NPAFC
Doc. 2112
Rev.

Relevance of the Catches of Steelhead in the Study of the Ocean Ecology of Pacific Salmon in the Gulf of Alaska in the Winter of 2022

by

Richard Beamish[1], Chrys Neville[2], and Brian Riddell[3]

[1]Emeritus Scientist, Pacific Biological Station, Fisheries and Oceans Canada
3190 Hammond Bay Road, Nanaimo, BC, V9T 6N7 Canada

[2]Pacific Biological Station, Fisheries and Oceans Canada
3190 Hammond Bay Road, Nanaimo, BC, V9T 6N7 Canada

[3]Pacific Salmon Foundation
1682 W 7th Avenue, Vancouver, BC, V6J 4S6 Canada

Submitted to the

NORTH PACIFIC ANADROMOUS FISH COMMISSION

by

Canada

April 2023

THIS PAPER MAY BE CITED IN THE FOLLOWING MANNER:
Beamish, R., C. Neville, and B. Riddell. 2023. Relevance of the catches of steelhead in the study of the ocean ecology of Pacific salmon in the Gulf of Alaska in the winter of 2022. NPAFC Doc. 2112. 25 pp. Fisheries and Oceans Canada and Pacific Salmon Foundation. (Available at https://npafc.org).

Abstract

There were 57 steelhead caught in a study of the winter ecology of Pacific salmon in the Gulf of Alaska from February 25 to March 25, 2022. The study used experimental gillnets and baited longlines to capture Pacific salmon with steelhead only captured in gillnets. Steelhead catches were the largest of all Pacific salmon catches with most steelhead caught in the top 4 m of the gillnet that was set at the surface and all steelhead were caught in the top 6 m. These catches and a review of published studies indicated that steelhead spend virtually all of their life in the open ocean in the surface few meters. There were 34 ocean age 1 and 21 ocean age 2 steelhead with 9 of these fish mature. DNA identification of these mature steelhead indicated they were returning to the Columbia River, Puget Sound, West Coast of Vancouver Island and the Nass River area. These fish would arrive in rivers after the calendar winter and would be expected to spawn quickly. There were 45 other fish identified to their spawning location using DNA, but the spawning location assignments of all steelhead are tentative because of the limited baseline data base. There were no ocean age 2 fish that had a second annulus and 16 of 33 ocean age 1 fish had an annulus. The circuli on the scales of ocean age 1 fish that formed after the annulus ranged from 2 to 7 indicating that annuli on the scales of all steelhead form over a protracted period. Steelhead were caught at some stations where surface temperatures exceeded the upper thermal limit published for steelhead in the winter. The inherited requirement to live at the ocean surface and the continued ocean warming that includes recent marine heat events, identify the urgent need to better understand the ocean ecology of steelhead, particularly in the winter.

Keywords: steelhead, ocean winter habitat, scale annulus

Introduction

There were 57 steelhead (*Oncorhynchus mykiss*) caught in the study of the ocean ecology of Pacific salmon in the Gulf of Alaska in the winter of 2022 (Neville et al. 2023). This appears to be the largest catch of steelhead in the winter in any scientific study in the last 50 years (Myers 2018). There is a poor understanding of the life history of steelhead in the ocean after they quickly leave the coastal areas (Burgner et al. 1992, Myers 2018; Courtney et al. 2022). Thus, this catch of 57 steelhead provides a unique opportunity to study their biology in the open ocean and particularly in the winter at a time of unprecedented ocean warming events (Cheung and Frölicher 2020; Barkhordarian et al. 2022).

Steelhead are the anadromous life history type of the freshwater resident rainbow trout. Steelhead are not abundant relative to the major species of Pacific salmon (*Oncorhynchus* spp.), but they are highly esteemed as a recreational species resulting in being widely studied (Myers 2018). They also have mostly declined throughout their distribution with an understanding that the decline appears to be mainly a result of declining ocean survival (Friedland et al. 2014; Ward 2000; Welch et al. 2000). Kendall et al. (2017) reported that populations from British Columbia to Oregon declined over 80% in abundance since 1980. More northerly populations in British Columbia and Alaska appear to be surviving better (Augerot 2005; Catterson et al. 2020), although the distribution of steelhead in Alaska is limited to Southeast and Southcentral Alaska.

Steelhead smolts enter the ocean at a larger size than other Pacific salmon (Love et al. 2012; Myers 2018) and quickly leave the coastal areas (Burgner et al. 1992; Quinn and Myers 2004). Thus, their residence time in the coastal ocean is considerably shorter than other Pacific salmon (Beamish, 2018). Most spend one to three years in the ocean before returning to spawn in natal rivers (Burgner et al. 1992; Busby et al. 1996; Myers 2018). Ocean age 2 is the modal age at maturity (Myers 2018). A few of the spawning fish will also return to the ocean and thus spawn more than once, although the rate of iteroparity varies among populations (Burgner et al. 1992; Myers 2018). The repeat spawning steelhead, called kelts, have been reported to spawn up to five times with females being the most repeat spawners and with some skipping a year after spawning once (Busby et al. 1996; Keefer et al. 2008; Myers 2018). In this report, we summarize the information collected from the catch of 57 steelhead in the winter survey in the Gulf of Alaska in March of 2022 and consider the relevance of the catches in relation to steelhead ocean survival in a future of ocean surface warming.

Methods

The survey from February 25 to March 25, 2022, on the Canadian charter trawler *Raw Spirit* (Neville et al. 2023) fished gillnets and longlines. Gillnets were 2.4 km long research gillnets imported from Japan. The nets consisted of panels 50 m in length and 8 m in depth (Figure 1). There were nine panels of commercial gillnet (115 mm) at each end. Between these commercial panels were three panels each of 10 different mesh sizes (Figure 1). The headrope of the gillnet was re-enforced with 9-11 mm spectra rope (Neville et al. 2023).

Longlines were 1.5 km long with 350-500 baited hooks (size 4, 5, 6) on 1 m leads spaced with quick snaps along the length of the longline. The bait included salted anchovy, salted herring and squid (Neville et al. 2023).

The targeted soak times for gillnets was overnight from predusk (prior to civil twilight, sun > 6º above horizon) to post-dawn (after civil dawn, sun > 6º above horizon). When both dusk and dawn could not be fished due to travel periods, the gear was targeted to fish over one of the twilight periods. The targeted soak time for the longlines was 1-4 hours and was either over dawn or dusk, based on results in the 1960s (Turner and Aro 1968). Recorded soak time for both gear types was the time between the completion of setting the gear and the initiation of hauling the gear. Both gear types were tracked during the set using satellite trackers (Neville et al. 2023).

