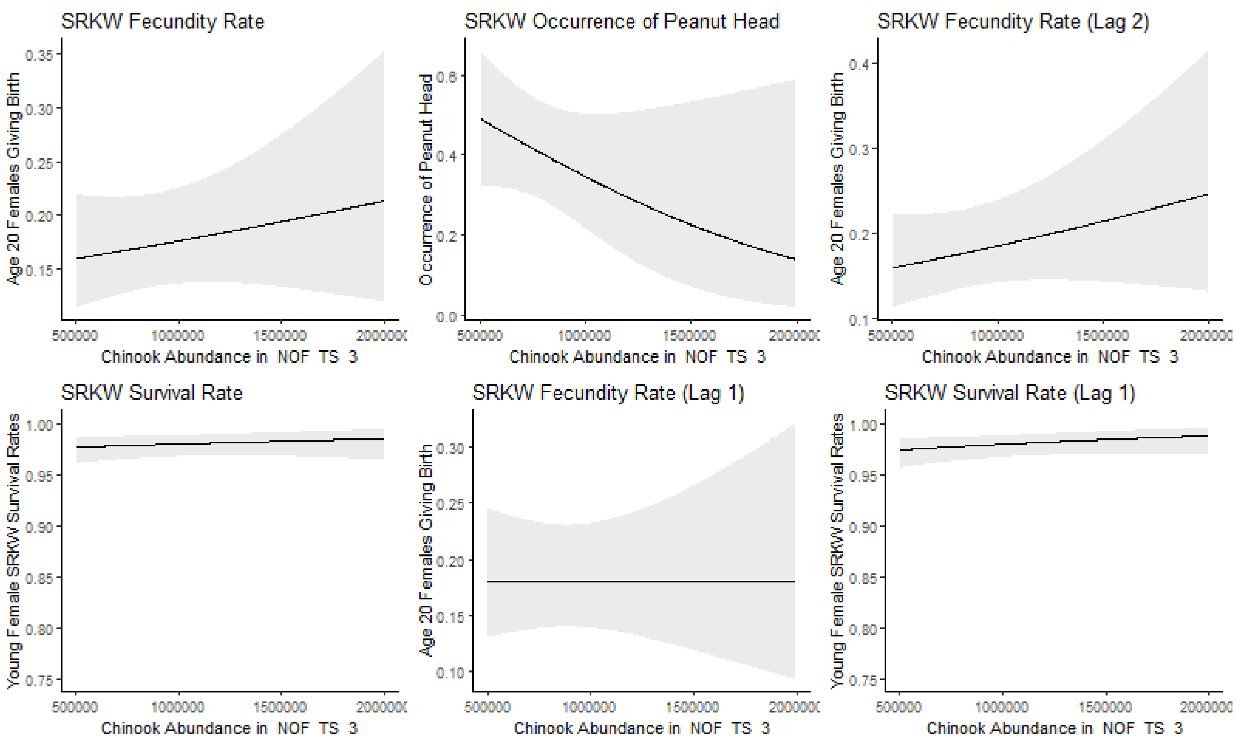
Appendix C Figure 4. North of Falcon Timestep 1



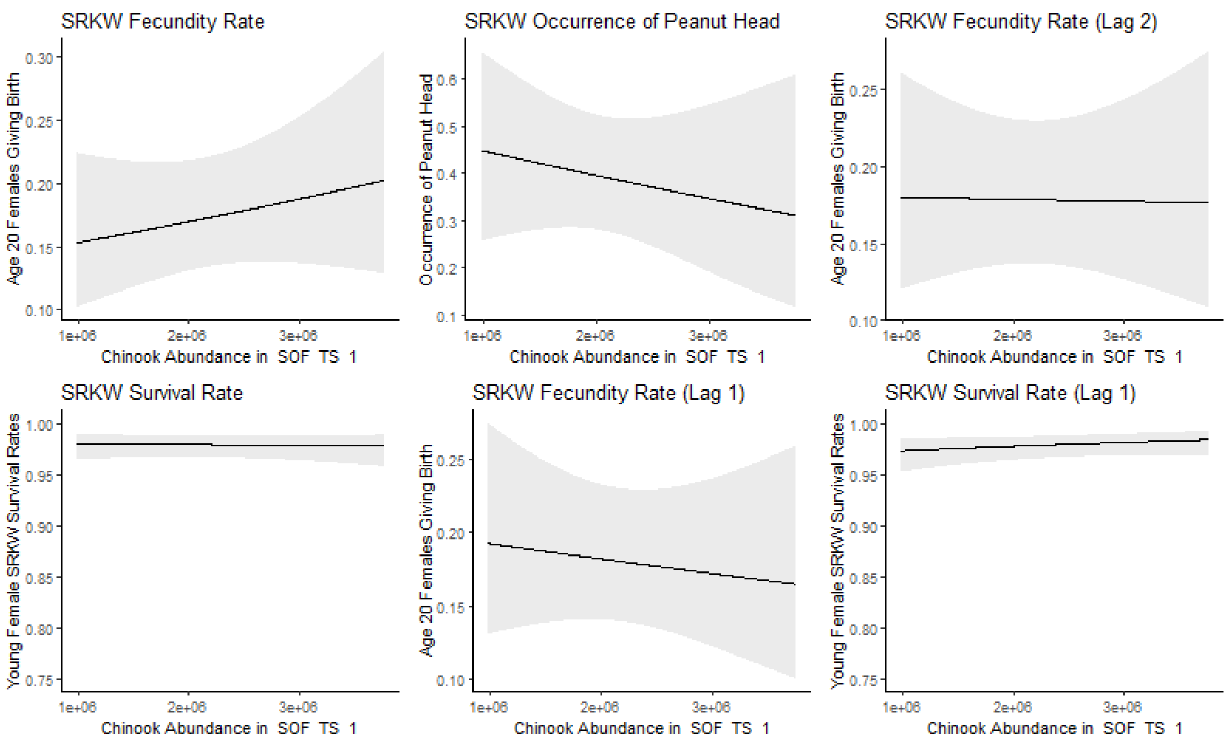
Appendix C Figure 5. North of Falcon Timestep 2



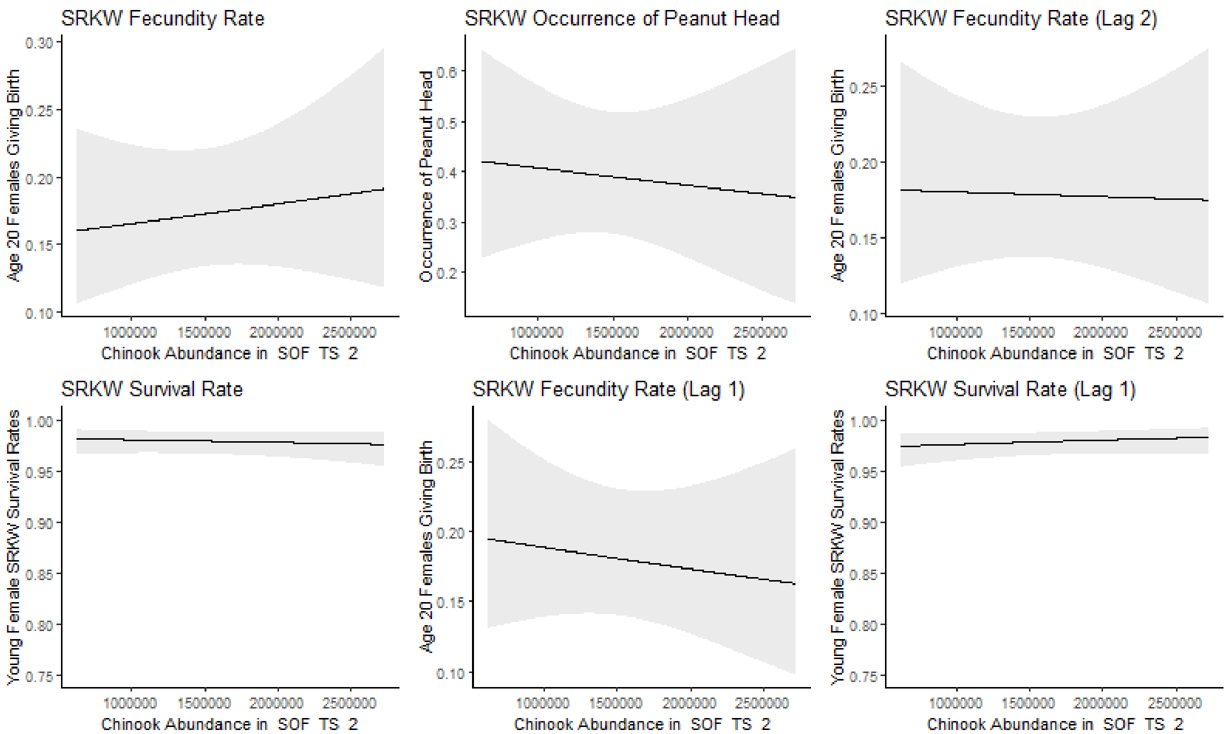
Appendix C Figure 6. North of Falcon Timestep 3



