Klawock Lake Sockeye Salmon Retrospective Analysis

2016

By

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ACKNOWLEDGEMENTS

We would like to thank Meg Cartwright, Jeff Lundberg (POWHA), Steve Heinl (ADF&G), Jan Conitz (ADF&G), Neil Stichert (USFWS), Lauren Sill (ADF&G), Dennis Landwehr (USFS), Jeff Nichols (ADF&G), Jeff Reeves (USFS), Shiela Jacobson (USFS), Norman Cohen (TNC), and Michael Kampnich (TNC) for their thorough review and ongoing support during the writing of this retrospective analysis. Other helpful information and support was provided by Scott Walker (ADF&G), Mark Minnillo (ADF&G), Mary Edenshaw (Klawock Heenya Corporation), Ann Wyatt (Klawock Cooperative Association), Cathy Needham (Kai Environmental), Andy Piston (ADF&G), Ryan Kovach (USFS), David Barto (USFS), Colin Shanley (TNC), Mary Richards (TNC), Serena Olive (ADF&G), Flip Pryor (ADF&G), and Chuck Guthrie (NOAA). We would also like to thank funders who provided support for this report; it was funded in part by the Gordon and Betty Moore Foundation and additional funds were provided by a subaward through the North Pacific Research Board.

Table of Contents

TABLE OF TABLES

Table of Figures

EXECUTIVE SUMMARY

Sockeye salmon from Klawock Lake have been important to people on Prince of Wales Island for thousands of years. Although the abundance of Klawock sockeye salmon has not been consistently monitored over this time period, it is evident that abundance over the last two decades is significantly less than historical values, and this has been a concern of local residents for some time. Because of these declines, there have been many previous efforts to address declines through research and management. This retrospective analysis serves as a single source of information regarding the many research, management, assessment, and watershed restoration projects that concern Klawock Lake sockeye salmon, presenting many of the relevant data and conclusions about Klawock Lake sockeye and the factors that may influence their productivity. Review of this previous research reveals that multiple factors likely conspire to influence the sockeye decline, and that while various research efforts have been completed over the years, significant data gaps still exist. Because climatic influences on sockeye salmon productivity are complex and ecosystem dynamics may be highly variable between individual systems, it is likely that some of the decline in sockeye productivity can be explained by natural causes. Long-term datasets on harvest and escapement, as well as lake and ocean conditions are not currently available, but would provide better insight into the relative importance of these factors. It is also likely that historic timber harvest practices have negatively impacted sockeye salmon spawning potential. Although a large amount of restoration in the watershed has likely been positive for fish habitat, a targeted systematic analysis of restoration most likely to benefit the most important sockeye spawning areas would be beneficial. The extent and effect of predation of juvenile sockeye, both by hatchery-produced coho salmon and other predators, is also largely unknown and should be assessed. If predation is determined to be an important factor, then attempting to adjust temporal or spatial overlap between predators and juvenile sockeye could be effective. Improvements to harvest management could be considered, including validation of harvest and escapement estimates, estimation of the contribution of the commercial fishery to total harvest, and a management regime to encourage a locally-driven conservation-based approach to harvest, especially in years with poor sockeye returns. To be effective, research and management activities will require a collaborative approach between multiple stakeholders to ensure lasting results.

Introduction

Sockeye salmon from Klawock Lake (Figure 1) have been important to people on Prince of Wales Island for thousands of years, serving as a food source for Tlingit settlers (Ratner et al. 2006), a robust commercial fishery from the 1880s-1940s (Langdon 1977; Moser 1898), and supporting an economically and culturally important subsistence fishery to the residents of Klawock and Craig (Alaska Department of Fish and Game 2015; Fall et al. 2014; Prince of Wales Watershed Association 2014; Ratner et al. 2006). Although the abundance of Klawock sockeye salmon has not been consistently or accurately monitored during this time period, it is evident that abundance over the last two decades is significantly less than historical values, and this has been a concern of local residents for some time.

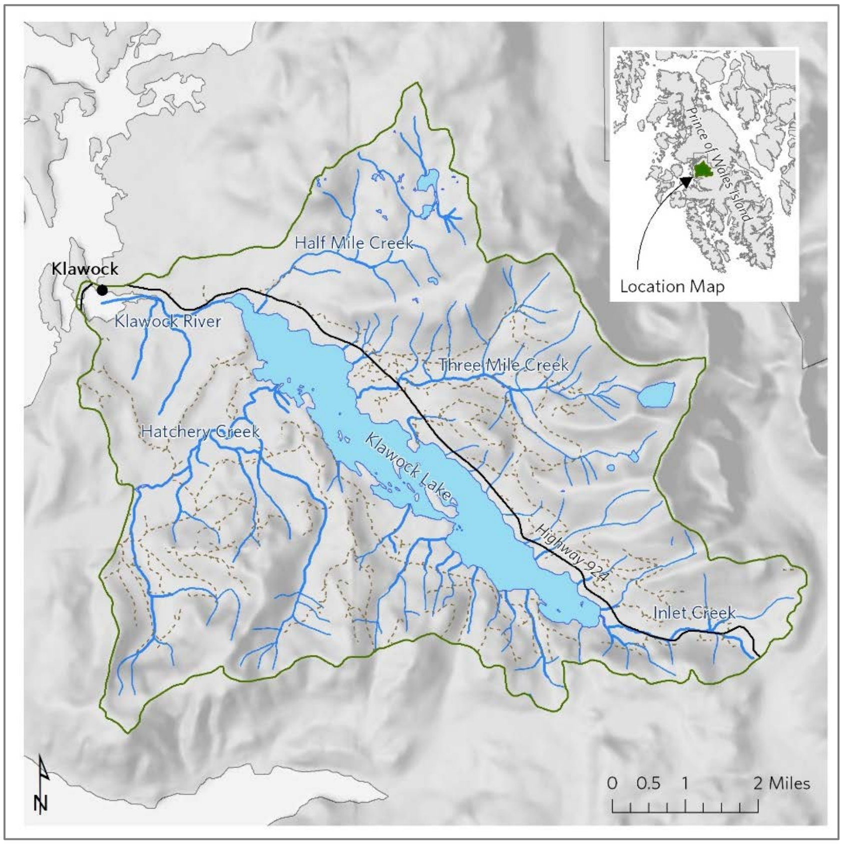

Figure 1. The Klawock Lake watershed on Prince of Wales Island.

Because declines have been apparent for several decades, there have been many previous efforts to address declines through research and management in the past. However, to date, there has been no single source of information regarding the many research, management, and watershed restoration projects that concern Klawock Lake sockeye salmon. This report begins by providing a historical account of Klawock Lake sockeye management and research, providing one location where all relevant citations can be found. It also attempts to compile results from projects, portions of which are often found within many reports but not always compiled into a single report. It also serves as a repository of unpublished or hard-to-find historical datasets within its appendices. Finally, this document attempts to synthesize all of this information and suggest potential future research and management actions to address sockeye salmon decline. With renewed interest in sockeye populations in Klawock Lake, this document can serve as an historical reference and potential blueprint for those hoping to improve sockeye salmon abundance in the future.

History of Klawock Lake sockeye management and research

Human habitation of the Klawock watershed on Prince of Wales Island by the Tlingit people began at least 6,000 years ago, and it is likely that salmon were a crucial part of their diet at this time (Ratner et al. 2006). Fish weirs and traps capable of harvesting mass quantities of salmon have been found on Prince of Wales Island as old as 3,800 years (Moss 1998).

Early history of sockeye salmon commercial fishing in the area began soon after the United States purchased Alaska from Russia in 1867. A saltery was established in Klawock in 1872, which was converted to one of the first Alaskan salmon canneries in 1878. Documented history of commercial harvest was sporadic before 1930, although Moser (1898) and Rich and Ball (1933) provide historical review of early commercial harvest and management. Early commercial fishermen used beach seines for harvesting near estuaries and stream mouths, but the mackerel purse seine, used in Southeast Alaska for the first time in 1893, allowed for more efficient harvesting in open water areas (Ratner et al. 2006). By the 1910s, it was common practice to barricade streams completely to harvest all salmon at that time using fish traps, but as the salmon run declined in Klawock, in-river barricades were removed and the system was not fished as extensively. Harvests as large as 62,000 fish were recorded during this era (see "Commercial harvest"). The first hatchery was built in Klawock for sockeye production in 1897 and was abandoned in 1917 (Roppel 1982). The years from 1921 to 1940 are considered the "boom period" of the Klawock fisheries (Langdon 1977), and the minimum sockeye escapement into the lake was estimated intermittently from 1930-1938 (Lewis & Zadina 2001).

The commercial fishery of Klawock declined from 1941 to 1958 (Langdon 1977). Fish traps were outlawed in 1958 and a limited entry permit system was enacted in 1973, resulting in continuing decline of commercial harvest of Klawock sockeye salmon. A new hatchery was built in Klawock in 1976 to produce chum salmon, coho salmon, and later sockeye salmon and this hatchery has been operated through current day by the Alaska Department of Fish and game (ADF&G; 1977-1993); the cities of Klawock and Craig (1994-1996), and the Prince of Wales Hatchery Association (POWHA; 1996-2015). Meanwhile, commercial logging operations on Prince of Wales Island were ramping up during this era, resulting in road building, including a major roadway along the north shore of Klawock Lake. After the passage of the Alaska Native Claims Settlement Act in 1971, the Klawock-based Alaska Native village corporation, Klawock Heenya Corporation (KHC), and the Craig-based Alaska Native village corporation, Shaan Seet, received ownership of the majority of the Klawock watershed. Logging and associated road-building by these entities in this watershed took place between 1977 and 1997, with most efforts occurring in the 1980s. The majority of logging activities in this watershed took place before modern riparian buffer management was enacted as part of the State of Alaska's Forest Practices Act.

Research on sockeye salmon during this period of time was intermittent and varied in scope. Minimum escapement to the lake was estimated intermittently between 1977 and 2000, when age, sex, and length data were also recorded by ADF&G (Lewis & Zadina 2001). These estimates are considered minimums because it was assumed that the weir construction and timing was insufficient to capture full escapement. Commercial catches of sockeye salmon in the region were accurately recorded beginning in 1960, although separation of stocks destined for the Klawock Lake drainage was not done (Lewis & Zadina 2001). Subsistence harvest during this period continued to be important to the indigenous people of the region, and subsistence catches were reported on permits beginning in 1969 (Alaska Department of Fish and Game 2015). Other biological studies during this time include documenting sockeye salmon presence and spawning areas in the lake (Edgington & Larson 1979; Headlee 1950-1960), intermittent limnology data including zooplankton and water chemistry in Klawock Lake (Lewis & Zadina 2001), juvenile sockeye salmon population and population structure estimates in 1986, 1987, 1988, and 1995 (Lewis & Zadina 2001), smolt age and weight data in 1987, 1988, and 1995 (Lewis & Zadina 2001) and data on adult salmon age and sex (Lewis & Zadina 2001). Several traditional ecological knowledge studies done during this time were used to document historical and current use and management of Klawock Lake sockeye salmon (Ellana & Sherrod 1986; Langdon 1977).

Perceived declines in Klawock Lake sockeye salmon in the late 1990s resulted in a flurry of research activities. First was a series of retrospective analyses intended to better understand previous work and current concerns. In 1999, the U.S. Forest Service (USFS) along with the Prince of Wales Hatchery Association (POWHA) convened a series of meetings designed to capture the concerns surrounding Klawock Lake sockeye salmon by local residents (Prince of Wales Hatchery Association 1999). Shortly thereafter, ADF&G published summaries from several historical studies and assessments of the lake (Lewis & Zadina 2001). Numerous regional conservation prioritizations featured the Klawock watershed as a watershed of interest (Albert et al. 2008; Central Council Tlingit and Haida Tribes of Alaska 1999). In addition, the Klawock Watershed Council (KWC) was formed in the early 2000s and joined the many landowners and regulatory agencies into a single unified partnership dedicated to improving conditions for sockeye salmon in the watershed.

Following these initial summaries, a series of research projects during the 2000s were completed in hopes of better understanding sockeye salmon declines and other fish and wildlife issues. The KWC initiated two efforts to look at habitat issues within the Klawock Lake watershed. One was a watershed assessment intended to identify the proper functioning condition of streams and wetlands within the watershed (Central Council Tlingit and Haida Tribes of Alaska & US Forest Service 2002). The other was a road condition assessment intended to assess the impacts of numerous historical roads throughout the watershed on freshwater habitat (Nichols et al. 2002). These studies resulted in the development of a watershed restoration plan by the KWC (Keta Engineering 2003), and the resulting leveraging of more than $750,000 for watershed restoration projects that closed the majority of roads and removed most high-risk or failing culverts and bridges. Projects also repaired erosional areas along roads in order to reduce sediment from road surfaces to streams, thinned alder to improve the growth of long-lived conifer trees in riparian areas, and replaced culverts to improve passage for migratory fish.

The other research projects conducted during this time period were primarily initiated by ADF&G between 2001 and 2009. After the weir was improved in 2000 to better capture full escapement, ADF&G conducted studies of adult sockeye escapement, using mark-recapture techniques to ultimately validate new weir estimates, as well as determining hatchery contribution and age, sex, and length estimates of returning fish (Bednarski 2010; Cartwright et al. 2006; Cartwright & Lewis 2004; Conitz

2008, 2009, 2010; Conitz & Cartwright 2007; Conitz et al. 2006; Lewis & Cartwright 2002). Additionally, these studies focused on collecting accurate subsistence harvest information that was not possible using the standard permit return system (Bednarski 2010; Cartwright et al. 2006; Cartwright & Lewis 2004; Conitz 2008, 2009, 2010; Conitz & Cartwright 2007; Conitz et al. 2006; Lewis & Cartwright 2002). These studies used a combination of direct observation and interviews during open fishing periods, and allowed managers to estimate harvests from direct catch data. Some of these ADF&G studies focused on juvenile sockeye rearing and lake habitat conditions, including studies on nutrient concentrations (Cartwright & Lewis 2004; Lewis & Cartwright 2002), smolt age (Cartwright et al. 2006; Cartwright & Lewis 2004; Conitz 2009; Lewis & Cartwright 2002), fry populations (Cartwright et al. 2006; Cartwright & Lewis 2004; Lewis & Cartwright 2002), zooplankton abundance (Cartwright et al. 2006; Cartwright & Lewis 2004; Conitz 2009; Conitz et al. 2006; Lewis & Cartwright 2002), lake temperature profiles and light penetration (Cartwright et al. 2006; Cartwright & Lewis 2004; Conitz 2009; Conitz et al. 2006; Lewis & Cartwright 2002), and sediment core studies (M. Cartwright, unpublished data). Finally, a traditional ecological knowledge study was implemented to understand recent and historical changes in the fishery (Ratner et al. 2006).

Currently, the subsistence fishery is regulated under both state and federal subsistence management. The state subsistence fishery allows for harvest on weekdays from July 7 – August 7 (Alaska Department of Fish and Game 2014a). Regulations have allowed permit holders to possess 20 sockeye salmon at a time with no annual limit. Only boats with less than 50 horsepower are allowed in the state fishery and beginning in 2015, no fishing will be permitted above the Klawock Bridge (Figure 2). Any gear type legal for state-wide subsistence finfish fisheries, including gillnets, seines, and dipnets, is legal in Klawock under these state permits. Under federal subsistence regulations, harvest is permitted in federal waters upstream of the highway bridge; however, the use of seines and gillnets is prohibited during July and August (J. Reeves, USFS, personal communications). There are no seasonal closures on this federally-regulated fishery, although the daily possession limits of 20 fish still applies and cannot be accumulated with State limits.

Figure 2. Aerial imagery of the mouth of the Klawock River, and the Klawock highway bridge that marks the upstream limit of state regulated sockeye salmon harvest.

Commercial harvest of pink and sockeye salmon in fishing districts likely to intercept Klawock Lake sockeye salmon in the purse seine fishery is managed by ADF&G (Alaska Department of Fish and Game 2012). Current ongoing research involves monitoring of the Klawock river weir for sockeye salmon escapement and sampling of length, sex, and age of incoming fish (J. Reeves, USFS, personal communication). The Klawock River Hatchery (KRH) stopped releasing sockeye salmon smolt in 2005, but still runs a robust coho production operation.

The following section describes the major data, trends and findings from these studies over the years.

RESULTS FROM PREVIOUS STUDIES

SOCKEYE SALMON ABUNDANCE STUDIES

Although annual estimates of harvest and escapement are often nonexistent or minimal (see "Sockeye salmon harvest and escapement"), general trends in productivity are thought to be that sockeye salmon have declined in the last century (Figure 3). Commercial harvest estimates during the late 1880s through 1930 were often larger than harvest and escapement figures from recent decades (Figure 3); furthermore, traditional ecological knowledge studies consistently note observations of Klawock Lake sockeye salmon declines within the lifetime of the Klawock elders (Langdon 2006; Ratner et al. 2006). In addition, young subsistence harvesters note declines over the last thirty years (Ratner et al. 2006). Since 2000, harvest and escapement numbers have been more reliable and have demonstrated a likely period of historical low productivity compared with the previous decade from 2010-2014 (Figure 4).