The mesh size of gillnet or hook size that caught a fish was recorded. Additionally, the relative location of the fish in the gillnet was documented by depth (four quadrants, 2m each) and in relation to other fish in the net. Sensors that recorded depth were attached to the headrope and footrope of the net and to the longline. Additional detail on gear and fishing protocols are available in Neville et al. (2023).

Fork and total length (mm), round weight (g), sex, and observations of wounds and parasites were recorded for each Pacific salmon. Fish were also examined for adipose fin clips and scanned for coded-wire tags or pit tags. The stomach and gonads were removed and individually frozen. The stomach was removed from just posterior to the gill arch to the start of the small intestine. In our usage "stomach" also includes this small piece of anterior intestine. Stomachs were classified as empty when the volume of stomach contents was less than 0.1 cc. Stomach analysis was conducted by an expert with over 25 years of experience. Items were identified to the lowest taxonomic level possible.

Scale samples for steelhead were selected from fish that were brought back to the laboratory. Scales were selected from the general area ventral to the posterior insertion of the dorsal fin and above the lateral line. Scales were selected individually to try to use only scales that had no resorption of freshwater circuli. About 6 to 8 scales were selected and despite the care taken to choose scales, usually only a few could be used for age determination. Scales were mounted dry between two microscope slides. Three experienced scale readers aged the scales. One reader was experienced with ageing steelhead scales.

There were scales from 57 fish that were examined for freshwater and ocean ages. Scales from each fish were also examined to determine if an annulus had formed. An annulus was defined as the last closely spaced circulus before the first widely spaced circulus as reported by Ricker (1962, 1964) and Bilton and Ludwig (1966). Other definitions on an annulus have considered that the band of closely spaced circuli is the annulus (Copeland et al. 2018; Love, 2016; Friedland et al. 2014; Davis and Light 1985). We used the definition of Ricker (1962, 1964) and Bilton and Ludwig (1966) as it identifies a more specific period of formation. It is difficult to find a definition of a circulus, but it has been identified as a complete or mostly complete ring of growth with relatively even spacing between each ring (Love 2016). The circulus is the ridge on the scale that appears dark because it is thicker and calcified. The well-recognized transitions between widely spaced and narrowly spaced circuli can correspond with a change in the structure of the ridge, with the ridge being thicker and more robust in periods of wider circuli development. Thus, the annulus can be identified as the last narrow spaced circulus before an abrupt change to wider spacing and a change in the thickness of circuli. We used a January 1 birthday to assign fish to ocean age groups. Within these groups, we identified if an annulus was present.

We did not measure circuli spacing or circuli ridge thickness but quantifying the spacing would confirm the abrupt transition in growth. Recognizing the change is abrupt and persistent, indicates that factors other than prey densities appear to be involved.

DNA was analyzed by the Molecular Genetics Laboratory at the Pacific Biological Station in Nanaimo, British Columbia, using microsatellite analysis (Beacham et al. 2005). There is no coast wide DNA baseline for steelhead. For this report, we are using the Canadian baseline that includes 59 stocks from the Nass River in northern British Columbia to the Columbia River in the United States.

A Seabird conductivity-temperature-depth recorder (CTD) was deployed to record the vertical temperature profile at each station. Standard procedures for deployment were followed including initial deployment of 1-3m to stabilize instrument prior to a cast from surface to 350m. We report temperatures recorded at 1m (0.95-1.04m) and at the surface (< 0.3m). The temperature at these depth strata were not recorded at some stations due to sea conditions.

Results and Discussion

Catches of Pacific salmon

There were16 stations in the study area (Figure 2, Table 1) with multiple sets made at some stations. Steelhead were caught in the gillnets but not with the longlines that fished at the surface in the same areas. Steelhead were encountered in 12 of the 13 stations that had gillnets set with catches ranging from one to 14 per set. The 57 steelhead caught in the gillnets were the most widely distributed Pacific in the survey (Table 1). There also were more steelhead caught than either coho, sockeye, chum or pink salmon (Table 1). Each of these species is more abundant than steelhead (Beamish, 2018) providing additional evidence that steelhead occupy an ocean habitat that generally differs from these other Pacific salmon. Two sets where 21% and 25% of all steelhead were caught were both on the eastern extent (135^0W) of the study area. Steelhead were captured in all mesh sizes except for the smallest (48 mm) and the largest (157 mm, Table 2). In 80% of the sets with two or more steelhead, the fish were caught in multiple mesh sizes over the length of the gillnet, indicating they were spread over an extended area. In five sets, two steelhead were caught within 3 m of each other. Ten (18%) of the steelhead had adipose fins removed but no coded-wire tags or pit tags were present. The relationship between the length of the steelhead and the capture mesh size was weak as some of the larger steelhead were captured in the smallest mesh sizes (Neville et al. 2022). Six of the steelhead were not measured due to predation or damage in the net. The average length and weight (± SD) of the remaining 51 steelhead was 50 ± 10.4 cm and 1382 ± 977 g.

Longlines that used similar bait were fished at the surface in the winter in the Gulf of Alaska in the 1960s (FRBC 1964, 1966, 1967). In 1963, 1964 and 1965 there were 4, 34 and 2 steelhead caught, respectively. We have no explanation why in 2022 we did not catch steelhead with the longlines.

There were four other ships that fished trawls at the ocean surface in the winter of 2022 as part of the International Year of The Salmon (https://yearofthesalmon.org/2022expedition/). No steelhead were caught in the trawls fished by these four ships (King et al. 2022; Murphy et al. 2022; Somov et al. 2022; Weitkamp et al. 2022, 2023). It is possible that some of the fishing effort was north of the distributions reported for the winter for steelhead (Burgner et al. 1992; Welch et al. 1998), but two of the ships (King et al. 2022; Weitkamp et al. 2022) were fishing within recognized winter distributions. It is probable that the trawls were not effectively fishing the top few meters of the ocean and thus not catching steelhead. An absence of steelhead in all trawl catches, is evidence that steelhead ocean habitat is in the surface few meters.

Age, size and annulus formation

Fish in our study were captured close to the end of winter. Thus, circuli spacing on the scale margin was closely spaced relative to the wider spacing that occurred in the preceding "summer growth" or more rapid growth period. Identifying the annulus required identifying the first widely spaced circulus at the edge of a scale which was difficult because the wider spacing of only one circulus may not be continuous around the edge. The second and subsequent wider spaced circuli were clearer and once the second wider spaced circuli appeared, the first widely spaced circuli was evident. The timing of the annulus formation is important as this defines the amount of time available for rapid growth before a maturing fish is genetically programmed to begin the migration to the natal river. Future studies of steelhead and other Pacific salmon in the winter could include specific studies of annulus formation in relation to population specific growth and spawning migration timing.