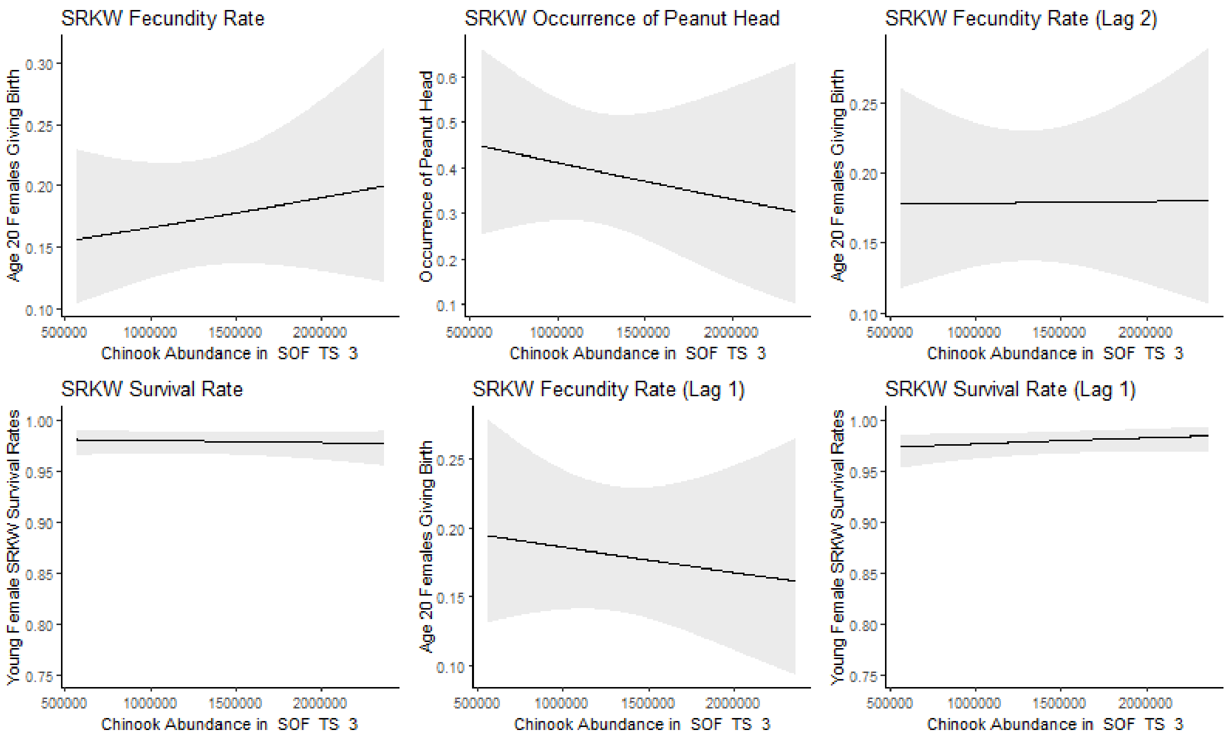
Appendix C Figure 7. South of Falcon Timestep 1



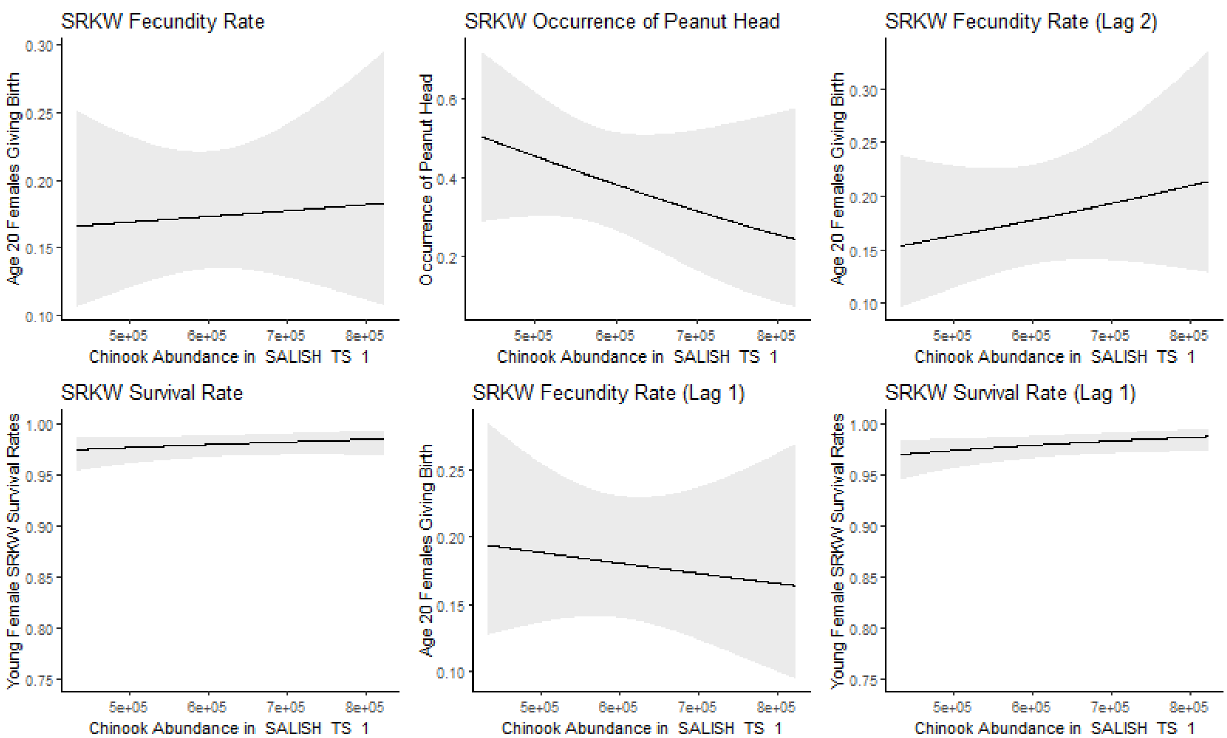
Appendix C Figure 8. South of Falcon Timestep 2



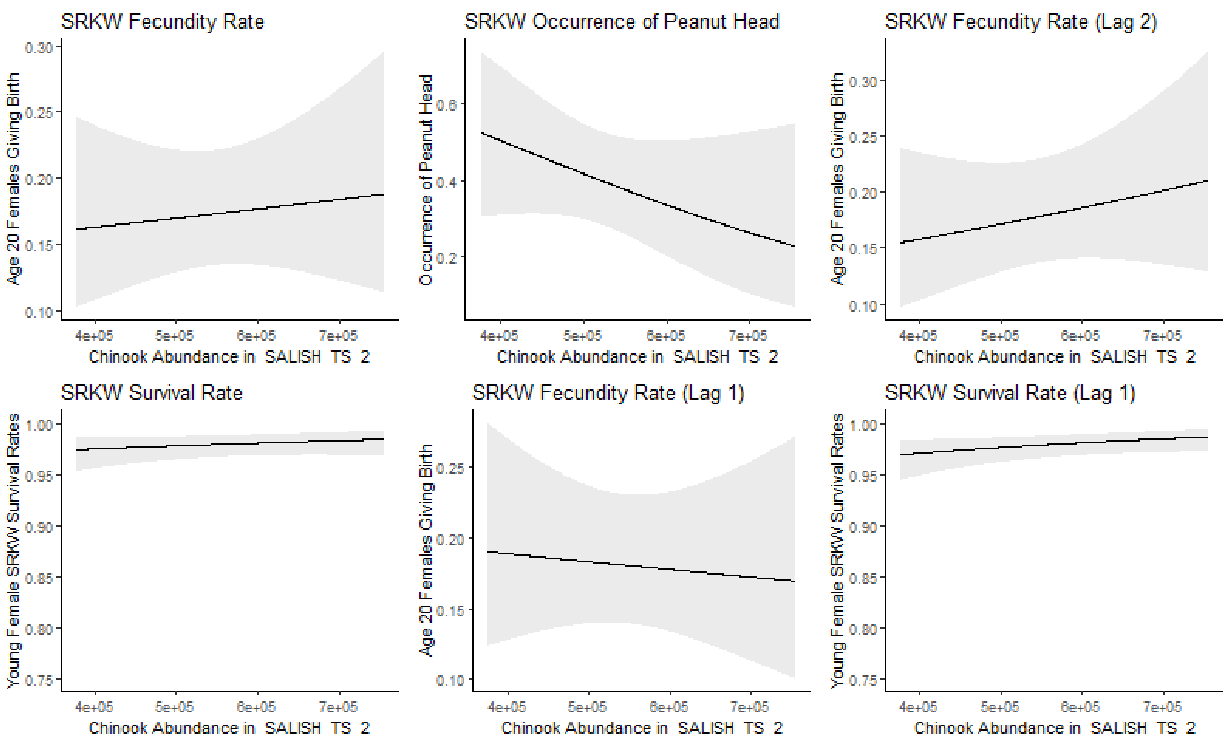
Appendix C Figure 9. South of Falcon Timestep 3