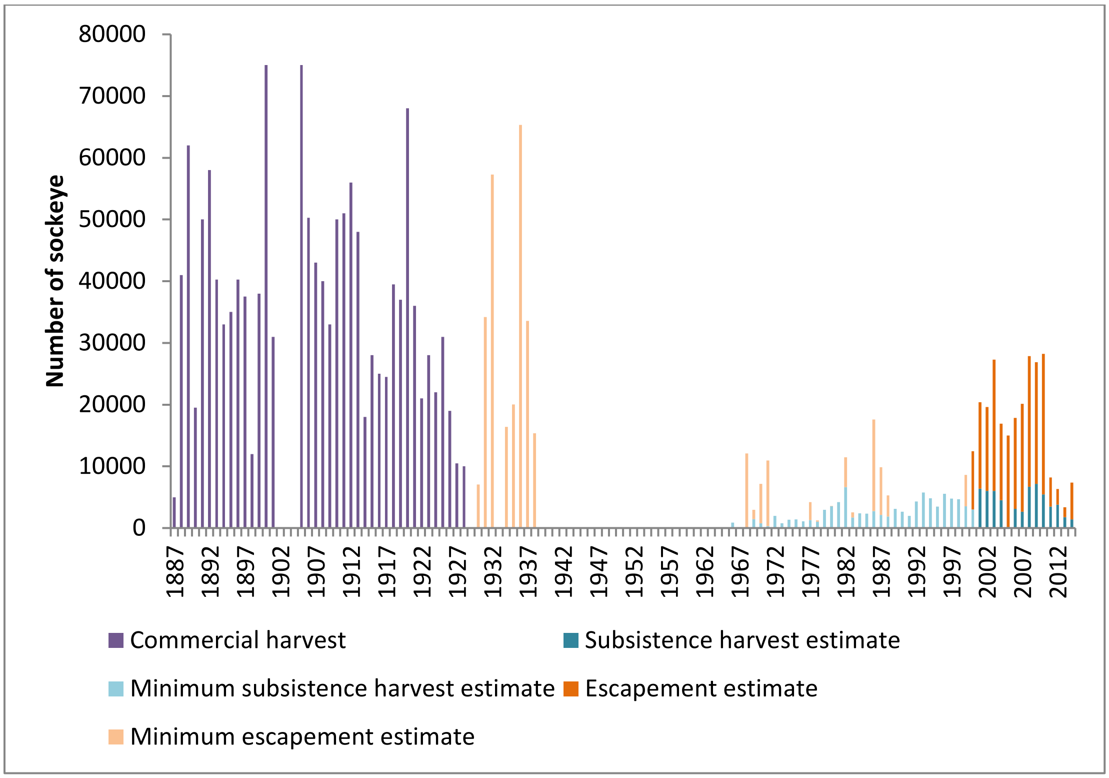

Figure 3. Known historical sockeye salmon harvest and escapement estimates. Years with no bars are years where no data are available, and not years of zero harvest and/or escapement. Data sources and assumptions are described in "Sockeye salmon harvest and escapement".

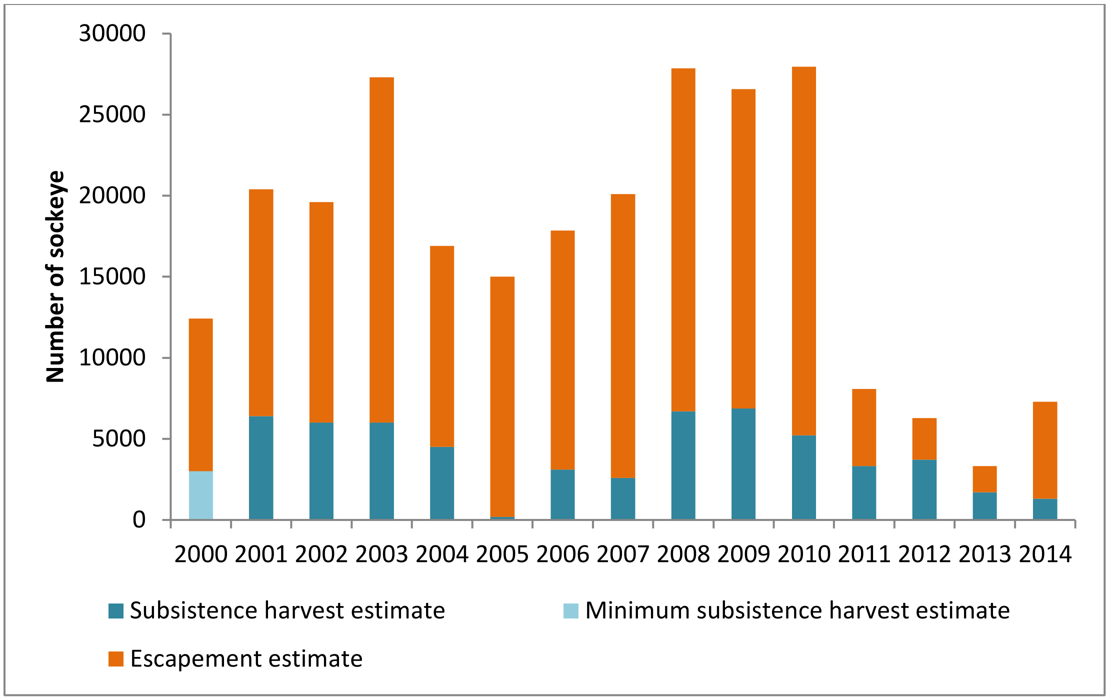

Figure 4. Sockeye salmon harvest and escapement in the Klawock Lake watershed from 2000 – 2014. Data sources and assumptions are described in "Sockeye salmon harvest and escapement".

Sockeye salmon harvest and escapement

Escapement

Escapement measured using a weir from 1930 to 1938 produced a mean annual escapement estimate of 30,000 fish, but range from just over 7,000 to just under 66,000 fish; escapement during this time was estimated by a weir that was operated intermittently and not always for the duration of the run, and thus is considered to represent minimum escapement (Figure 5; Lewis & Zadina 2001). A weir on Klawock River was built in 1977; because of high flow events and because of a gap in one end of the weir that allowed fish to pass undetected, estimates until 2000 are also considered minimum escapement estimates, averaging a minimum escapement of 7,000 sockeye salmon during the eight years that the weir was in operation (Figure 5; Lewis & Zadina 2001).

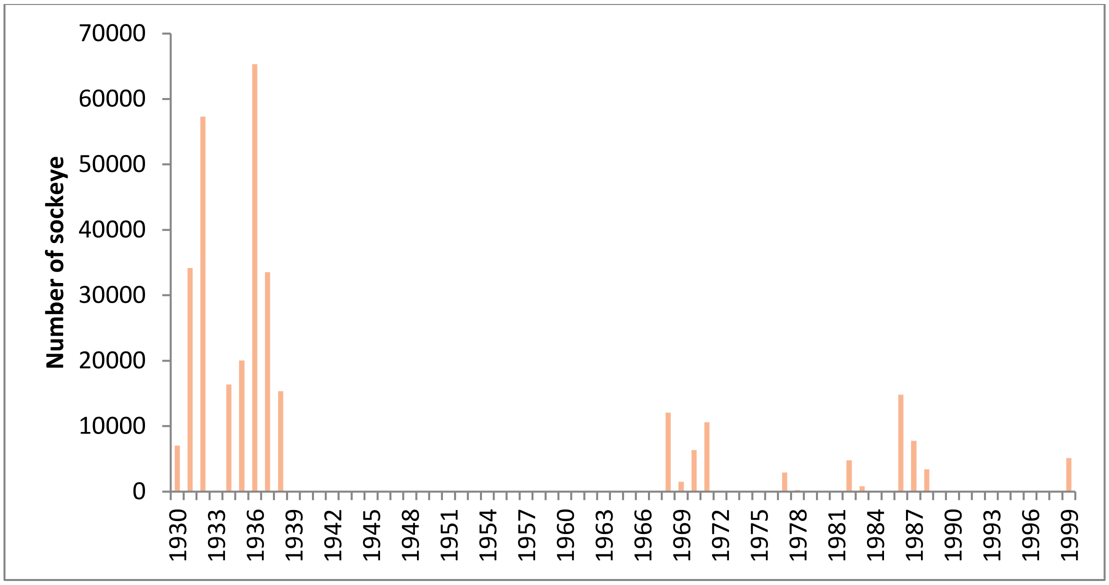

Figure 5. Minimum escapement estimates from 1930 – 2000 (Lewis & Zadina 2001).

Weir-based escapement estimates from 2000 to present are considered to be the most accurate because weirs are operated for the majority of the run and well built, and because much of the data from 2000 to 2008 is verified with mark recapture studies in the lake and tributaries (Figure 6; Cartwright et al. 2006; Cartwright & Lewis 2004; Conitz 2008, 2009, 2010; Conitz & Cartwright 2007; Conitz et al. 2006; Lewis & Cartwright 2002). These estimates show typically lower estimates than were seen historically, though returns were relatively stable and increasing from about 2003 until 2010. Returns have been considerably lower in the last 4 years and reached their lowest numbers in 2013 when slightly over 1,500 sockeye salmon returned to the lake. Fewer than 6,000 sockeye salmon returned to Klawock Lake in 2014.

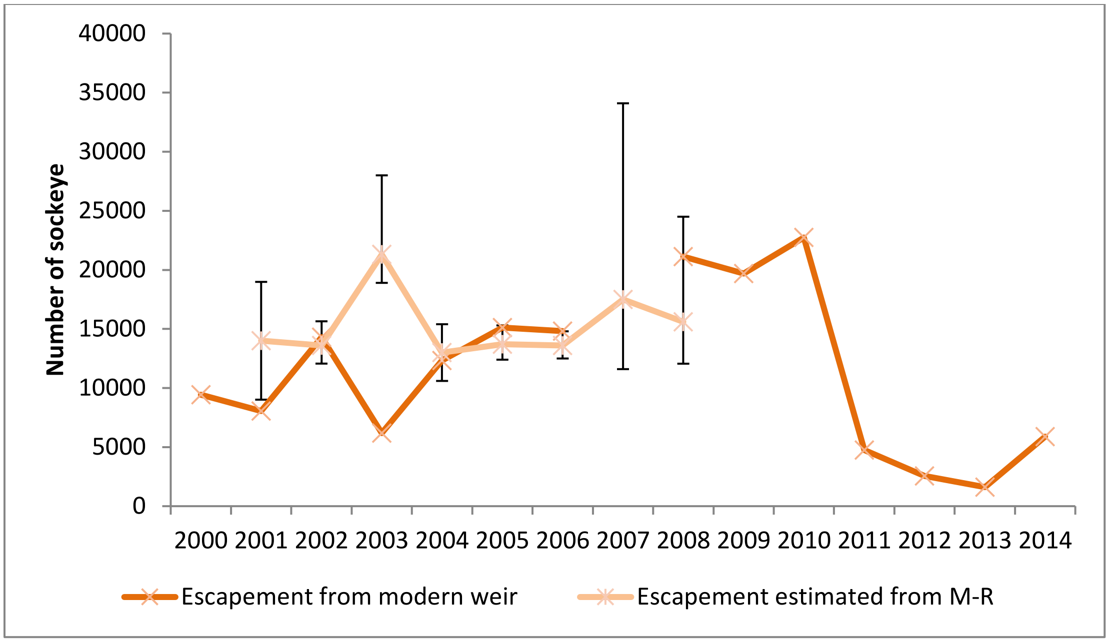

Figure 6. Escapement counts of sockeye salmon into Klawock Lake from 2000-2014 (S. Walker, ADF&G, unpublished data). Escapement to Klawock Lake was also estimated using mark-recapture techniques from 2001-2008 (Cartwright et al. 2006; Cartwright & Lewis 2004; Conitz 2008, 2009, 2010; Conitz & Cartwright 2007; Conitz et al. 2006; Lewis & Cartwright 2002). Error bars represent 95% confidence intervals around mark-recapture estimates.

Because of the lack of and uncertainty around early escapement numbers, a paleolimnology study using sediment cores was conducted in 2002 to assess historical salmon production by analyzing nitrogen stable isotope signatures (M. Cartwright, unpublished data). The purpose of paleolimnology coring is to estimate the historical production of sockeye salmon in the lake by measuring the amount of marine-derived N^{15} and C^{13} deposited in the sediment over hundreds of years. The core results showed that the majority of the N and C in Klawock Lake is terrestrially derived and not marine derived; thus researchers concluded that Klawock Lake flushes out marine derived nutrients too quickly for results to accurately reflect historical sockeye production (M. Cartwright, unpublished data). This is supported by high flushing rates documented in Klawock Lake (water residence time of 0.71 years; Barto 2004).

In 1985, ADF&G estimated an optimum escapement number of 67,000 fish to maximize sockeye production based on limnology-based estimates of productivity (Prince of Wales Hatchery Association 1999).

Commercial harvest

Commercial fishing for sockeye salmon and other species destined to the Klawock Lake watershed began around the late 1860s, but catches were not well-documented until the late 1880s (Figure 7; Moser 1898). The cannery at Klawock kept detailed records of fish harvested near the mouth of Klawock River, and it was believed that the Klawock watershed was "undoubtedly good for 35,000 redfish, and probably 40,000 under good conditions" and that "if properly cared for it could produce 80,000 redfish annually" (Moser 1898). Various sources document that many local residents believed that fish traps and the large harvests of sockeye salmon during this period caused significant declines in sockeye salmon over time (Ratner et al. 2006).

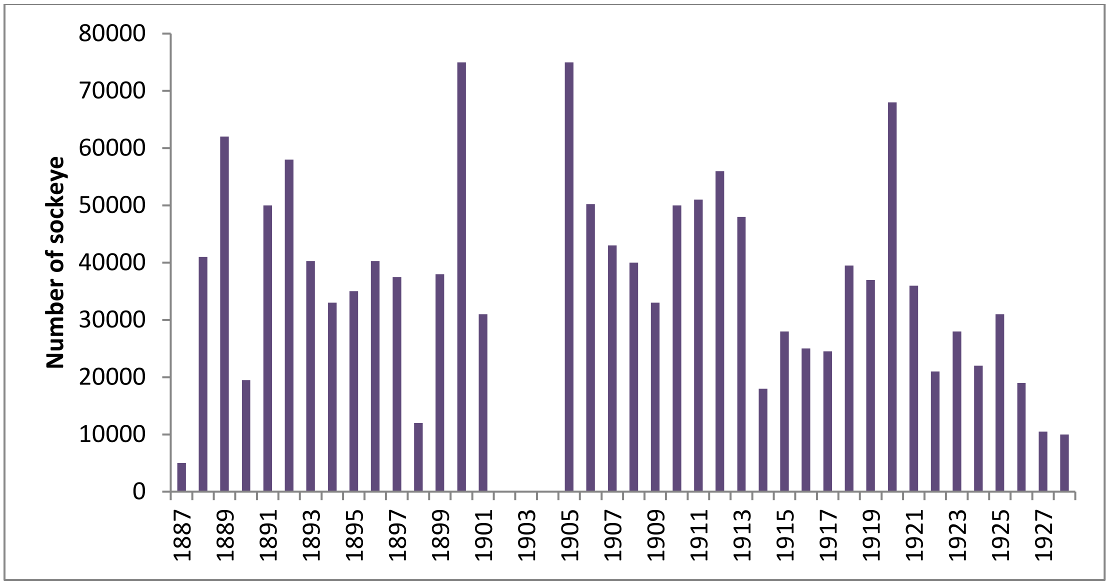

Figure 7. Commercial harvest estimates from the turn of the century reported for Klawock Inlet, based on cannery can pack records (Lewis & Zadina 2001).

The number of Klawock Lake sockeye salmon caught annually in modern-day commercial fisheries is not known. Given possible migratory routes, the most likely commercial fisheries to harvest Klawock sockeye salmon are the purse seine fisheries in the outer waters off the coast of Prince of Wales Island (District 104) and in the inside waters between the outer islands and Prince of Wales Island itself (District 103, Figure 8; Ratner et al. 2006). Between 1989 and 1998, ADF&G conducted a study to evaluate how many Klawock Lake sockeye salmon were caught in the commercial fisheries using coded wire tags but no reliable estimates were obtained due to low tag recovery rates in the fishery and lack of coordinated sampling effort in the escapement. The program was ended due to insufficient tag recoveries necessary to make statistically reliable estimates, the high cost of recovering tagged fish, and high fry mortality associated with tagging (Lewis & Zadina 2001).

