NPAFC
Doc. 1923
Rev.

Steelhead Trout and the High Seas; Where to Sample?

by

International Year of the Salmon Working Group
Committee on Scientific Research and Statistics
(CSRS)

Submitted to the

NORTH PACIFIC ANADROMOUS FISH COMMISSION

May 2020

THIS PAPER MAY BE CITED IN THE FOLLOWING MANNER:
International Year of the Salmon Working Group. 2020. Steelhead trout and the high seas; where to sample? NPAFC Doc. 1923. 14 pp. International Year of the Salmon Working Group, Committee on Scientific Research and Statistics (Available at https://npafc.org).

Abstract

Steelhead trout represent less than 1% of all salmonids caught during surveys on the high seas, making them challenging to study in this environment. Young of year steelhead trout of North American origin are mainly but not exclusively, located at the perimeter of the Gulf of Alaska. Rarely have they been caught on the continental shelf except when leaving coastal migratory pathways. Previous research efforts have focused on the freshwater and coastal life stages of steelhead due to the complications of finding, capturing and studying them on the high seas. Most of what is known about steelhead trout on the high seas was described in Burgner et al. (1992). Since then, this body of information has only been occasionally augmented (e.g. McKinnell et al. 1997). The lack of new information is due to reduced sampling on the high seas but may also be due to abrupt changes in high seas fishing gear. More recent surveys have employed surface trawls which are not considered effective at catching steelhead. However, even historical gear types have not caught steelhead of all age classes, even when they were catching sockeye of comparable size. This brings into question the idea that young of year steelhead are quickly moving offshore to the high seas after leaving fresh water. The current view of oceanic behaviour is that steelhead trout swim near the surface which should have put them in the path of these types of nets. Considering that most of the evidence to date is that steelhead trout ocean mortality is highest in coastal waters (Melnychuk et al. 2007, Kendall et al. 2017), it is difficult to imagine a high seas research program directed exclusively at their high seas life history phase, unless new data begin to suggest higher than average mortality among older steelhead. This report outlines the current understandings of the distribution and abundance of steelhead in the high seas.

Key Words: Steelhead trout, high seas, North Pacific Ocean, Pacific salmon

This document was prepared by Dr. Stewart McKinnell of Salmoforsk International Environmental Consulting for the International Year of the Salmon Initiative.

High-seas research conducted by INPFC member nations [Canada, Japan, U.S.A.] initially focussed on the Pacific salmons, and steelhead trout received little attention until the Protocol revision of 1978, which addressed all salmonids in Convention waters (Burgner et al. 1992).

Introduction

A host of reasons for widespread declines in abundance of southern populations of Pacific salmon (*Oncorhynchus* spp.) has emerged during the 21st century (Mantua et al. 1997, Beamish & Mahnken 2001, McKinnell et al. 2001, 2014). Many steelhead trout (*O. mykiss*) populations have experienced long-term declines as well (Kendall et al. 2017). A popular notion is that small fish do not survival as well as larger fish (Beamish et al. 2004). If that alone was the dominant factor, the ocean would be full of steelhead trout and pink salmon would be on endangered species lists. Clearly, that is not the case because steelhead trout are the largest smolts in the ocean and they are the least abundant ones (Myers 2018).
Considering their large size, their survival in the ocean is not so different from other species of *Oncorhynchus*.

In their review of marine survival patterns from Vancouver Island southward, Kendall et al (2017) inferred from their results that the factors determining the survival of steelhead trout are associated more with oceanic processes that are proximate (to their natal river) rather than regional or basin-scale processes. Because of this, they inferred that survival was primarily determined early in their ocean life. Marine mortality rates for Puget Sound steelhead trout based on acoustic tags were high (84.0% and 88.6% for wild and hatchery populations before leaving the Strait of Juan de Fuca). Mortality rates covaried among wild populations suggesting a common cause of mortality (Moore et al. 2015). As this is the widely accepted view of the biology of Pacific salmon, there is no particular incentive to try to challenge the idea at the present time. Of note, however, high mortality in coastal waters leaves remarkably little opportunity for additional mortality to occur during their entire high seas experience.

