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Auke Creek Research Station Report: Data Summary and Historical Trends from 1980 to 2020

S. C. Vulstek, J. R. Russell, and A. K. Gray

September 2022

U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration
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Auke Creek Research Station Report: Data Summary and Historical Trends from 1980 to 2020

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ABSTRACT

The Auke Creek weir, located in Juneau, Alaska, is a permanent fish counting structure that allows for near complete sampling of downstream and upstream migrant salmonid species. The weir has been in operation in its current configuration since 1980, creating one of the richest long-term series of anadromous salmonid data in the North America. Data include abundance, migration timing, age, length, and weight of trout and commercially important salmon species, as well as creek temperature, and gauge height. We summarize data collected in 2020 and report historical trends from 1980 to 2020. Since 1980, the temperature of Auke Creek has shown a significant increase. Coinciding with environmental changes, several biological attributes of Auke Creek salmonids have also been changing, such as migrations occurring earlier. Despite changing biotic and abiotic conditions, the abundance of most species and populations of Auke Creek salmonids has remained stable.

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Research Station Overview

Research Objectives

The two main objectives of all physical and biological sampling efforts at Auke Creek Research Station are to: (1) provide indices of salmon productivity to inform management of Transboundary Rivers and Northern Boundary regions of the Pacific Salmon Treaty and (2) understand the impact of climate variability on critical periods of Pacific salmon (*Oncorhynchus* spp.) life cycles by linking their freshwater and marine ecology. The complete enumeration of juvenile and returning adult coho, pink, and sockeye salmon provide indices of productivity that help inform science and management of those species in the Transboundary Rivers and Northern Boundary regions of the Pacific Salmon Treaty. Additionally, data collected at Auke Creek provide linkages to both nearshore and Gulf of Alaska marine environments and, when combined with marine surveys, allow for a more thorough examination of these larger ecosystem processes. The data collected between 1980 and 2020 provide 41 consecutive years of continuous, comparable data. Due to the volume of data encompassed by this report, analyses were limited in order to investigate as many basic historical trends as possible. For this report we have focused on the relationship of fish abundance, size, age, and migration timing with year in order to construct a baseline reference for past, present, and future research regarding more specific topics.

Study Site

Auke Creek Research Station is located on Auke Creek approximately 16 km northwest of downtown Juneau, Alaska (Fig 1; Latitude 58.38072 N, Longitude 134.64187 W). The creek (a 0.65 km outlet stream) drains the Auke Lake watershed (Wing and Pella 1998), which has a

catchment of 10 km^2 (Juneau Watershed Partnership 2009). Auke Lake has an area of 0.67 km^2. One main tributary, Lake Creek, flows into the lake.

A fish collection weir spans Auke Creek just above average high tide level. A fish tagging/incubating/rearing facility is adjacent to the weir. The current weir was built in 1979 and consists of a permanent structure that can be changed to either a downstream or upstream capture configuration. The steel framework of the weir is tied to a concrete pad on the stream floor and concrete retaining walls on each side of the creek to facilitate the capture of all upstream and downstream migrants, even in periods of high discharge.

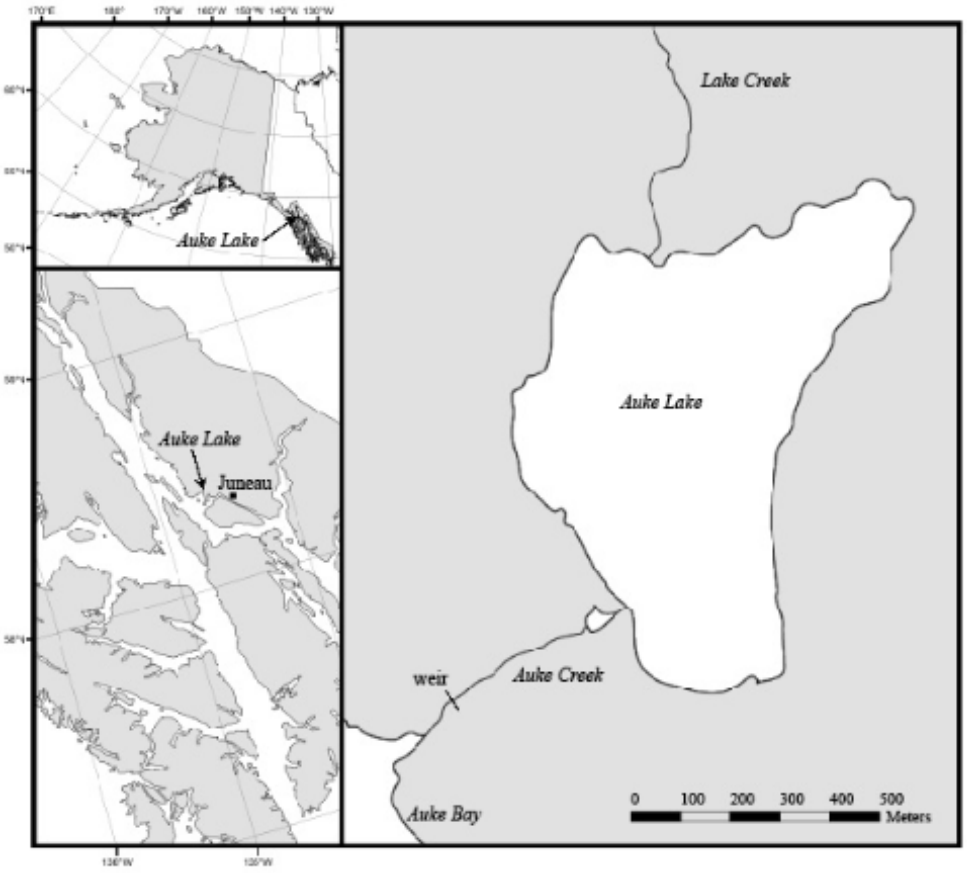

Figure 1. -- Location of Auke Creek Research Station in the Auke Lake watershed in Southeast Alaska.

Weir Operations

The downstream weir was operated from 13 February through 15 June in 2020. At minimum, all downstream migrants were identified and counted prior to release. Additionally, size and/or age data were collected for all species. Frequency of these additional data collections was based on availability of fish with the intent to collect a representative sample of the run for both size and age information. As downstream migration is strongly correlated with flow, temperature, and time of year, these sampling efforts were not evenly distributed throughout the downstream season. Fifty pink salmon fry were collected approximately once per week, anesthetized in an tricaine methanesulfonate (MS-222) solution, weighed to the nearest 0.001 g, and measured to the nearest 1 mm fork length before being released. All coho smolt were anesthetized, injected with a coded wire tag (CWT), marked by adipose-fin excision before released. Individuals from a random subsample of coho smolt were weighed to the nearest 0.01 g and measured to the nearest 1 mm fork length before being released. Additionally, scales were collected (4-8 per individual) to be aged at a later time. With the exception of CWT injection and external marking, sockeye smolts were sampled in the same manner as coho. All downstream migrant cutthroat trout and steelhead juveniles were counted and measured to the nearest 1 mm fork length before released. All downstream migrant Dolly Varden were also counted daily, and a minimum of 1 in 10 Dolly Varden were randomly chosen to be measured to the nearest 5 mm fork length before released.

The upstream weir operated from 15 June through 27 October in 2020. At minimum, all upstream migrants were identified and counted prior to release. Sex was determined for sockeye salmon, pink salmon, and coho salmon adults. Additionally, adult (age x.1) and jack (age x.0) coho salmon were examined for external marks prior to upstream release and enumerated by mark type. Additional length and scale data were collected at a frequency similar to that

employed during the downstream season. Individuals from a random subsample (including jacks) of the coho and sockeye populations were measured to the nearest 1 mm fork length and 1 (sockeye) or 4 (coho) scales were collected and placed on gummed cards. Scales were later pressed onto acetate and aged. Again, the current weir configuration may allow the two-way passage of smaller cutthroat, steelhead, and Dolly Varden through the weir panels. Therefore, while trout and char captured in the adult trap were counted, size data were not collected and the censuses are assumed to be incomplete. Weir operations have varied over the last 36 year and an historical accounting of operational changes can be found in Vulstek et al. (2022).

Salmon And Trout Observations

Pink salmon

Pink salmon spawn mainly in Auke Creek, and to a lesser degree, in the tributaries to Auke Lake. A small portion of pink salmon also spawn in the intertidal area downstream from the weir. Pink salmon have genetically isolated even and odd-year populations, resulting from strict two-year life cycles. Auke Creek pink salmon have historically consisted of distinct early and late runs. However, it is becoming increasingly difficult to differentiate early-run pink salmon from late-run pink salmon based on the sex ratio, general appearance of the fish, and daily abundance. The complete enumeration of pink salmon juveniles and returning adults at Auke Creek provide annual indices of freshwater productivity and ocean survival. This data is used by scientist and managers as an ecosystem indicator for management of pink salmon stocks in the Transboundary Rivers and Northern Boundary regions of the PST.

In 2020, the abundance of Auke Creek pink salmon fry (46,129) was below the 1980-2019 average (89,650; Figs. 2 and 3; Appendix Table A-1). A total of 280 fry migrated

downstream in February, 3,225 migrated in March, 41,848 migrated in April, 776 migrated in May, and 0 migrated in June. Wild pink fry production had a negative temporal trend between 1980 and 2015 for even-year broods (-3577.36 fry-yr, R2 = 0.4, P = < 0.01). Odd-year brood abundance has remained stable since 1980 (R2 = 0.1, P = 0.17).

The 2020 Auke Creek fry downstream migration was consistent with average migration timing (Fig. 4). The midpoint of migration in 2020 (15 April) was the same as the long-term average midpoint (15 April). Pink salmon fry had a trend towards earlier migration midpoints from 1980 to 2020 for both even (-0.31 days-yr, R2 = 0.19, P = 0.05) and odd-year broods (-0.38 days-yr, R2 = 0.24, P = 0.03).

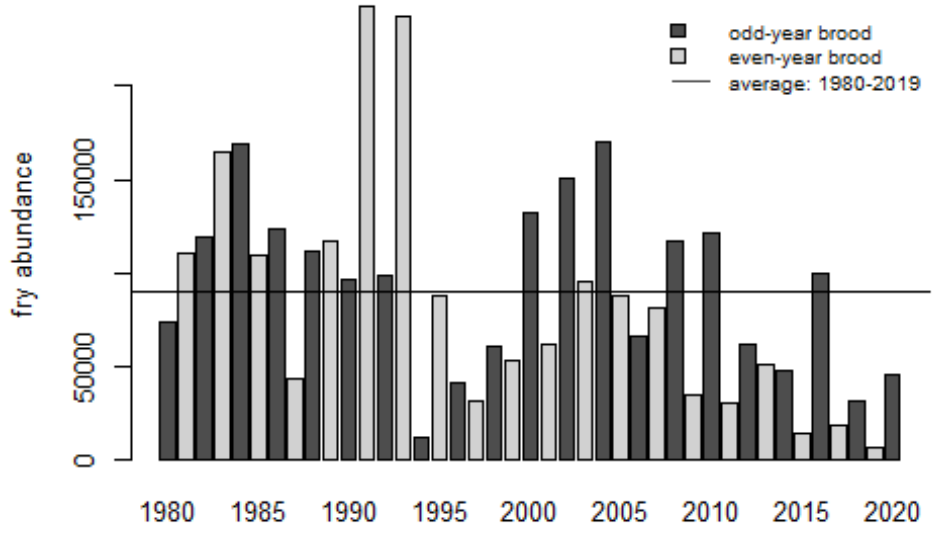

Figure 2. -- Yearly pink salmon fry downstream migration abundance against outmigration year for even and odd-year broods at Auke Creek, 1980-2020.

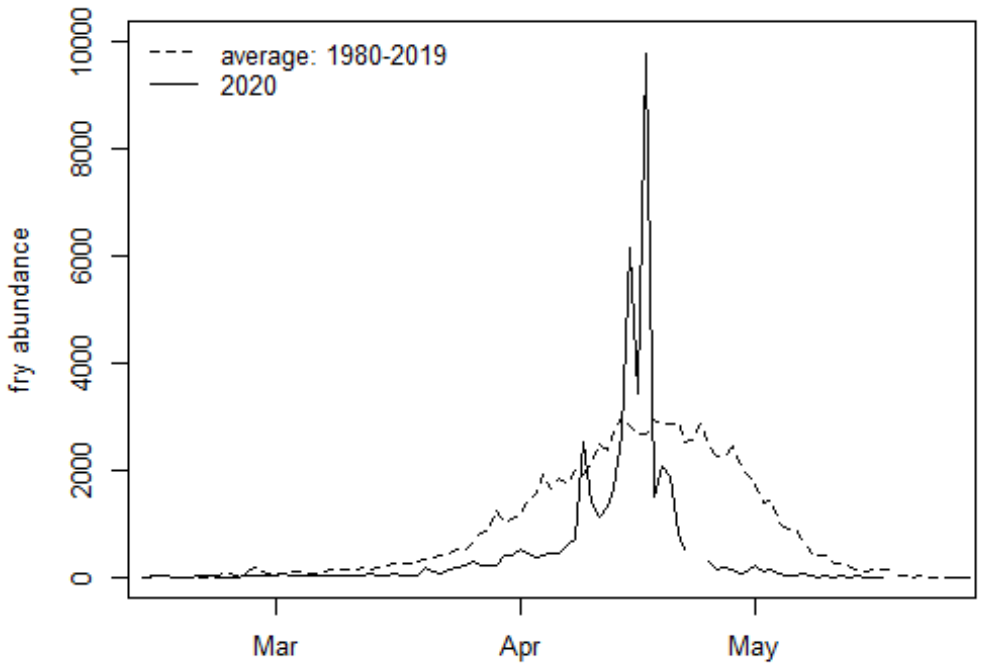

Figure 3. -- Daily pink salmon fry downstream migration abundance against date at Auke Creek for 2020 and the 1980-2019 average.