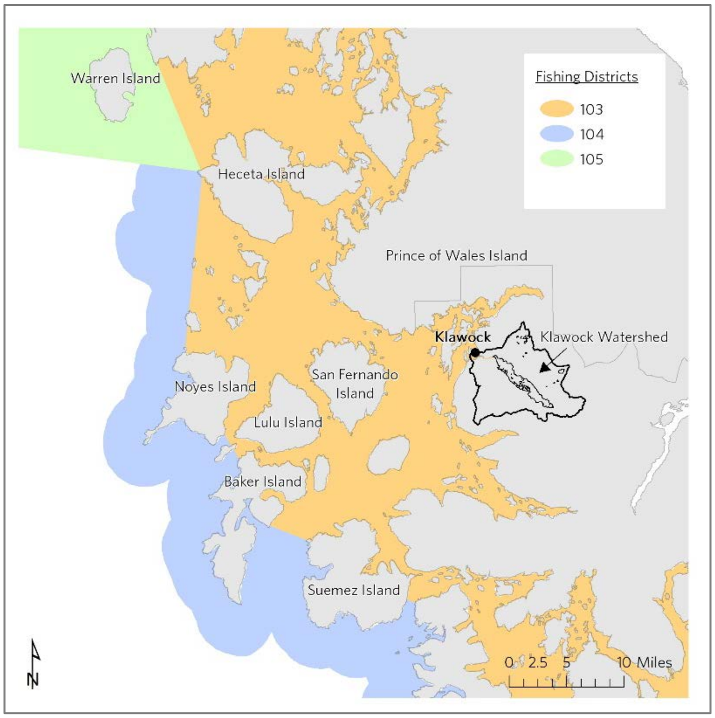

Figure 8. Locations of commercial fishing districts outside of the Klawock Lake watershed.

A genetic mixed stock analysis (MSA) study conducted by the National Marine Fisheries Service (NMFS) and ADF&G under funding by the Pacific Salmon Commission Northern Fund from 2004-2007 estimated the number of Klawock sockeye salmon harvested by the drift gillnet fleet in District 101 and the purse seine fleet in District 104 (Table 1; Guthrie et al. 2015a). The proportional point estimates of fish allocated to this reporting group during these years ranged from 0.0% to 3.0%; however, every credibility interval for each estimate throughout the 2006 and 2007 seasons included zero (Guthrie et al. 2015a). In acknowledgment of the limitations of reporting groups with low proportional point estimates, ADF&G has established a guideline that to retain a reporting group in genetic MSA, a reporting group should be expected to meet or exceed 5% of the sampled mixture (Habicht et al. 2012). Beginning in 2008, the Klawock reporting group was merged with a more inclusive reporting group for NMFS's MSA program (Guthrie et al. 2015b).

Table 1. Estimated harvest of Klawock Lake sockeye salmon in the District 101 Drift Gillnet fishery and the District 104 Purse Seine fishery performed under the Pacific Salmon Commission Northern Fund genetic mixed stock analysis in 2006 and 2007 (Guthrie et al. 2015a). Estimated harvest from 2004 and 2005 has not been published. All point estimates for the Klawock reporting group used to calculate these harvest numbers included zero in the credibility intervals.

Year	District 101 Drift Gillnet Estimated harvest	District 104 Purse Seine Estimated harvest
2006	22	1,471
2007	22	3,743

In addition to requiring the reporting group to meet or exceed 5% of a sampled mixture, ADF&G will only use Klawock Lake as a reporting group in any MSA analysis if this reporting group is genetically identifiable in MSA and adequately represented in the baseline (Habicht et al. 2012). The current ADF&G baseline is more extensive than the baseline used by Guthrie et al. (2015). Testing the MSA performance of the Klawock reporting group using this more extensive baseline is ongoing (S. Olive, ADF&G, personal communications).

Conclusions by ADF&G biologists and local fisherman have varied about the possible impacts that commercial harvest may have on Klawock sockeye salmon (Cartwright et al. 2006; Cartwright & Lewis 2004; Conitz 2008; Langdon 2006; Ratner et al. 2006). Examination of commercial sockeye harvest records in sub-districts closest to Klawock Lake (e.g., subdistrict 103-60) by Ratner et al. (2006) suggested that timing and amount of harvest of sockeye salmon could have potential impacts on Klawock Lake sockeye salmon, depending on migratory routes and timing.

Subsistence harvest

Subsistence harvests under state-issued harvest permits have been documented by ADF&G using returned fishing permits since 1969 (Alaska Department of Fish and Game 2015). Results from returned fishing permits show average reported subsistence harvest from 1,000-3,000 fish a year from Klawock Lake, with harvests being on average smaller since 2005 than was the case from 1992-2005 (Figure 9).

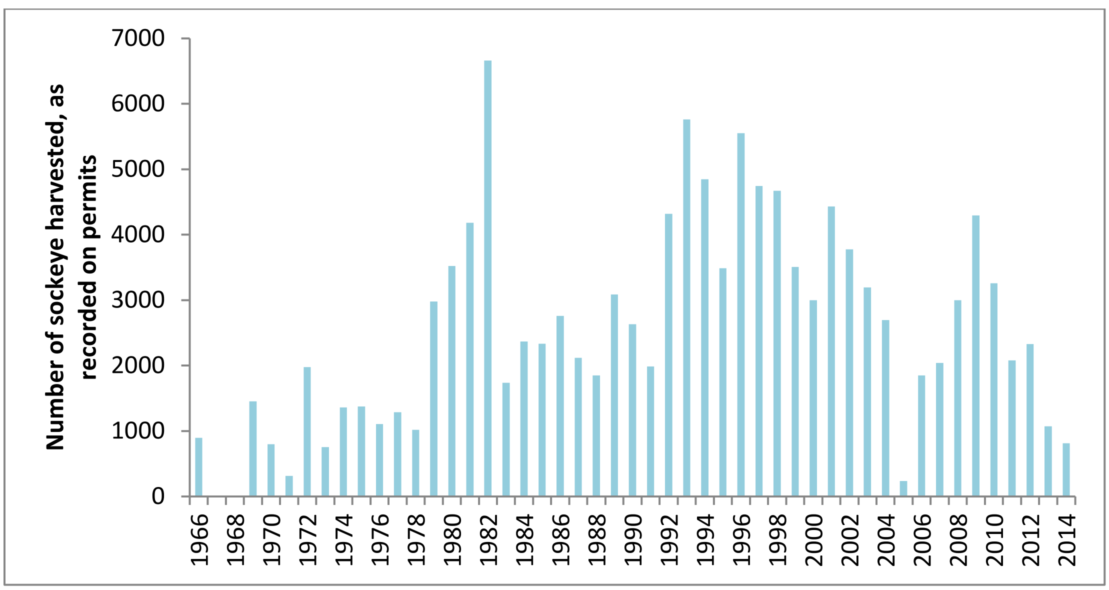

Figure 9. Number of sockeye salmon that were recorded on state-issued subsistence permits as having been harvested from Klawock Lake.

During the 2000s, ADF&G biologists performed more in-depth studies to estimate subsistence harvest, relying on interviews with fisherman and observed fishing efforts (Bednarski 2010; Cartwright et al. 2006; Cartwright & Lewis 2004; Conitz 2008, 2009, 2010; Conitz & Cartwright 2007; Conitz et al. 2006; Lewis & Cartwright 2002). These estimates of subsistence harvests were likely more than those reported on permits, and demonstrated that reported harvests generally ranged from 60 – 85% of actual harvest, depending on the community. During this time period, estimated catches have varied between 175 fish in 2005 to nearly 7,000 in 2008 (Figure 10). The extremely low subsistence harvest of sockeye salmon in 2005 was likely due to a high and early run of pink salmon, which complicates harvest in the Klawock estuary (Conitz & Cartwright 2007). Since 2008, harvests have been estimated using returned permits with an assumption of 60% return rate on permits (S. Walker, ADF&G, personal communication).

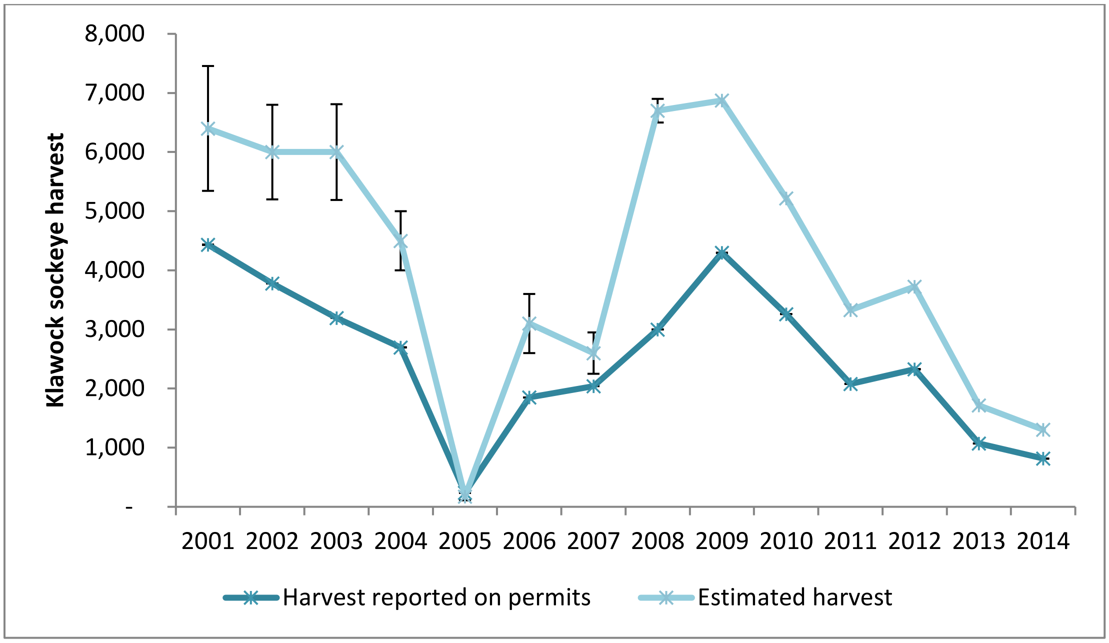

Figure 10. Estimated harvest of Klawock Lake sockeye salmon under state-issued harvest permits based on returned permits and interviews with fisherman and observed fishing efforts (S. Walker, ADF&G, personal communication; Bednarski 2010; Cartwright et al. 2006; Cartwright & Lewis 2004; Conitz 2008, 2009, 2010; Conitz & Cartwright 2007; Conitz et al. 2006; Lewis & Cartwright 2002). Error bars represent 95% confidence intervals when available. Estimation methods after 2007 are based on a 60% return rate on permits (S. Walker, ADF&G, personal communications).

During these in-depth subsistence harvest surveys, ADF&G biologists suggested that approximately 6,000 fish were necessary for subsistence uses (Conitz 2008), though they acknowledged that this amount varied from year to year and is difficult to quantify (Cartwright et al. 2006; Conitz 2008). The Alaska Board of Fisheries has made a positive customary and traditional use (C&T) determination for salmon in Section 3-B in waters east of a line from Point Ildefonso to Tranquil Point, the area that includes Klawock, and found the amount necessary for subsistence in Districts 1-4 combined to be 9,068 – 17,503 salmon (L. Sill, ADF&G, personal communication). However, this area also includes subsistence harvests from other important stocks on Prince of Wales Island.

In addition to state-issued subsistence permits, a smaller federal subsistence harvest occurs on Klawock Lake. Harvest of sockeye salmon in Klawock Lake under this fishery has ranged from zero to 300 fish between 2002 and 2014 (Figure 11; J. Reeves, USFS, unpublished data). These harvest estimates are thought to be reliable (J. Reeves, USFS, unpublished data).

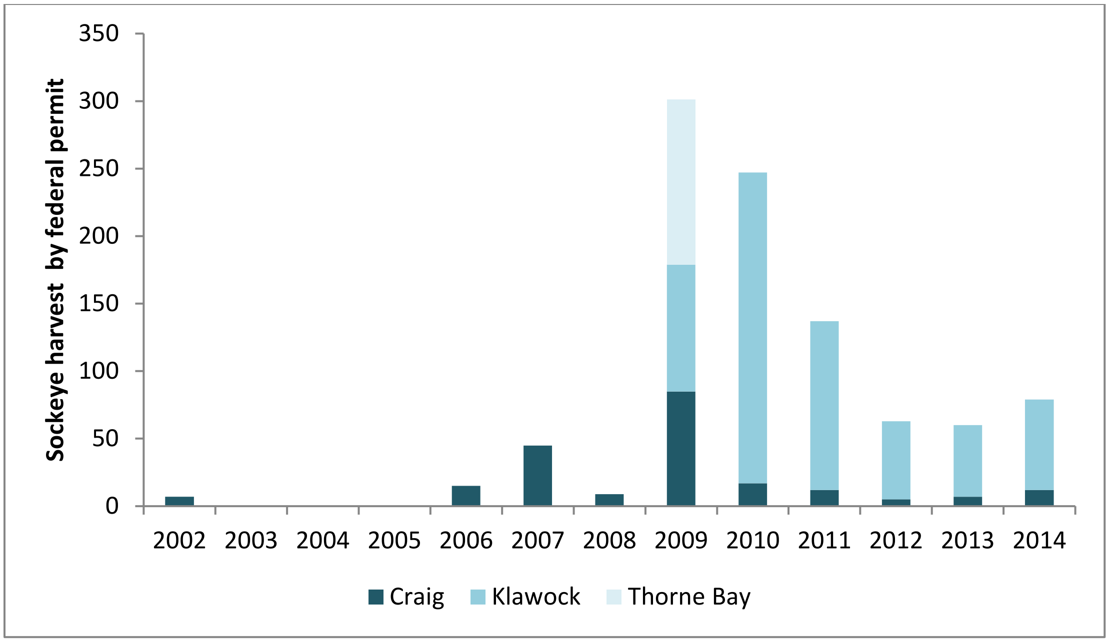

Figure 11. Subsistence harvest under federally-issued subsistence permits for Klawock Lake by the communities of Thorne Bay, Klawock, and Craig (J. Reeves, USFS, unpublished data).

The majority of Klawock Lake sockeye salmon are harvested by residents of the communities of Craig and Klawock, for which subsistence is an essential resource (Fall et al. 2013). Household surveys conducted in 1997 showed that every household in each community utilizes at least one wild resource (Alaska Department of Fish and Game 2015). These surveys also showed that sockeye salmon was the third most harvested resource (by weight) in Klawock and ninth in Craig; it was estimated that 69% of Klawock households and 55% of Craig households used sockeye salmon. Almost all of the sockeye salmon harvested by the community of Klawock and up to one third of the sockeye salmon harvested by the community of Craig is from Klawock Lake (Brown et al. 2006; Fall et al. 2014; Fall et al., 2011; Fall et al. 2009a; Fall et al. 2003a; Fall et al. 2003b; Fall et al. 2003c; Fall et al. 2009b; Fall et al. 2007a; Fall et al. 2007b; Fall et al. 2013).

Klawock elders have mentioned harvest by subsistence fishers as potentially impacting sockeye salmon runs (Ratner et al. 2006), although many younger subsistence users do not cite this as a factor causing sockeye salmon declines (Langdon 2006).

Hatchery enhancement

The first hatchery in Klawock was located at the lake outlet, and was opened in 1897. From 1897 to 1916 sockeye egg takes averaged 3.0 million eggs with a maximum of 7.82 million eggs, although it is assumed that given the practices used at the time, the hatchery's contribution to sockeye abundance would have been minimal (Roppel 1982). The current hatchery was built in 1978. From 1987 to 2004, when sockeye hatchery production ended, nearly 14 million juvenile sockeye salmon were released into Klawock Lake (Figure 12; Klawock River Hatchery, unpublished data). Sockeye fry releases were variable but appeared to stay relatively consistent over the last 5 years of hatchery production. Coho are currently released at this hatchery; coho management is discussed under "Sockeye salmon life history studies – early life history".