We examined scales from all 57 steelhead and 55 were used for age determination. Ages were estimated separately by one expert familiar with ageing steelhead scales and then by two experts working together. There was agreement in 48 of the 55 estimates and a final determination resolved the 7 that were not in agreement. None of the 21 ocean age 2 fish (as determined using a January 1 birthday) had a second annulus. This included 9 mature fish. There were 16 of the 34 ocean age 1 fish (8 female, 6 male and 2 not determined) that had an annulus (Figure 3). The number of widely spaced circuli after the annulus ranged from 2 to 7 and averaged 4.1 (Figure 4). These results are preliminary, as more detailed studies of annulus development are needed for steelhead that are sampled in the ocean shortly before and after the calendar winter. However, our preliminary results identify the annulus formation occurring over a wide period while still being initiated as an abrupt change in growth and scale formation. The biological consequences of such an apparent wide range in the beginning of the rapid growth period (plus growth) remains to be determined. The abruptness of the change in growth and the diversity in timing identifies the complexity in understanding the factors affecting the winter ecology of steelhead in the period around the ocean winter.

Ocean age 1 steelhead averaged 419 $\pm$ 28.9 mm and ocean age 2 steelhead averaged 624 $\pm$ 34.9 mm (Figure 5). Ocean age 1 males (417 mm) were similar to size of ocean age 1 females (424mm). The average length of ocean age 2 males (613 mm) was similar to age 2 females (630 mm). There were very few measurements reported for steelhead in their first ocean winter in Burgner et al. (1992). The average sizes we report for ocean age 1 and 2 steelhead are slightly smaller than their reported monthly averages (Figure 6).

If we assume that the size of ocean age 1 Pacific salmon about March 21 is a measure of the size at ocean age 1, we can compare sizes of ocean age 1 steelhead with sizes of other Pacific salmon at the end of the calendar winter. In all cases, steelhead were larger than chum, coho, pink salmon caught in this survey (Table 3). We did not catch ocean age 1 sockeye salmon in the gillnets or on the longlines in 2022, but if we use catches of ocean age 1 sockeye salmon caught in our previous two winter surveys (Pakhomov et al. 2019; Somov et al. 2020), ocean age 1 steelhead were also larger than the average size of these sockeye salmon (Table 3). Steelhead are larger than other Pacific salmon when they enter the ocean as fry or smolts (Myers 2018), but the difference in size at the end of the first calendar winter indicates that steelhead grow more in the first ocean year than other Pacific salmon as has been reported in other studies (Catterson et al. 2020; Atcheson et al. 2012a).

We assigned freshwater ages to 51 steelhead. Interpreting freshwater ages was difficult and our assignments are not validated. However, they are the interpretations by one person experienced in the estimating ages of steelhead and two with experience ageing scales of other Pacific salmon. Ages were determined by the one expert that aged steelhead scales and then separately by two different experts together. There was agreement in 43 of the 51 determinations. The ages of the 8 that differed were reassessed. The final interpretations need to be considered to be approximate as there was no validation of the interpretations. The 10 we identified from scale growth as originating from hatcheries was consistent with their determination from adipose clips. There were 21 freshwater age 3, 20 freshwater age 2 and 10 freshwater age 1. All freshwater age 1 were hatchery fish (Figure 7). There were mature fish in each of the freshwater age groups.

<u>Vertical distribution</u>

Most steelhead (n = 48) were caught in the top 4 m. Only three were caught below 4 m and there were no catches below 6 m. There were six steelhead that could not be assigned to a capture depth because of the rolling up of the gillnet. There is evidence that steelhead spend virtually all of their ocean life in the top few meters of the ocean. Two post spawn steelhead kelts that were tagged with an archival tag and recovered back in fresh water after 16 months in the ocean, spent 97% of their 16 months at depths less than 6 m and mostly at 3 to 4 m (Nielsen et al. 2011). A more recent study that applied pop-up satellite archival tags on steelhead kelts returning to the ocean tracked vertical movements for 30 fish over a combined period of 2034 days (Courtney et al. 2022). There were tags on 15 of these tagged steelhead that survived from July up to January. The combined number of days from June to January showed that steelhead were in the top 5 m over 90% of the time. There also have been a number of diet studies that concluded steelhead feed at or near the ocean surface (Taylor and LeBrasseur, 1957; Pearcy et al. 1988; Brodeur 1989; Burgner et al. 1992; Atcheson et al. 2012a). There is evidence of occasional deeper dives (Walker et al. 2000a, 2000b) but it is clear that steelhead have an inherited behavior to remain at the surface of the ocean. While other Pacific salmon species may occur at the ocean surface, it appears that steelhead are uniquely confined to the top few meters.

Thermal limits

Steelhead are reported to have relatively narrow thermal limits (Welch et al. 1998; Courtney et al. 2022) which Abdul-Aziz et al. (2011) reported as a sea surface temperature of 6 -12.5^0 C as a general reference level and 5 – 11^0 C in the winter. These temperatures were recorded at the ocean surface in a number of studies such as reported in Welch et al. (1998). These are not upper lethal temperatures, but temperatures that define the known boundaries of steelhead in the open ocean. Thermal limits have been used to project changes in distribution as oceans warm from the impacts of increasing heat content (Welch et al. 1998; Abdul-Aziz et al. 2011). Surface temperatures in Table 1 ranged from 5.9^{0}C to 13.2 ^{0}C with an average of 9.7 ^{0}C. There were three stations where steelhead were caught that had surface temperatures that exceeded the range for winter thermal limits of 5 – 11 ^{0}C published by Abdul-Aziz et al. (2011). The 1 m temperatures ranged from 6.1 ^{0}C to 10.7^{0}C (Table 1). However, it is the surface temperatures that relate to the published thermal limits. The high temperatures found in this study would be a concern as steelhead will be threatened in a future of ocean warming events that have recently occurred (Bond et al. 2015; Di Lorenzon and Mantua 2016; Cornwall 2019; Suryan et al. 2021). The combination of inherited behavior to live at the ocean surface and the current trends in ocean warming events indicate an urgency to better understand the ocean ecology of steelhead, particularly in the winter.