With the development of a regional genetic stock identification baseline (148 populations) for steelhead trout from the Columbia River and elsewhere in the Pacific Northwest, a study of stock-specific differences found that distributions of populations were related to emigration timing from the river (Van Doornik et al. 2019). Those more likely to leave earlier were located further north in the ocean than those likely to leave the river later. As about 80% of them were released from hatcheries in the Columbia, it is difficult to determine the extent to which release timing influenced these distributions, although hatchery and wild smolt migration timing is not so different

(Weitkamp et al. 2015). Coastal marine sampling also described finding greater abundance at offshore stations than inshore (Van Doornik et al. 2019). Combined with the relatively low catches compared to other species other than chinook salmon (*O. tshawytscha*), this combination of rarity and distribution has fostered the view that steelhead trout move more rapidly offshore than other species of Pacific salmon. The main problem with this view of steelhead trout life history is that the small/young steelhead that are supposed to be offshore are not caught there in a relative abundance that would be expected. *High seas research vessel data for juvenile (ocean age-0) steelhead are insufficient to describe distribution, particularly in late autumn and winter* (Myers 2018).

High seas catch

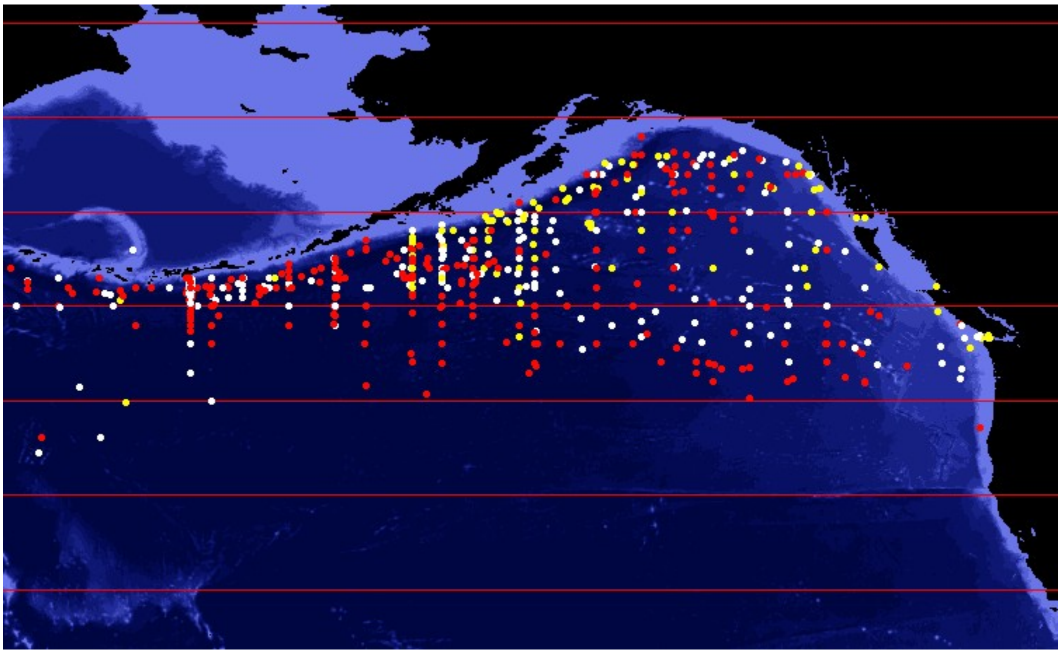

Figure 1: Locations where steelhead trout were caught during high seas surveys with purse seine, longlines, and gillnets by U.S. salmon research vessels. Yellow dots are young of year, orange after the first winter, and white dots after the second winter and older. Age here is based on fork lengths as the modes are relatively well determined. Horizontal lines are spaced at 5° intervals of latitude.

Steelhead trout represent less than 1% of all salmonids caught during surveys on the high seas. Young of year steelhead trout are mainly, but not exclusively, located at the perimeter of the eastern Gulf of Alaska. Rarely were they caught on the continental shelf except when leaving coastal migratory pathways. Most of the catches were caught just beyond the continental shelf (Figure 1). None were caught north of about 58°N. West of Kodiak Is., the latitudinal range of YOY steelhead trout expands southward. West of the Shumagin Islands their abundance falls off, becoming quite rare further west.

Likewise, very few were found south of 50°N where the older age classes were caught. Only small numbers of one sea winter and older steelhead trout were caught west of Adak. The older age classes were widely intermixed from Adak eastward. Overall densities appear to be lowest in the central and eastern Gulf of Alaska. One sea winter fish were dominant along most of the southern fringe of their distribution compared with older fish.

Some aspects of their distribution are related to freshwater origins in addition to age. Using coded- wire tags recovered from steelhead trout caught on the high seas in the 1980s, McKinnell et al. (1997) found that Columbia River steelhead trout were more abundant south of the Aleutian Islands at an earlier age than steelhead trout from the Georgia Basin including Georgia Strait, Puget Sound, and waters connecting with the open Pacific. That may help to explain why there were a few YOY individuals scattered at more southerly latitudes far beyond the continental shelf in the Gulf of Alaska. They also found that if more than one tagged steelhead trout was caught in a fishing operation, they were more likely to have come from the same hatchery than would have been expected by chance; suggesting that at least some individuals may have been travelling together for lengthy periods of time (years) after entering the ocean.