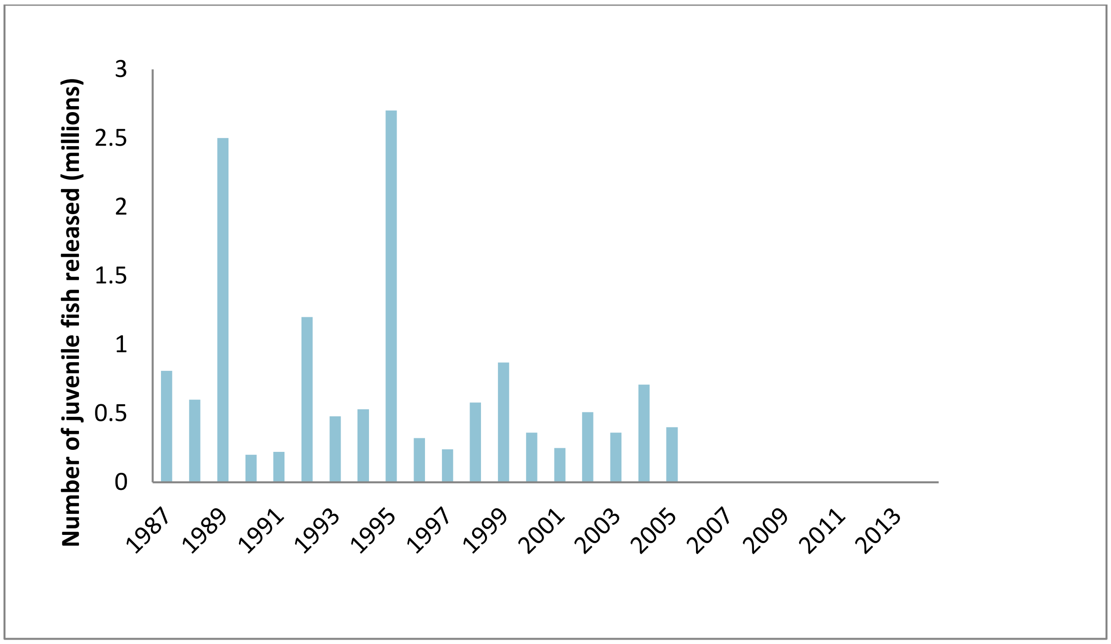

Figure 12. Number of juvenile sockeye salmon released into Klawock Lake by the Klawock River Hatchery.

Juvenile and smolt abundance

Studies on the abundance of juvenile sockeye salmon in Klawock Lake using hydroacoustic population and mid-water trawl abundance estimates were completed in 1986, 1987, 1988, 1995, 2000, and 2001 (Table 2; Lewis & Cartwright 2002; Lewis & Zadina 2001). Estimates were limited by technical difficulties with sonar equipment and led to unreliable values (Cartwright and Lewis 2004).

Table 2. Summary of hydroacoustic population and mid-water trawl abundance estimates of rearing sockeye salmon fry in Klawock Lake, 1987 – 2001 (Cartwright et al. 2006; Lewis & Cartwright 2002; Lewis & Zadina 2001).

Sample date	Type of estimation	Population estimate
Fall 1986	Duration-in-beam	912,000
Fall 1987	Duration-in-beam	272,000
Fall 1988	Duration-in-beam	364,000
Spring 1995	Echo integration	322,000
Fall 2000	Echo integration	311,000
Summer 2001	Echo integration	718,000
Summer 2002	Echo integration	384,000
July 2003	Echo integration	320,000

Although smolt have been studied throughout the years (see “Early life history”), no study to date has attempted to generate population estimates for sockeye smolt.

SOCKEYE SALMON LIFE HISTORY STUDIES

Early life history

No studies have looked at egg survival or emergence timing for sockeye salmon in Klawock Lake systems. It has been suggested that egg survival in Klawock Lake could be severely impacted by increases in stream discharge, channel instability, and bank erosion, associated with logging activities, especially in Three- mile, Half-mile, and Hatchery Creeks (see "Habitat condition"; M. Cartwright, personal communication; Alaska Department of Fish and Game 2006a; Central Council Tlingit and Haida Tribes of Alaska & US Forest Service 2002; Prince of Wales Hatchery Association 1999). Several Klawock elders have noted an increased number of gulls congregating in freshwater and feeding on salmon fry and eggs in Klawock Lake (Ratner et al. 2006). A study was conducted on fry emigration from Three-mile and Hatchery Creek in 2002 and Three-mile, Half-mile, and Inlet Creeks in 2003 (Alaska Department of Fish and Game 2006a). It was found that sockeye fry migrated out of these systems between the end of March and late July, peaking in mid-April to late May, depending on the year (Figure 13); however, it is unclear as to whether hatchery stocking events may have influenced these results.

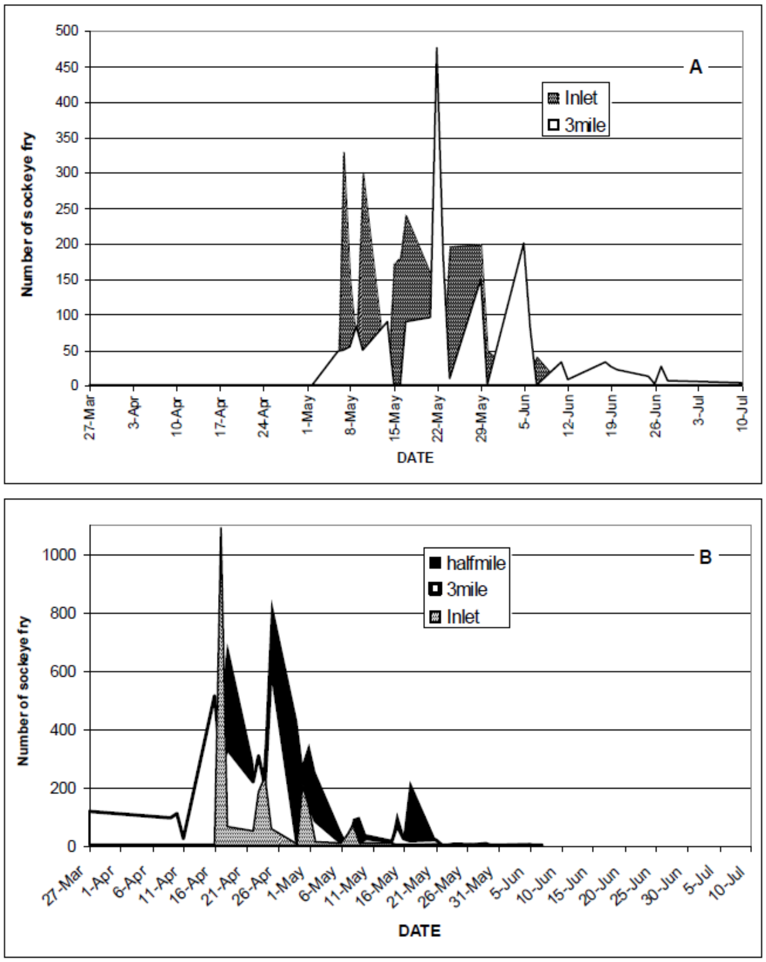

Figure 13. The timing of the migration of sockeye fry from the three major inlet streams into Klawock Lake in 2002 (A) and 2003 (B). Sampling began about 1 month earlier in 2003. This figure taken directly from ADF&G (2006a).

After migrating from their natal streams, sockeye salmon spend one, two, or three years rearing in Klawock Lake (Conitz & Cartwright 2007; Lewis & Zadina 2001). Several efforts have attempted to understand juvenile salmon rearing patterns and productivity through limnological studies in Klawock Lake (see “Juvenile and Smolt Abundance” and “Lake Habitat”). In addition, in 2001 and 2002, ADF&G investigated survival rates of hatchery fish in the lake (Table 3; Alaska Department of Fish and Game 2006a). This study found that very few hatchery fish survived to July during their first season in the lake compared with wild fish, although survival was higher after the first year.

Table 3. This figure is taken directly from ADF&G (2006a) and illustrates the proportion of thermally marked fish (i.e., hatchery fish) of sockeye salmon sampled in the lake, as smolt, and as adults from 2001-2003. The n value is "based on the proportion of aged fish from the thermal mark brood year, i.e., 89% of the smolt collected in 2001 was Age-1 and their brood year was 1999" (Alaska Department of Fish and Game 2006a).

Year Sampled	Brood Year	Life History Stage (dominate age)	Unmarked	Mark02	Mark01	Mark00	Mark99	Total	n*	% Marked
2001	1999	Smolt (Age 1.0)	568				14	582	506	2.8%
2003	1999	Adults	606				5	611	51	9.9%
2001	2000	Fry (Age 0.0)	121			1		122	122	0.8%
2002	2000	Smolt (Age 1.0)	477			3		480	437	0.7%
2002	2001	Fry (Age 0.0)	45		1			46	43	2.3%
2003	2001	Smolt (Age 1.0)	330		3			333	333	0.9%

Klawock residents and subsistence fishers have been critical of hatchery management over the years, especially in regards to the potential impacts of hatchery coho on wild sockeye salmon, including juvenile sockeye salmon (C. Woll, personal observation; Langdon 2006; Ratner et al. 2006). Hatchery coho smolt release and coho escapement are shown in Figure 14. Juvenile coho were all released June 1 prior to 2011; since 2011, the number of smolt released in May has been increasing, with 1.2 million released on May 15 in 2014. Release sites are located in both Klawock Lake and in the Klawock estuary. In 2014, 900,000 smolt were released from Klawock Lake estuary, with the remaining fish released from the lake net pens.

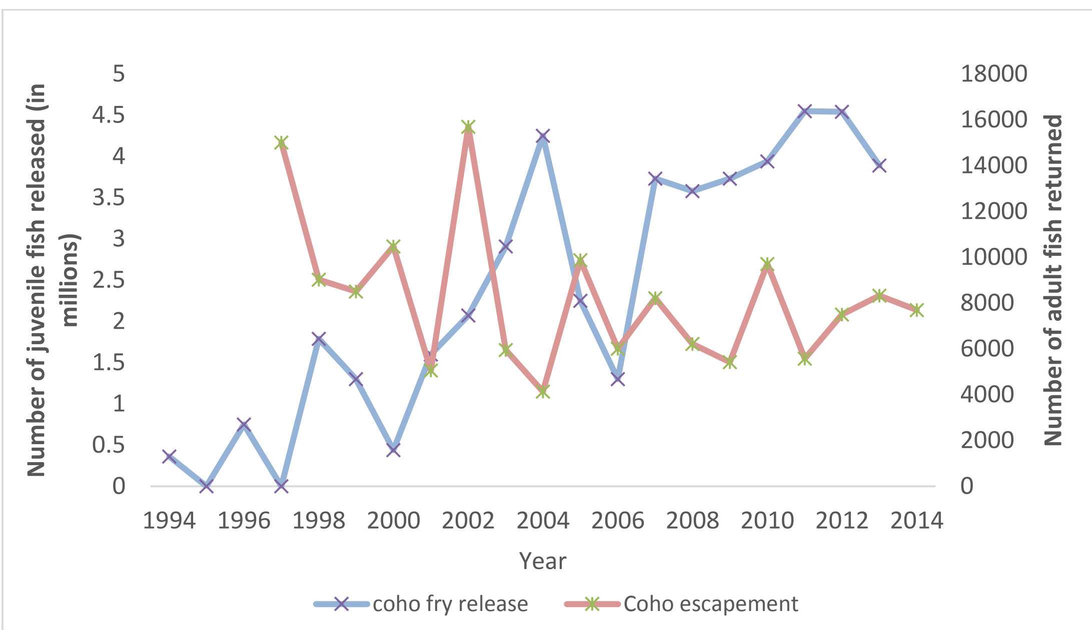

Figure 14. Hatchery coho release and coho escapement data from 1994 to present.

Preliminary studies were conducted by ADF&G in 2002 and 2003 to help better understand potential predation on sockeye salmon in Klawock Lake, including by hatchery-reared coho smolt (M. Cartwright, unpublished data; Alaska Department of Fish and Game 2006a). This included stomach content analysis of potential predators, including juvenile coho, coho smolt, cutthroat trout, Dolly Varden char, and rainbow trout near lake inlet streams. Fish and fish parts were identified in stomach content analysis, but these fish were not identified to species. Cutthroat trout had the highest incidence of fish in their diet, with 28% of those sampled in 2002 and 14% of those sampled in 2003 having fish in their stomach. This rate was usually highest at the mouth of Three-mile Creek. Fish or fish parts were found in the stomachs of 16% of sampled coho in 2002 and of 3% in 2003, with fish sampled off Three-mile Creek having more the highest likelihood of having fish in their stomachs. The largest coho juveniles (105-115mm) and cutthroat trout (200 – 235 mm) were most likely to have fish in their stomachs. Coho juveniles sampled in April and May were on average much larger (mean ~ 110mm) and more abundant than those sampled in June and July (mean ~85 mm); coho juveniles sampled in June and July were extremely unlikely to have fish in their diet. This study also included a code-wire tagging study to try to determine when smolt were leaving the lake; however, results were inconclusive.

In 1987, 1988, 1995, 2001-2003, and 2007, ADF&G also sampled outmigrating sockeye smolt using fyke nets and live box traps to determine, among other things, how many years juvenile salmon typically reared in Klawock Lake (Conitz 2009; Lewis & Zadina 2001). Alaska Department of Fish and Game smolt sampling found that between 60 and 98% of sockeye salmon emigrated from the lake after one year (Figure 15), but they note that larger smolt may have avoided being trapped and therefore may not have been sampled adequately (Conitz 2007). This estimated percentage of juveniles emigrating after one year was noted as being lower than would be expected in other southeast Alaska lake systems (see "Lake Habitat"; Conitz & Cartwright 2007). 1988 was the only year in which smolt that had spent three years in freshwater were documented, representing 3% of the smolt sampled (Lewis & Zadina 2001).

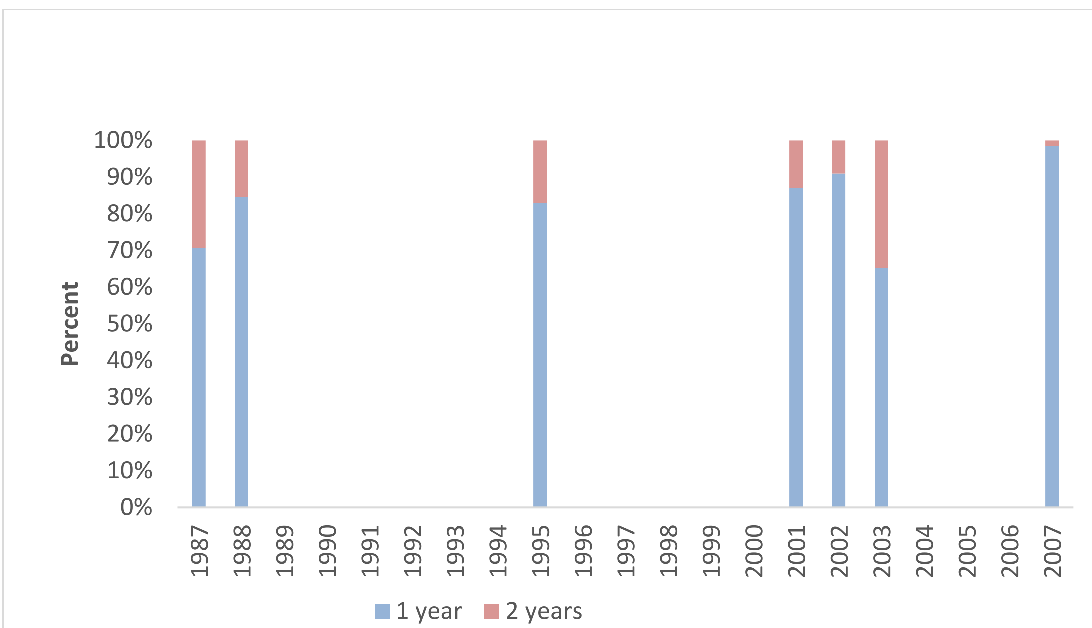

Figure 15. Ages of migrating smolt sampled in the Klawock River (Conitz & Cartwright 2007; Lewis & Zadina 2001).

In addition to information on lake residence time, aforementioned smolt sampling provided information on smolt size and smolt timing (Lewis & Zadina 2001). Smolt average length and weight were found to be variable in size year to year (Table 4). Smolt migration through the weir usually peaked in late May (Conitz 2009).

Table 4. Average sockeye salmon smolt length and weight by year (Cartwright & Lewis 2004; Lewis & Cartwright 2002; Lewis & Zadina 2001).

Year	Age	Length (mm) (SE)	Weight (g) (SE)
1987	1	79.2	4.3
	2	115.9	12.8
1988	1	87.1	6.0
	2	110.2	11.0
	3	129.4	17.4
1995	1	83.0	5.0
	2	114.0	11.5
2001	1	79.4 (0.3)	4.3 (0.05)
	2	127.0 (1.7)	17.4 (0.58)
2002	1	84.5 (0.35)	5.6 (0.06)
	2	127.0	18.0

Despite several years of research on smolt size, fry abundance, juvenile abundance, and survival estimates, no explicit analysis was completed to understand the connections between these factors. Similarly, these factors have not been explicitly tied to data collected on lake habitat. Researchers' assumptions about these lake productivity connections are discussed in the "Lake Habitat" section.

Ocean survival and migration

Little is known about what happens to sockeye salmon once they pass the Klawock River weir as smolt. Sockeye smolt have been documented utilizing eelgrass habitats within Klawock estuary and in Klawock Bay in May, as well as passing through both exits from the Klawock estuary, under the bridge and through the causeway (The Nature Conservancy 2012). A small number of juvenile sockeye salmon were also documented within Klawock estuary during August of 2010 using a beach seine, although they were not documented in the estuary or bay during this time of year during several other years of sampling (The Nature Conservancy 2012). Klawock elders have noted changing ecological interactions in the nearshore environment for young salmon, related to increases in gulls and gull predation on young salmon and decreases in gull prey sources including Pacific herring and Pacific sandlance (Ratner et al. 2006).