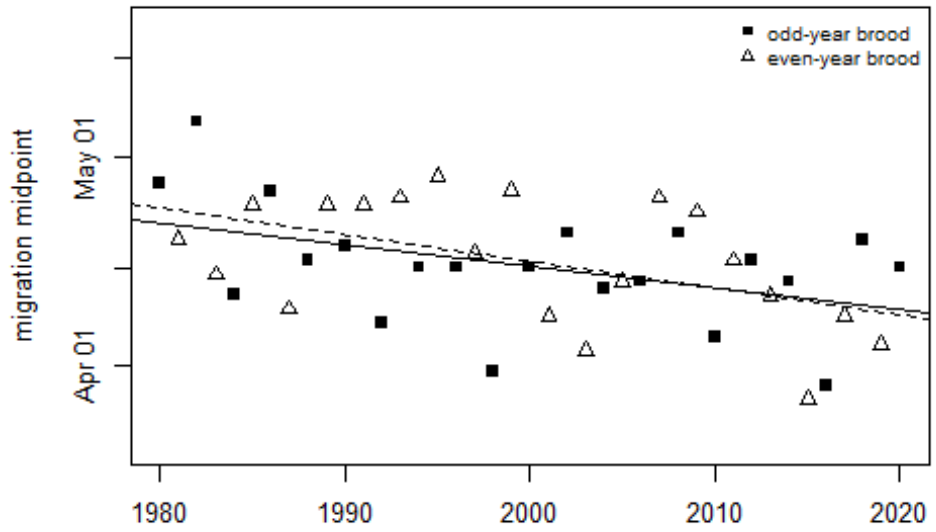

Figure 4. -- Yearly pink salmon fry downstream migration midpoint dates against year at Auke Creek for even and odd-year broods and temporal trends, 1980-2020. The trend line is solid for even-year broods and broken for odd-year broods.

Marine survival of the 2018 brood (20.67%) was above the long-term average (10.92%). Pink salmon marine survival did not have temporal trends for either the even (R2 = 0.03, P = 0.44) or odd-year broods (R2 = 0.02, P = 0.56).

The abundance of upstream migrant pink salmon adults in 2020 (1,304) was below the long-term average (9,394; Fig. 5; Appendix Table A-1). A total of 15 adult pink salmon migrated in July, 1,222 migrated in August, and 67 migrated in September. Abundance of adult pink salmon did not have a temporal trend for either the even (R2 = 0, P = 0.99) or odd-year broods (R2 = 0.27, P = 0.02).

The midpoint of the 2020 wild adult upstream migration (17 August; Fig. 6) was earlier than the 1980-2019 average (23 August). As with pink salmon fry, pink salmon adults had a trend towards earlier migration midpoints for both even (-0.22 days-yr, R2 = 0.18, P = 0.06) and odd-year broods (-0.18 days-yr, R2 = 0.06, P = 0.29).

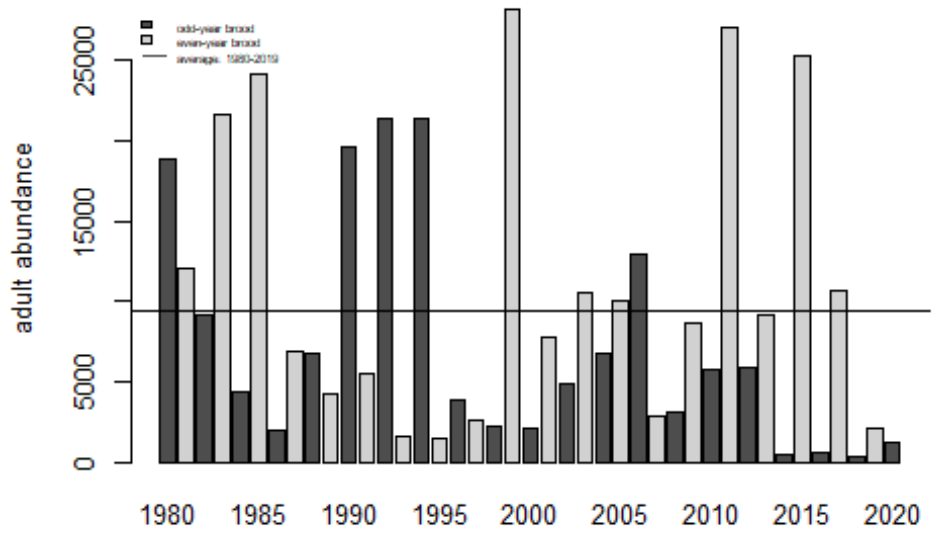

Figure 5. -- Yearly adult pink salmon upstream migration abundance against year for even and odd-year broods at Auke Creek, 1980-2020.

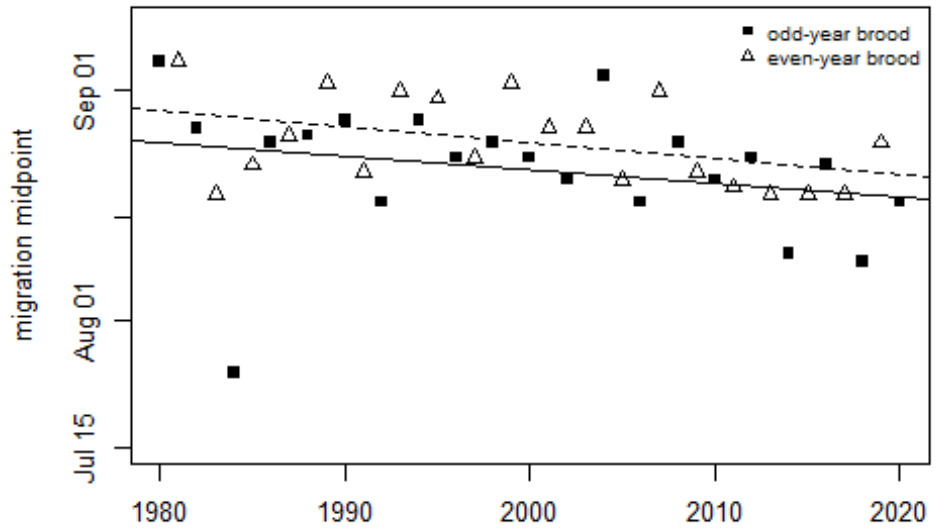

Figure 6. -- Yearly adult pink salmon upstream migration midpoint dates against year for even and odd-year broods at Auke Creek, 1980-2020. The trend line is solid for even-year broods and broken for odd-year broods.

Sockeye Salmon

A sharp decline was seen in Auke Creek sockeye salmon escapement during the late 1970s and early 1980s until enhancement research boosted subsequent escapements. Multiple enhancement and hatchery projects have been conducted on sockeye salmon at the Auke Creek Research Station. Hatchery-reared sockeye juveniles stocked in Auke Lake in 1974-75 and 1987-89 contributed to smolt downstream migrations in 1975-77 and 1988-91. Sockeye enhancement from 1988-1992 included the release of age-zero (under one year of age) smolts reared in the Auke Creek hatchery and in seawater net pens in Auke Bay. Sockeye fry reared in the hatchery were released into Auke Lake in 2012-2014, began downstream migration in 2013, and finished in 2016.

Auke Creek sockeye salmon spawn in tributaries to Auke Lake and to a lesser extent on submerged gravel beds in Auke Lake. Juvenile rearing likely occurs mainly in Auke Lake.

Distinct size differentiation allows for visual identification of age-1 and age-2 smolts (Figs. 11 and 12). When compared to scale ageing, this technique has proven to be fairly accurate, and scale samples are taken several times each year to confirm that size differentiation persists. Before 1980, it was estimated that age-2 smolts represented < 5% of the production, and some broods produced no age-2 smolts. The complete enumeration of Sockeye salmon juveniles and returning adults at Auke Creek provide annual indices of freshwater productivity and ocean survival. This data is used by scientist and managers as an ecosystem indicator for management of sockeye salmon stocks in the Transboundary Rivers and Northern Boundary regions of the PST.

The abundance of downstream migrant sockeye salmon smolt during 2020 (7,347) was below the 1980-2019 average (16,539; Fig. 7, Appendix Table A-2). A total of 6,570 smolt migrated downstream in May, and 777 migrated in June. The 2020 year class consisted of approximately 1,094 age-1 smolts (2018 brood) and 6,253 age-2 smolts (2017 brood). The 2017 brood has completed the downstream migration. The total production for the 2017 brood (6,283) was below the 1978-2016 brood average (16,984; Fig. 8). Abundance of sockeye smolt did not have a linear temporal trend for either year class ($R2 = 0$, $P = 0.86$) or brood year ($R2 = 0$, $P = 0.88$).

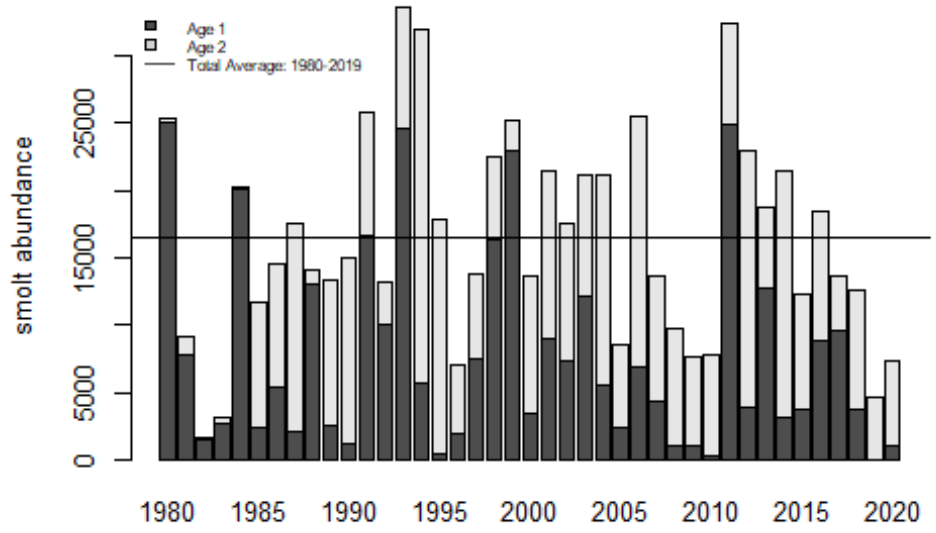

Figure 7. -- Yearly sockeye salmon smolt downstream migration abundance against year for age-1 and age-2 smolts at Auke Creek, 1980-2020.

The proportion of age-1 smolts has varied between 0.48% and 98.02% with an average of 44.04% for the 1978 to 2016 broods. The 2017 brood stock consisted of 0.48% age-1 smolts. Since 1978, sockeye smolts have had a trend towards a lower proportion age-1 (-0.01-yr, R2 = 0.18, P0.01; Fig. 8).

Age-2 smolts migrated slightly earlier than did age-1 fish, with median dates of 27 May and 29 May, respectively (Fig. 9). The overall migration midpoint in 2020 (27 May) was later than the 1980-2019 average (23 May). The migration midpoints of sockeye smolts did not have a temporal trend (R2 = 0, P = 0.68; Fig. 10).

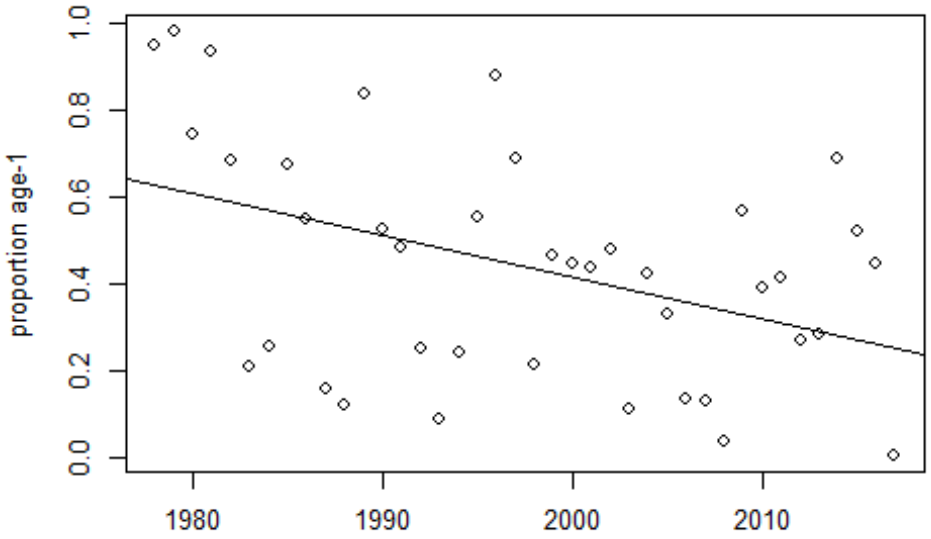

Figure 8. -- Yearly proportion of downstream migrant age-1 sockeye smolts (by brood year) against year and temporal trend, 1978-2017.