Population identification

The limited genetic baseline for steelhead (59 populations with no populations north of the Nass River, British Columbia) limited certainty in the individual assignments. Because of this uncertainty, we report all probabilities over 50%. There were no coded-wire tags in the hatchery fish which could be used to assess the accuracy of the DNA determinations. We grouped the population identifications into six major areas because of the limited number of populations in the data base. When grouped into six major areas (Figure 8), there were 54 steelhead that were identified to a location with a probability of over 50%. There were 18 from the Nass River area, 16 from the West coast of Vancouver Island, 12 from Puget Sound, 4 from the Skeena River, 3 from the Columbia and 1 from the Fraser River (Figure 8). If probabilities over 80% were considered more reliable, there were 1(100%) fish from the Fraser River, 11(92%) fish from Puget Sound, 15 (83%) fish from the Nass River, 2 (67%) fish from the Columbia River, 9 (56%) fish from the west coast of Vancouver Island and 2(50%) fish from the Skeena River. In the two largest catches (sets 17 and 26), for probabilities over 80% there were steelhead from West coast of Vancouver Island (4), Puget Sound (3), Nass River (2) and the Fraser River (1) in set 17 and from Nass River (4), West Coast of Vancouver Island (3), Puget Sound (2) and the Skeena River (1). It is clear that there were a diversity of populations in the survey area in the winter. We found no evidence of schooling as reported for coho and chum salmon (Beamish et al. 2023). This may be the first DNA-based population study of steelhead distributions in the winter. One important conclusion from the population identification study is that there needs to be a coordinated international effort to produce a more comprehensive baseline for DNA analysis.

Mature steelhead

There were seven female and two male steelhead that had mature gonads (Table 4, Figure 9). There was no evidence from the scales that these nine fish and spawned previously. The DNA analysis indicated that these fish would be returning to rivers in the general location of the Columbia River, Puget Sound, West Coast of Vancouver Island and the Nass River (Table 4). As previously reported, these locations were determined using a limited genetic baseline. Two mature fish identified as originating from rivers on the west coast of Vancouver Island had an adipose clip, but no coded-wire or PIT tag. It is possible that these fish originated from the Robertson Creek hatchery. The most direct distance to the approximate entrance to natal river areas from the capture sites would be approximately 1100 km for Puget Sound, 650 km for the West Coast of Vancouver Island,700 km for the Nass River and 1000 km for the Columbia River. These fish would be winter run life history types that mostly matured in the ocean. Two mature fish from the Nass River and three mature fish from Puget Sound were caught at stations 11 and 14 respectively. The sample size is small but could indicate that site specific populations were returning in small groups to natal river locations. These mature fish were also feeding. Five of the steelhead had contents in their stomachs with prey volume ranging from 0.5cc to 1.7 cc (Table 6). Davis and Light (1985) reported that winter-run steelhead can arrive in fresh water as late as April and spawn immediately. Myers (2018) reported spawning as late as July with spawning in some rivers in Alaska commonly occurring from mid-April to early June. It appears that the mature fish in our catches would spawn very soon after returning to their natal rivers

Winter feeding

There were 49 steelhead stomachs examined and 20 (41%) were empty. This compares to a percent of empty stomachs for coho salmon (60%), chum salmon (57%), sockeye salmon (78%) and pink salmon (80%) (Neville et al. 2023). Sample sizes were small, but it appears that steelhead feed more actively in the winter than these other Pacific salmon. The average volume of the contents for steelhead was 3.2 cc. Squid were the major item in the stomachs with 47% of the volume identified as squid and an additional 1% as cephalopods. This is consistent with other studies that showed squid to be the dominant prey during periods of rapid growth (Burgner et al. 1992; Atchenson et al. 2012a, 2012b). Our observations provide additional evidence that squid are the dominant prey throughout the year. The carapace lengths that could be measured reliably indicated the squid were 42 to 60 mm. The species of squid identified included *Boreoteuthis borealis, Okutnia anonych, Gonatus onyx and Chiroteuthis calyx* (Neville et al. 2023). Fish remains were the second most common diet item, accounting for 30% of all contents. The dominance of fish is also consistent with previous diet studies (Burgner et al. 1992, Atcheson et al. 2012a, 2012b). Myctophids (Family Myctophidae) were 13% of the fish remains. The myctophid *Tarletonbeania crenularis* (Figure 10) was caught in surface trawls fished at dusk-night (Pakhomov et al. 2019; Somov et al. 2020) and was the dominant myctophid in the steelhead diet. The remaining 17% of the fish remains were not identified to species. Euphausiids (Family Euphausiidae) including both *Euphausia pacifica* and *Thysanoessa spinifera* were 10% of the diet. The remaining 12% of diet included eggs (4%), amphipods (2%), isopods (1%), shrimp (1%) and digested material (4%).

Steelhead are virtually confined to the surface waters for their entire ocean residence as reported in this study. Thus, the diet items would be prey that were in the surface few meters. Myctophids and squid are not in the surface waters during the day (Beamish et al. 1999, Esenkulova et al. 2022), thus the consumption of these species would not be during the day. Myctophids and squid are very abundant and would be dependable prey. It is speculation, but the preference for fish and squid in the winter and particularly for prey that migrates into the surface waters at dusk may indicate that there is relatively little competition for prey between steelhead and the dominant abundance of chum and pink salmon.

Conclusion

The use of gillnets to catch steelhead allowed scales to be collected that could be used to determine age and identify how steelhead grow including when an annulus is formed on the scales. The timing of the formation of the annulus is important as it also established the timing of the beginning of a period of rapid growth. It is this period of rapid growth that defines the time available for a fish to increase substantially in size before it is cued to begin to return to a natal river. The annulus as defined by the first widely spaced circulus after the last closely spaced circulus was not observed on scales of ocean age 2 fish and on scales of less than 50% of the ocean age 1 fish. When an annulus was identified on ocean age 1 fish, there was a wide range in the date that the change to more rapid growth would have occurred. This indicated that the abrupt change in growth that is commonly considered to be fast or “plus growth” occurs over a protracted period. These observations indicate that the ocean growth of steelhead needs to be studied in more detail by sampling in the ocean throughout the late fall to early spring.

Steelhead were the dominant fish species in the catches probably because gillnets effectively fished the surface of the ocean and possibly because other species of Pacific salmon were not abundant in the survey area fished. This study and other studies identified in this report show that steelhead are confined to the surface few meters of the ocean. This inherited behaviour will result in a major impact on steelhead ocean behaviour and possibly survival if the ocean warming events that occurred in the past decade increase in intensity and frequency. Even in this study, we caught steelhead at temperatures that exceeded published thermal limits. If warming events continue, one stewardship challenge could be to identify populations with the best resilience for surviving in the warming ocean surface waters. This requires a better understanding of when, where and how ocean mortality occurs.