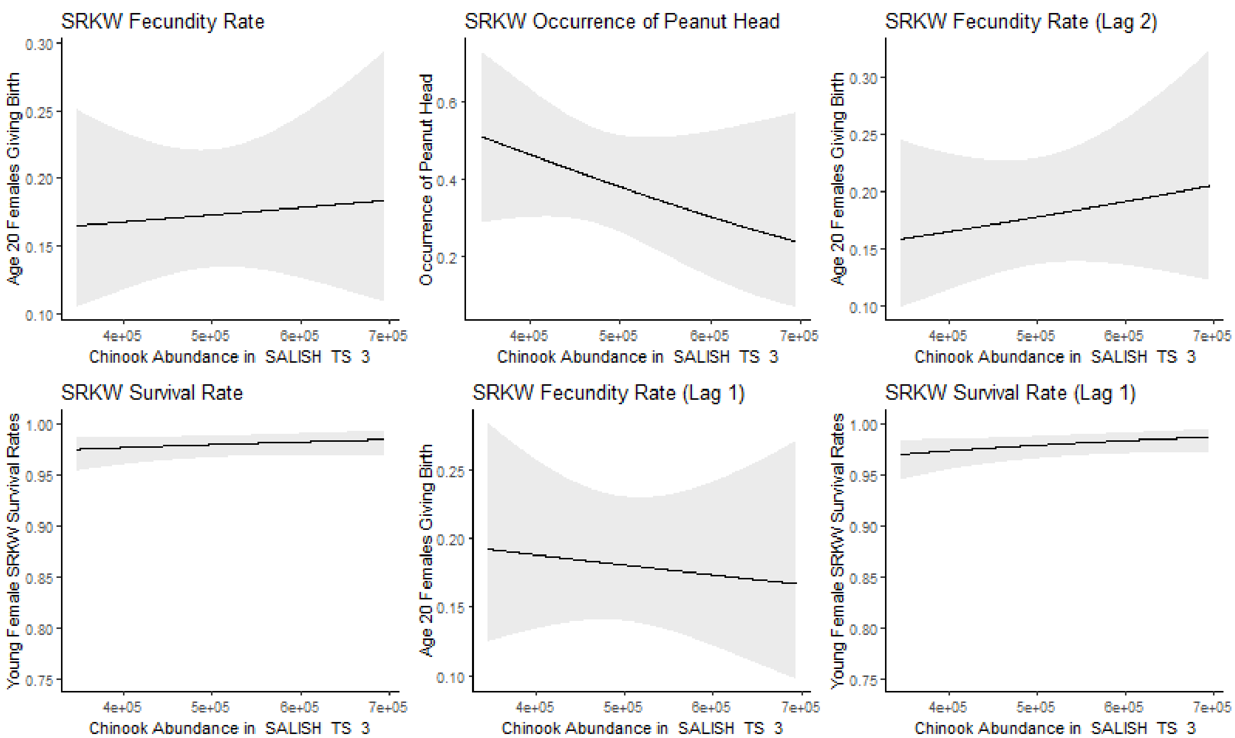
Appendix C Figure 10. Salish Sea aggregate Timestep 1



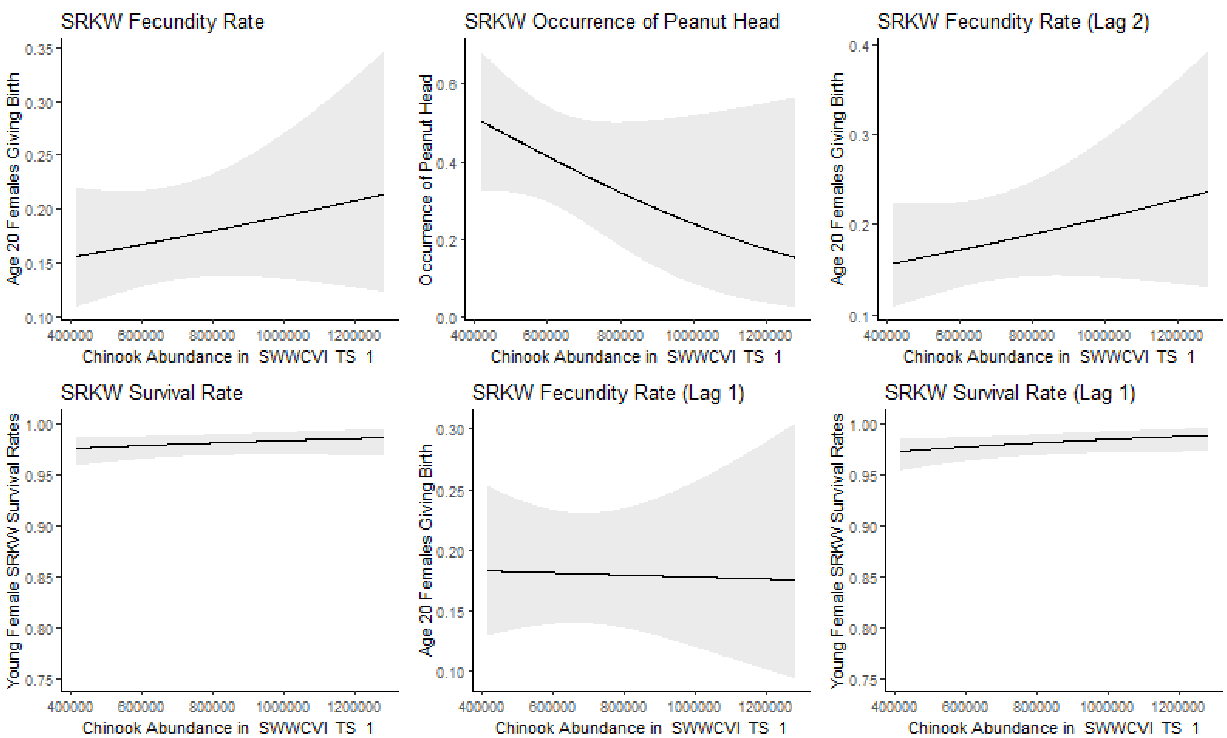
Appendix C Figure 11. Salish Sea aggregate Timestep 2



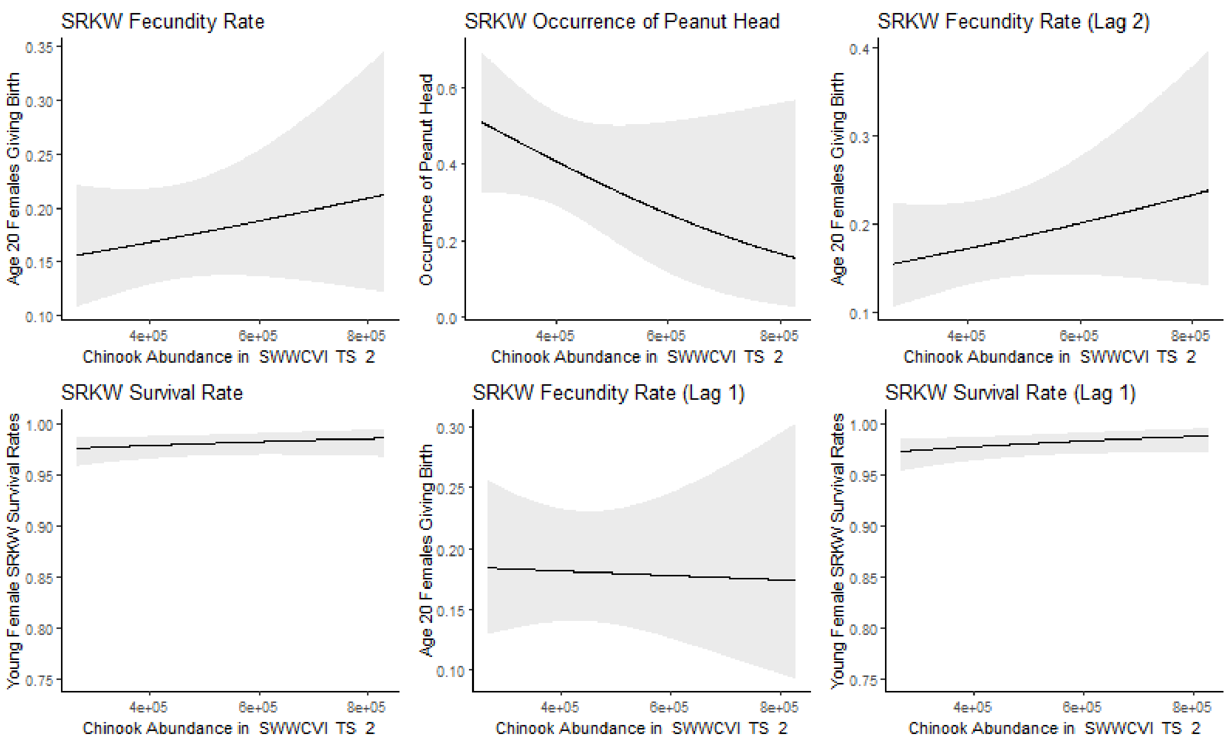
Appendix C Figure 12. Salish Sea aggregate Timestep 3



Appendix C Figure 13. South West / West Coast of Vancouver Island aggregate Timestep 1



Appendix C Figure 14. South West / West Coast of Vancouver Island aggregate Timestep 2