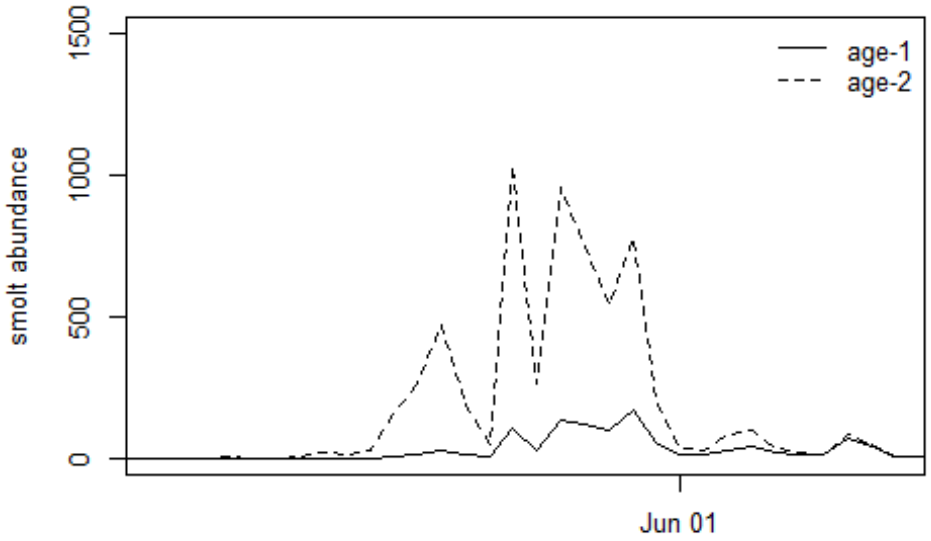

Figure 9. -- Daily sockeye salmon smolt downstream migration abundance against date for age-1 and age-2 smolts at Auke Creek in 2020.

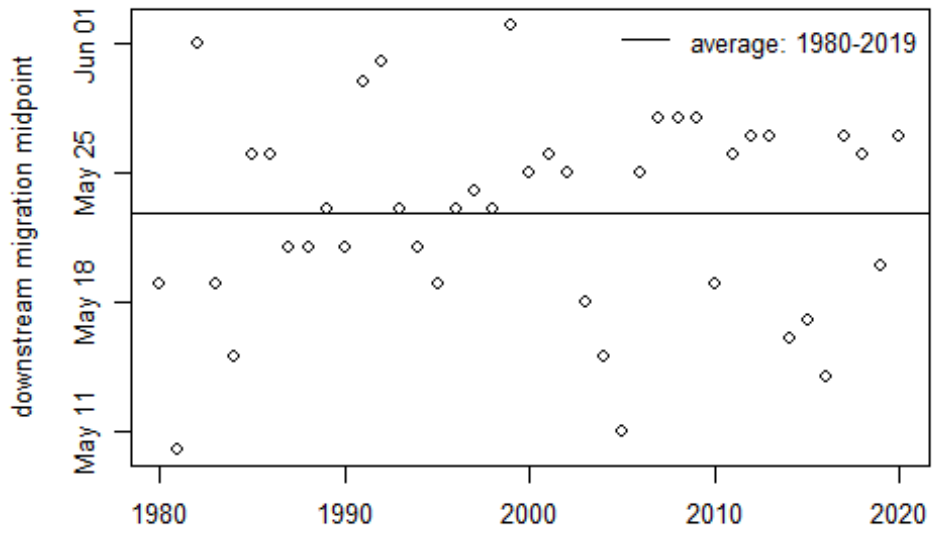

Figure 10. -- Annual sockeye salmon smolt downstream migration midpoint dates against year at Auke Creek, 1980-2020.

In 2020, the average length and weight of both age-1 (86 mm, 6 gm) and age-2 (136 mm, 24 gm) smolts were substantially above the 1980-2019 average for age-1 smolts (80 mm, 5 gm) and age-2 smolts (118 mm, 15 gm; Figs. 11 and 12). Age-2 smolts had a significant increase in both length (0.75 mm-yr, R2 = 0.37, P = < 0.01) and weight (0.05 gm-yr, R2 = 0.16, P = 0.01) between 1980 and 2020. Age-1 smolts also had a trend toward greater length (0.26 mm-yr, R2 = 0.18, P = 0.01; Fig. 13) and weight (0.05 gm-yr, R2 = 0.16, P = 0.01; Fig. 14) since 1980.

The total biomass (total weight of all smolts in a migration year) of sockeye smolts in 2020 (156 kg; Fig. 15) was below the 1980-2019 average (157 kg). The annual biomass has a positive temporal trend since 1980 (3.27 kg-yr, R2 = 0.26, P = < 0.01).

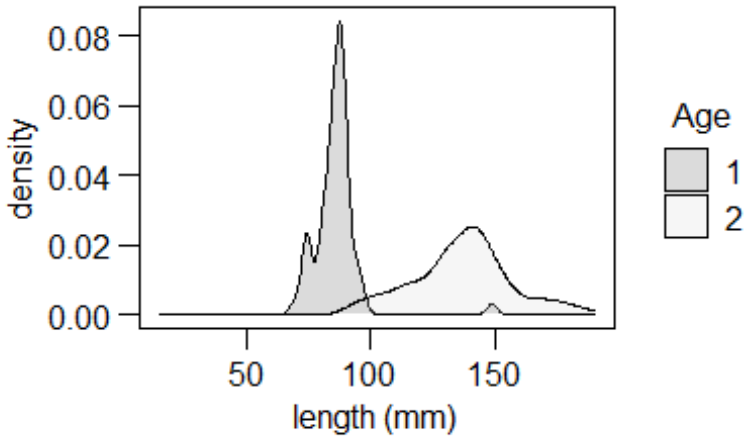

Figure 11. -- Frequency of downstream migrant sockeye salmon smolt lengths (mm) for age-1 and age-2 smolts at Auke Creek in 2020.

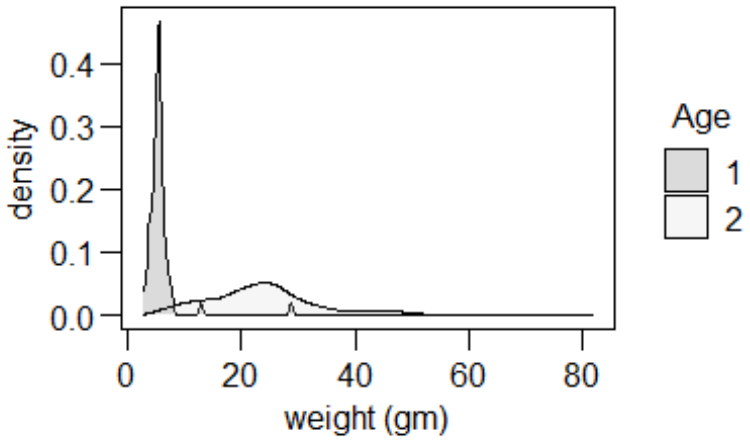

Figure 12. -- Frequency of downstream migrant sockeye salmon smolt weights (gm) for age-1 and age-2 smolts at Auke Creek in 2020.

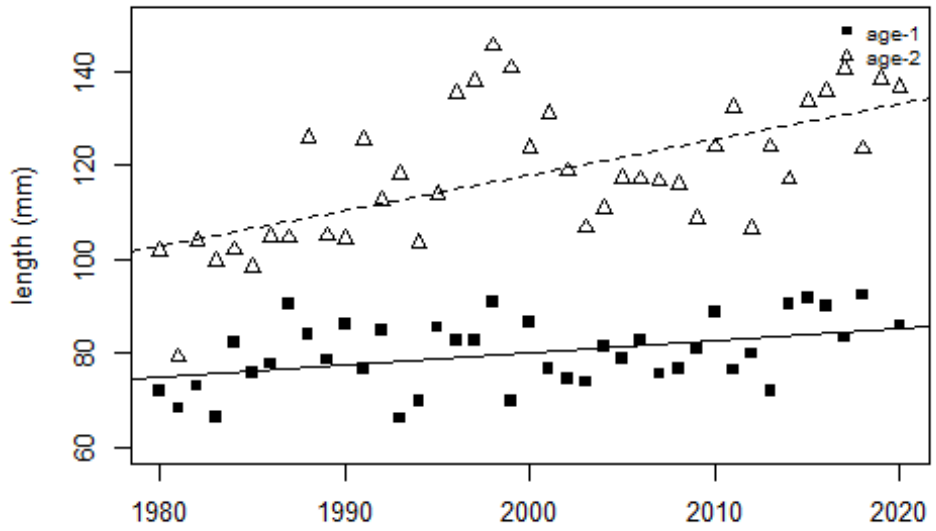

Figure 13. -- Yearly downstream migrant sockeye salmon smolt average length (mm) against year at Auke Creek for age-1 and age-2 smolts and temporal trends, 1980-2020. The trend line is solid for age-1 smolts and broken for age-2 smolts.

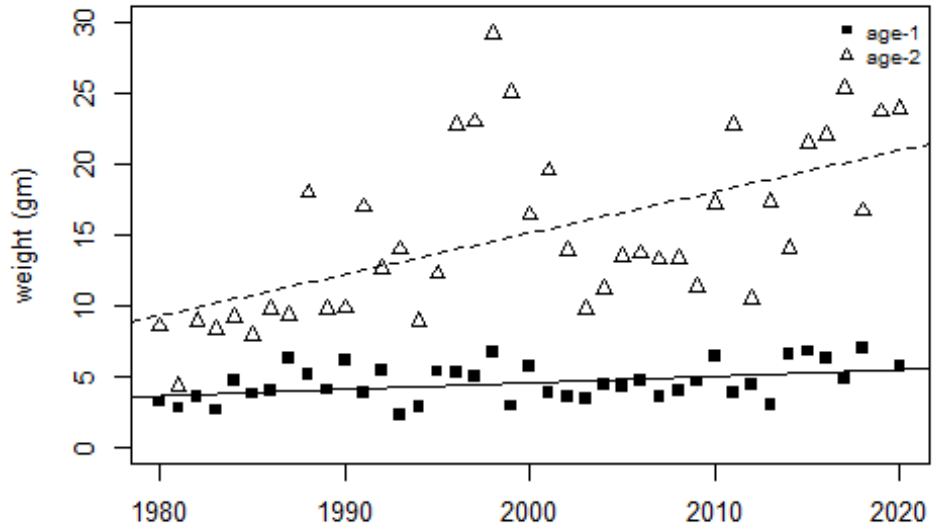

Figure 14. -- Yearly downstream migrant sockeye salmon smolt average weight (gm) against year at Auke Creek for age-1 and age-2 smolts and temporal trends, 1980-2020. The trend line is solid for age-1 smolts and broken for age-2 smolts.

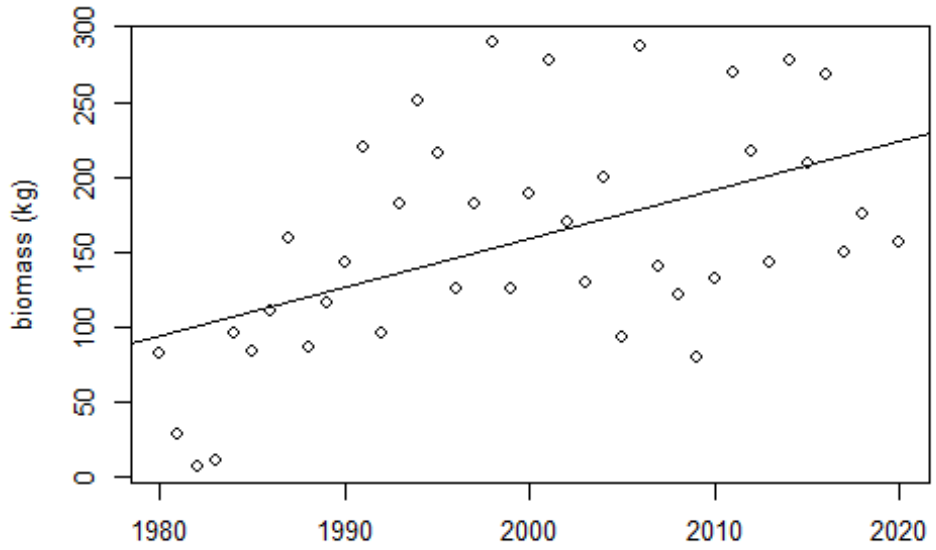

Figure 15. -- Yearly downstream migrant sockeye salmon smolt biomass (kg) against year at Auke Creek and temporal trend, 1980-2020.

A useful measure of freshwater survival is the number of smolts produced per spawner. The 2017 brood produced fewer smolts per spawner (1.73) than the long-term average (8.02; Fig. 16). The 2017 brood produced fewer age-1 smolts per spawner (0.01) than the long-term average (3.44). Additionally, the 2017 brood produced fewer age-2 smolts per spawner (1.73) than the long-term average (4.58).

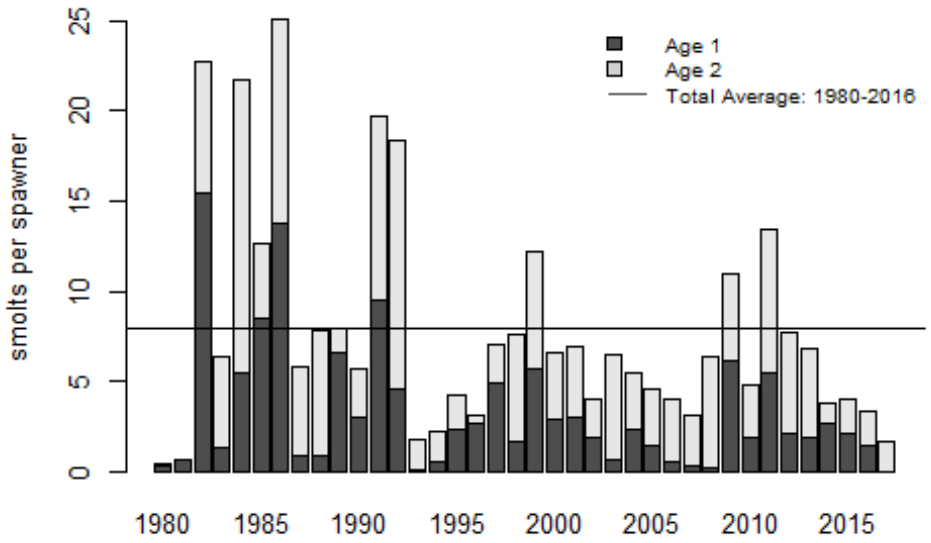

Figure 16. -- Yearly downstream migrant sockeye salmon smolts produced per spawner (by brood year) against year at Auke Creek, 1980-2017.