Klawock Lake sockeye salmon spend one to four years at sea (see "Adult and spawning salmon"). Ocean survival of Klawock Lake sockeye salmon is unknown. General conclusions about ocean productivity and survival can often be interpreted from age, sex and length information. This data is presented in "Adult and spawning salmon" section.

Nothing is known about ocean migration patterns of Klawock Lake sockeye salmon, although several possible migration routes from the open ocean to the Klawock River before spawning have been identified by individuals in the past (Ratner et al. 2006). In 1944 Charles Demmert testified that Klawock Lake salmon entered inside waters on the north shore of Noyes Island, passed through Arriaga Passage and then migrated along the south side of San Christoval Channel before entering Klawock Bay; several Klawock elders and retired fishermen suggested that Klawock Lake sockeye salmon entered the area from the south, through Bucareli Bay and beyond Fern Point on San Fernando Island (Langdon 2006; Ratner et al. 2006). Tagging studies of sockeye salmon conducted in the 1980s suggests that the migration routes may change annually due to oceanic conditions (Pella et al. 1993).

Adult and spawning salmon

Weather and tides tend to affect how much time sockeye salmon spend in the Klawock estuary before heading up Klawock River; it has been observed that sockeye salmon may hold in the estuary during periods of low flow, and also that most fish migrate upriver with the incoming tide (Ratner et al. 2006).

Daily weir counts collected to monitor escapement act as indices of run timing (Bednarski 2010; Cartwright et al. 2006; Conitz 2008, 2009, 2010; Conitz & Cartwright 2007; Conitz et al. 2006; Edgington & Larson 1979; Lewis & Zadina 2001). Figure 16 and Figure 17 show examples from sockeye salmon runs through time, demonstrating that runs have, on average, occurred later and later over the years. An analysis of historic run timing for Klawock Lake sockeye salmon was published in 2000, finding that the mean date of migration was significantly earlier and its duration significantly greater in the past (Halupka et al. 2000). However, it does note that these significant differences may be attributed to larger historical escapements. Traditional ecological knowledge studies of Klawock elders have suggested that the Klawock Lake sockeye salmon run was occurring later than it had in the past (Langdon 2006; Ratner et al. 2006). Some even suggested that the first sockeye salmon used to arrive in the Klawock River in May. Weirs were never installed before mid-June or later, so it is difficult to assess this (Ratner et al. 2006). One respondent noted that elders had told him the Klawock Lake sockeye salmon run used to have seven peaks, which may correspond to a tidal relationship, and/or to populations temporally separated based on where they spawn (Ratner et al. 2006).

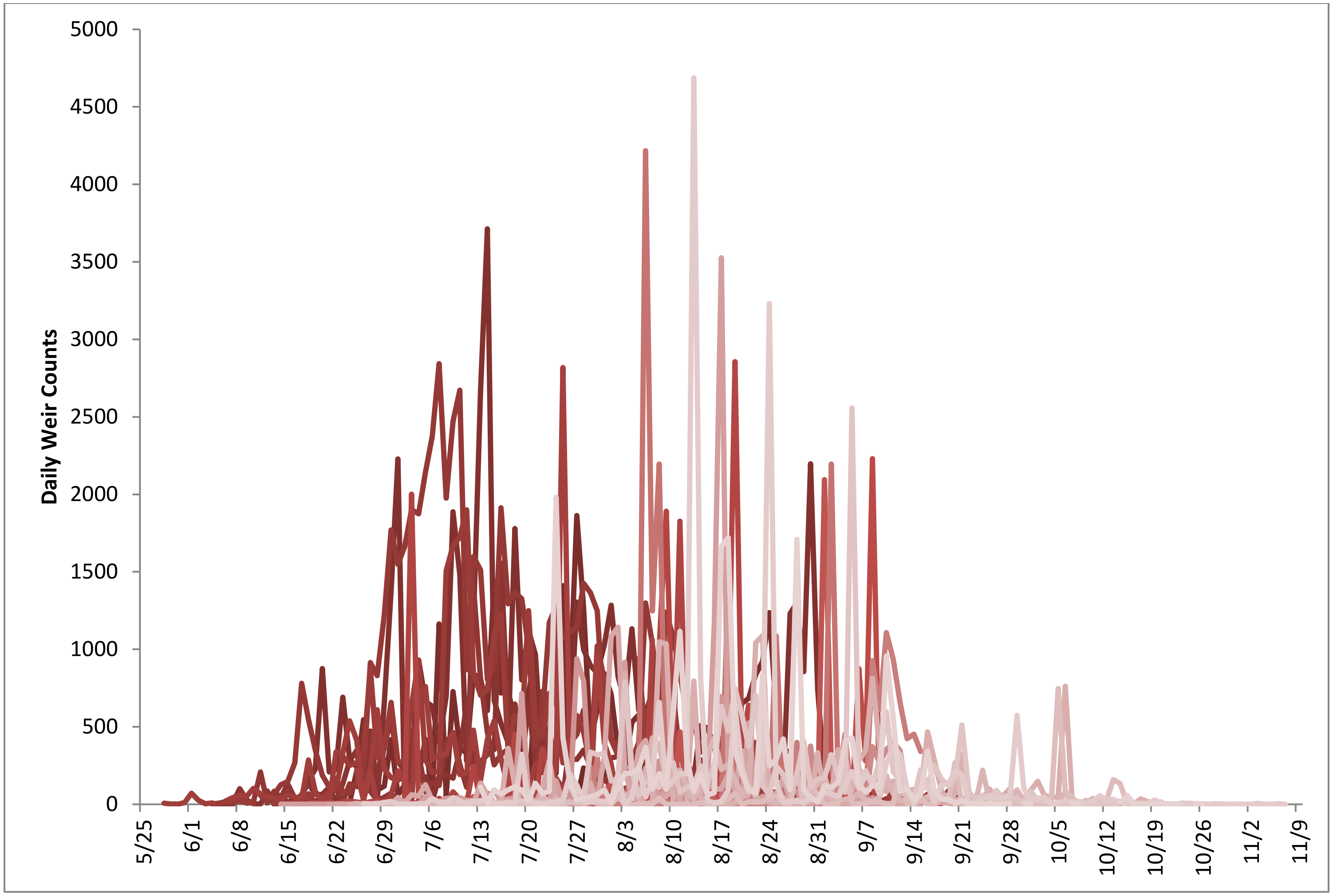

Figure 16. Daily weir counts between 1930 and 2009 for available yearly data (Bednarski 2010; Cartwright et al. 2006; Conitz 2008, 2009, 2010; Conitz & Cartwright 2007; Conitz et al. 2006; Edgington & Larson 1979; Lewis & Zadina 2001). More recent years are progressively lighter in shade, illustrating how sockeye salmon run timing has shifted later through the years.

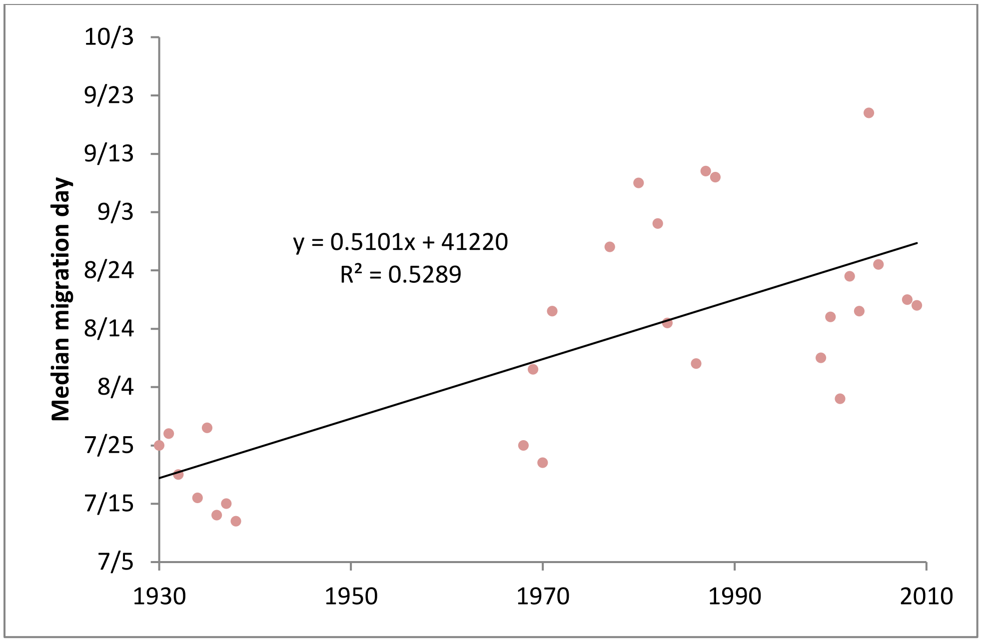

Figure 17. Median migration day of sockeye salmon through the Klawock River from 1930 - 2009 (Bednarski 2010; Cartwright et al. 2006; Conitz 2008, 2009, 2010; Conitz & Cartwright 2007; Conitz et al. 2006; Edgington & Larson 1979; Lewis & Zadina 2001).

It has been noted that the subsistence season for Klawock Lake sockeye salmon typically occurs when less than 10% of the total escapement has passed the weir, and in some years less than 5% of the total escapement has passed (Cartwright et al. 2006; Ratner et al. 2006). It has been suggested that harvesting the early returning fish may be detrimental to a genetically unique early run or a stock specific to a tributary (Cartwright et al. 2006; Prince of Wales Hatchery Association 1999). Alaska Department of Fish and Game has consistently sampled adult sockeye salmon for length, sex, and age (using scales) since 1982 (S. Heinl, unpublished data; Lewis & Zadina 2001). In most years, less than 20% of the returning adults have spent one year in the lake before migrating to the ocean (Figure 18). However, from 2001 to 2007, more than 30% of returning adults had spent two or more years in freshwater (with the exception of 2006). Two or three years is the most common length of time for Klawock Lake sockeye salmon to spend at sea.

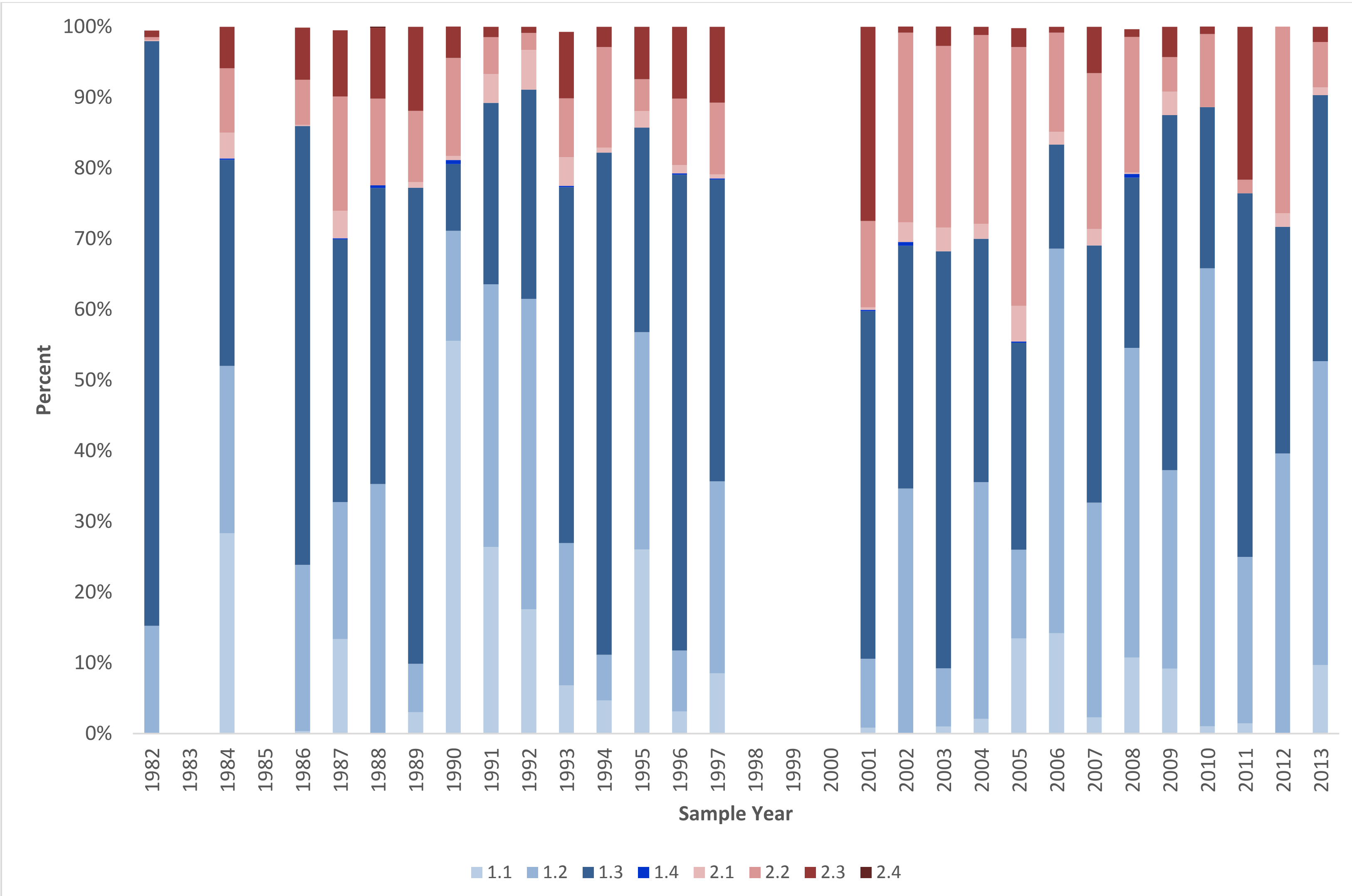

Figure 18. Age structure (1.2 represents a fish that spent one year in freshwater and two years in salt water) of fish returning to the weir by sample year (S. Heinl, unpublished data; Lewis & Zadina 2001).

Length data by age and sex are available for all sampling years by request from ADF&G (S. Heinl, personal communication). Preliminary analysis of these data in 2006 showed that freshwater age appeared to have little relation to adult size, although ocean age was related to adult size (Cartwright et al. 2006). Historical trends in sex and length structure have not been analyzed to date.

Otoliths were also sampled from 1999-2009 to estimate the number of hatchery-produced sockeye adults returning to the lake (Alaska Department of Fish and Game 2006a; Bednarski 2010; Cartwright et al. 2006; Conitz 2008, 2009, 2010). In many years, it was estimated that the number of returning adults did not even replace the numbers originally taken for broodstock; in other years, it was estimated that between 3 and 7 % of returning fish were from the hatchery, with the maximum estimate of 15% in 2008.