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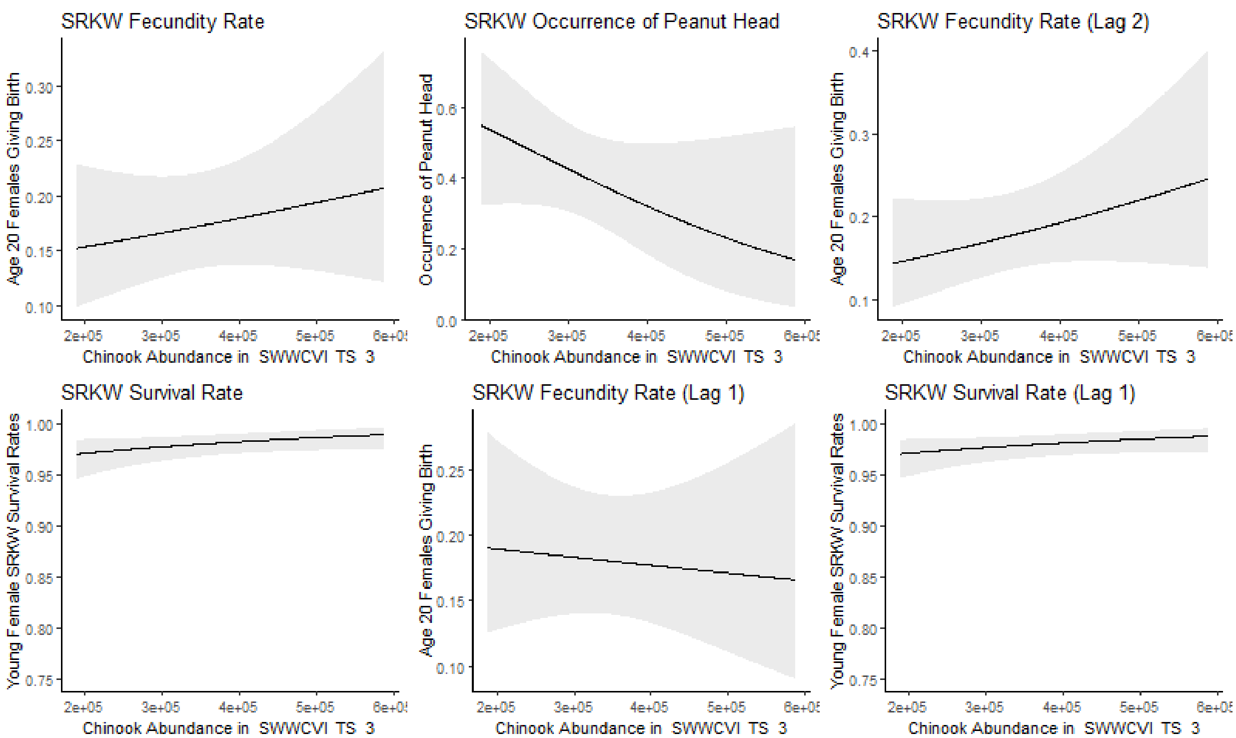
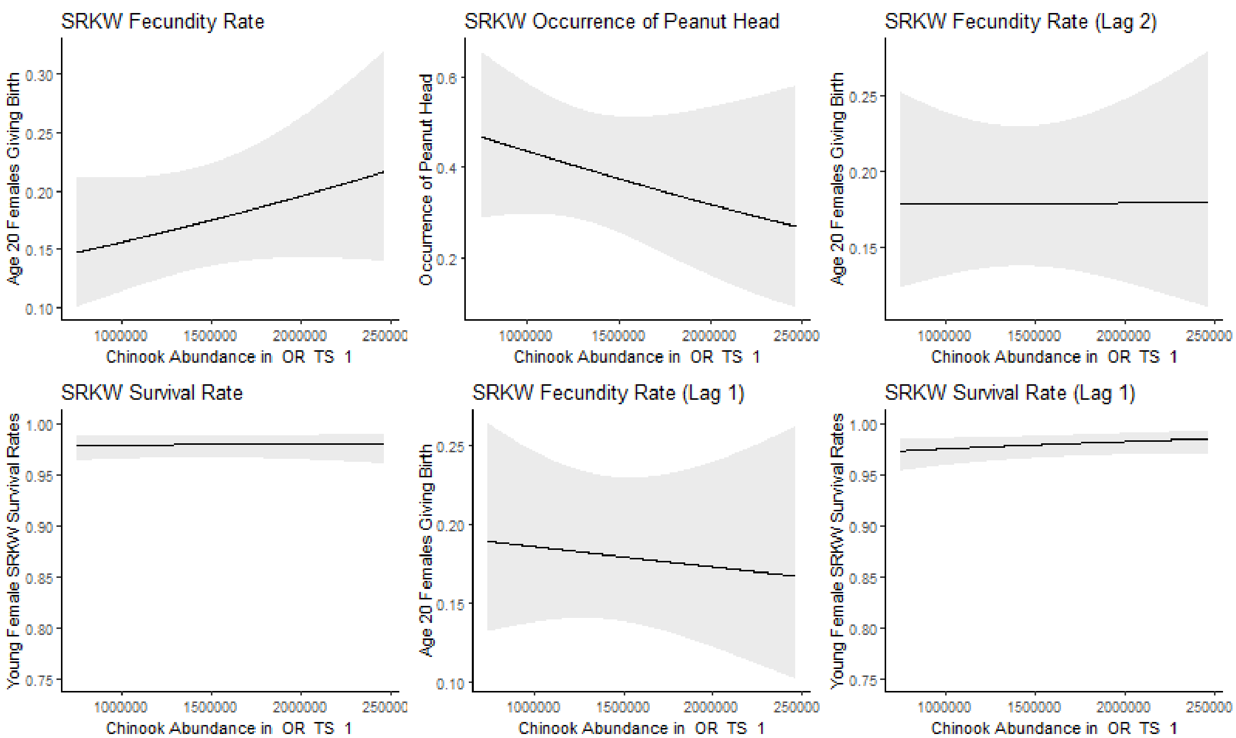
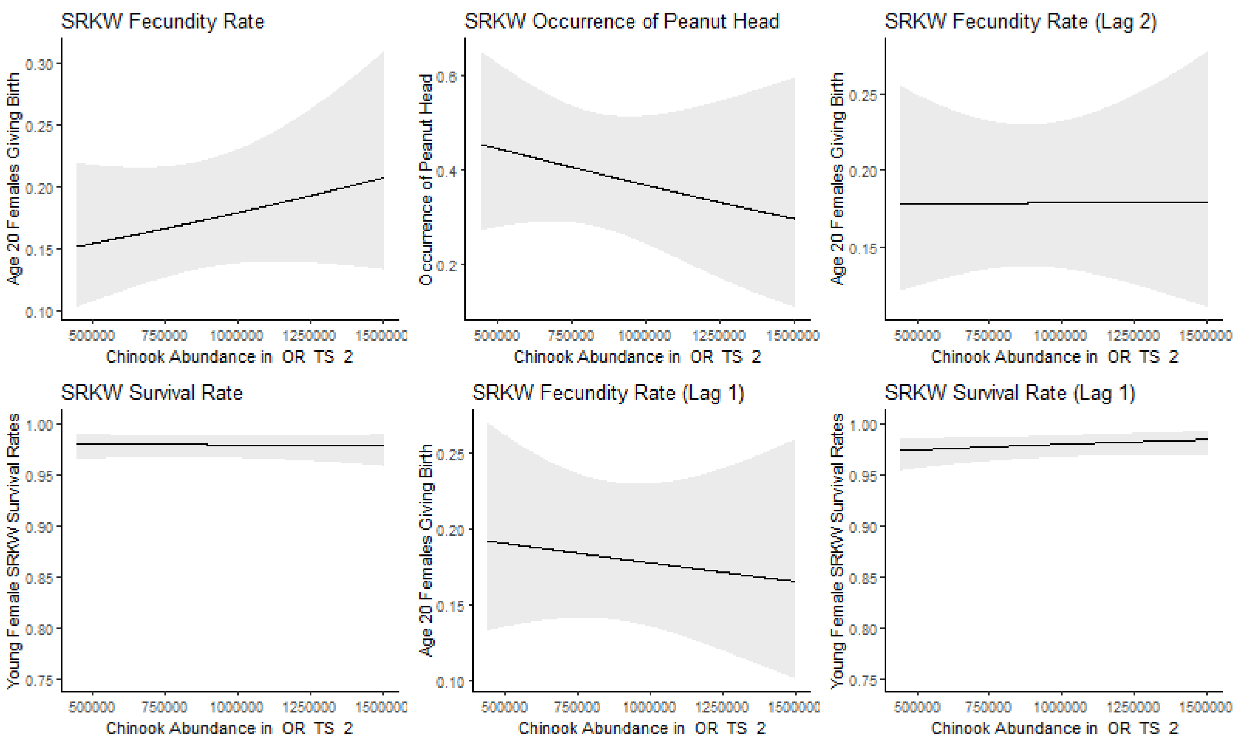
Appendix C Figure 15. South West / West Coast of Vancouver Island aggregate Timestep 3