The 2020 sockeye upstream migration abundance (775) was below the 1980-2019 average (2,598; Fig. 19; Appendix Table A-2). The 2020 sockeye run consisted of 771 adults and 4 jacks. A total of 33 sockeye migrated in June, 680 sockeye migrated in July, 61 migrated in August, and 1 migrated in September. Adult sockeye salmon abundance did not have a temporal trend ($R2 = 0$, $P = 0.77$). Some of the returning sockeye salmon were hatchery reared. The proportion of hatchery reared fish will be determined in the future using genetic parentage-based tagging.

The upstream migration midpoint of sockeye salmon in 2020 (11 July) was earlier than the long-term average (20 July). Upstream migration midpoint had a trend towards occurring earlier from 1980 to 2019 (-0.25 days-yr, $R2 = 0.08$, $P = 0.07$; Fig. 18). Midpoints from 1990 to 1995 include hatchery fish and may not be representative of the midpoint for wild sockeye. However, the exclusion of these years does not affect the significance of the trend.

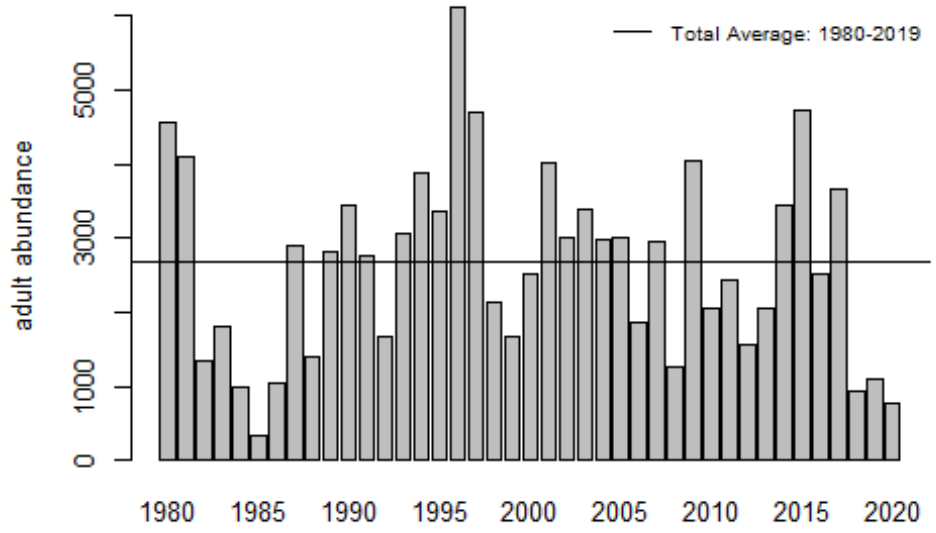

Figure 17. -- Yearly sockeye salmon adult upstream migration abundance against year at Auke Creek for hatchery and wild adults, 1980-2020. Hatchery adults were produced from lake-stocked fry and age-0 smolts.

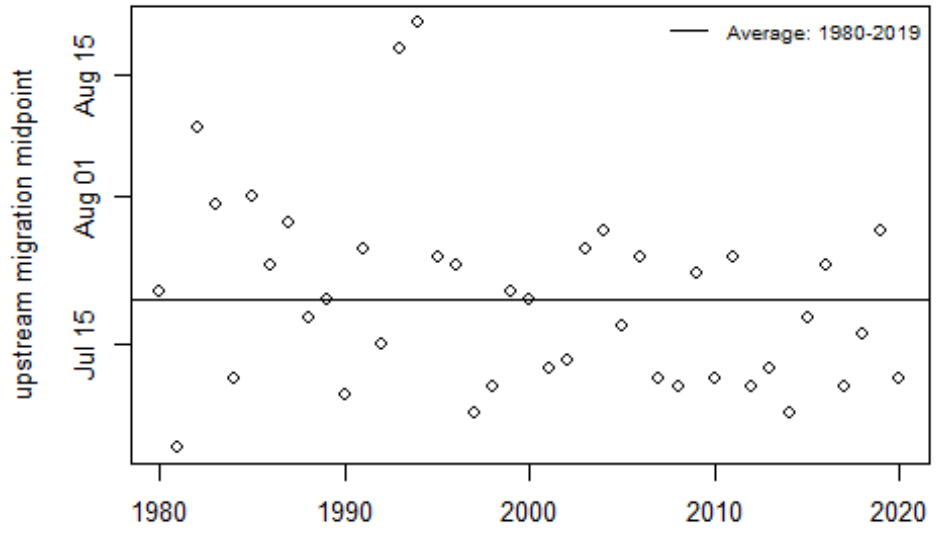

Figure 18. -- Yearly sockeye salmon adult upstream migration midpoint dates against year at Auke Creek 1980-2020. Midpoints from 1990-1995 include hatchery releases that may influence migration timing.

Coho Salmon

Coho salmon spawn in the tributaries to Auke Lake and in the upper 100 m of Auke Creek. Juvenile rearing occurs predominantly in Auke Lake and likely throughout most of the watershed, although the exact areas are not known.

Coho salmon were spawned for hatchery incubation at Auke Creek in 1978, 1980-84, and 1996-97. All hatchery smolts were tagged with coded wires and marked with an adipose and ventral fin clip to distinguish them from wild fish. All hatchery coho jacks and adults with double fin marks were sacrificed when they returned to Auke Creek. From 1976 to 1980, there were marked and unmarked coho salmon jacks and adults from Auke Creek and from Alaska Department of Fish and Game (ADFG) enhancement projects in the Juneau area. In those years, tagged fish (missing the adipose fin) were sampled at different rates at Auke Creek weir to recover coded wire tags. Those recoveries and tag release data for hatchery coho released locally were used to estimate the origin of coho in Auke Creek.

As with sockeye smolts, coho migrate downstream as either age-1 or age-2 smolts. When compared to sockeye salmon smolts, age-1 and age-2 coho salmon smolts show considerable overlap in length and weight (Figs. 23 and 24). This overlap occurs every year and makes scale aging a challenge, and visual determination of age impossible. Part of the reason for the overlap in size is because of the growth of age-1 smolts in the lake after the age-2 fish migrate. This phenomenon is visible on the scales of later migrants leaving Auke Lake, and in some years reflects rapid growth before the fish leave.

All coho smolts are injected with coded wire tags during downstream migration. Adipose fins are removed to allow for identification of tagged fish. Recovery of coded wire tags in commercial and sport fishery port sampling programs provides an estimate on the harvest of

coho salmon from Auke Creek (Clark et al. 1994) and Auke Creek coho serve as a wild indicator stock for fisheries management in Southeast Alaska. Wild Auke Creek coho escapement, marine survival, and exploitation rates (both total and fishery-specific) are critical for the assessment of Southeast Alaska coho salmon fisheries and data collected at Auke Creek Research Station are reported to the Pacific Salmon Commission on a yearly basis (Pacific Salmon Commission 2021).

The abundance of coho smolt downstream migrants in 2020 (4467) was below the 1980-2019 average (6,004; Fig. 19; Appendix Table A-3). A total of 3 coho smolts migrated downstream migrated in April, 4,376 migrated in May, and 88 migrated in June. In 2020, 4,364 smolts were successfully marked by adipose fin clip, tagged with coded wires, and released. The 2020 year class consisted of approximately 1,608 age-1 smolts (2018 brood) and 2,859 age-2 smolts (2017 brood). Coho smolt abundance did not have a temporal trend between 1980 and 2020 by year class ($R2 = 0.08$, $P = 0.08$)

The 2017 brood production (4,112) was below the 1978 to 2016 average (5,990). Coho smolt abundance did not have a linear temporal trend by brood year ($R2 = 0.04$, $P = 0.22$).

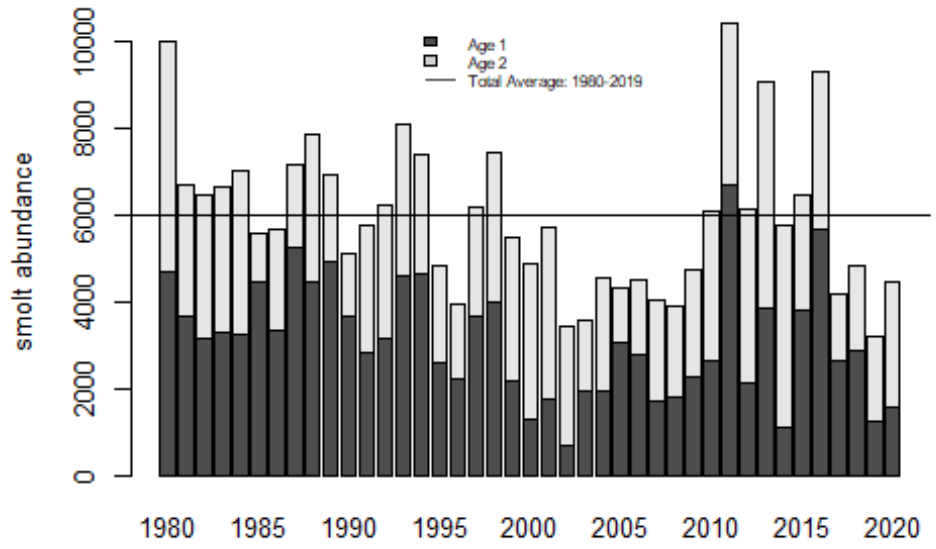

Figure 19. -- Yearly coho salmon smolt downstream migration abundance against year for age-1 and age-2 smolts at Auke Creek, 1980-2020.

The proportion of age-1 smolts has varied between 25.21% and 78.87% with an average of 52.17% for the 1978 to 2016 broods. The 2017 brood stock consisted of 30.47% age-1 smolts. Since 1978, coho smolts have exhibited a trend towards a lower proportion age-1 (0-yr, R2 = 0.12, P = 0.03; Fig. 20).

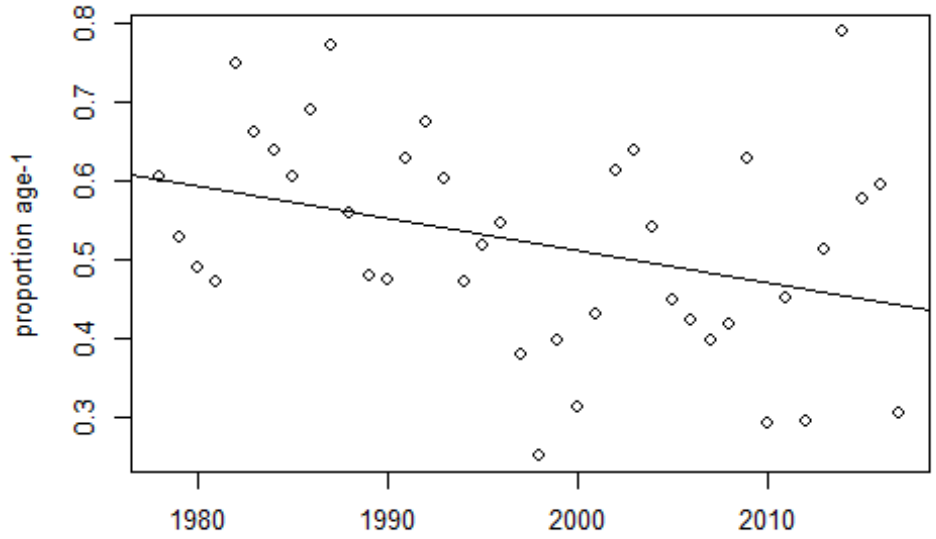

Figure 20. -- Yearly proportion of downstream migrant age-1 coho smolts (by brood year) against year and temporal trend, 1978-2017.

In 2020, the migration midpoint of age-2 smolts (16 May) was earlier than that of age-1 smolts (20 May; Fig. 21). The coho smolt migration midpoint in 2020 (17 May) was earlier than the 1980-2019 average (18 May). Coho smolt had a trend towards earlier migration midpoints since 1980 (-0.17 days-yr, R2 = 0.21, P = < 0.01; Fig. 22).

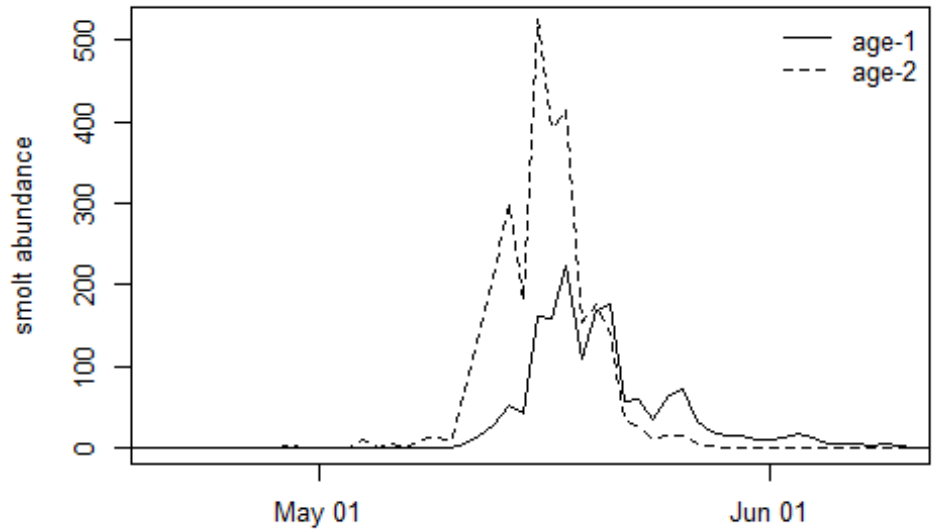

Figure 21. -- Daily coho salmon smolt downstream migration abundance against date for age-1 and age-2 smolts at Auke Creek in 2020.