Our results are a look at the winter ecology of steelhead in the Gulf of Alaska at a time in which the ecosystem differs from the studies in past decades as evidenced by the recent ocean warming events. These results identify the importance of continuing the winter surveys of steelhead.

Acknowledgements

This was the third privately funded and organized study of the winter ecology of steelhead and other Pacific salmon in the Gulf of Alaska. We appreciate the financial support of all donors. The science team who volunteered for the expedition included M. Banks, D. Bouillon, S. Esenkulova,

R. LaForge, B. Lewis, G. Martynuik, and A. Schubert with Chrys Neville as Chief scientist. The Captain and crew (Hans-Peter Jesson, Matt Roszmann, Roman Moizis, Eden Thibideau, Wayne Edwards, George Boutilier, Kyle Erickson, Dustin McDonell, Stephane Tourangeau, Chris Shufelt, Marlowe Mathieson) skillfully adapted to the experimental fishing challenges. The Pacific Salmon Foundation managed our budget. Carol Cooper analyzed all salmon stomachs. Barbara Campbell and Mike McCulloch aged steelhead scales. We appreciated the comments of Megan McPhee, Bob Hooton and Mike McCulloch on a previous draft of this document.

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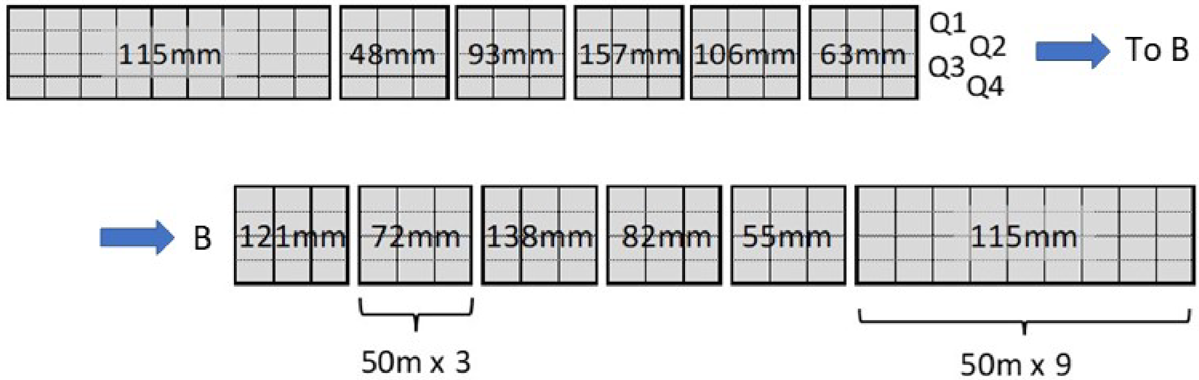

Figure 1. Diagram of the experimental gillnet showing horizontal panels of varying mesh size (mm) and depth quadrants Q1-Q4, each 2m in depth.

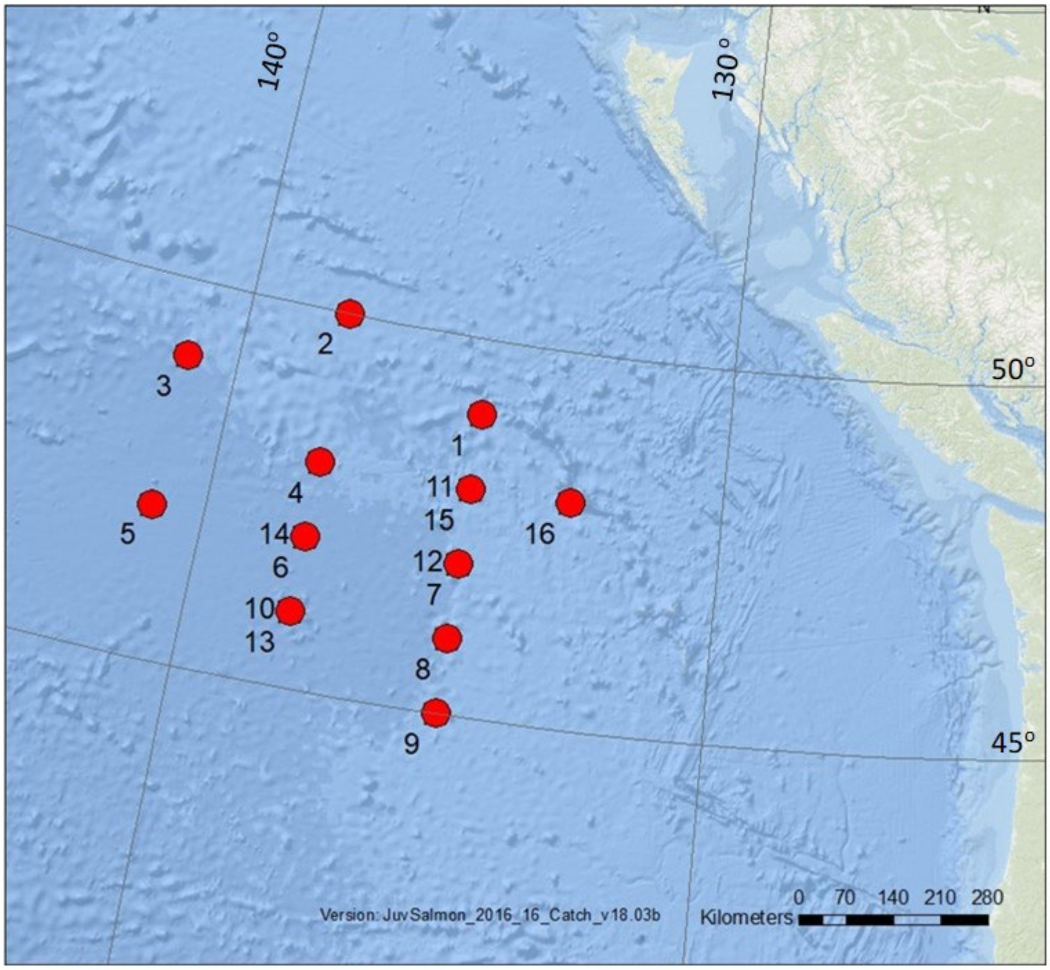

Figure 2. Red circles are station locations. The numbers beside locations indicate station numbers. There were two stations at four locations because of repeat fishing in the second part of the survey.