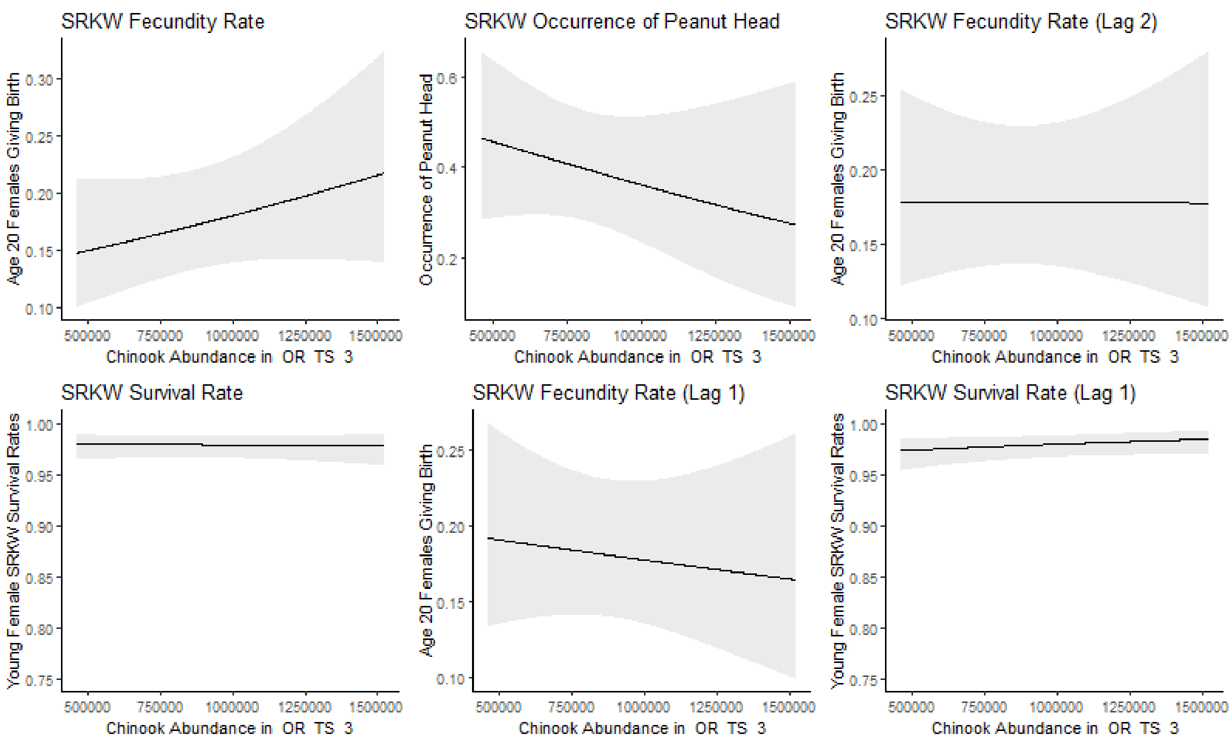
Appendix C Figure 16. Oregon Coast Timestep 1



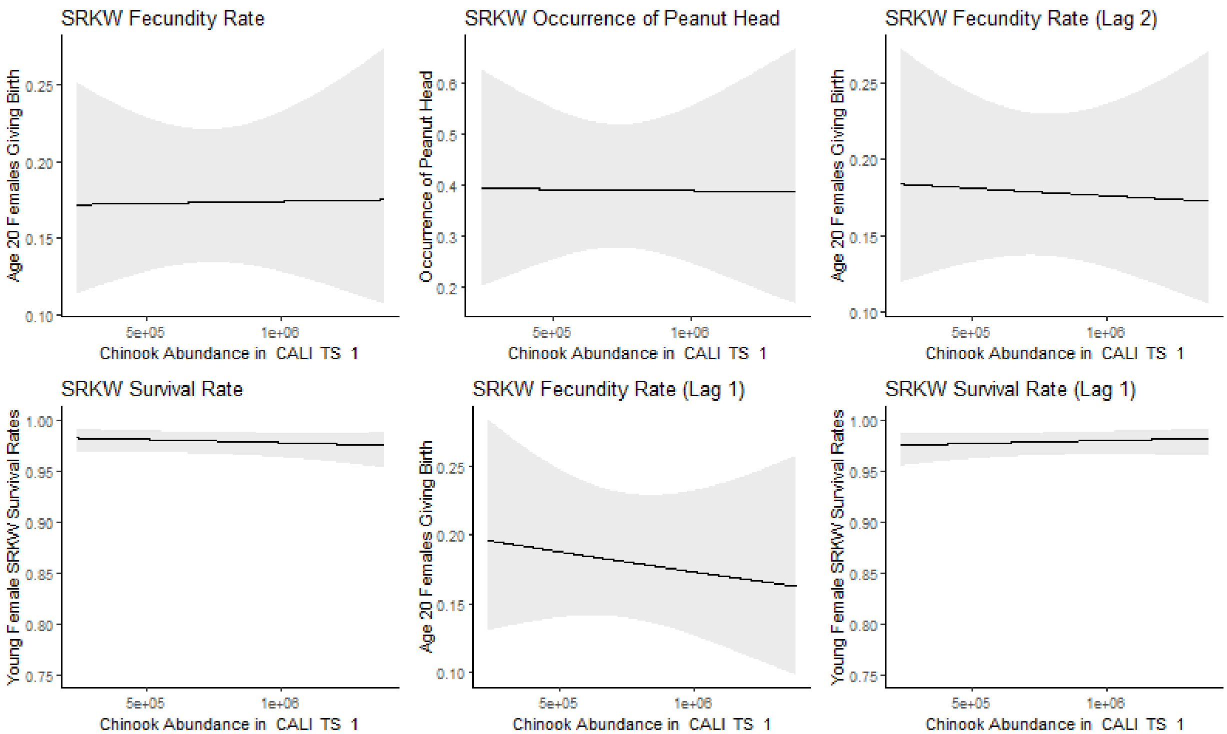
Appendix C Figure 17. Oregon Coast Timestep 2



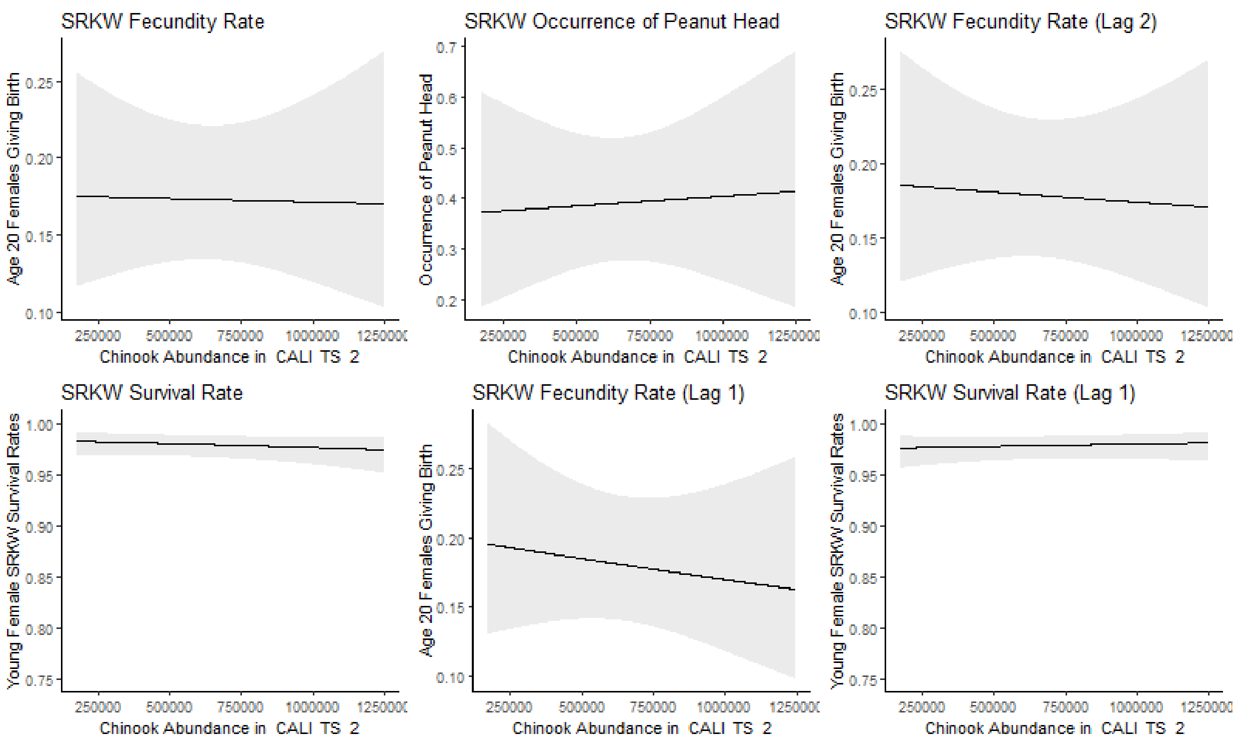
Appendix C Figure 18. Oregon Coast Timestep 3