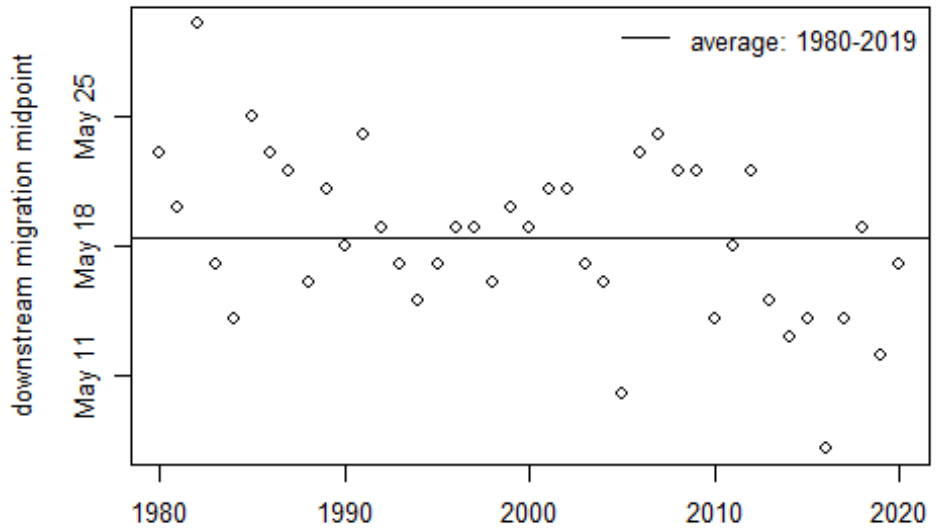

Figure 22. -- Yearly coho salmon smolt downstream migration midpoint dates against year at Auke Creek, 1980-2020.

In 2020, the average length and weight of both age-1 (97 mm, 9 gm) and age-2 (120 mm, 18 gm) smolts were near the 1980-2019 average for age-1 smolts (106 mm, 11 gm) and age-2 smolts (126 mm, 18 gm; Figs. 23 and 24). Age-2 smolts had no significant change in either length (R2 = 0.01, P = 0.46) or weight (R2 = 0, P = 0.88) between 1980 and 2020. Age-1 smolts also had no trends in length (R2 = 0, P = 0.85; Fig. 25) and weight (R2 = 0, P = 0.88; Fig. 26) since 1980.

The total biomass of coho smolts in 2020 (65 kg) was below the long-term average (87kg). Biomass did not have a temporal trend between 1980 and 2015 (R2 = 0.05, P = 0.18; Fig. 27).

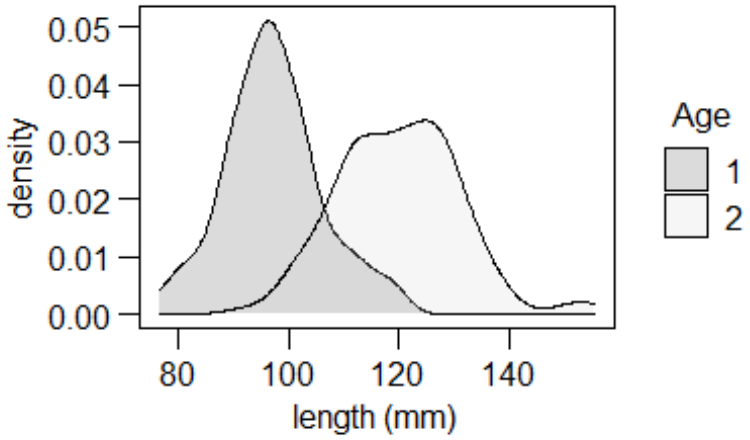

Figure 23. -- Frequency of downstream migrant coho salmon smolt lengths (mm) for age-1 and age-2 smolts at Auke Creek in 2020.

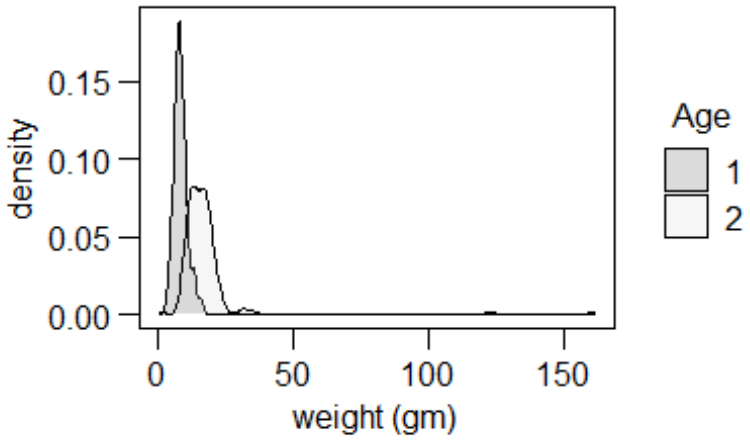

Figure 24. -- Frequency of downstream migrant coho salmon smolt weights (gm) for age-1 and age-2 smolts at Auke Creek in 2020.

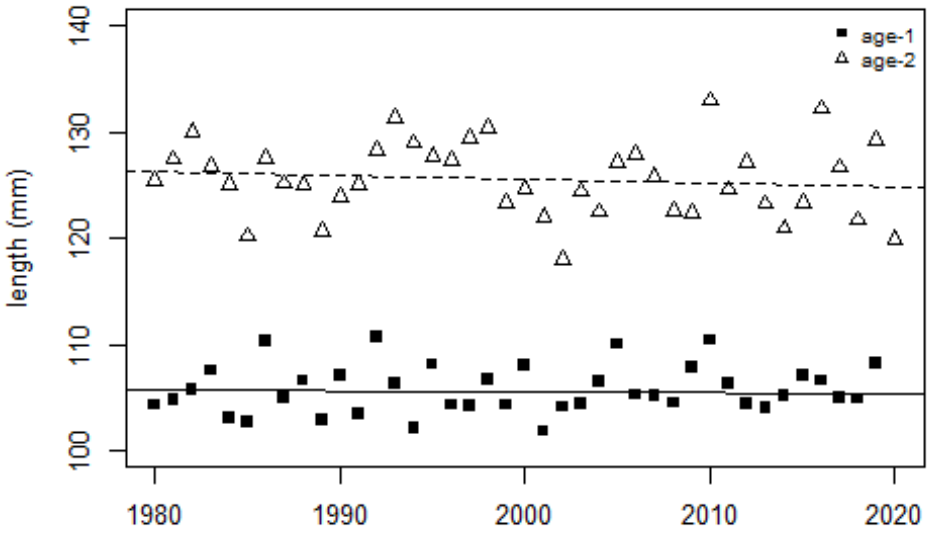

Figure 25. -- Yearly downstream migrant coho salmon smolt average length (mm) against year at Auke Creek for age-1 and age-2 smolts and temporal trends, 1980-2020. The trend line is solid for age-1 smolts and broken for age-2 smolts.

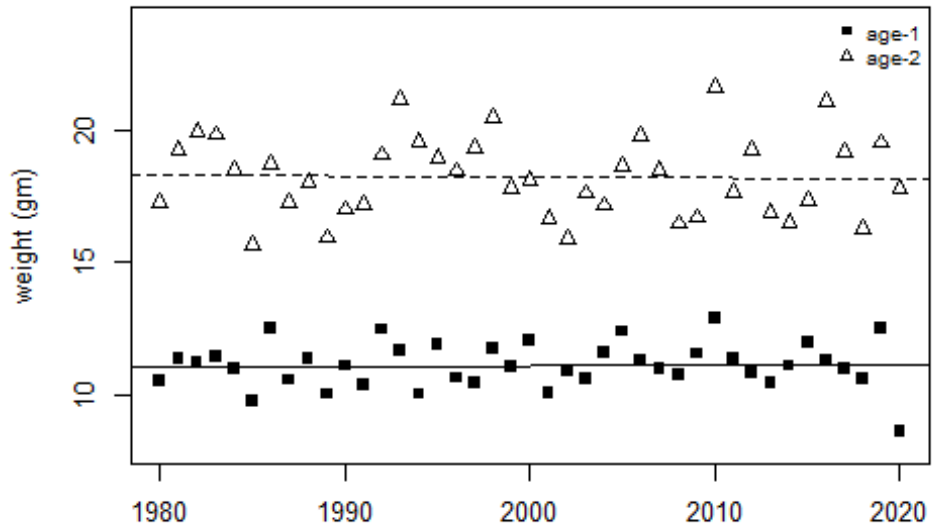

Figure 26. -- Yearly downstream migrant coho salmon smolt average weight (mm) against year at Auke Creek for age-1 and age-2 smolts and temporal trends, 1980-2020. The trend line is solid for age-1 smolts and broken for age-2 smolts

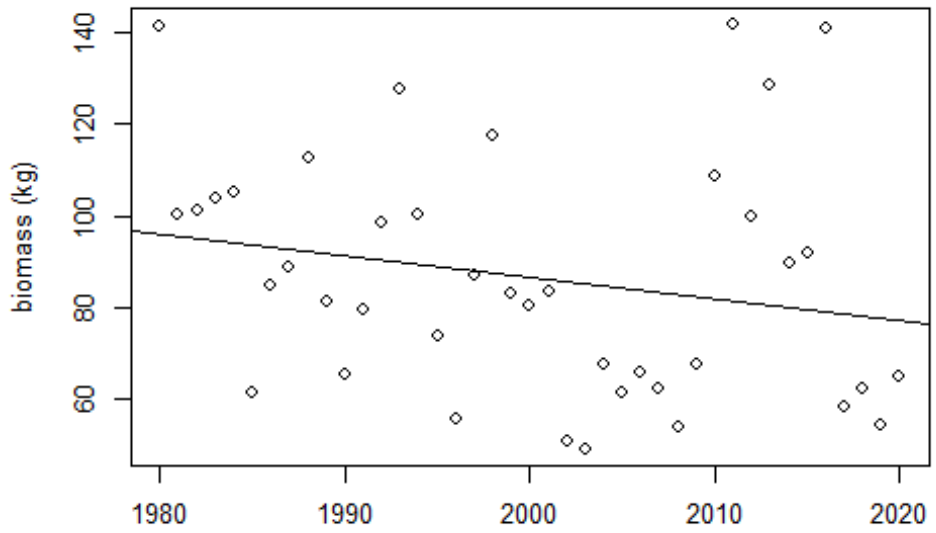

Figure 27. -- Yearly downstream migrant coho salmon smolt biomass (kg) against year at Auke Creek, 1980-2020.

The 2017 brood produced smolts per spawner (14.53) above the long-term average (10.19; Fig. 28). The 2017 brood produced fewer age-1 smolts per spawner (4.43) than the long-term average (5.4). Additionally, the 2017 brood produced more age-2 smolts per spawner (10.1) than the long-term average (4.79).

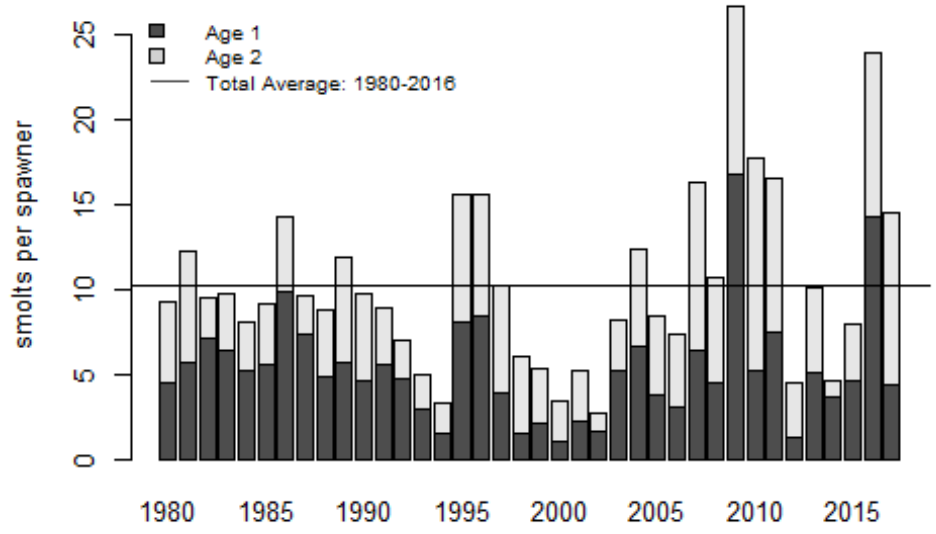

Figure 28. -- Yearly downstream migrant coho salmon smolts produced per spawner (by brood year) against year at Auke Creek, 1980-2017.

The abundance of upstream migrant adult coho salmon in 2020 (312) was lower than the 1980-2019 average (651; Appendix Table A-3). In 2020, a total of 56 coho adults migrated upstream in August, 231 migrated in September, and 25 migrated in October. The yearly abundance of upstream migrant coho salmon did not have a significant temporal trend from 1980 to 2020 ($R2 = 0.15$, $P = 0.01$).

The upstream migration midpoint for adult coho in 2020 (06 September) was earlier than the 1980-2019 average (19 September). Coho adults have a significant and dramatic trend

towards earlier migration midpoints between 1980 and 2020 (-0.45 days-yr, R2 = 0.71, P = < 0.01; Fig. 29).