Length frequencies

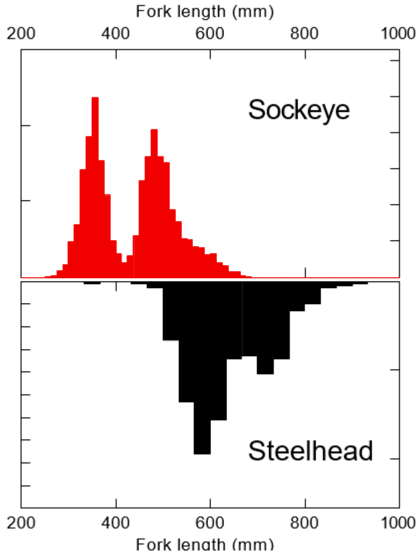

Figure 2: Length frequencies of all sockeye salmon and all steelhead trout caught in multimesh gillnets in July from 1955-1972.

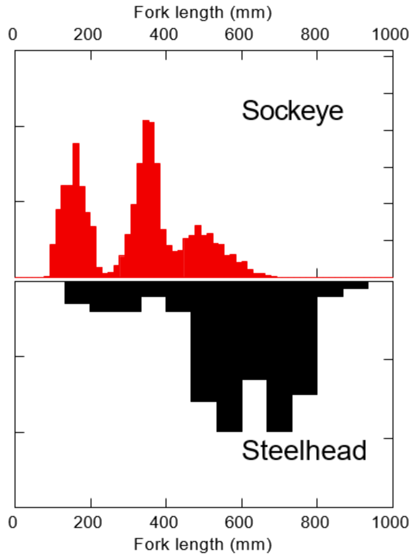

Figure 3: Length frequencies of all sockeye salmon and steelhead trout caught bypurse seine in all months from 1955-1991

Fish length is one of the easiest measurements to make on a fish so these data tend to be found in greater abundance than other biological properties. With sufficient samples sizes, modes pertaining to age are readily apparent because growth in length is initially relatively rapid. Steelhead trout have rarely been the focus of oceanic sampling despite recommendations in that regard (Ward et al. 1989). They were caught infrequently (max. 5 individuals per year) by a two boat surface trawl in the Strait of Georgia during the Fraser Plume Study in the 1960s where they had an average length of 160 mm (range 131-184)(McKinnell & Perry 2016). Only 13 individuals were caught in the Strait of Georgia in spring sampling over a five year period. During the same era, however, 62 juvenile steelhead were caught in Saanich Inlet during two years of sampling. All but one were caught in 1968. Their average length was 175 mm (range: 130-275). The average length of Chilliwack River (lower Fraser River watershed) smolts was 165 mm at two years old and 200 mm at three years old (Maher & Larkin 1955). Multiple smolt ages means that the average size of a sample of pooled ages may not be very meaningful because the average may be more influence by age composition than by growth.

It takes a sockeye salmon almost an entire year of feeding at sea to reach the average length of these three year old steelhead trout smolt at ocean entry (Figure 2). Comparing length frequencies of steelhead trout with those of sockeye salmon caught on the high seas in July by gillnet from 1955 to 1972, the first length mode of sockeye salmon is age x.1 (second summer at sea) and this mode is approximately equal in relative abundance to the second mode which includes all older ages of sockeye salmon caught in July (Figure 2). Apart from one individual, this smaller mode is missing from the distribution of steelhead trout lengths (N.B. all months were included in this panel as there were too few in July to create a meaningful length frequency). Clearly the missing mode is not because the gillnets were unable to catch fish of that size as the sockeye salmon length frequency demonstrates that point clearly. More likely it is because the steelhead trout of that age/size never intersected the gillnets on the high seas, or fancifully that young steelhead trout are exceptionally adept at extricating themselves from gillnets after being gilled. This brings into question the idea that young of year steelhead are quickly moving offshore to the high seas after leaving fresh water. The current view of oceanic behaviour is that steelhead trout swim near the surface which should have put them in the path of these types of nets. As steelhead trout are lighter at length than other species of salmon, perhaps with their linear form they simply swim through the gillnets? Purse seine catches would seem to be able to resolve that question. Length frequencies of the two species in the purse seine differ significantly from the pattern that is found in the gillnet data (Figure 3). For both species, the purse seine picks up a mode for age x.0 (young of year) fish that was missing for both species in the gillnet data. Note that the YOY steelhead trout are almost twice the size of sockeye salmon in these samples. Considering their large average size at smoltification, perhaps this is not too surprising. A key feature of the steelhead trout length frequency is the lack of abundance of the smallest mode.