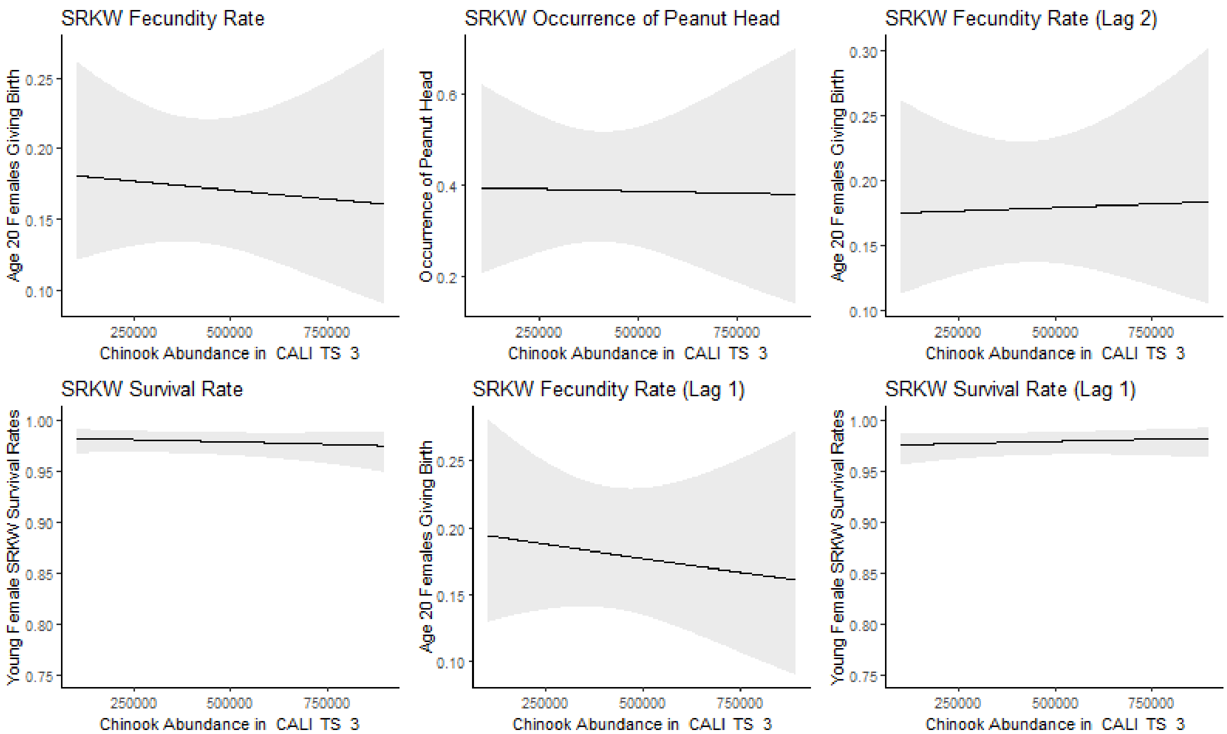
Appendix C Figure 19. California Coast Timestep 1



Appendix C Figure 20. California Coast Timestep 2



Appendix C Figure 21. California Coast Timestep 3



Appendix D

Clustering Analysis

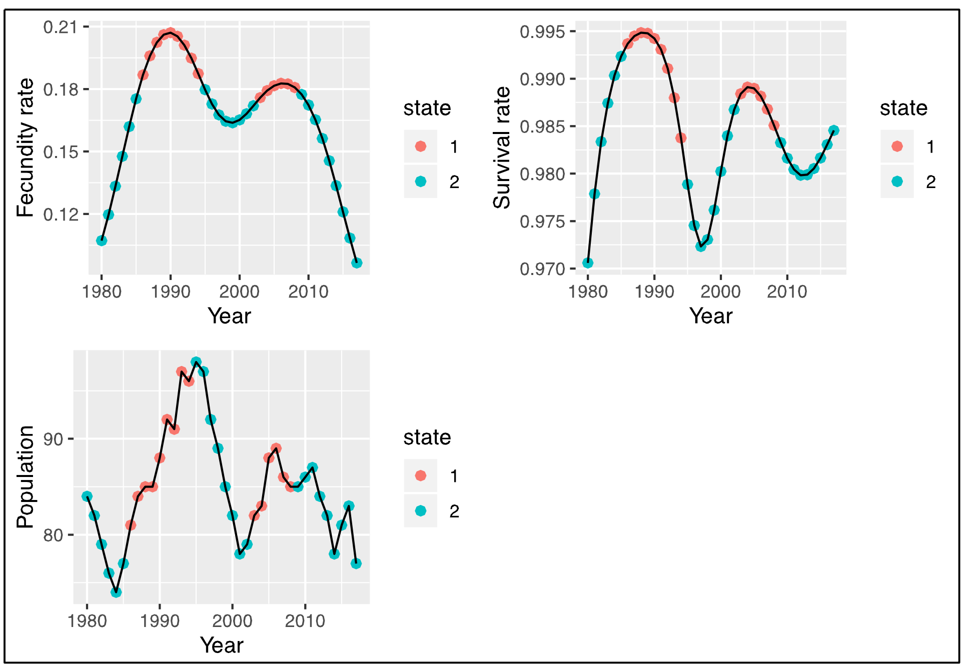
SRKW population trends were also considered as an assessment metric for clustering analyses attempting to identify years of high versus low risk to SRKW, represented as a binomial variable with 1 corresponding to population increases and 0 corresponding to no population increases (including decreases or no growth). Periods of population increase and decrease/no growth were estimated by fitting a GAM (total SRKW population ~ year), with inflection points in the GAM representing changes in the direction of the population trend. Unlike fecundity, survival, or the occurrence of peanut head, relationships between Chinook salmon abundance and SRKW population trends were not examined in isolation because population increase/decrease is a simple function of births and deaths, which can be modeled separately while also accounting for the effects of age/sex structure and deaths that are clearly not food-related.

In the workgroup's first attempt at cluster analysis (July 2019), we used partitioning around medoids (PAM) to explore possible associations between Chinook salmon abundance and the SRKW population metrics (fecundity, survival, occurrence of whales with peanut head condition, indicators of SRKW population trends). This analysis grouped together years based on annual summary modeled (estimated) values for selected demographic variables (details on statistical smoothing available at https://www.fisheries.noaa.gov/webdam/download/94054344), optimizing the degree of association between the values of variables examined. For example, one group of years may be associated with high values for fecundity, survival, and SRKW population trends, but low values for the occurrence of peanut head syndrome. Thus, these years may be assigned to a cluster of years that represent above average demographic rates or population performance. Local Chinook salmon abundance can also be considered in defining clusters, or related to assigned clusters post-hoc. For the cluster analysis, we considered between two and four groups of years to examine associations. These clustering analyses are documented in the link referenced above, but the workgroup could not fully interpret the analyses with more than two groups, and had concerns about how the clustering algorithm treated variables with very different ranges (*e.g.*, annual survival indices varied from 0.969 to 0.997 while coastwide Chinook abundance varied by millions of fish), scales (*e.g*., the maximum fecundity rate was 0.231), and distributional forms (e.g. some metrics, like demographic rates were continuous variables, while indicators of population growth were binary).

As a second approach, we refined the cluster analysis in October 2019, with several important changes. First, the working group voted to not include the occurrence of peanut head syndrome as an indicator. While the occurrence of peanut head syndrome has the potential to include new information not accounted for by other metrics, concerns were that it has the potential to be redundant with survival estimates and the quality of the data before 1994 is unknown. As a second update, the group limited the analysis to only including two clusters, rather than two to four. Third, the group switched the modeling approach away from the partitioning around medoids algorithm to an approach that better allowed for mixed data types. Specifically, we fit a two state mixture model with varying data types (fecundity and survival modeled with Gaussian distributions, population growth as a binomial response). We used the expectation – maximization (EM) algorithm to find the maximum likelihood solution. Given the known issues of these approaches getting trapped in false maxima, we initialized estimation from 100 independent starting values. We used the R package depmixS4 (Visser and Speekenbrink 2010) to perform all estimation. After clusters were assigned, we examined the distribution of Chinook abundances by cluster to examine the utility in using clusters to also identify better and worse periods of salmon abundance (repeating this analysis by season and area).

Results from clustering analysis applied to SRKW demographic indices and specifying 2 clusters identified several periods of relatively higher and lower risk for SRKW (because 2 clusters were specified *a priori*, the model only identified these two states). Because of the known label-switching problem with clustering approaches, we examined the relationship between the cluster centers for each variable and corresponding state. For these results, we are assigning state 2 to represent periods of higher risk because it is associated with lower survival, lower birth rates, and not increasing population size (Appendix D Figure.1). Periods of low risk (state 1) that the model identified were 1986-1994, and 2003-2008. It should be noted that the cluster assignments may not appear to capture trends and variability perfectly (*e.g.* the pulse of births in 2014-2015 does not appear to be captured by the trend in fecundity rates, and are assigned to state 2). These discrepancies are caused by the inputs to the clustering algorithm being time series of predicted values estimated from a generalized additive model (GAM). If other approaches were used instead (*e.g.* year effects treated as fixed or random effects), we would expect different cluster assignments.

Another source of discrepancy is that the cluster assignment represents the state that on average explains trends in population size and variability in demographic rates. There may be periods where one or more of these indicators is not in agreement with the other two. Because cluster analyses may be sensitive to the choice of initial values, we repeated the clustering algorithm from 100 starting values, and used AIC to select the most parsimonious clustering across replicates (many of these resulted in identical cluster assignments, however several iterations appeared to converge on solutions with lower likelihoods). Finally, we examined the utility of linking the assigned states (lower, higher risk) to periods of below or above average Chinook salmon abundance. We examined the average estimated abundance (aggregated across stocks) by time period and area and found little relationship; in other words the 'lower risk' periods 1986-1994 and 2003-2008 corresponded to years with both below and above average Chinook abundance.