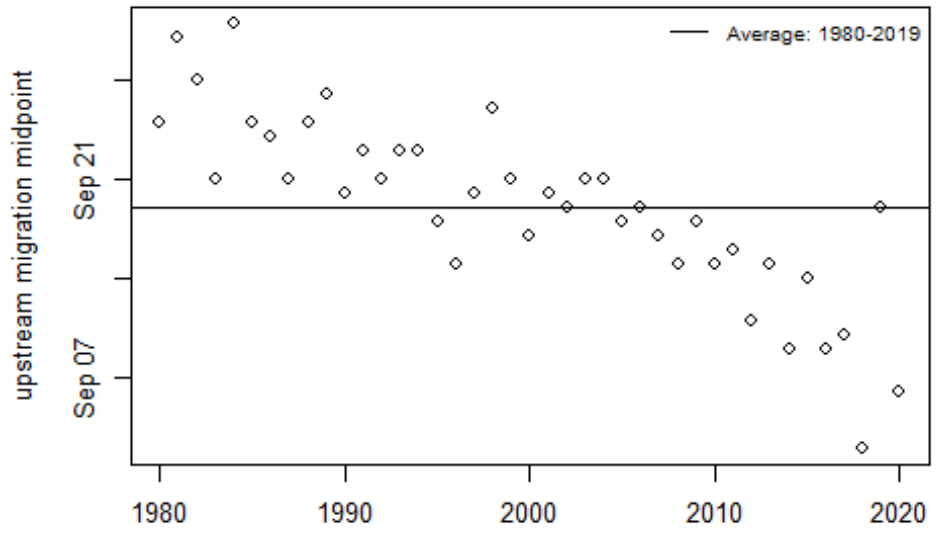

Figure 29. -- Yearly coho salmon adult upstream migration midpoint dates against year at Auke Creek and temporal trend, 1980-2020.

The estimated harvest of Auke Creek coho salmon in 2020 (11; Fig. 30; Appendix Table A-4) was lower than the 1980-2019 average (395). Likewise, the estimated harvest rate of Auke Creek coho salmon in 2020 (3.73%) was below the long-term average (29.38%). For 2020 returns, marine survival (9.12%) was below 1980-2019 average (21.72%).

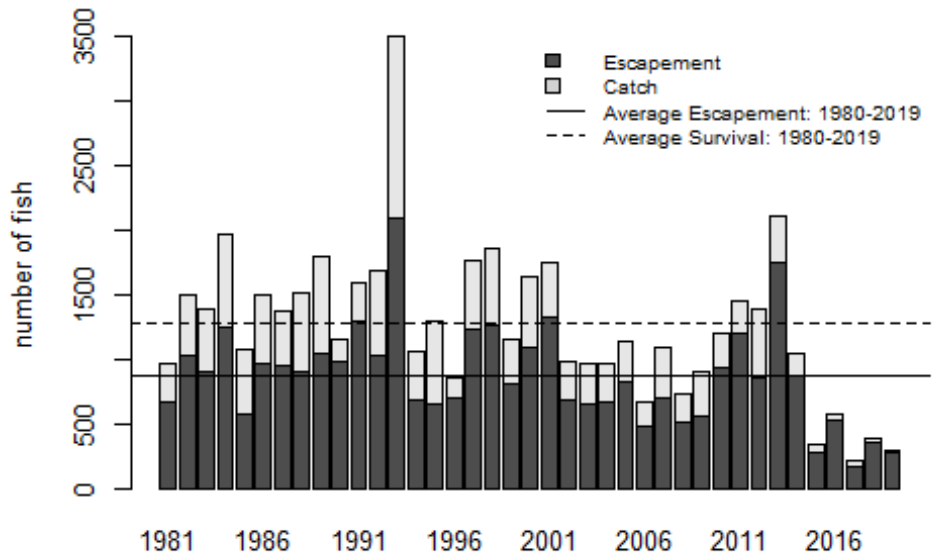

Figure 30. -- Yearly coho salmon smolt marine survival (returning adult abundance; by year of smolt migration) against year, including both catch (harvested adults) and escapement (weir captured adults), for coho salmon native to Auke Creek, 1981-2020.

Dolly Varden

The Auke Lake system is important for spawning, rearing, and over-wintering Dolly Varden in the Juneau area. Dolly Varden spawner numbers and smolt production in the Auke Lake watershed are not known. Since the reconfiguration of the upstream weir in 2007, the smallest Dolly Varden may have been able to pass the weir undetected during upstream migration, and censuses are not considered complete. Thus, we only present data for the downstream migration of Dolly Varden.

The Dolly Varden downstream migration abundance in 2020 (2,647) was below the 1980-2019 average (5,855; Fig. 31; Appendix Table A-6). A total of 1 Dolly Varden migrated downstream in February, 1 migrated in March, 434 migrated in April, 2,194 migrated in May, and 17 migrated in June. Dolly Varden downstream abundance did not have a linear trend between 1980 and 2020 ($R2 = 0.01$, $P = 0.61$). The Dolly Varden downstream migration

midpoint in 2020 (11 May) was later than the long-term average (07 May; Fig. 32). Downstream migration midpoints did not have a temporal trend between 1980 and 2020 (R2 = 0.02, P = 0.33).

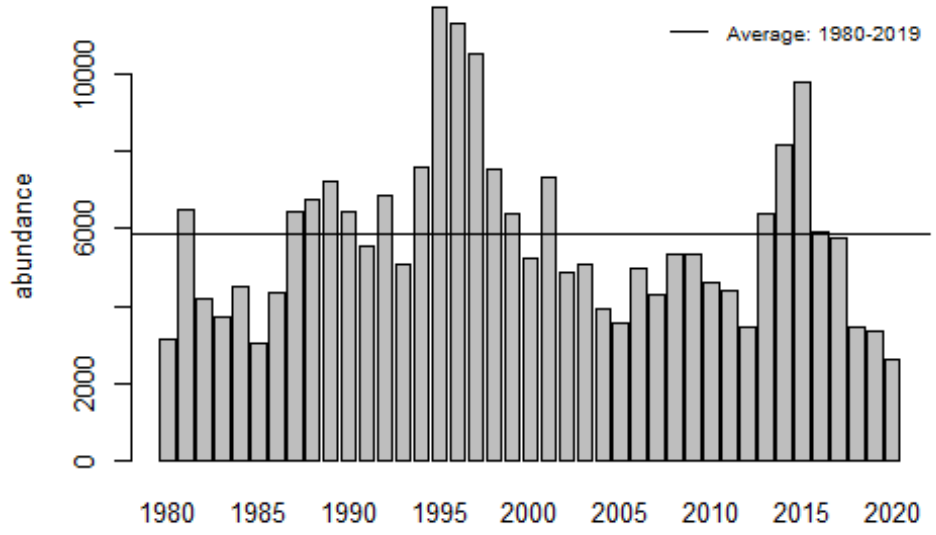

Figure 31. -- Yearly Dolly Varden downstream migration abundance against year at Auke Creek, 1980-2020.

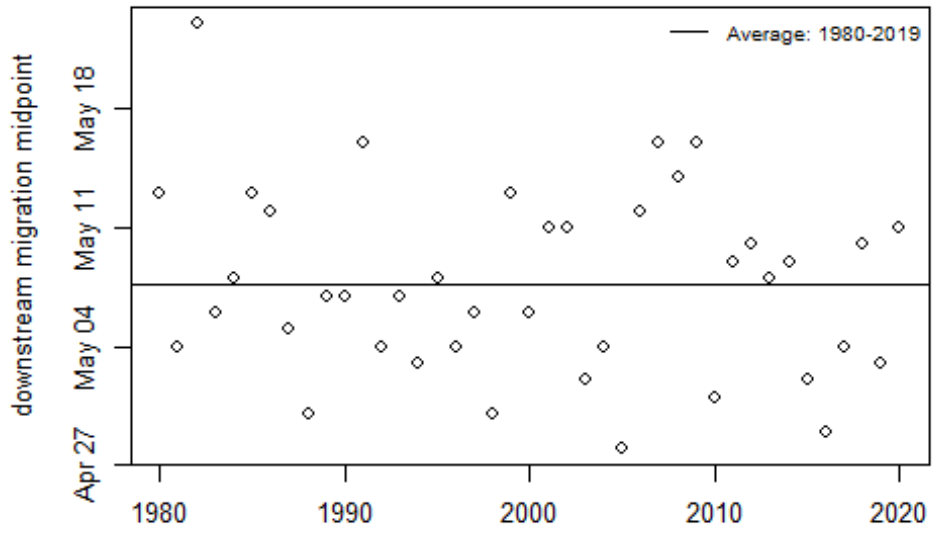

Figure 32. -- Yearly Dolly Varden downstream migration midpoint dates against year at Auke Creek, 1980-2020.

Cutthroat Trout

Little was known about the life history of cutthroat trout in the Auke Lake system before the start of tagging programs in 1994 and lake population estimates in 1998 (Lum and Taylor 2006). These projects and concurrent weir operations show that Auke Lake cutthroat have a complex life history involving anadromous components, freshwater residency, and use of other lake and stream systems in the nearby area. Upstream migration was fully enumerated from 1997 to 2006. Mature downstream migrants were spawned for hatchery incubation in 1981to 1982, 1985 to 1986, 1991, and 1993. The resulting progeny were fin marked, released in Auke Lake, and migrants were captured at the weir in subsequent downstream migrations. None of the cutthroat captured during the 2020 downstream migration were fin marked and had a detectable passive integrated transponder (PIT) tag that was implanted during the 2006 downstream season. Tagging of downstream migrant cutthroat trout has not been done since 2006.

The wild downstream migrant cutthroat count in 2020 (517) was the above the 1980-2019 average (345) (Fig. 33; Appendix Table A-7). A total of 24 migrated in April, 443 migrated in May, and 50 migrated in June. Cutthroat trout abundance shows an increasing trend between 1980 and 2020 (2.96 total-yr, $R2 = 0.04$, $P = 0.22$).

The downstream migration midpoint of cutthroat trout in 2020 (20 May) was later than the long-term average (13 May). Cutthroat trout downstream migration shows no significant temporal trends since 1980 ($R2 = 0.09$, $P = 0.05$; Fig. 34).

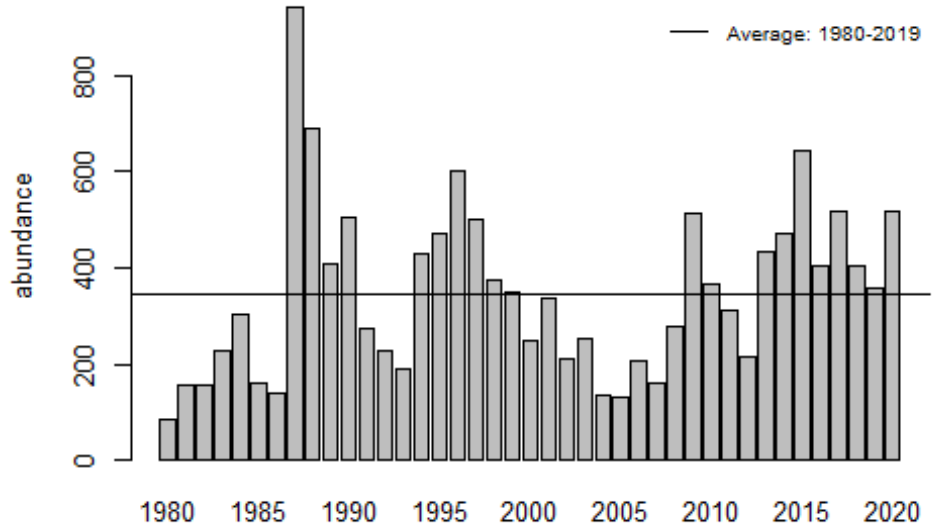

Figure 33. -- Yearly cutthroat trout downstream migration abundance against year at Auke Creek, 1980-2020.

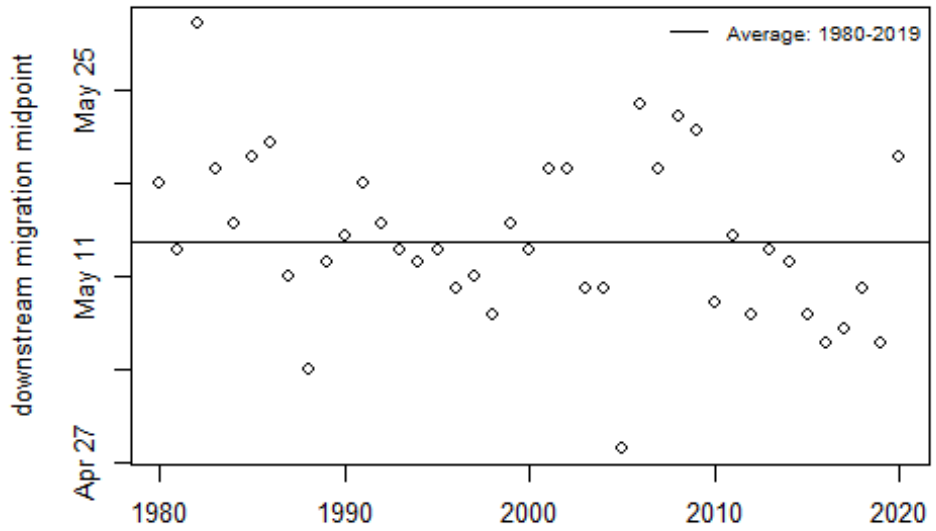

Figure 34. -- Yearly cutthroat trout downstream migration midpoint dates against year at Auke Creek, 1980-2020.

Chum Salmon

It is not known if chum salmon encountered at the Auke Creek weir are native to Auke Creek or strays from other local systems. Probably few chum salmon were ever produced in the Auke Lake system, although adults were observed in all spawning areas, including the intertidal. From 1976 to 1985, NMFS conducted chum salmon enhancement projects, and examined the use of a small population for brood stock development, marine survival of juveniles, and the heritability of age at maturity. Hatchery chum salmon fry were released in 1977-84 and 1986. All hatchery fry, except in 1984, were marked by ventral fin clip or adipose fin clip and coded wire tag. No adults were released in Auke Creek from 1976 to 1983. In those years all chum adults were captured and spawned for hatchery incubation, thus, no wild fry were captured at Auke Creek from 1977 to 1984. Chum salmon adults seen at Auke Creek since 1994 are most likely strays from releases of Macaulay hatchery juveniles at Amalga Harbor and other local release sites.