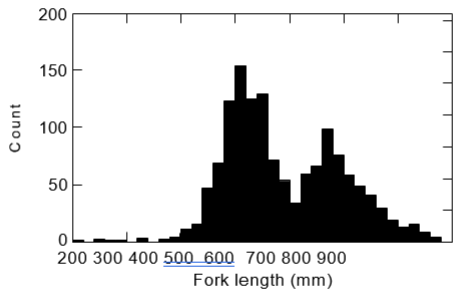

Figure 4: Length frequency of all steelhead caught in all months during Canadian longline fishing from 1962-1967.

A similar pattern appears in Canadian longline data from the Gulf of Alaska from 1962-1967 (Figure 4). The cohort that should be most abundant is not represented, except for a couple of individuals.

Run timing

From land, the oceanic effects on spawning adult steelhead trout are first evident as they enter coastal rivers. Indeed, most of what is known about their time at sea is traditionally learned by waiting for their return. The average speed of migration in rivers, opposing the current, is about double that of the minimum speed determined from high seas tagging to coastal fishery recovery (19.9 – 23.4 km d^{-1}) (McKinnell et al. 1997, English et al. 2006). Oceanic effects on variability of migration timing can be explored as the fish are approaching or just entering fresh water. Daily counts of steelhead trout are made at Bonneville Dam on the Columbia River (www.fpc.org), at the Nass River fish wheel at Gitwinksihlkw, and during the Pacific Salmon Commission's test fisheries in the Strait of Juan de Fuca and Queen Charlotte Strait. After smoothing with a 3-day running average, the daily data were log- transformed and potential pulses of abundance during spawning migrations were found using the method described in McKinnell (2019).

The model estimates parameters for skewness, compression, peak date, and proportion of the total return in each pulse. The skewness parameter has a value of -1.0 at symmetry, less than that if there is a slow rise and an abrupt falloff, greater than that if there is an abrupt rise and a slow falloff. The compression parameter takes values from 0 to 1 representing the proportion passing on the peak day. A highly compressed run will have higher values. Peak date is the sequential day of year when the estimated peak of the curve occurs for each pulse (DOY: e.g. June 1 is 152, July 1 is 182, August 1 is 213).

Columbia River

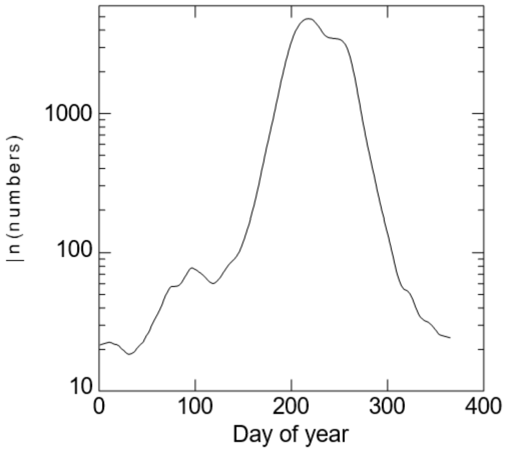

Figure 5: Average daily numbers of steelhead passing Bonneville Dam (1980-2019) using a lowess smoother.

Daily counts of steelhead trout have been made at Bonneville Dam since 1938 but analyses were restricted to years from 1980. Most are destined for the Snake River watershed but some also ascend the mainstem (currently only)[1] as far as the Okanagan River drainage. Beginning in 1994, adipose clipped steelhead were counted separately from unclipped fish at Bonneville Dam. For the present analysis, clipped and unclipped fish were recombined to make the contemporary data more comparable with period prior to 1994. In the earlier years, counting began later in the year than recently so a common period of days resembling the early period counts was selected for model fitting. The span of counting dates was based on the year with the shortest range of days observed.

The model was constrained to find three pulses based on a pattern that was evident in the long-term average (Figure 5). Without this constraint, the procedure found both fewer or more than three (Figure 6) but two or three were the most common. Finding only two pulses in some years suggests either that the small spring peak had a very low abundance and did not qualify, or perhaps the larger summer peaks overlapped to the extent that it was not possible to distinguish two separate peaks. Only one year (2001) found as many as five pulses. As this was atypical, some of the pulses may have been a result of river flow patterns impeding progress. Migration abundance during winter is low and variable but not zero with some evidence of slightly greater abundance through the new year.