Appendix D Figure.1. Clustering analysis for a two *a priori* state evaluation to determine if periods of relatively higher and lower risk for SRKW demographics were present between 1980 and 2016.

Appendix D References

Visser, I. and M. Speekenbrink. 2010. depmixS4: An R Package for Hidden Markov Models. Journal of Statistical Software, 36(7), 1-21. URL: http://www.jstatsoft.org/v36/i07/.

APPENDIX E

Fishery Reductions

The following tables capture starting abundances during time step one, meaning starting abundances in the October-April time step for "zero PFMC" fishing runs. They also capture the subsequent annual fishery abundance reduction, which represents the difference between end of year abundances absent fishing and end of year abundances with PFMC fisheries that occurred during 1992-2016 (e.g., total mortalities resulting from fisheries across the entire management year). These numbers are reported here in the stratifications used in the methodology describe in Section 5.1, with the resulting percent reductions calculated from the annual estimated reduction attributable to fishing mortality.

Appendix E Table 1. Coastwide (EEZ).

Year	Starting abundance in Oct-April Timestep	PFMC Fishery Abundance Reduction	Percent Reduction
1992	2,193,832	406,988	18.6%
1993	2,862,854	605,134	21.1%
1994	2,317,797	531,229	22.9%
1995	4,071,145	1,224,997	30.1%
1996	3,325,766	763,829	23.0%
1997	3,351,693	880,562	26.3%
1998	2,507,320	479,717	19.1%
1999	2,673,606	435,959	16.3%
2000	3,459,941	679,535	19.6%
2001	4,838,052	586,087	12.1%
2002	5,985,560	902,991	15.1%
2003	5,781,691	1,021,112	17.7%
2004	5,173,880	1,329,810	25.7%
2005	3,898,795	725,804	18.6%
2006	2,819,693	448,376	15.9%
2007	2,131,210	258,956	12.2%
2008	2,259,704	66,384	2.9%
2009	2,267,670	20,597	0.9%
2010	3,926,476	121,041	3.1%
2011	3,269,850	155,502	4.8%
2012	4,422,392	452,627	10.2%
2013	6,040,198	651,732	10.8%
2014	4,714,616	573,296	12.2%
2015	4,939,468	329,203	6.7%
2016	2,823,910	170,725	6.0%
Time series average	3,682,285	552,888	14.9%
Recent 10 year average	3,679,549	280,006	7.0%

Appendix E Table 2. North of Falcon

Year	Starting abundance in Oct-April Timestep	PFMC Fishery Abundance Reduction	Percent Reduction
1992	1,041,932	58,593	5.6%
1993	1,087,009	56,291	5.2%
1994	819,183	31,238	3.8%
1995	1,030,293	79,088	7.7%
1996	1,043,645	56,444	5.4%
1997	1,152,375	61,715	5.4%
1998	866,538	42,367	4.9%
1999	1,051,720	39,196	3.7%
2000	1,041,262	48,705	4.7%
2001	1,929,921	88,837	4.6%
2002	2,144,581	136,080	6.3%
2003	1,968,874	144,602	7.3%
2004	1,986,923	150,729	7.6%
2005	1,488,104	109,068	7.3%
2006	1,294,450	45,159	3.5%
2007	950,804	29,733	3.1%
2008	1,255,132	18,864	1.5%
2009	1,062,698	12,883	1.2%
2010	1,941,645	56,881	2.9%
2011	1,523,499	41,613	2.7%
2012	1,556,212	68,699	4.4%
2013	2,446,093	92,111	3.8%
2014	1,981,173	124,077	6.3%
2015	2,295,939	97,678	4.3%
2016	1,441,061	36,723	2.5%
Time series average	1,456,043	69,095	4.6%
Recent 10 year average	1,645,426	57,926	3.3%

Appendix E Table 3. Salish Sea

Year	Starting abundance in Oct-April Timestep	PFMC Fishery Abundance Reduction	Percent Reduction
1992	617,641	13,794	2.2%
1993	598,158	12,430	2.1%
1994	433,095	2,244	0.5%
1995	499,241	5,017	1.0%
1996	511,553	5,178	1.0%
1997	686,152	8,618	1.3%
1998	502,160	7,772	1.5%
1999	638,259	11,244	1.8%
2000	434,752	5,828	1.3%
2001	707,099	13,622	1.9%
2002	690,088	18,532	2.7%
2003	677,273	21,020	3.1%
2004	666,545	20,318	3.0%
2005	600,655	17,746	3.0%
2006	676,921	11,119	1.6%
2007	546,430	8,903	1.6%
2008	599,624	6,613	1.1%
2009	441,122	4,070	0.9%
2010	823,676	14,782	1.8%
2011	607,633	10,711	1.8%
2012	522,026	15,742	3.0%
2013	741,030	15,992	2.2%
2014	634,819	19,234	3.0%
2015	639,674	15,190	2.4%
2016	568,889	7,966	1.4%
Time series average	602,581	11,747	1.9%
Recent 10 year average	612,492	11,920	1.9%

Appendix E Table 4. Southwest West Coast Vancouver Island

Year	Starting abundance in Oct-April Timestep	PFMC Fishery Abundance Reduction	Percent Reduction
1992	541,157	13,348	2.5%
1993	529,682	12,821	2.4%
1994	418,484	5,879	1.4%
1995	493,154	14,257	2.9%
1996	519,938	10,872	2.1%
1997	521,769	12,433	2.4%
1998	430,246	9,547	2.2%
1999	516,628	9,494	1.8%
2000	418,416	9,503	2.3%
2001	777,325	17,713	2.3%
2002	919,884	26,659	2.9%
2003	889,789	30,697	3.4%
2004	924,845	30,919	3.3%
2005	733,401	23,063	3.1%
2006	651,164	11,010	1.7%
2007	484,972	8,008	1.7%
2008	613,707	4,777	0.8%
2009	513,370	3,277	0.6%
2010	888,483	12,183	1.4%
2011	732,093	9,647	1.3%
2012	729,967	16,692	2.3%
2013	1,283,502	19,145	1.5%
2014	957,234	24,146	2.5%
2015	1,135,093	19,799	1.7%
2016	727,196	8,644	1.2%
Time series average	694,060	14,581	2.1%
Recent 10 year average	806,562	12,632	1.5%

Appendix E Table 5. Oregon coast (Cape Falcon, OR south Horse Mountain, CA).

Year	Starting abundance in Oct-April Timestep	PFMC Fishery Abundance Reduction	Percent Reduction
1992	773,048	132,840	17.2%
1993	1,134,747	216,252	19.1%
1994	908,210	170,198	18.7%
1995	1,787,381	394,183	22.1%
1996	1,406,397	285,070	20.3%
1997	1,252,483	277,549	22.2%
1998	985,760	150,944	15.3%
1999	925,410	137,735	14.9%
2000	1,443,107	236,358	16.4%
2001	1,858,529	209,794	11.3%
2002	2,417,603	310,577	12.8%
2003	2,492,455	424,715	17.0%
2004	2,037,921	536,591	26.3%
2005	1,489,504	251,155	16.9%
2006	959,973	161,603	16.8%
2007	794,726	104,051	13.1%
2008	760,853	36,659	4.8%
2009	929,713	6,483	0.7%
2010	1,525,621	43,731	2.9%
2011	1,284,170	61,378	4.8%
2012	1,946,515	181,196	9.3%
2013	2,440,226	257,405	10.5%
2014	1,909,754	218,642	11.4%
2015	2,039,608	128,168	6.3%
2016	1,018,116	61,310	6.0%
Time series average	1,460,873	199,783	13.5%
Recent 10 year average	1,464,930	109,902	7.0%

Appendix E Table 6. California coast, south of Horse Mountain

Year	Starting abundance in Oct-April Timestep	PFMC Fishery Abundance Reduction	Percent Reduction
1992	378,852	215,555	56.9%
1993	641,098	332,591	51.9%
1994	590,405	329,793	55.9%
1995	1,253,472	751,725	60.0%
1996	875,724	422,315	48.2%
1997	946,835	541,299	57.2%
1998	655,023	286,407	43.7%
1999	696,476	259,027	37.2%
2000	975,571	394,472	40.4%
2001	1,049,602	287,456	27.4%
2002	1,423,376	456,335	32.1%
2003	1,320,362	451,795	34.2%
2004	1,149,036	642,489	55.9%
2005	921,187	365,582	39.7%
2006	565,271	241,614	42.7%
2007	385,680	125,172	32.5%
2008	243,719	10,861	4.5%
2009	275,259	1,231	0.4%
2010	459,210	20,430	4.4%
2011	462,181	52,511	11.4%
2012	919,665	202,732	22.0%
2013	1,153,879	302,216	26.2%
2014	823,689	230,577	28.0%
2015	603,920	103,357	17.1%
2016	364,733	72,693	19.9%
Time series average	765,369	284,009	34.0%
Recent 10 year average	569,194	112,178	16.6%