Residency times while fish are between the weir and spawning grounds has been found to be short (Conitz et al. 2006). Sockeye salmon have been documented, mostly during surveys in the late 1970s and early 1980s, as spawning in eleven large and small tributaries of Klawock Lake (Figure 19; Alaska Department of Fish and Game 2014b). In 1898, Moser identified Three-mile Creek, Half-mile Creek, and Inlet creek as the largest producers of sockeye salmon in the Klawock Lake watershed; according to this report, sockeye in Three-Mile Creek "spawn in this stream for a long distance". Three-mile Creek and Half-mile Creek were identified as the largest producers of sockeye salmon in the 1990s (Prince of Wales Hatchery Association 1999). The Alaska Department of Fish and Game identified Three-mile Creek, Half-mile Creek, Hatchery Creek, and Inlet Creek as the largest producers of sockeye salmon producing streams in the 2000s and focused spawning ground surveys and mark-recapture estimates on these four systems. Occasional lake shoreline surveys were conducted in 2001 and 2002 although no significant spawning populations were found (Cartwright & Lewis 2004; Lewis & Cartwright 2002). Mark-recapture estimation efforts in streams yielded highly variable abundance estimates for the four streams from 2001 – 2005, but these efforts confirmed Three-mile and Inlet Creeks as the most productive tributary streams, and Hatchery Creek as the lowest (Table 5; Cartwright et al. 2006; Cartwright & Lewis 2004; Conitz 2008; Conitz & Cartwright 2007; Conitz et al. 2006; Lewis & Cartwright 2002)

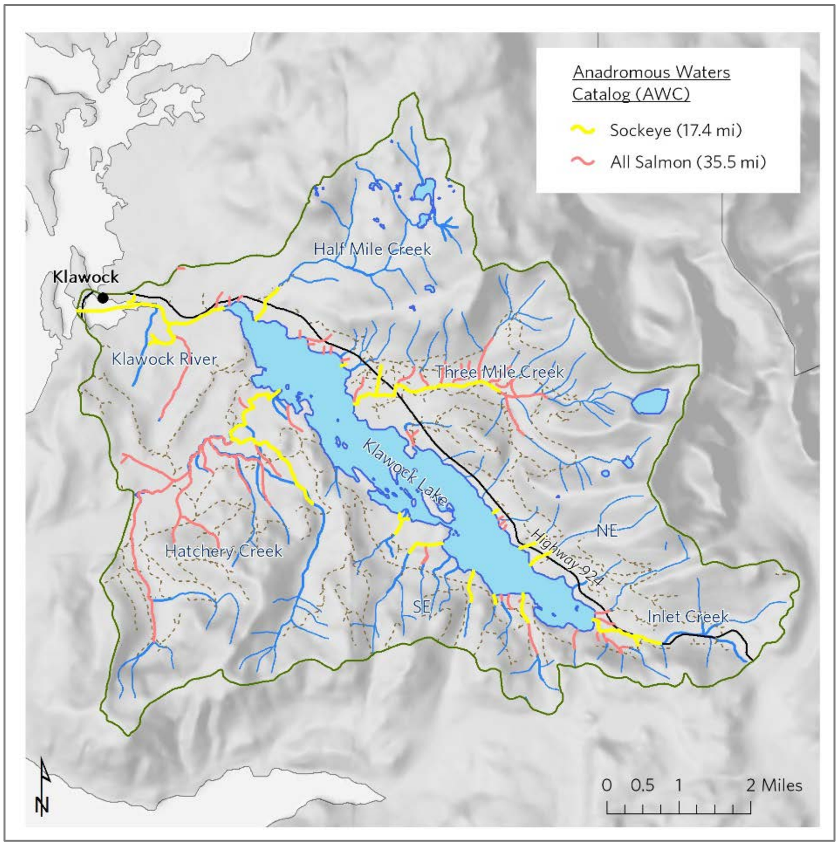

Figure 19. Extent of sockeye salmon habitat documented in the Anadromous Waters Catalog (Alaska Department of Fish and Game 2014b).

Table 5. Adult salmon abundance estimates from mark-recapture estimation efforts on three streams (Conitz 2008, 2009, 2010; Conitz & Cartwright 2007; Conitz et al. 2006).

	Three-mile	Half-mile	Inlet
2004	9,000 (6,000-15,000)	260 (190-430)	1,700 (500-4,800)
2005	10,000 (7,000-19,000)	170 (80 – 340)	
2006	8,100 (6,100-17,700)	1,000 (600 – 1,900)	1,600 (800-3,700)
2007	8,000 (5,400 – 14,900)	1,400 (1,000 – 2,300)	8,100 (5,200 – 16,900)
2008	7,500 (6,200 – 10,500)	700 (160 – 1,900)	7,400 (5,700 – 12,100)

Although tagging of fish in 2004 provided evidence that a higher proportion of fish from the first half of the run were destined for Inlet Creek than other streams (Conitz et al. 2006), other years did not show any trends in differential run timing between streams (Conitz 2008, 2009, 2010; Conitz & Cartwright 2007). Spawning timing at each of these four streams is best documented in the peak spawning surveys that were conducted from 2001-2003 (Figure 20; Cartwright et al. 2006; Cartwright & Lewis 2004; Lewis

& Cartwright 2002). These studies do not suggest that there is consistently differential spawning timing between any of the stream systems they monitored.

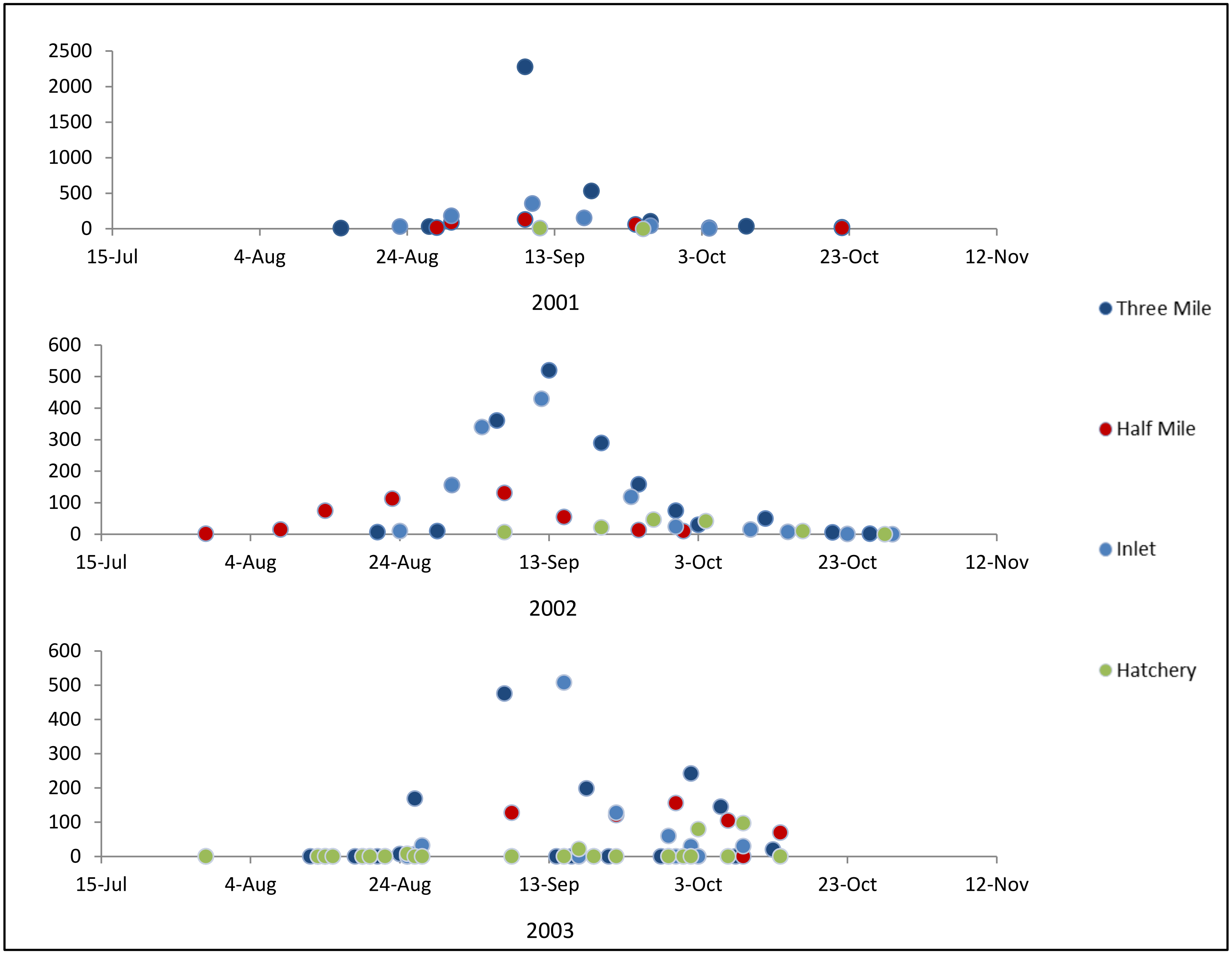

Figure 20. Spawning timing from 2001-2003 on the four major tributaries.

WATERSHED CONDITION

Lake habitat

Limnology studies with mostly consistent methods were conducted on Klawock Lake occasionally through the 1980s and 1990s and more consistently as part of ADF&G studies in the 2000s (Cartwright et al. 2006; Cartwright & Lewis 2004; Conitz 2009; Conitz et al. 2006; Lewis & Cartwright 2002; Lewis & Zadina 2001). Lake habitat condition surveys were conducted in order to better understand the relationship between juvenile rearing habitat and sockeye salmon productivity. Most sampling took place at consistent sites in the watershed, including Sites A and C in Station A and Sites B and D in Station B (Figure 21; Lewis & Zadina 2001).

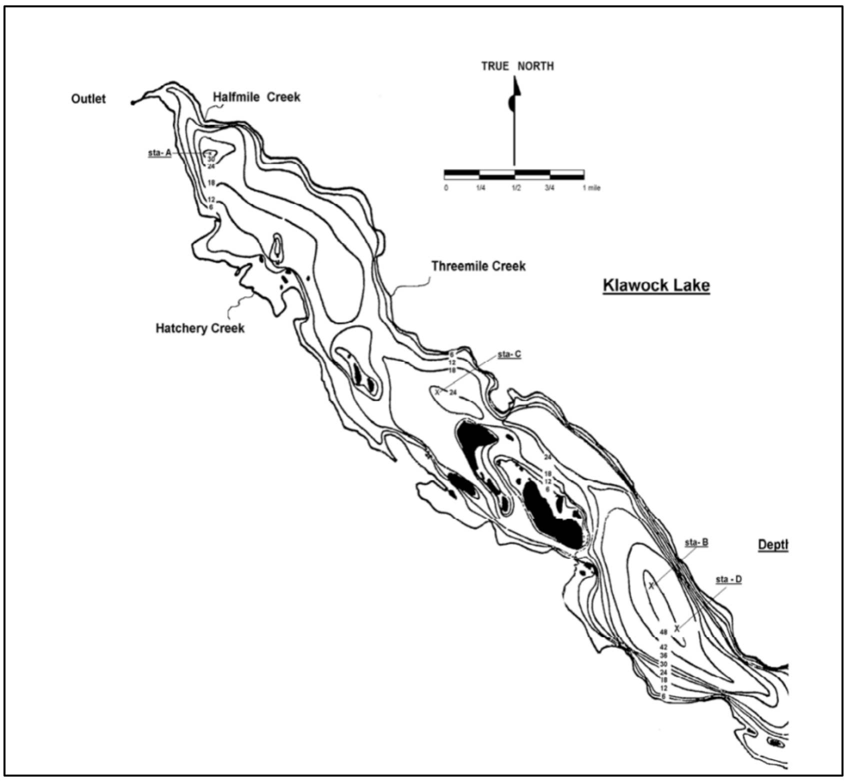

Figure 21. Bathymetric map of Klawock Lake, Southeast Alaska with limnological sampling stations and inlet stream references. This figure is taken directly from Lewis and Zadina (2001).

Klawock Lake is stained and oligotrophic, typical of coastal Alaskan Lakes (Lewis & Zadina 2001). Calcium, magnesium, iron, phosphorus, and nitrogen, were sampled intermittently between 1979 and 2004. Calcium, magnesium, and iron concentrations ranged from 3.4 to 5.9 mg • L^{-1}, 0.4 to 0.8 mg • L^{-1} and 11 to 160 µg • L^{-1}, respectively, which is considered to be low compared to other southeastern Alaska lakes (Lewis & Zadina 2001). Phosphorous and nitrogen values, both essential for primary productivity, ranged from 3.2 - 24.7 µg • L^{-1} and 23.9 – 244.0 µg • L^{-1}, respectively; these were considered normal compared to other southeastern Alaska lakes, with phosphorous thought to be likely the limiting factor in primary productivity in these lakes (Lewis & Zadina 2001).

The sediment core analyses that were implemented in 2002 shed light on the history of sediment deposition in Klawock Lake (M. Cartwright, unpublished data). One noticeable result was an abrupt 1000-fold increase in the rate of sediment deposition in the 1930s. The authors attributed the sudden increase in sediment deposition to naturally occurring landslides that deposited material into the lake, and suggested that a sediment load of this magnitude would likely have had a profound negative effect on salmon production for several decades. Sediment loading rates returned to similar rates seen before 1930 by the late 1960s. Sediment rates that increased 2-fold from historical levels in the 1990s were thought most likely to be due to road building and logging in the Klawock Lake drainage.

Water temperature and dissolved oxygen (DO) profiles at these sampling stations were taken in 1974, 1986-88, 2000-2004, and 2007 (Cartwright et al. 2006; Cartwright & Lewis 2004; Conitz 2009; Lewis & Cartwright 2002; Lewis & Zadina 2001). Temperature profiles generally follow temperature regimes of typical dimictic lakes with thermal stratification occurring around mid to late June and relatively high maximum water temperatures reaching only a few meters in depth; epilimnetic temperatures tended to peak at about 17° C. Dissolved oxygen levels ranged between 70 % and 95% saturation.

Lake water temperature and dissolved oxygen data has also been monitored daily in Klawock Lake by the KRH since it was opened in 1979; however, digital records of these values are currently only available since 2012 (Figure 22, J. Lundberg, KRH, unpublished data). It is likely that there are undigitized records of these daily water temperatures in ADF&G archives from when the hatchery was a state-owned facility, from 1978-1993 (G. Pryor, ADF&G, personal communication).

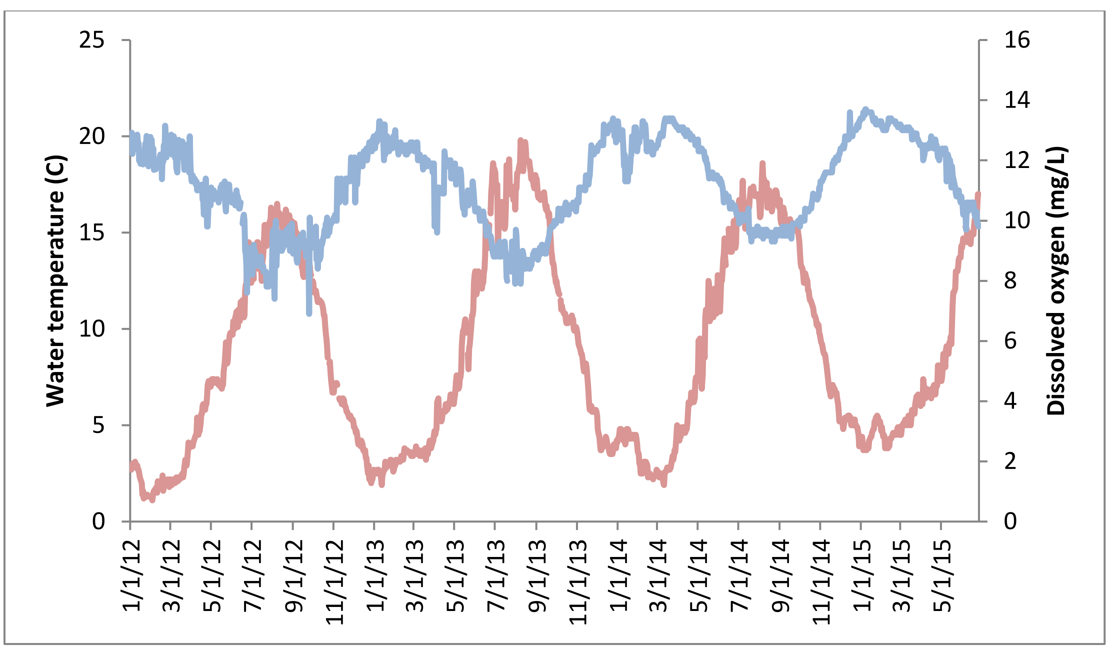

Figure 22. Daily water temperature (red) and dissolved oxygen (blue) from 2012 – 2015 at the Klawock River Hatchery (J. Lundberg, KRH, unpublished data).

Limnological surveys related to primary production included chlorophyll a and phaeophytic a concentrations collected in 1986-1988 and 2000-2002 and euphotic zone depth (EZD) measurements in 1986-1988 and 2000-2004 (Cartwright et al. 2006; Cartwright & Lewis 2004; Conitz et al. 2006; Lewis & Cartwright 2002; Lewis & Zadina 2001). Euphotic zone depths, which indicate the depth at which light penetrates, measured using secchi discs, are shown in Table 6. EZD generally changed by less than 3 meters among years for each sampling period. Chlorophyll a concentrations are considered indicators of algal biomass, which is essential for juvenile sockeye salmon productivity. Chlorophyll a values within Klawock Lake ranged from 0.05 to 2.84 $\mu g \bullet L^{-1}$; these values are low, but were considered typical for a southeast Alaska oligotrophic lake (Lewis & Zadina 2001).

Table 6. Euphotic zone depth measurements in Klawock Lake from 1986 – 1988 and 2000 – 2004 (Cartwright et al. 2006; Cartwright & Lewis 2004; Conitz et al. 2006; Lewis & Cartwright 2002; Lewis & Zadina 2001).