In 2020, the abundance of adult chum salmon was 376. Based on run timing and chum salmon adult abundance, it is suspected that most of the adults were strays from Macaulay hatchery releases. Before 1994, chum salmon in Auke Creek typically migrated after during the last week of August of early September and were much smaller in size than the suspected strays that currently migrate earlier in the year. In an effort to minimize the impact of such a large number of strays, only fish believed to be endemic to Auke Creek were allowed to spawn in 2019. In 2019 there were no chum that fit this criteria so 0 chum were passed upstream of the weir to spawn. Therefore, 0 chum fry were seen in the spring of 2020. Due to the confusion surrounding adult chum salmon in Auke Creek, historical averages also have little meaning.

Wild and hatchery adults are differentiated as accurately as possible; September upstream migrants are typically counted as wild.

Chinook Salmon

Chinook salmon are not native to the Auke Lake system. Chinook captured at Auke Creek are hatchery fish from releases of juveniles in the Juneau area, including Auke Bay near Auke Creek. Those releases began as a three-year cooperative study in 1986 to examine survival, homing, and straying of hatchery Chinook. The original study plan and fish transport permit required that all Chinook be killed when they entered Auke Creek. This was to prevent the ingress of Chinook to the Auke Lake system, as well as prevent the potential transport of infectious hematopoietic necrosis (IHN) virus. The project continues under an arrangement between Sport Fish Division, ADFG, and Douglas Island Pink and Chum Incorporated.

At Auke Creek, Chinook are captured at the weir and classed as mini-jacks or adults based on length. All mini-jacks are precocious males < 250 mm fork length that mature and return to fresh water the same year they are released. Adults are > 250 mm and remain at large for one year or more. In 2020, Chinook mini-jacks numbered 1 and adult Chinook numbered 46 (Fig. 35; Appendix Table A-5).

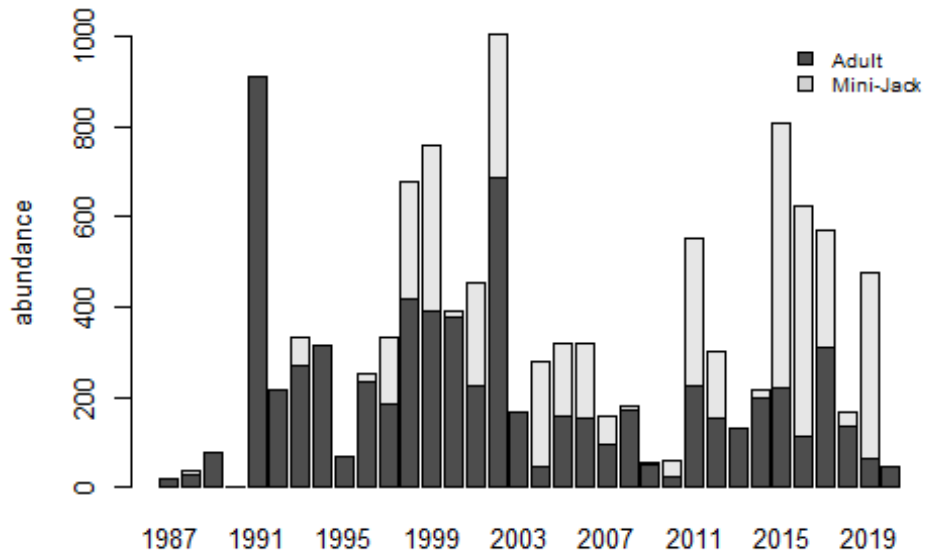

Figure 35. -- Yearly Chinook salmon immigration abundance against year for mini-jacks and adults at Auke Creek, 1987-2020.

Climate Observation

The average annual temperature of Auke Creek has increased over the last 36 years (0.02°C yr-1, R2 = 0.17, P = 0.01; Fig. 36). Temperatures increased during both the downstream (0.02°C yr-1, R2 = 0.05, P = 0.14) and upstream migration periods (0.02°C yr-1, R2 = 0.15, P = 0.01; Fig. 37). Furthermore, average and maximum temperatures had positive temporal trends for all months from 1980 to 2019. In addition to warming, creek temperatures appear to have become more variable from May through September, months in which much of annual migrations occur.

The average temperature of Auke Creek in 2020 (7.2°C) was cooler than the 1980-2019 average (7.8°C). Temperature during the 2020 downstream migration period (March-June) was below the 1980-2019 average by 0.8°C (Fig. 38). However, temperatures during the 2020 upstream migration period (July-October) were generally near the 1980-2019 average. The ice-

out date of Auke Lake in 2020 (01 May) was 16 days later than the 1980-2019 average (16 April; Fig. 39).

The average gauge height in Auke Creek during 2020 (21.75 ft) was near the 2006-2019 average (21.69 ft; Fig. 40).

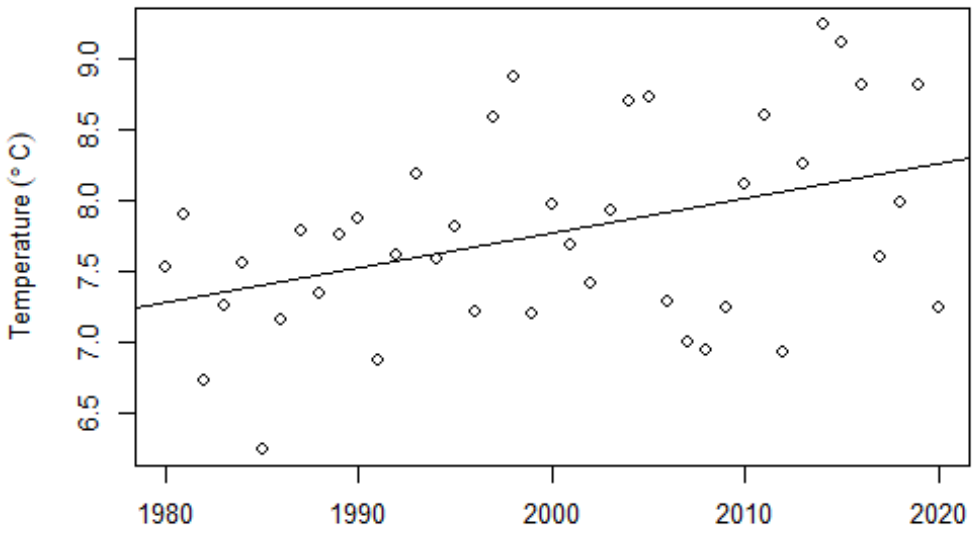

Figure 36. -- Average yearly temperature against year for Auke Creek and temporal trend, 1980-2020.

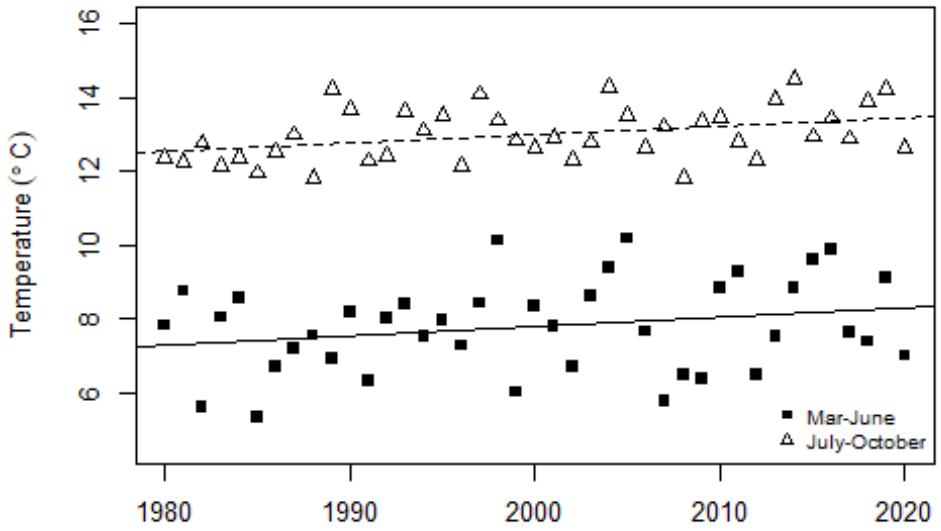

Figure 37. -- Average temperature during downstream (1 Mar. – 30 Jun.) and upstream migration periods (1 Jul. – 31 Oct.) against year for Auke Creek and temporal trends, 1980-2020. The trend line is solid for downstream migration and broken for upstream migration.

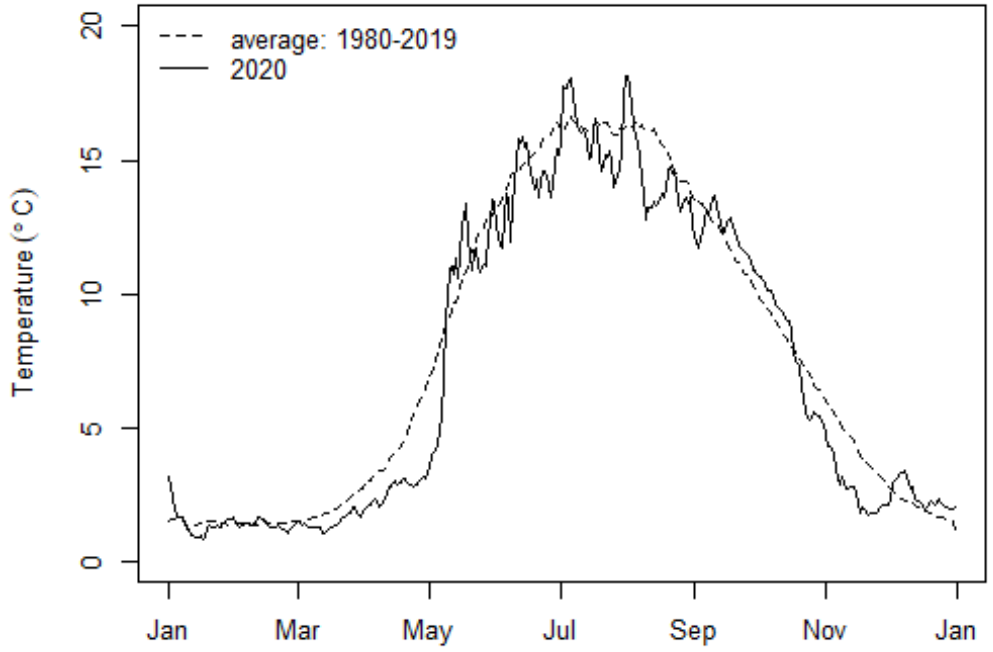

Figure 38. -- Average daily Auke Creek temperatures (°C) against date for 2020 and the 1980-2019 average.

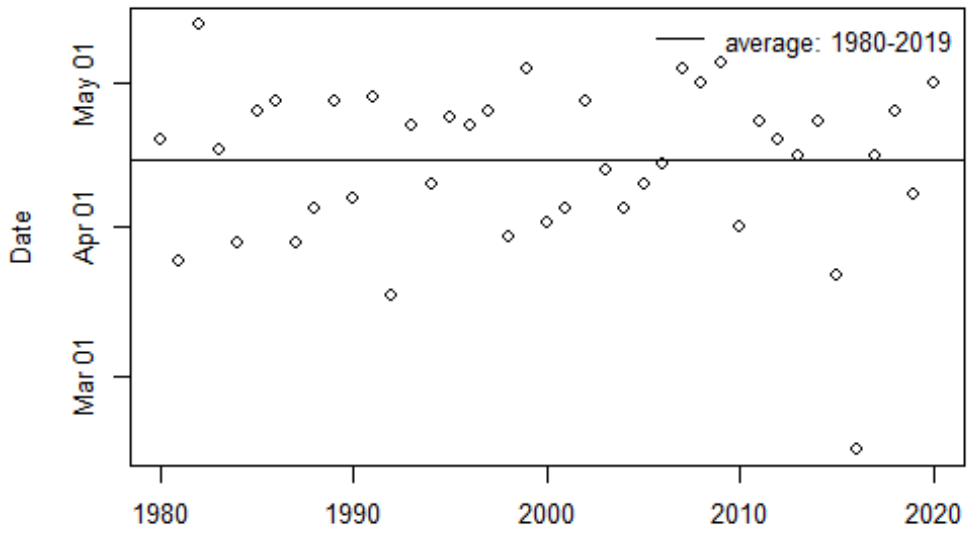

Figure 39. -- Dates of Auke Lake ice-out against year, 1980-2020.

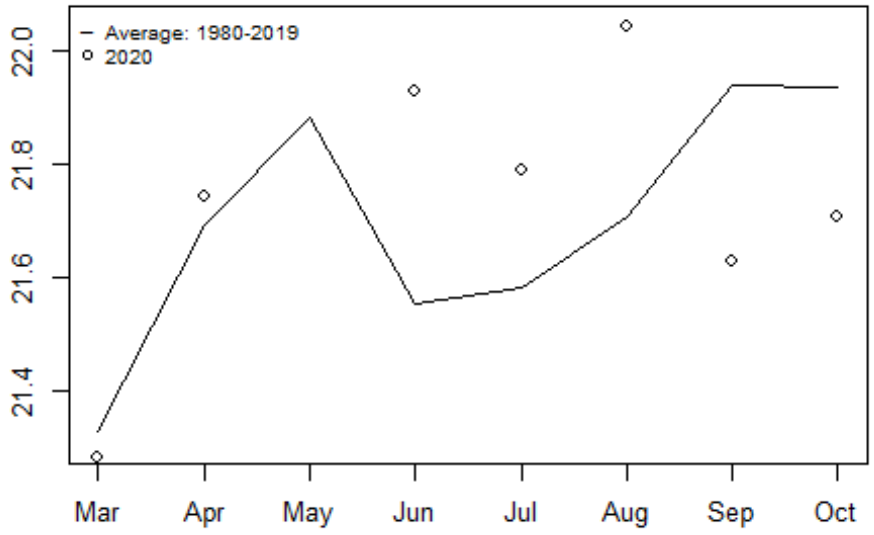

Figure 40. -- Average monthly gage height against month in Auke Creek for 2020 and the 1980-2019 average.