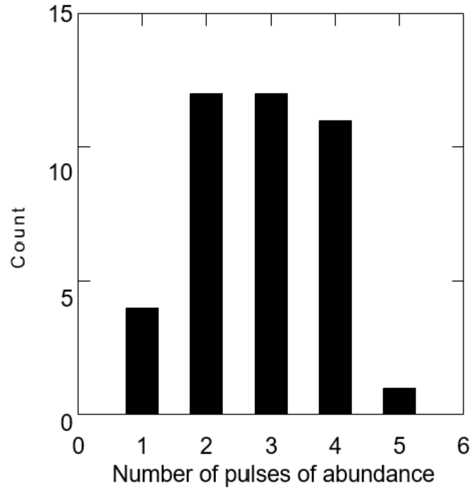

Figure 6: Number of pulses of retained by the model annually ranged from 4 years with single pulses to 1 year with 5 pulses.

It is clear that the summer run abundance (Figure 7:right panel) has been considerably lower than average beginning in 2017 and every daily anomaly has been negative. Reduced abundance of the second summer peak was particularly noteworthy in August of 2019 (Figure 8).

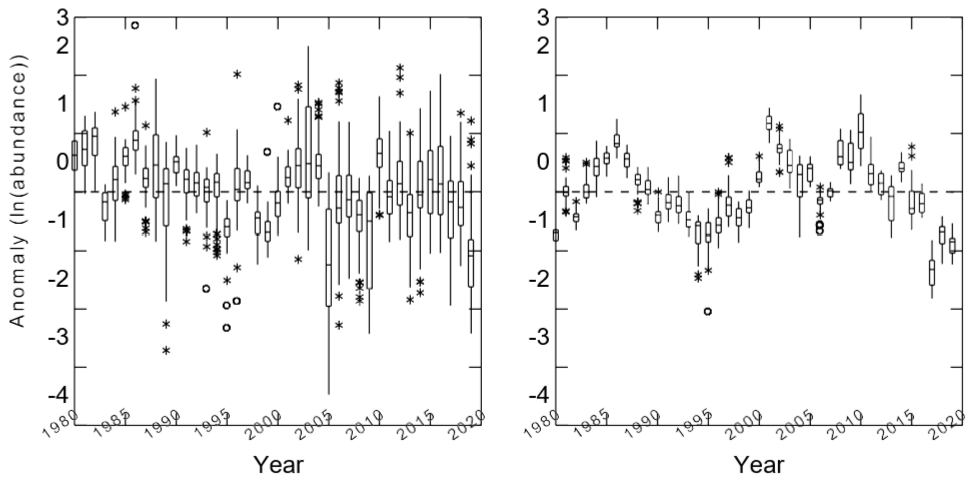

Figure 7: Box and whisker plots of daily abundance anomalies by year during the periods Feb-Apr (left) and month of July (right).

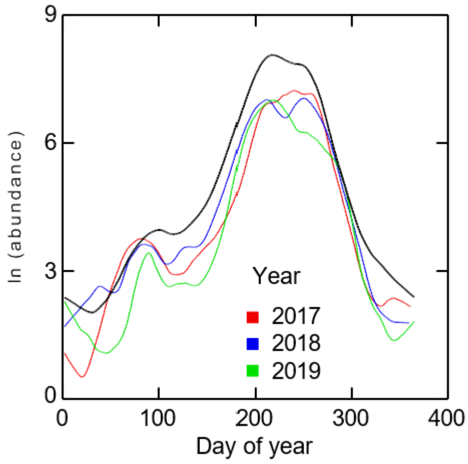

Figure 8: Long-term average steelhead abundance (ln transformed) at Bonneville Dam (black) compared to the recent three years of returns.

There do not appear to be substantial changes in the peak date of each migration pulse of steelhead trout at Bonneville Dam (Figure 9). The only noteworthy feature is that the timing of the first, and relatively small (~1.5% of the total return), pulse has been relatively constant during that last decade. Perhaps this is an artefact of choosing a common range of days to analyze for all years. The first peak is near the starting date (DOY= 76) so if the peak had shifted slightly earlier, this may not have appeared in these estimates. This question could be resolved re-estimating these years using all available data for each year. Likewise, there are no significant changes in either compression or skewness during this period. The steelhead trout return seems to be doing as it always has during this 40 year period, only at lower abundance.