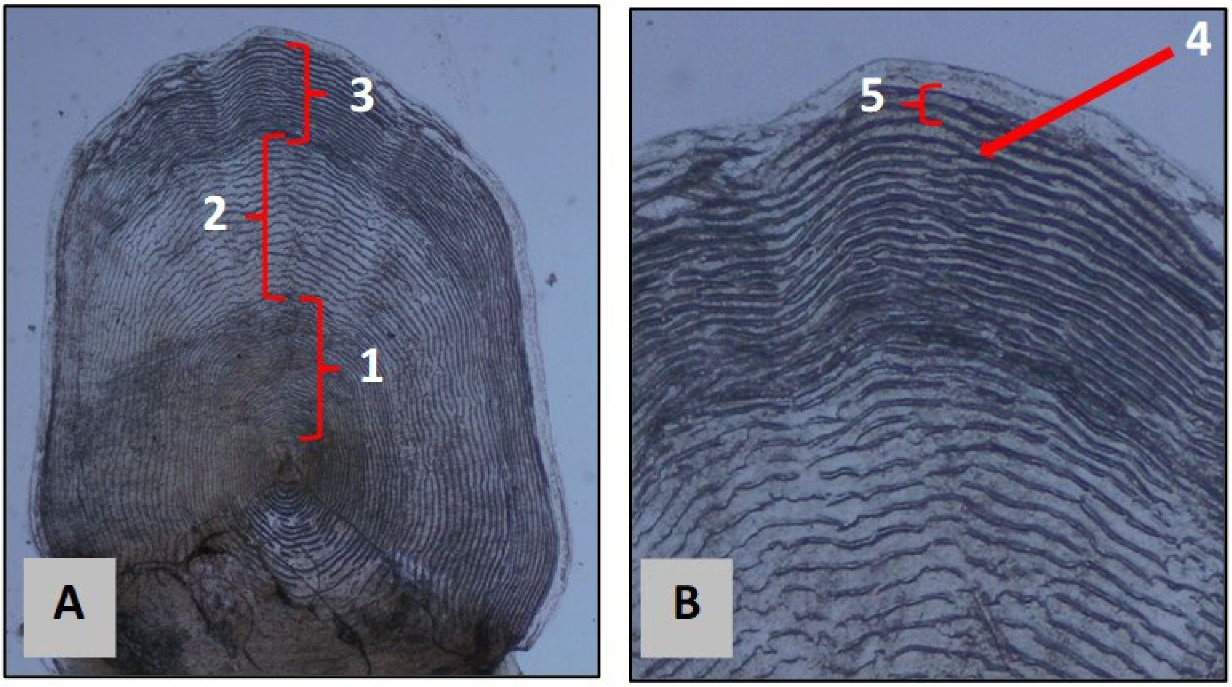

Figure 3 (A). Ocean age 1 steelhead showing (1) growth in fresh water, (2) growth in first ocean summer and fall and (3) first ocean winter growth. (B). Edge of the scale show in A showing the annulus (4) and (5) two widely spaced circuli representing "plus growth" and the beginning of the rapid growth period.

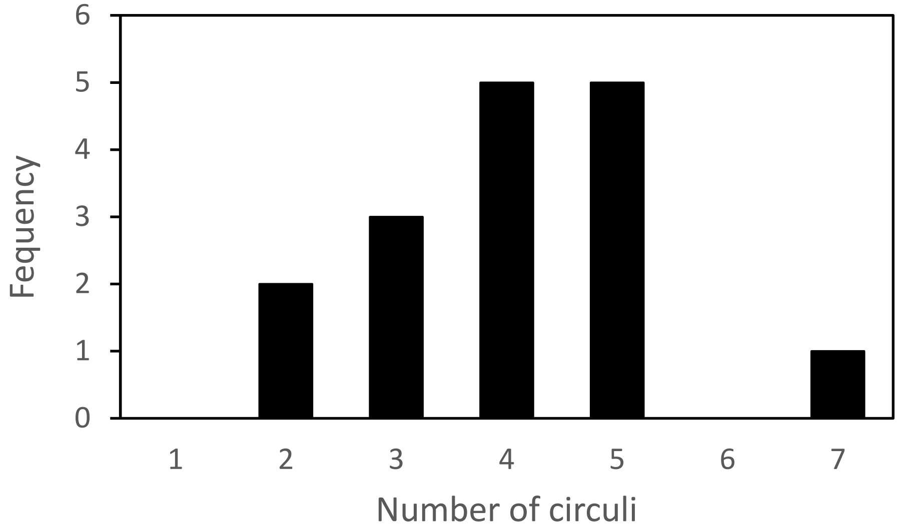

Figure 4. Number of widely spaced circuli (plus growth) on ocean age 1 steelhead that form after the annulus.

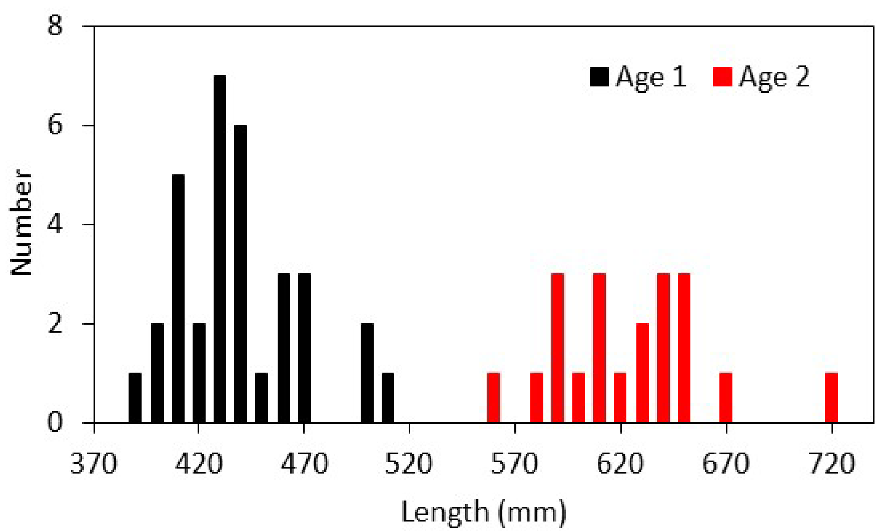

Figure 5. Length frequency of ocean age 1 (n=33) and ocean age 2 (n=20) steelhead. Lengths were not available for all fish that were aged.