	Station A	Station B
May 1986	6.1	
November 1986	3.1	2.7
April 1987	4.6	5.7
November 1987	2.8	2.5
March 1988	3.3	
August 1988		4.0
November 1988	3.8	4.8
May 2000	4.7	4.5
June 2000	5.2	5.0
August 2000	3.1	4.7
September 2000	3.6	4.0
May 2001	3.72	3.83
June 2001		4.48
July 2001	4.71	4.98
September 2001	3.67	4.47
October 2001	3.76	4.75
May 2002	5.28	5.72
June 2002	5.97	5.65
July 2002	5.65	5.96
September 2002	6.75	4.28
October 2002	3.46	3.93
May 2003	4.5	4.0
June 2003	4.2	4.2
July 2003	4.9	4.2
September 2003	3.4	4.2
October 2003	3.7	3.8
April 2004	4.3	4.4
June 2004	4.7	5.1
July 2004	5.1	5.3

August 2004	5.9	6.4
October 2004	3.8	5.2

Zooplankton densities were sampled in the lake in 1986-1988, 2000 – 2004, and 2007 (Cartwright et al. 2006; Cartwright & Lewis 2004; Conitz 2009; Conitz et al. 2006; Lewis & Cartwright 2002; Lewis & Zadina 2001). The zooplankton found in highest densities were copepods (*Cyclops* spp. and *Epischura* spp.), followed by cladocerans (*Bosmina* sp. and *Daphnia longerimis*). Zooplankton densities were highest in 2000-2004; these were also the years with the largest percentage contribution by *Daphnia* (Figure 23).

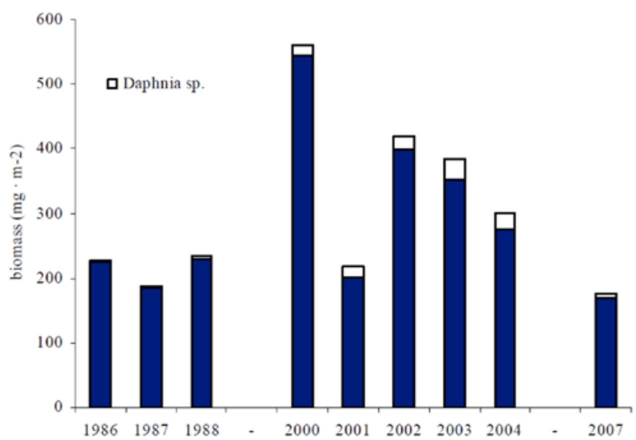

Figure 23. Seasonal mean biomass of Klawock Lake zooplankton and contribution of *Daphnia* sp. in three time periods from 1986 to through 2007. This figure is taken directly from Conitz (2009).

As part of the sediment core analyses of 2002, fossil records of *Bosmina* and *Daphnia* were sampled from the deepest part of Klawock Lake (M. Cartwright, unpublished data). These results showed that the density of *Daphnia* and *Bosmina* were very variable as a function of core depth and years (Figure 24 and Figure 25). However, their densities were found to be higher in the preceding century than prior to the late 1800s. *Daphnia* densities were estimated at about 1,000 specimens per gram dry weight of sediment prior to 1700; less than 500 between 1700 to about 1820, peaking between 2000 – 3000 until 1994, when densities began to decline. *Bosmina* density was around 3000 animals per gram dry weight of sediment during pre-1650, as high as 6,000 *Bosmina* per gram dry weight of sediment in the early 1900s, and have declined to as low as 1,000 in the last decade of study.

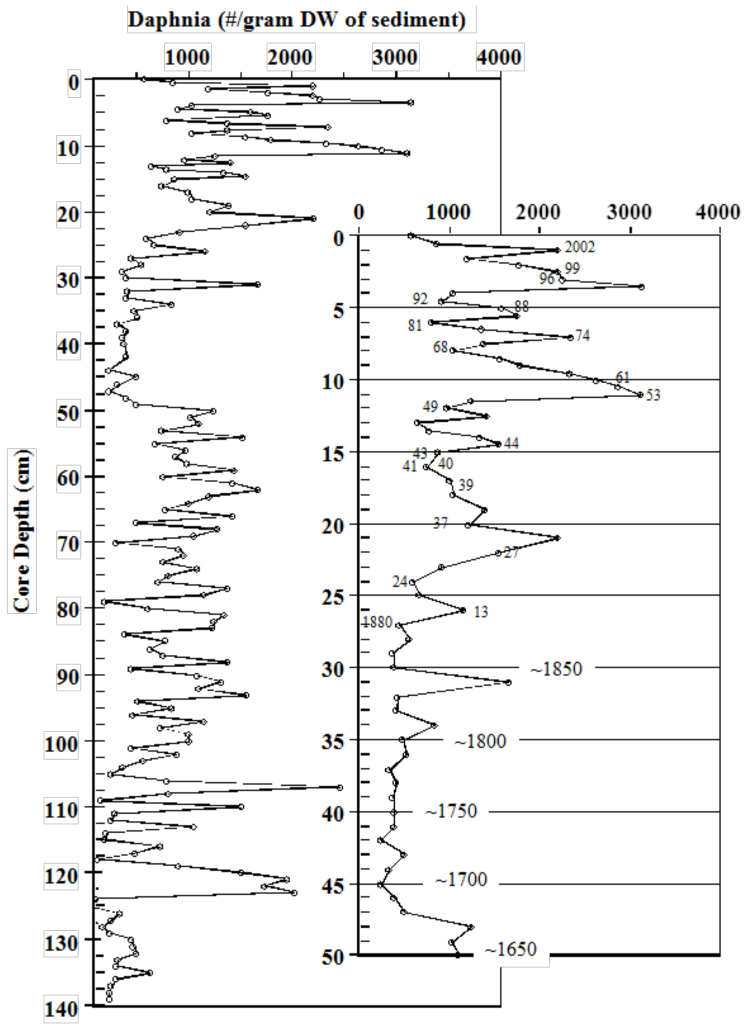

Figure 24. The concentrations of *Daphnia* fossil density (number of planktors per grams (dry weight of sediment)) as a function core depth and time from Core #4 taken from the deepest basin (Basin B) of Klawock Lake, Alaska. Figure provided by M. Cartwright.

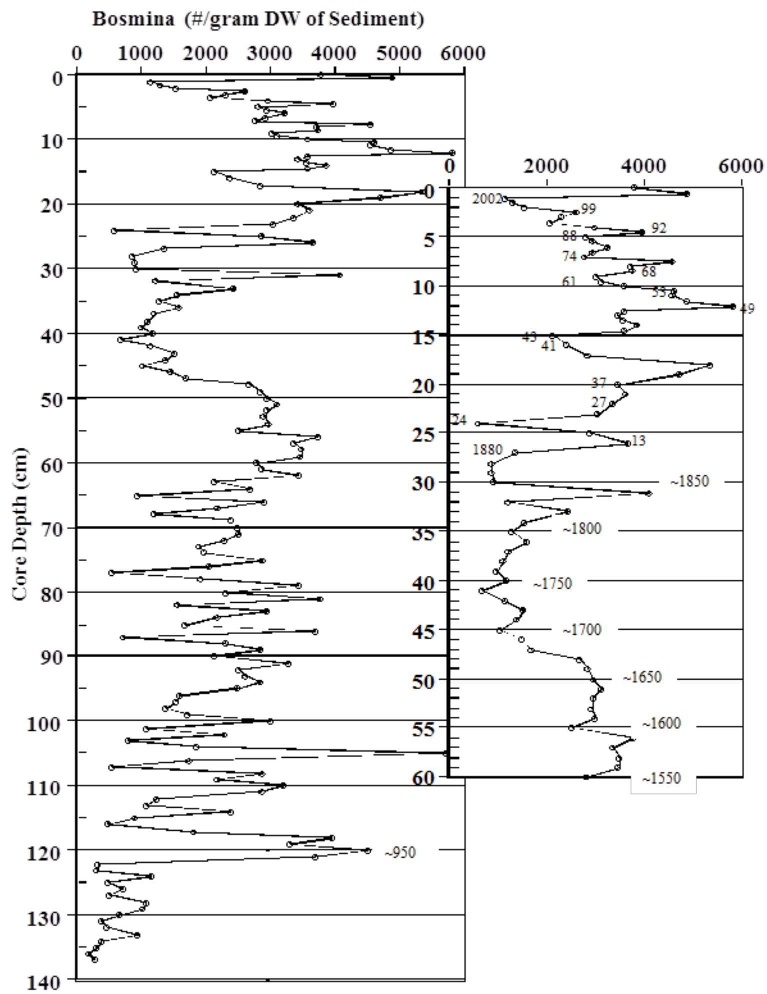

Figure 25. The concentrations of *Bosmina* fossil density (number of planktors per gram (dry weight) of sediment) as a function of core depth and time from the core taken from the deepest basin (Core #3) of Klawock Lake, Alaska. Figure provided by M. Cartwright.

Biologists' opinions on the extent to which lake habitat and primary and secondary productivity have influenced sockeye productivity have differed over the years and datasets are often contradictory. During early years of ADF&G limnological studies (2000-2004), a higher percentage of sockeye fry holding over for 2 years in Klawock Lake, combined with the fact that more returning adults had spent two years in freshwater than in the 1980s and 1990s, led some to speculate that food availability was limiting growth (M. Cartwright, unpublished data; Cartwright et al. 2006; Conitz et al. 2006). This theory was supported in years where the cladoceran zooplankton preferred by sockeye salmon (Daphnia) were relatively low, and it was suggested that this may be a result of sockeye salmon stocking efforts (M. Cartwright, unpublished data). In other years, it was thought that secondary production was "adequate" (Conitz 2009), and sediment core analyses that showcased elevated densities of zooplankton in the last century compared to previous centuries also contradict a food-limited hypothesis (M. Cartwright, unpublished data). Researchers recommended continuing with studies of Klawock Lake in a more systematic way, noting that their ability to fully analyze freshwater productivity issues were likely confounded by the complex interactions between top-down (predators) and bottom-up (food and environmental conditions impacting food) processes (M. Cartwright, unpublished data).

Stream habitat

Moser (1898) noted that Three-Mile and Half-Mile Creeks featured with “ideal” stream beds for spawning. The earliest analysis of stream habitat condition occurred as part of an anadromous streams survey in May 1977 (Edgington & Larson 1979). This survey included detailed mapping of stream channels and bank features, and estimated available salmon spawning area (ASA) for Three-mile Creek, Half-mile Creek, Inlet Creek, and Hatchery Creek. This survey was completed before the majority of logging and road building activities in the watershed. Three-mile Creek was estimated to have 5,846 m^2 of ASA, Half-mile Creek 3,371 m^2 of ASA, and Inlet Creek 2,640 m^2 of ASA; maps demonstrated significant quantities of f large woody debris (LWD) in all systems. Available spawning area was not calculated for Hatchery Creek, but marsh and muskeg areas were mapped and juvenile coho rearing habitats noted. Maps of stream channels and bank features from this survey are included in Appendix A.

The Klawock Watershed Condition Assessment (Central Council Tlingit and Haida Tribes of Alaska & US Forest Service 2002) is the most comprehensive analysis of stream habitat condition to date, and was a conducted to assess watershed health in response to local concerns about sockeye salmon numbers. This assessment begins by summarizing basic information about stream habitat in the watershed at the time by major sub-basin, including hydrology, geology, geomorphology, and other physical processes (Table 7; Figure 26). This assessment characterizes usual hydrologic regimes as a snowmelt-dominated spring runoff and precipitation-dominated fall runoff, with winter and late summer low flow periods. It also describes the history of glaciation in each sub-basin, and south-originating gale-force winds that are a major disturbance factor that can directly and indirectly affect fish habitat through blowdown events in riparian areas.

Table 7. Summary information from the Klawock Watershed Condition Assessment (Central Council Tlingit and Haida Tribes of Alaska & US Forest Service 2002) by major sub-basin (Figure 24).

	Half-mile	Three-mile	Inlet	Hatchery	Klawock River	N.E.	S.E.	Watershed total
Watershed (Acres)	3,361	5,217	2,375	4,890	2,993	3,782	3,642	29,152
Wetlands (Acres)	2,540	1,894	624	1,983	N/A	N/A	N/A	13,725
Streams (Miles)	14	29	13.3	26.8	8.4	17.4	23	132*
Floodplains and alluvial fans (Acres)	154	410	169	409	N/A	N/A	N/A	N/A
Lakes/Ponds (Acres)	70	97.7	0.1	0	N/A	N/A	N/A	N/A
* Timber Harvest (Acres)	32	1,768	388	1,597	N/A	N/A	N/A	N/A
Roads (Miles)	0.6	17.9	8.4	16.2	11.5	23.6	18.1	96.3

* Low estimate, actual numbers considerably higher.

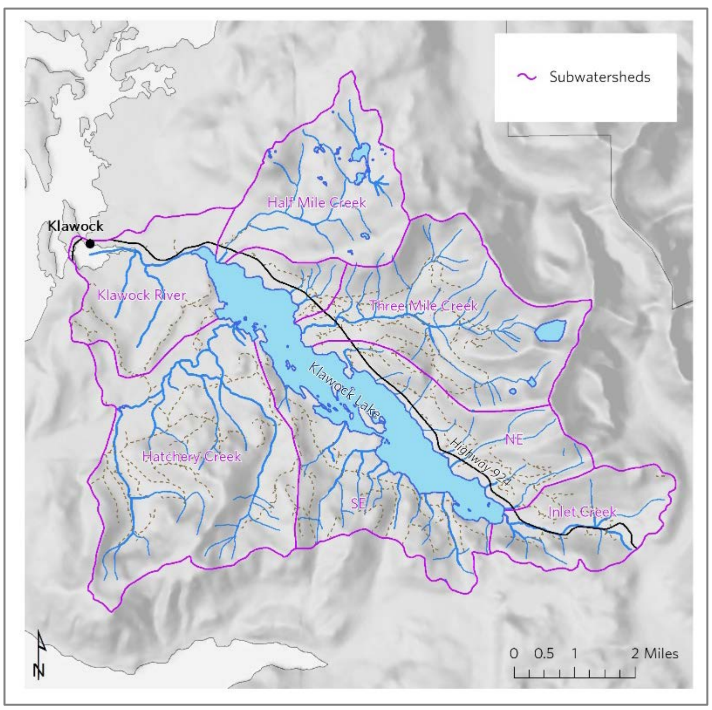

Figure 26. Major sub-basins and streams of the Klawock Watershed.

This assessment also describes the wetlands and important stream process groups (Paustian et al. 2010) in the watershed. Stream process groups characterize streams by their differences in hydrologic function, landform, and channel morphology, which have implications on the type of fish habitat they support. Floodplain and alluvial fan process groups likely have the highest quality sockeye salmon spawning habitat. The major floodplains are located near the mouth of Hatchery Creek and on Inlet Creek, with other floodplains in the southeastern watershed and on Three-mile Creek (Table 9). There are major alluvial fans at the mouths of Three-mile and Half-mile Creeks (Table 9).

Table 8. Available spawning area rating of various process groups for sockeye salmon (Paustian et al. 2010).

Process group	Available spawning area rating for sockeye salmon
Alluvial fan	Low - Moderate
Estuarine	Negligible
Floodplain	High
High Gradient Contained	Negligible
Low Gradient Contained	Low
Moderate gradient contained	Negligible - Low
Moderate gradient mixed control	Low
Palustrine	Low - Moderate

Table 9. Miles of stream by process group (Paustian et al. 2010) for sub-basins in the Klawock Watershed, from the Klawock Watershed Condition Assessment (Central Council Tlingit and Haida Tribes of Alaska & US Forest Service 2002).

Process group / miles of stream	Half-mile	Three-mile	Hatchery	Inlet	Klawock River	Northeast	Southeast
Estuarine	0	0	0	0	0.7	0	0
Palustrine	0.1	0	7.4	0.3	1.0	0.3	1.4
Floodplain	0.4	0.3	2.9	3.2	3.2	0.7	4.6
Alluvial Fan	0	3.4	0.8	0.1	0	2.5	0.6
Large contained	0	0	0	0	0.2	0.1	0
Moderate Gradient Mixed Control	0.5	2.4	1.9	0.7	1.4	1.1	1.7
Moderate Gradient Contained	3.5	0.7	1.6	1.3	1.1	0.1	0.5
High Gradient Channel	9.5	22.1	12.2	7.8	0.4	12.7	14.2
Total Miles	13.9	29	26.8	13.3	8.4	17.4	23

This assessment also used historical photos and land use history information to describe potential impacts of logging on these streams (Central Council Tlingit and Haida Tribes of Alaska & US Forest Service 2002). Figure 27 shows estimated timber harvest dates within the watershed (The Working Forest Group 2013). This assessment noted that timber harvest influences stream flows, remarking that it can both increase or decrease flows depending on the location or time of year, which could influence spawning habitat. In addition, it notes that loss of instream structure from LWD could cause less retention of streambed gravels. The authors thought that Three-mile Creek would be particularly susceptible to these impacts due to the high percentage of this watershed harvested in the 1980s and 1990s. Analysis of pre- and post-harvest aerial photos indicated an increase in the number of beaver ponds in the watershed (Figure 28). They noted that this was particularly a problem in places where spawning habitats in floodplains or areas upstream of floodplain spawning areas had been converted into palustrine channels or where beaver dams had prevented access to spawning gravels; specifically in Hatchery, Swamp, Chutes and Ladders, Deadhead, and Alder Creeks.