1 The Grand Coulee Dam eliminated all upstream migration after the 1930s

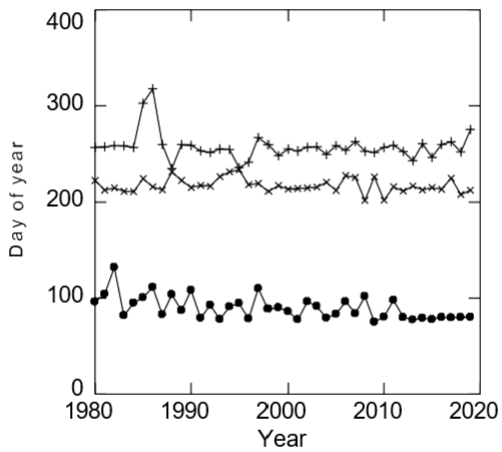

Figure 9: Peak date of migration of three pulses of steelhead migration past Bonneville Dam (Columbia River).

<u>Nass River</u>

At first glance, the long-term average timing of the summer run of steelhead trout to the Nass River (Figure 10) does not seem so different from that of the Columbia River (Figure 5). Sampling in the Nass River captures the entire period of the summer run which begins after midsummer and ends by mid-September. On average, the peak date estimated from cumulative daily average counts from 1994 to 2019, is day 234 (August 22). As in the Columbia River, summer run steelhead in the Nass River migrate to different tributaries within the Nass River watershed (Parken 1997). Unlike the Columbia River, however, the long-term average often does not resemble the timing of yearly returns. The return each year to the Nass River seems to be made up of a number of small peaks that do not appear regularly at or near certain dates. Nevertheless, at a watershed level, the peak date of the entire run does not appear to have changed during the period of record at the fish wheels (Figure 11).

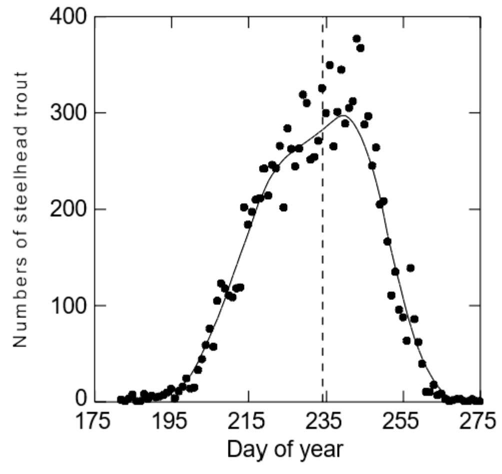

Figure 10: Average abundance of steelhead trout at G' fishwheels by day from 1994 to 2019.

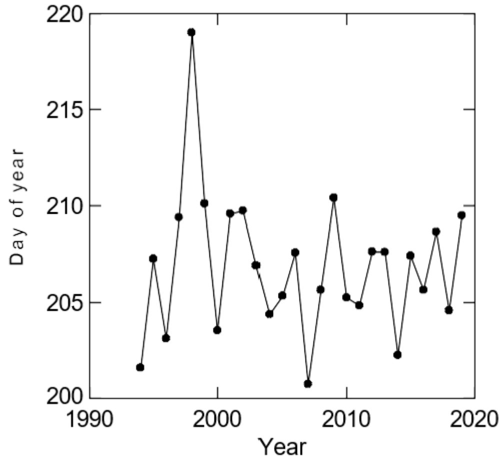

Figure 11: Peak dates of migration of steelhead trout in the Gitwinksihlkw fishwheel from 1994-2019.

Fraser River

The Pacific Salmon Commission operates gillnet and seine test fisheries in the approaches to the river. While steelhead trout are caught from time to time, the numbers are too low to examine run timing in any detail. The largest number caught in any one year by two gear types in each of two locations was 115 in 2002. The least number caught was 16 in 2019.

Summary

Most of what is known about steelhead trout on the high seas was described in Burgner et al. (1992). Only rarely (e.g. McKinnell et al. 1997) was this body of information been augmented. The lack of new information is due to reduced sampling on the high seas but may also be due to abrupt changes in high seas fishing gear. Prior to the 1990s, gillnets, longlines, and purse seines were used, but since then trawl nets have been used almost exclusively. Intercalibrations with trawl net results have not been done. The general consensus has been that trawl nets are ineffective at catching steelhead trout. For example, two decades of sampling the Strait of Georgia and west coast of Vancouver Island with trawl nets by DFO has resulted in total catches of only two steelhead trout. A consideration for future work is that among these four gear types, only the floating longline and the purse seine provide live fish. Considering the low abundance of many steelhead trout populations, non-lethal sampling sampling seems like the way forward.