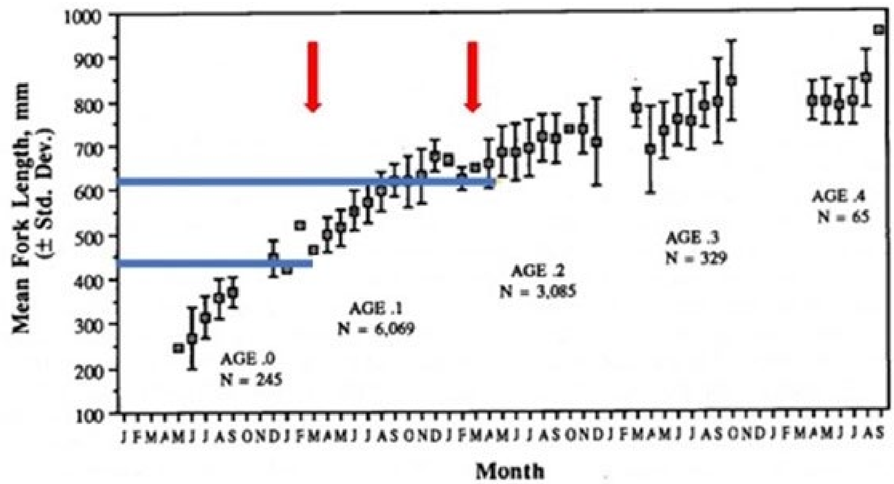

Figure 6. The average length (blue lines) of ocean age 1 (421mm) and ocean age 2 (624mm) steelhead caught in 2022 (see Figure 5) displayed on the steelhead ocean growth curve published by Burgner et al.(1992). The red arrows indicate the month fish were sampled in 2022.

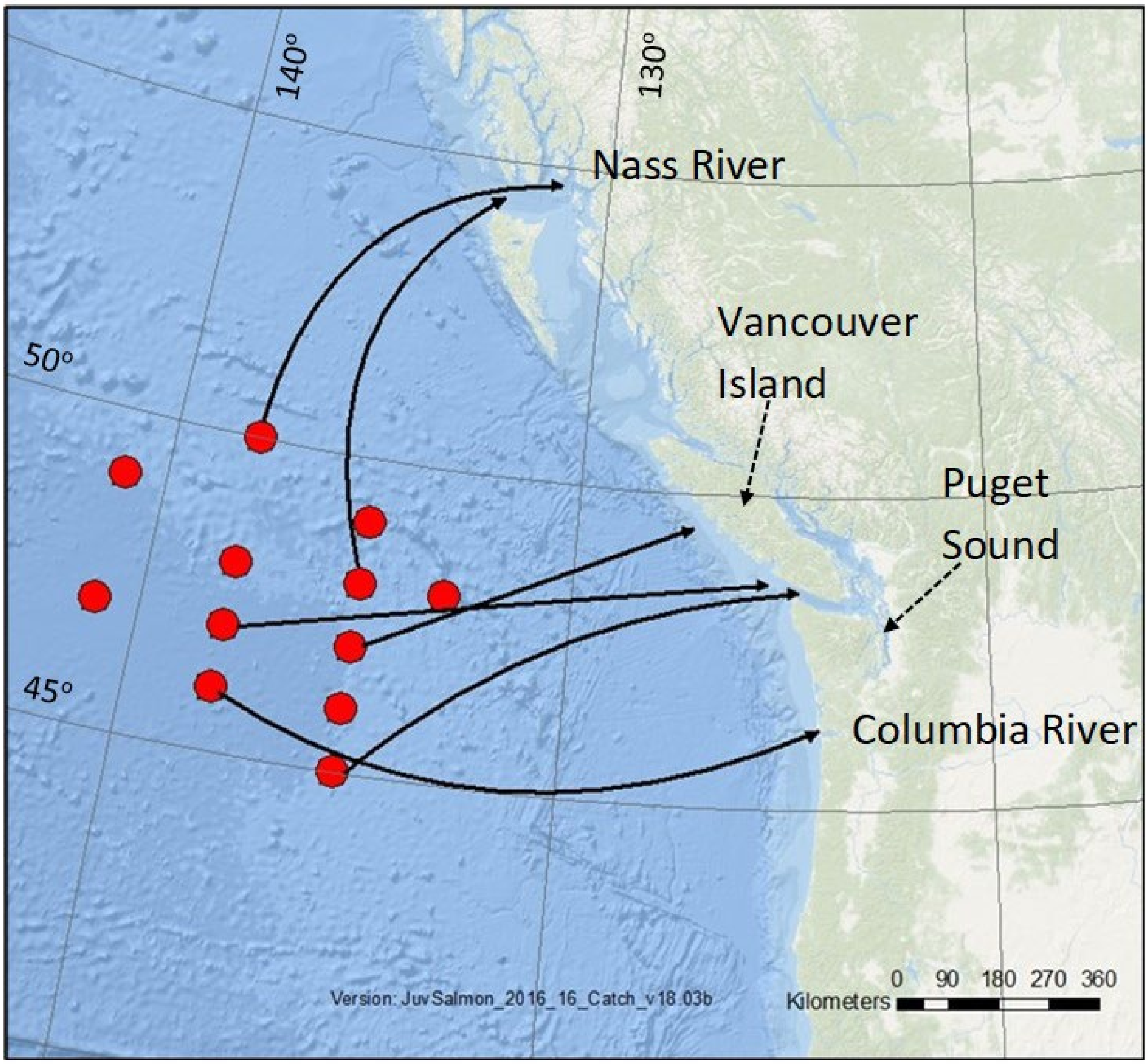

Figure 7. Catch locations of maturing steelhead and the distances to potential spawning regions (Columbia River, Puget Sound, West Coast Vancouver Island, Nass River.) as identified by genetic assignment.