Discussion

The use of Auke Creek coho salmon as a Southeast Alaska wild indicator stock allows comparison to other regional stocks and helps inform management in the Transboundary River and Northern Boundary areas of the Pacific Salmon Treaty. The below average exploitation rate of Auke Creek coho in 2020 was similar to the other two wild indicator stocks in Southeast Alaska, Berners River and Hugh-Smith Lake. Below average marine survival among Southeast Alaska coho stocks in 2020 was also a consistent trend, where smolt to adult survival has been at low levels for the last five years (PSC 2021). Escapement levels, however, were more variable among systems in Southeast Alaska. Auke Creek coho failed to meet the lower bound of the biological escapement goal in 2020, along with the Chilkat River, Berners River, and Peterson Creek in Northern Southeast Alaska, and Hugh-Smith Lake in Southern Southeast Alaska. Two monitored systems in Northern Southeast Alaska saw coho escapements that fell within their biological escapement goal ranges, Taku River and Montana Creek (PSC 2021).

Rising temperatures in Auke Creek over the last 41 years appear to have had numerous influences on salmonids. Trends towards earlier migration midpoints have been reported previously across multiple species during both upstream and downstream migration in Auke Creek (Taylor 2008; Kovach et al. 2013). This trend has continued during recent years with 2020 again having some of the earliest migrations on record. Adult sockeye salmon were the only species and life history stage that was reported to be occurring significantly later (Kovach et al. 2013). However, over the last several years adult sockeye salmon have been migrating upstream earlier than average, and sockeye adults now also appear to have a trend towards earlier migration.

Additionally, trends toward higher proportion age-2 smolts and larger smolt sizes have been documented for both coho and sockeye salmon (Kovach et al. 2014). Data in recent years, including 2020, are consistent with these trends, though a higher proportion of age-1 coho smolts was seen in 2020. In 2020, lengths and weights were above average for sockeye and coho. The higher proportion age-2 and large size of smolts has also increased biomass for outmigrating sockeye salmon. Although coho biomass does not have a strong temporal trend since 1980, coho biomass has been below average for the last four years. Adult pink returns during the 2020 season were well below average.

Although warming conditions in Auke Creek have been associated with changing biological conditions, the abundance of almost all species has remained stable since 1980, the only exception being even-year brood pink fry which appear to have decreased in abundance. Salmon populations in Auke Creek thus appear to have been resilient to the changing environmental conditions thus far. Resiliency of Auke Creek salmon may be due to intra-specific and inter-specific diversity of salmon, as well as habitat diversity in the Auke Lake system. Continued monitoring of Auke Creek salmon will be necessary to understand whether populations will remain resilient during future warming.

Citations

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Appendix

Appendix Table A-1. -- Yearly abundance of pink salmon downstream migrant fry and upstream migrant adults at Auke Creek, 1980-2020.

Year	Fry	Adults
1980	74047	18875
1981	110552	12047
1982	119548	9232
1983	164784	21563
1984	169552	4437
1985	110001	24118
1986	123887	2007
1987	43502	6922
1988	111932	6787
1989	116873	4299
1990	96654	19589
1991	242771	5566
1992	98449	21319
1993	237073	1637
1994	11603	21312
1995	88197	1548
1996	41359	3858
1997	31092	2666
1998	60785	2267
1999	53535	28127
2000	132075	2180
2001	61504	7857
2002	150149	4923
2003	95132	10576
2004	169568	6798
2005	87928	10004
2006	65889	12895
2007	81899	2930
2008	117591	3133
2009	34847	8698
2010	121639	5835
2011	30924	26995
2012	61802	5890
2013	51191	9211
2014	47350	584
2015	14178	25235
2016	100198	667
2017	18105	10711
2018	31540	351
2019	6309	2094
2020	46129	1304
Average	88589	9196

Appendix Table A-2. -- Yearly abundance of sockeye salmon downstream migrant smolts and upstream migrant adults at Auke Creek, 1980-2020.

Year	Age 1 Smolt	Age 2 Smolt	Total Smolts	Adults	Jacks	Total Adults
1980	24988	311	25299	4553	17	4570
1981	7870	1313	9183	4021	68	4089
1982	1460	159	1619	1295	39	1334
1983	2674	507	3181	1800	5	1805
1984	20067	184	20251	964	11	975
1985	2438	9309	11747	240	85	325
1986	5353	9150	14503	952	81	1033
1987	2051	15547	17598	2829	67	2896
1988	13088	983	14071	1338	54	1392
1989	2626	10806	13432	2508	299	2807
1990	1282	13773	15055	3297	155	3452
1991	16683	9174	25857	2587	177	2764
1992	10008	3240	13248	1260	408	1668
1993	24648	8968	33616	2989	69	3058
1994	5796	26213	32009	3699	170	3869
1995	499	17358	17857	3224	147	3371
1996	2013	5056	7069	5998	125	6123
1997	7590	6258	13848	4671	34	4705
1998	16404	6092	22496	2068	71	2139
1999	22952	2297	25249	1572	109	1681
2000	3423	10276	13699	2480	33	2513
2001	8993	12435	21428	3963	46	4009
2002	7318	10276	17594	2882	130	3012
2003	12103	9051	21154	3239	158	3397
2004	5582	15524	21106	2958	20	2978
2005	2395	6118	8513	2879	140	3019
2006	6903	18612	25515	1848	20	1868
2007	4344	9372	13716	2754	188	2942
2008	1011	8827	9838	1223	37	1260
2009	1105	6535	7640	4001	47	4048
2010	288	7505	7793	2018	45	2063
2011	24860	7585	32445	2308	118	2426
2012	3853	19084	22937	1516	53	1569
2013	12811	5998	18809	1953	107	2060
2014	3164	18293	21457	3345	98	3443
2015	3795	8519	12314	4589	131	4720
2016	8894	9592	18486	2501	18	2519
2017	9655	4010	13665	3624	42	3666
2018	3794	8886	12680	911	12	923
2019	30	4696	4726	1081	23	1104
2020	1094	6253	7347	771	4	775
Average	7705	8638	16343	2554	89	2643

Appendix Table A-3. -- Yearly abundance of coho salmon downstream migrant smolts and upstream migrant adults at Auke Creek, 1980-2020.

Year	Age 1 Smolt	Age 2 Smolt	Total Smolts	Adults	Jacks	Total Adults
1980	4714	5308	10022	698	266	964
1981	3667	3061	6728	578	217	795
1982	3176	3279	6455	462	339	801
1983	3325	3316	6641	694	261	955
1984	3282	3730	7012	651	315	966
1985	4494	1107	5601	942	123	1065
1986	3378	2288	5666	453	307	760
1987	5262	1917	7179	661	204	865
1988	4468	3420	7888	744	405	1149
1989	4921	2012	6933	501	369	870
1990	3678	1454	5132	680	163	843
1991	2859	2905	5764	818	314	1132
1992	3154	3108	6262	988	169	1157
1993	4611	3492	8103	859	662	1521
1994	4683	2730	7413	1437	229	1666
1995	2611	2258	4869	459	185	644
1996	2237	1725	3962	469	144	613
1997	3696	2511	6207	558	375	933
1998	3993	3437	7430	862	422	1284
1999	2179	3312	5491	844	150	994
2000	1331	3560	4891	669	227	896
2001	1794	3948	5742	865	155	1020
2002	726	2708	3434	1168	103	1271
2003	1982	1592	3574	584	244	828
2004	1979	2602	4581	415	222	637
2005	3067	1251	4318	450	256	706
2006	2794	1738	4532	581	141	722
2007	1713	2358	4071	352	106	458
2008	1802	2095	3897	599	110	709
2009	2284	2458	4742	401	150	551
2010	2681	3439	6120	418	419	837
2011	6714	3721	10435	516	376	892
2012	2168	3975	6143	835	121	956
2013	3855	5222	9077	736	214	950
2014	1119	4674	5793	1533	301	1834
2015	3811	2671	6482	576	78	654
2016	5692	3628	9320	204	252	456
2017	2653	1525	4178	283	21	304
2018	2900	1944	4844	146	13	159
2019	1253	1982	3235	345	111	456
2020	1608	2859	4467	173	139	312
Average	3130	2837	5967	639	229	868

Appendix Table A-4. - - Yearly marine survival of coho salmon smolts tagged with coded wires at Auke Creek by year of smolt migration, 1981-2019.

Year	Smolts	Adults	Jacks	Escapement	Catch	Total Return	Percent Catch	Marine Survival
1981	6728	462	217	679	290	969	29.9	14.40
1982	6455	694	339	1033	473	1506	31.4	23.33
1983	6641	651	261	912	488	1400	34.9	21.08
1984	7012	942	315	1257	710	1967	36.1	28.05
1985	5601	453	123	576	498	1074	46.4	19.18
1986	5666	661	307	968	531	1499	35.4	26.46
1987	7178	744	204	948	433	1381	31.4	19.24
1988	7888	501	405	906	616	1522	40.5	19.30
1989	6933	680	369	1049	750	1799	41.7	25.95
1990	5132	818	163	981	183	1164	15.7	22.68
1991	5764	988	314	1302	296	1598	18.5	27.72
1992	6262	859	169	1028	654	1682	38.9	26.86
1993	8103	1437	662	2099	1403	3502	40.1	43.22
1994	7413	459	229	688	369	1057	34.9	14.26
1995	4869	469	185	654	638	1292	49.4	26.54
1996	3962	558	144	702	162	864	18.8	21.81
1997	6207	862	375	1237	533	1770	30.1	28.52
1998	7430	844	422	1266	600	1866	32.1	25.11
1999	5491	669	150	819	334	1153	29.0	21.00
2000	4891	865	227	1092	553	1645	33.6	33.63
2001	5742	1168	155	1323	425	1748	24.3	30.44
2002	3434	584	103	687	302	989	30.5	28.80
2003	3574	415	244	659	315	974	32.3	27.25
2004	4581	450	222	672	299	971	30.8	21.20
2005	4318	581	256	837	298	1135	26.3	26.29
2006	4532	352	141	493	184	677	27.2	14.94
2007	4071	599	106	705	394	1099	35.9	27.00
2008	3897	401	110	511	233	744	31.3	19.09
2009	4742	418	150	568	346	914	37.9	19.27
2010	6120	516	419	935	277	1212	22.9	19.80
2011	10435	835	376	1211	244	1455	16.8	13.94
2012	6143	736	121	857	531	1388	38.3	22.59
2013	9077	1533	214	1747	370	2117	17.5	23.32
2014	5793	576	301	877	173	1050	16.5	18.13
2015	6482	204	78	282	66	348	19.0	5.37
2016	9320	283	252	535	41	576	7.1	6.18
2017	4178	146	21	167	50	217	23.0	5.19
2018	4844	345	13	358	41	399	10.3	8.24
2019	3235	173	111	284	11	295	3.7	9.12
Average	5901	639	230	869	388	1257	29.0	21.00

Appendix Table A-5. -- Yearly Chinook salmon upstream migration abundance at Auke Creek, 1987-2020. Mini-jacks returned the same year of smolt release, adults returned 1 or more years later.

Year	Mini Jacks	Adults
1987	0	18
1988	9	27
1989	0	77
1990	0	0
1991	0	912
1992	0	214
1993	62	272
1994	2	314
1995	0	68
1996	15	236
1997	149	183
1998	264	416
1999	367	392
2000	15	377
2001	228	224
2002	319	687
2003	0	165
2004	232	46
2005	162	158
2006	165	152
2007	63	96
2008	8	173
2009	2	52
2010	36	22
2011	329	225
2012	148	155
2013	1	132
2014	18	198
2015	589	219
2016	508	115
2017	263	309
2018	33	135
2019	413	65
2020	1	46
Average	129	202

Appendix Table A-6. -- Yearly Dolly Varden downstream migration abundance at Auke Creek, 1980-2020.

Year	Total
1980	3132
1981	6472
1982	4172
1983	3718
1984	4512
1985	3052
1986	4358
1987	6443
1988	6770
1989	7230
1990	6426
1991	5559
1992	6839
1993	5075
1994	7604
1995	11732
1996	11323
1997	10506
1998	7532
1999	6393
2000	5254
2001	7356
2002	4858
2003	5067
2004	3955
2005	3544
2006	4975
2007	4300
2008	5364
2009	5319
2010	4625
2011	4382
2012	3472
2013	6405
2014	8187
2015	9805
2016	5899
2017	5756
2018	3449
2019	3370
2020	2647
Average	5777

Appendix Table A-7. -- Yearly cutthroat trout downstream migration abundance at Auke Creek, 1980-2020.

Year	Total
1980	85
1981	157
1982	157
1983	228
1984	304
1985	161
1986	138
1987	942
1988	690
1989	410
1990	506
1991	273
1992	227
1993	190
1994	431
1995	470
1996	601
1997	500
1998	374
1999	351
2000	250
2001	337
2002	210
2003	254
2004	136
2005	133
2006	208
2007	162
2008	276
2009	515
2010	364
2011	312
2012	217
2013	434
2014	470
2015	645
2016	405
2017	518
2018	405
2019	357
2020	517
Average	349

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