Historically, at least one steelhead trout was caught in 32% of all U.S. gillnet sets (n=2208), but only 10% of all U.S. purse seine sets (n= 4254). No doubt the longer soaking times of gillnets contributed to the difference. On average, steelhead trout accounted for 0.7% of all salmonids caught in U.S. purse seine sets whereas they accounted for only 1-2% of all salmonids caught in U.S. gillnets. Therefore it appears that sampling efforts on the high seas directed only at steelhead trout will not be very economical. Increasing the hit rate may be possible if sampling is restricted to warmer subarctic waters, but their general lower abundance in recent decades will be reflected in high seas catches as well.

Decades of research cruises by Hokkaido University in the subarctic North Pacific and Bering Sea in summer found that steelhead trout and coho salmon tended to be caught at warmer (~ +1.5°) surface temperatures than the other species. One Canadian high seas salmon expedition in 1990 in the south- central Gulf of Alaska during summer reported:

Steelhead trout represented 11.7% of the catch of salmonids, and seem to be present in the southern region of the area of salmonid distribution to a greater extent than other salmonids. (McKinnell et al. 1990).

Historical catches support the idea that they will be found in greater abundance in the southern part of the Gulf of Alaska (Figure 12).

All steelhead trout caught on longlines in 1990 were tagged and released but only one tag was reported recovered later that year, in northern Oregon. CWTs are applied to juvenile steelhead trout, usually in hatcheries, and some of these tags have been recovered in high seas research or as bycatch from commercial fishing. McKinnell et al. (1997) noted that there was a spatial/temporal pattern in recoveries of CWTagged steelhead trout on the high seas that suggested a more southerly distribution of fish from the U.S. mainland coast compared with those from the Salish Sea. While not enough sampling was done to be conclusive, there is a possibility that high seas sampling would need to be directed to different regions according to interest. For example, most recoveries of young of year ocean migrants were caught in the northern Gulf of Alaska along or just beyond the continental slope although some were caught in deeper water at that age.

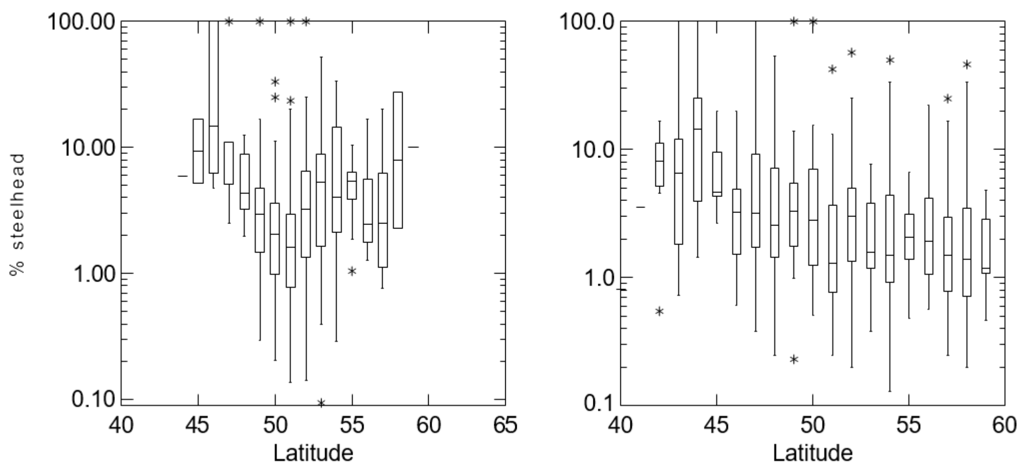

Figure 12: If a steelhead trout was caught on the high seas, what fraction of the total catch in each fishing operation did it represent? Box and whisker plots by latitude; [left] U.S. gillnet and [right] U.S. purse seine.

In some respects, studying steelhead trout in the ocean can be easier than studying other salmonids as they are not genetically programmed to die after spawning. This provides a pool of large fish (kelts) that are readily available for sampling in freshwater. Kelts returning to the ocean are more amenable than smolts to sophisticated tracking by satellite (pop-up tags) or other means (Teo et al. 2011). It is considerably less expensive to send a tagged fish to sea than a vessel. If a steelhead trout is caught at sea, applying a pop-up tag to an immature fish would seem to provide the greatest opportunity for new knowledge as recovery of the tag is not an essential criterion. Pop-up tags have proven effective for tagging Atlantic salmon caught at sea (Lacroix 2013, Strøm et al. 2019) but some skill is required to attach them to the fish. Substantially reduced fishing effort by both commercial and recreational fishing fleets and anglers severely diminishes the probability of recovery of a data storage or other type of traditional tag.