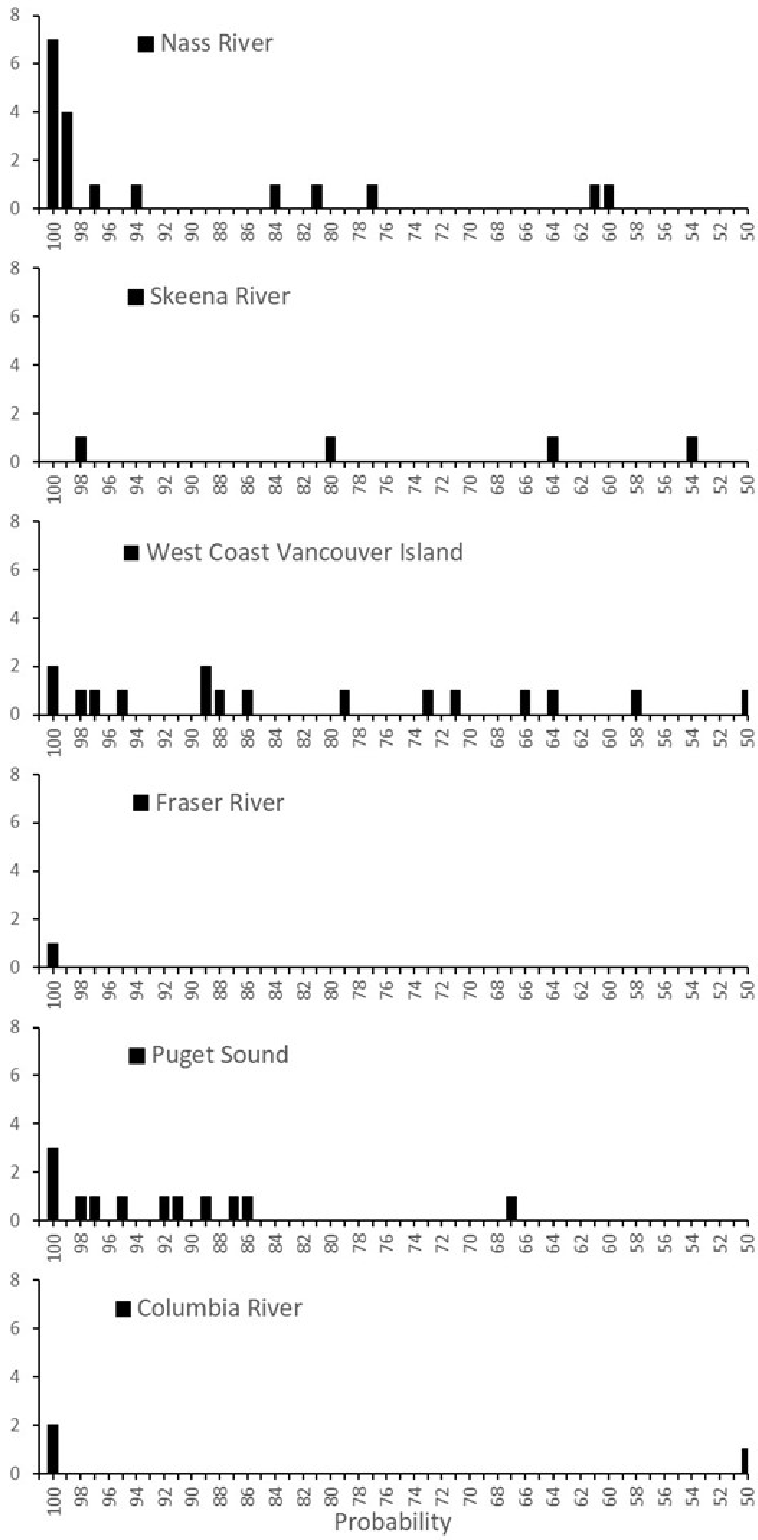

Figure 8. Populations of steelhead identified using DNA showing the frequency of occurance at probabilites from 50-100%.

Figure 9. Example of images of mature male (right) and female (left) gonads in steelhead.

Figure 10. Myctophids, *Tarletonbaenia crenularis*, from the stomach of a steelhead (Steelhead 13, set 15, station 6, March 6, 2022).

Table 1. Station locations, water temperatures at the surface and 1m depth, and salmon catches by set number. Location is latitude (°N) and Longitude (°W) for the station. Date is the date the gear was set. Multiple sets were conducted at some station.Temperature is from CTD deployed during sets at each station.

Station number	Lat/Long	1m (°C)	Surface (°C)	Set number	Set date	Steelhead	Sockeye salmon	Coho salmon	Chum salmon	Pink salmon	Chinook salmon
1	49°N,135°W	7.0	7.3	2	27-Feb			2	7	1	
				3	27-Feb	4					
2	50°N,138°W	6.1	5.9	5	1-Mar	2	29	2	4	1	1
3	49°N,141°W	7.4	7.5	7	2-Mar	1	9	1		1	
4	48°N,138°W	8.6	9.5	9	3-Mar		6	3			
6	47°N,138°W	10.5	10.7	12	4-Mar	2		14			
				15	5-Mar	4		5	1		
7	47°N,135°W	9.1	11.7	16	6-Mar	1		4	2	3	
				17	6-Mar	12	1	1	1	1	
8	46°N,135°W	9.2	-	19	7-Mar			4	2	2	
				20	7-Mar	1		4	1		
9	45°N,135°W	10.7	13.1	22	8-Mar	1					
				23	8-Mar						
10	46°N,138°W	10.2	13.2	25	9-Mar	1		4			
11	48°N,135°W	8.6	9.9	26	11-Mar	14	4	1	1	1	
14	47°N,138°W	-	-	30	20-Mar	3			1		
				31	20-Mar	2		1	8		
15	48°N,135°W	8.4	-	34	22-Mar	5					
16	48°N,133°W	8.3	8.5	36	23-Mar	4	1	1	1		
Total						57	50	47	29	10	1

Table 2. Steelhead catch by mesh size in the gillnet .

			Mesh size (mm)											
Station number	Set number	Catch	115	48	93	157	106	63	121	72	138	82	55	115
1	3	4								1				3
2	5	2	1											1
3	7	1					1							
6	12	2					1					1		
6	15	4			2							2		
7	16	1						1						
7	17	12	2					4	1			3	1	1
8	20	1	1											
9	22	1					1							
10	25	1					1							
11	26	14					1	1		4		5	2	1
14	30	3	1					1						1
14	31	2	2											
15	34	5	1							3		1		
16	36	4						1		1	1	1		
	Total	57												

Table 3. Average length and standard deviation of ocean age 1 Pacific salmon.

Species	N	Average length (cm)	SD
Steelhead	33	41.9	2.9
Chum salmon	18	28.4	2.5
Coho salmon	42	39.3	3.4
Pink salmon	10	30.1	1.7
Sockeye salmon*	41	28.2	3.8

* sockeye from 2019 and 2020 surveys as no ocean age 1 fish caught in 2022

Table 4. Information for mature steelhead. The region of origin was determined from DNA analysis.

Date	Station	Set	Length (mm)	Sex	Diet	Region (% probability)
1-Mar-22	2	5	645	female	Squid	Nass River (100%)
4-Mar-22	6	12	408	female	emtpy stomach	Columbia River (100%)
6-Mar-22	7	17	629	male	emtpy stomach	West Coast Vancouver Island (98%)
8-Mar-22	9	22	612	female	emtpy stomach	Puget Sound (89%)
11-Mar-22	11	26	597	female	Euphausiids	Nass River (100%)
11-Mar-22	11	26	647	female	Euphausiids	Nass River (100%)
20-Mar-22	14	30	715	female	emtpy stomach	Puget Sound (91%)
20-Mar-22	14	31	640	male	Squid	Puget Sound (97%)
20-Mar-22	14	31	665	female	Shrimp	Puget Sount (92%)