Appendix F

Modeled SRKW Demographic Changes in the Presence and Absence of Fisheries

The table below represents mean estimates of change in survival (lag 0, lag 1), fecundity (lag 0, lag 1, lag 2), and occurrence of peanut head across the series of years available in the analysis if PFMC salmon directed fisheries did not occur, as predicted using the regressions in Appendix C and the fishery removals in Appendix E. Time steps 1, 2, and 3 represent "October through April", "May through June", and "July through September", respectively. Annual changes used in the mean represent predicted SRKW metrics from the post-season runs subtracted from the "zero PFMC" run. Survival is expressed as an annual change in survival rate (positive values indicate increase in the absence of fishing) for young females. Fecundity is expressed as an annual change fecundity rate (positive values indicate increase in the absence of fishing) for age 20 females. Occurrence of peanut head represents the change in the annual number of predicted peanut heads (negative values indicate decrease in the absence of fishing). Note that because each demographic metric represents an annual change predicted in demography under a scenario where all PFMC salmon fisheries are closed in a calendar year. Therefore, it is inappropriate to add effects across time steps or across areas. E.g., if considering NOF time step 2 abundance versus fecundity (lag 0) to be the most informative regression, the absence of fisheries (year round) produces an estimated 0.2% annual increase to fecundity in age 20 females. Because NOF time step 3 also considers annual fecundity and fishery closures year round, the estimated fecundity increase would also be 0.2% (rather than 0.5%; 0.1% from time step 1 + 0.2% from time step 2 + 0.2% from time step 3).

Area	TimeStep	Survival	Fecundity	Peanut Head	Fecundity L 1	Survival L 1	Fecundity L 2
CALI	1	0.0%	0.0%	0.00	-0.1%	0.0%	0.0%
CALI	2	-0.1%	0.0%	-0.01	-0.6%	0.2%	0.2%
CALI	3	-0.5%	-0.5%	-0.07	-1.8%	0.4%	2.2%
COASTWI	1	0.0%	0.2%	-0.01	0.0%	0.0%	0.1%
COASTWI	2	0.0%	0.6%	-0.03	-0.3%	0.2%	0.4%
COASTWI	3	0.0%	1.2%	-0.06	-0.7%	0.3%	1.2%
NOF	1	0.0%	0.1%	0.00	0.0%	0.0%	0.1%
NOF	2	0.0%	0.2%	-0.01	0.0%	0.1%	0.3%
NOF	3	0.0%	0.2%	-0.02	-0.1%	0.1%	0.4%
OR	1	0.0%	0.2%	-0.01	-0.1%	0.0%	0.0%
OR	2	0.0%	0.6%	-0.02	-0.3%	0.1%	0.1%
OR	3	-0.1%	1.6%	-0.04	-0.8%	0.2%	0.1%
SALISH	1	0.0%	0.0%	0.00	0.0%	0.0%	0.0%
SALISH	2	0.0%	0.0%	-0.01	-0.1%	0.0%	0.1%
SALISH	3	0.0%	0.1%	-0.01	-0.2%	0.0%	0.1%
SOF	1	0.0%	0.2%	0.00	-0.1%	0.0%	0.0%
SOF	2	-0.1%	0.6%	-0.02	-0.5%	0.2%	0.2%
SOF	3	-0.2%	1.8%	-0.06	-1.3%	0.3%	0.6%
SWWCVI	1	0.0%	0.0%	0.00	0.0%	0.0%	0.0%
SWWCVI	2	0.0%	0.1%	-0.01	0.0%	0.0%	0.2%
SWWCVI	3	0.1%	0.2%	-0.01	-0.2%	0.1%	0.4%

APPENDIX G

Pacific Fishery Management Council's

Salmon Technical Team Report

SRKW Priority Prey Stocks

With Model Representation

The following Appendix is reproduced from an STT report presented the table to the Council on March 12, 2019 (Agenda Item D.8.a, Supplemental STT Report 2). As described in the Risk Assessment, the Workgroup decided not to use this list to inform its analysis and established its own methodology to estimate prey availability.

Agenda Item D.8.a
Supplemental STT Report 2
March 2019

SALMON TECHNICAL TEAM REPORT 2
SOUTHERN RESIDENT KILLER WHALES PRIORITY PREY STOCKS
WITH MODEL REPRESENTATION

At the March 2019 Council meeting, The National Marine Fisheries Service (NMFS) announced plans to re-initiate Endangered Species Act consultation on the effects of Council-area fisheries on Southern Resident Killer Whales (SRKW). The Council then directed the Salmon Technical Team (STT) to examine a draft list of SRKW priority Chinook salmon prey stock and identify the stocks that are represented in models used annually in the ocean salmon fishery planning process. In response the STT created a table identifying models that include priority prey stocks, as well as the stocks with no model representation. This table (Table 1) is appended to this statement.

PFMC
03/12/19

Appendix G Table 1. NMFS' draft list of priority prey Chinook stocks for SRKW aligned with PFMC Chinook stocks with model representation (Page 1 of 2).			
Priority Chinook Stock Group	**Model**	**Model Stocks**	**Comment**
Northern Puget Sound Fall	FRAM	Nooksack/Samish Fall	
		Skagit Summer/Fall Fingerling	
		Skagit Summer/Fall Yearling	
		Snohomish Fall Fingerling	
		Snohomish Fall Yearling	
		Stillaguamish Fall Fingerling	
		Tulalip Fall Fingerling	
		Strait of Juan de Fuca Tributaries	Includes production from the Dungeness and Elwha systems
Southern Puget Sound Fall	FRAM	Mid PS Fall Fingerling	Includes production from Lake Washington, Green/Duwamish, Puyallup, Grovers, and Gorst systems
		South Puget Sound Fall Fingerling	Includes production from Nisqually, Minter, Chambers, and Deschutes systems
		South Puget Sound Fall Yearling	Includes yearling Hatchery production from Icy Creek Hatchery
		Hood Canal Fall Fingerling	Includes production from Skokomish, Hoodsport, and other miscellaneous Hood Canal systems
		Hood Canal Fall Yearling	Includes yearling hatchery production from Hoodsport Hatchery
Lower Columbia Fall	FRAM	Columbia River Oregon Hatchery Tule	Lower River Hatchery stocks originating from Oregon
		Columbia River Washington Hatchery Tule	Lower River Hatchery stocks originating from Washington
		Lower Columbia River Wild	
		Columbia River Bonneville Pool Hatchery	
		Lower Columbia Natural Tule	
Strait of Georgia Fall	FRAM	Fraser River Late	Includes fall Chinook production from lower Fraser River tributaries
		Lower Georgia Strait	Includes fall Chinook production from Lower Georgia Strait tributaries
Upper Columbia/Snake Fall & Middle Columbia Fall	FRAM	Columbia R Upriver Bright	Includes Mid-Columbia Brights & Lower River Brights
		Snake River Fall	
Fraser Spring & Fraser Summer	FRAM	Fraser River Early	Includes Spring 1.3, Spring 1.2, Summer 0.3, and Summer1.3
Lower Columbia Spring	FRAM	Cowlitz River Spring	Includes spring Chinook production from Cowlitz, Kalama, and Lewis systems
Snake River Spring- Summer	No Model Representation	NA	
Northern Puget Sound Spring	FRAM	North Fork Nooksack Spring	
		South Fork Nooksack Spring	
		Skagit Spring	
Washington Coast Spring	No Model Representation	NA	

Appendix G Table 1. NMFS' draft list of priority prey Chinook stocks for SRKW aligned with PFMC Chinook stocks with model representation (Page 2 of 2).			
Priority Chinook Stock Group	**Model**	**Model Stocks**	**Comment**
Washington Coast Fall	FRAM	Washington North Coast Fall	Includes fall Chinook production from the Quillayute, Hoh, Queets, Quinault, and Grays Harbor systems
		Willapa Bay	
Central Valley Spring	No Model Representation	NA	
Middle & Upper Columbia Spring	No Model Representation	NA	
Middle & Upper Columbia Summer	FRAM	Columbia River Upriver Summer	
Central Valley Fall and Late Fall	SHM	Sacramento Fall	
Klamath River Fall	KOHM	Klamath River Fall	
Klamath River Spring	No Model Representation	NA	
Upper Willamette Spring	FRAM	Willamette River Spring	
Southern Puget Sound Spring	FRAM	White River Spring Fing	
		White River Spring Year	
Central Valley Winter	WRHM	Central Valley Winter	
North & Central Oregon Coast Fall	FRAM	North Oregon Coast Fall	Includes Oregon coastal fall Chinook production from the Necanicum in the north to the Siuslaw in the south
		Mid Oregon Coast Fall	Includes Oregon coastal fall Chinook production from the Umpqua in the North to the Elk in the south
West Coast Vancouver Island Fall	FRAM	West Coast Vancouver Island Fall	
Southern Oregon & Northern California Coastal Fall	No Model Representation	NA	
Southern Oregon & Northern California Coastal Spring	No Model Representation	NA	
California Coastal Fall	No Model Representation	NA	
California Coastal Spring	No Model Representation	NA	
Southeastern Alaska Spring	No Model Representation	NA	

Northern BC Spring	No Model Representation	NA	
Central BC mostly Summer	No Model Representation	NA	
			Preliminary_March 12,2019_Salmon Technical Team