Considering that most of the evidence to date is that steelhead trout ocean mortality is highest in coastal waters (Melnychuk et al. 2007, Kendall et al. 2017), it is difficult to imagine a high seas research program directed exclusively to the high seas life history phase, unless the data begin to suggest higher than average mortality among older steelhead. Nevertheless, continuous efforts to learn what can be learned about steelhead trout on the high seas from limited sampling will be valuable even if they accumulate slowly. Because steelhead management issues related to abundance and survival have a regional scale and are not unique to British Columbia, cooperative planning efforts with steelhead trout biologists in Washington and Oregon would ensure that samples that might be collected on the high seas, are collected. But first, everyone needs to be aware of the opportunity.

References

English, K.K., Robichaud, D, Sliwinski, C., Alexander, R.F., Koski, W.R., Nelson, T.C., Nass, B.L, Bickford, S.A., Hammond, S., Mosey, T.R. 2006. Comparison of adult steelhead migrations in the Mid- Columbia hydrosystem and in large naturally flowing British Columbia rivers. Trans. Am. Fish. Soc.
135: 739-754.

Maher, F.P. And Larkin, P.A. 1954. Life history of the steelhead trout of Chilliwack River, B.C. Trans. Am. Fish. Soc. 84: 27-38.

Lacroix, G. 2013. Population-specific ranges of oceanic migration for adult Atlantic salmon (Salmo salar) documented using pop-up satellite archival tags. Can. J. Fish. Aquat. Sci. 70: 1011-1030, https://doi.org/10.1139/cjfas-2013-0038

McKinnell, S. and Perry, R.I. 2016. Number, size composition and food of larval and juvenile fish caught with a two-boat surface trawl in the Strait of Georgia 1968, 1969, and 1973. Can. Data. Rep. Fish. Aquat. Sci. 1264: v + 208p.

McKinnell, S.M., Curchitser, E., Groot, K., Kaeriyama, M., and Trudel, M. 2014. Oceanic and atmospheric extremes motivate a new hypothesis for variable marine survival of Fraser River sockeye salmon. Fisheries Oceanography 23(4): 322-341, doi:10.1111/fog.12063.

McKinnell, S., Pella, J.J. and Dahlberg, M.L. 1997. Population-specific aggregations of steelhead trout (*Oncorhynchus mykiss*) in the North Pacific. Canadian Journal of Fisheries and Aquatic Sciences 54:2368- 2376.

McKinnell, S.M., Shaw, W., Ladell, J. 1990. The 1990 pelagic research cruise of the W.E. Ricker. 19p. (Document submitted to the Annual Meeting of the International North Pacific Fisheries Commission, Vancouver, British Columbia, Canada, October, 1990). Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, B.C., Canada V9R 5K6.

McKinnell, S.M., Wood, C.C., Rutherford, D.T., Hyatt, K.D. and Welch, D.W. 2001. The demise of Owikeno Lake sockeye salmon. North American Journal of Fisheries Management 21: 774-791.

Melnychuk, M.C., Welch, D.W., Walters, C.J., Christensen, V. 2007. Riverine and early ocean migration and mortality patterns of juvenile steelhead trout (*Oncorhynchus mykiss*) from the Cheakamus River, British Columbia. In: Almeida P.R., Quintella B.R., Costa M.J., Moore A. (eds) Developments in Fish Telemetry. Developments in Hydrobiology 195, vol 195. Springer, Dordrecht

Parken, C.K. 1997. Nass River steelhead life history characteristics pertaining to the Nass habitat capability model. Skeena Fisheries Report SK#110, BC Ministry of Environment, Lands and Parks.

Strøm, J.F., Rikardsen, A.H., Campana, S.E., Righton, D., Carr, J., Aarestrup, K., Stokesbury, M.J.W., Gargan, P., Caballero Javierre, P., Thorstad, E.B. 2019. Ocean predation and mortality of adult Atlantic salmon. Nature, DOI: 10.1038/s41598-019-44041-5

Teo, S.L.H., Sandstrom, P.T., Chapman, E.D., Null, R.E., Brown, K., Klimley, A.P., Block, B.A. 2011. Archival and acoustic tags reveal the post-spawning migrations,diving behavior, and thermal habitat of hatchery-origin Sacramento River steelhead kelts (*Oncorhynchus mykiss*). Environ. Biol. Fishes. DOI 10.1007/s10641-011-9938-4