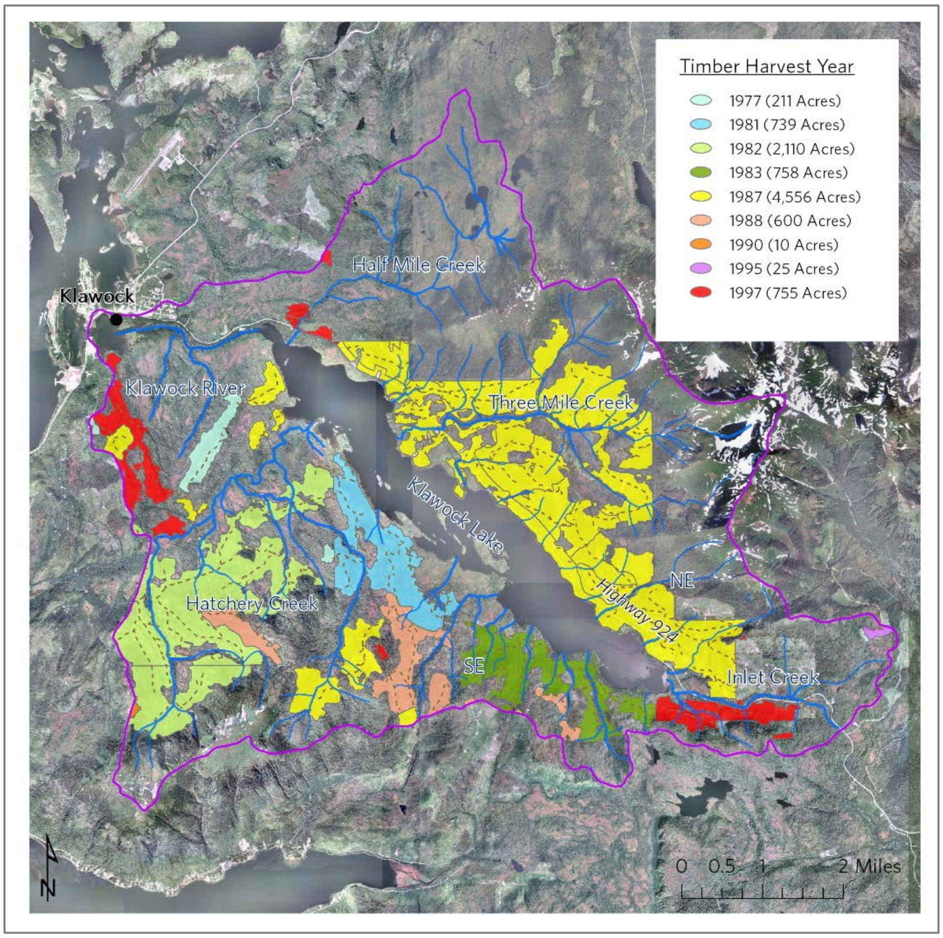

Figure 27. Timber harvest within the Klawock Lake Watershed (The Working Forest Group 2013).

Figure 28. Three-mile Creek alluvial fan, in 1971 (pre-timber harvest; left), and in 1991 (post-timber harvest; right). Photo from the Klawock Watershed Condition Assessment (Central Council Tlingit and Haida Tribes of Alaska & US Forest Service 2002).

In addition, the assessment contained a proper functioning condition (PFC) assessment for the entire watershed. This assessment was conducted on 82.5 miles of stream and 100% of the known fish bearing streams in the watershed. The assessment was used to classify the health or state of physical processes of the riparian-wetland area, and characterize stream reaches as “Proper Functioning”, “Functional-at-risk”, and “Not functioning”. Definitions of these terms are found in Table 10. Summary results from the analysis are shown in Table 11 and the final assessment of each reach is shown in Figure 29. The rating for Half-mile Creek was Proper Functioning Condition. Three-mile Creek sub-basin was rated Functional at Risk due to lack of LWD, inadequate riparian buffers for channel maintenance and recovery, and landslide impacts (excessive erosion and/or deposition); there were also reaches within Three-mile Creek sub-basin rated as non-functional. Inlet and Hatchery Creek were both rated as Proper Functioning Condition overall, but both featured reaches that were rated as functional-at-risk or non-functional. The northeast and southeast basins both featured reaches with a variety of ratings from non-functional to proper functioning condition. Considerable amount of detail and description of reasons for condition ratings are provided by sub-basin and by reach in the assessment but are not described here.

Table 10. Proper functioning condition classification categories from the Klawock Watershed Condition Assessment (Central Council Tlingit and Haida Tribes of Alaska & US Forest Service 2002).

Proper Functioning Condition Classification Categories	Definition
Proper Functioning Condition	The stream channel, floodplain, and/or wetland have the physical characteristics that provide stability through various frequency events. This resiliency allows an area to produce desired values such as fish and wildlife habitat over time.
Functioning-at-risk	The stream or wetland is functioning but is lacking enough vegetation, soils or landform characteristics to withstand various frequency events without significantly damaging the riparian corridor. FAR is the only category that is further stratified by trend (up, down, not apparent). A downward trend rating indicates deteriorating conditions that could become NF. Deteriorated conditions can be transmitted both up and downstream. Trends that are not apparent require further study.
Not Functional	The stream or wetland is not stable because it lacks most of the stabilizing physical characteristics and may continue to deteriorate. The degraded area or reach cannot sustain long-term desired values and return to proper-functioning condition without intervention (change in management).

Table 11. Results of the PFC analysis in the Klawock Watershed by sub-basin. Table from the Klawock Watershed Condition Assessment (Central Council Tlingit and Haida Tribes of Alaska & US Forest Service 2002).

PFC Category	Three-mile	Half-mile	Hatchery	Inlet	Klawock River*	NE*	SE*
Miles of stream	29.0	13.9	26.8	13.3	8.4	17.5	23
Percent sampled total	100	100	100	100	100	100	100
Non-functional	2.7	0	1.1	1.8	0	1.7	0
Functional-at-risk with downward trend	4.7	0	2.0	0.6	1.0	2.7	3.2
Functional-at-risk with no apparent trend	0.4	0	0.6	0.45	0	0	5.1
Functional-at-risk with an upward trend	1.1	0	0	0	0.3	0	0
Proper Functioning Condition	0.7	13.9	14.0	5.4	5.9	4.8	8.5
Total miles analyzed PFC	9.6	13.9	17.7	8.25	7.2	9.2	16.8
*Composite basins, not true sub-basins							

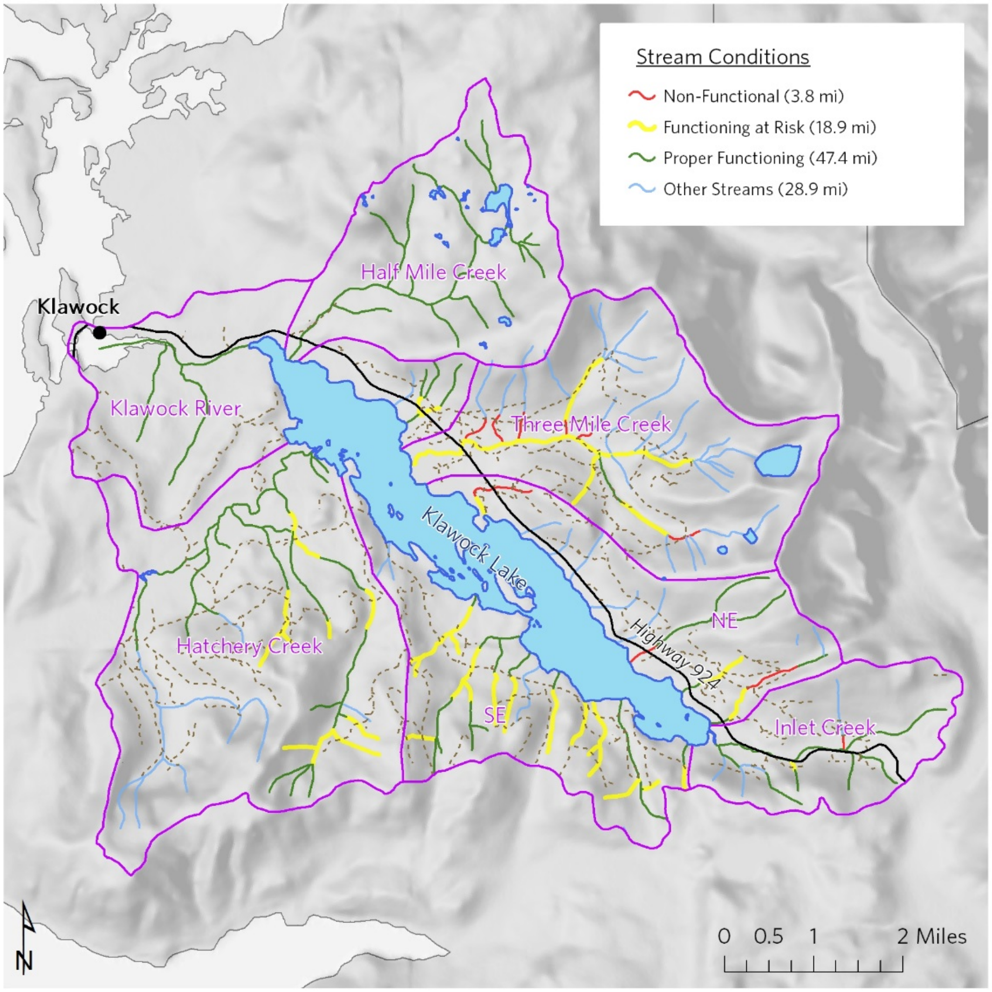

Figure 29. The Klawock Watershed PFC Assessment from 2000 (Central Council Tlingit and Haida Tribes of Alaska & US Forest Service 2002).

A road condition survey was implemented by ADF&G in 2002 for the entire Klawock Lake watershed in order to understand potential impacts of road features on stream systems (Nichols et al. 2002). This survey provided a comprehensive inventory of roads, stream crossings (Figure 30), and stream crossing structures (Figure 31) within the entire watershed, as well as the collection of associated attributes documenting the condition of these roads and structures (Figure 32). In addition, this survey noted major erosional features (Figure 33). Finally, this survey used a red-grey-green analysis of pipes on anadromous streams; this analysis uses several attributes to evaluate fish passage. A green rating indicates that conditions at crossings are likely adequate for fish passage, a gray rating indicates the conditions at crossings may be inadequate for fish passage, and a red rating indicates that conditions at the crossing are likely to inadequate for fish passage. 29 of the 31 culverts assessed in this analysis were classified as red, or assumed to be inadequate for fish passage (Figure 34).

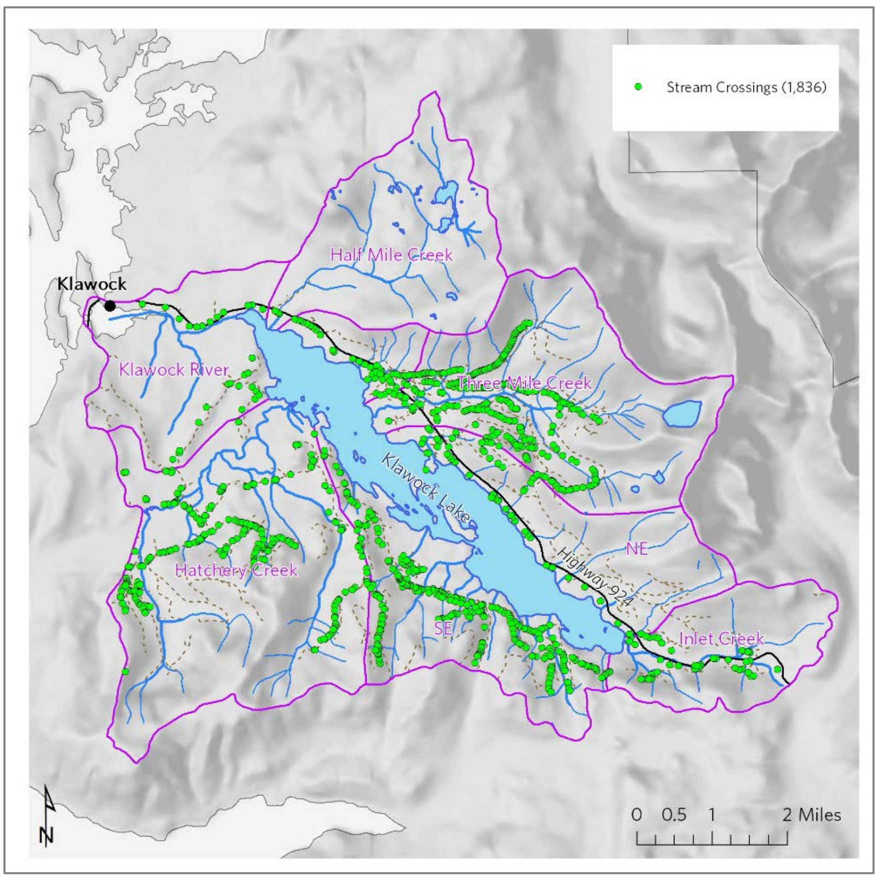

Figure 30. Location of all stream crossings associated with permanent and temporary roads in the Klawock Lake watershed, Southeast Alaska (Nichols et al. 2002).

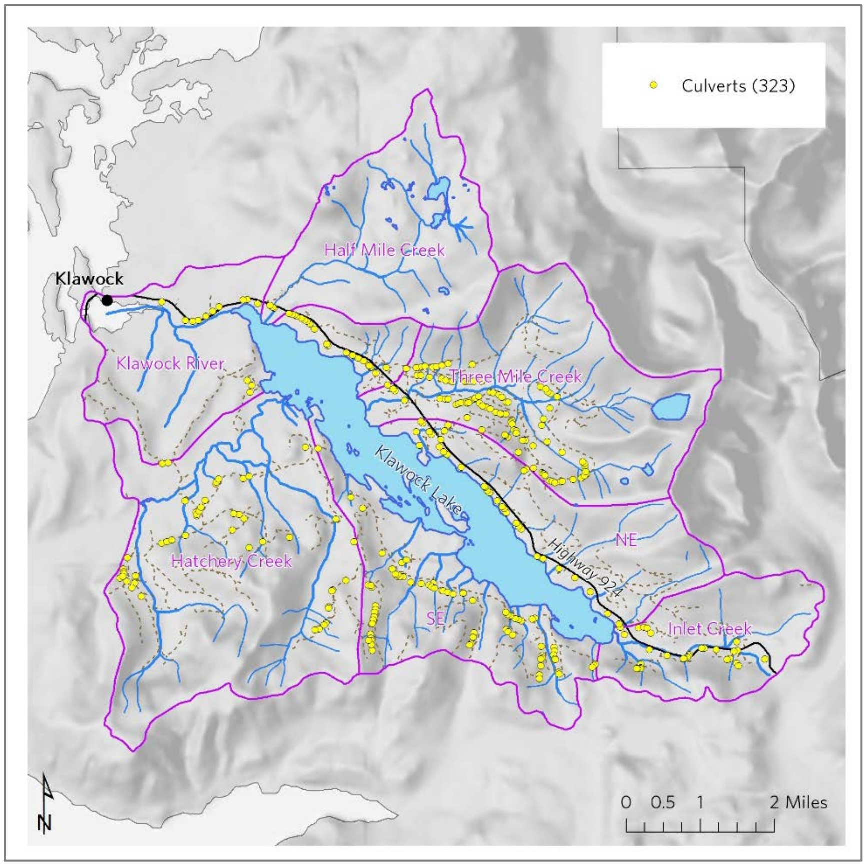

Figure 31. Location of all culvert pipes associated with permanent (Klawock-Hollis Highway) and temporary (watershed) roads in the Klawock Lake watershed, Southeast Alaska (Nichols et al. 2002).

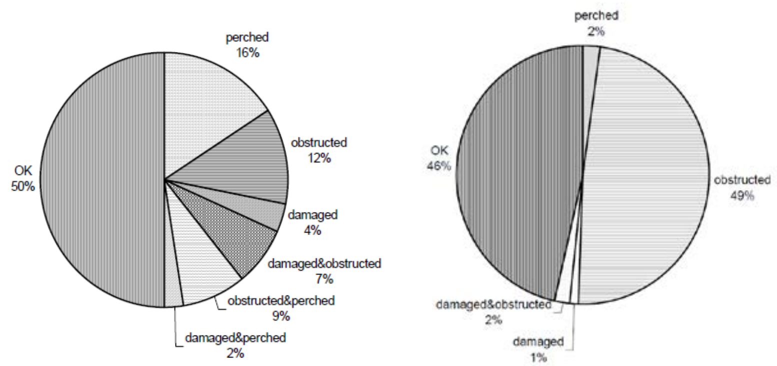

Figure 32. Condition of all culvert pipes associated with the Klawock-Hollis Highway (n=82) and condition of all culvert pipes associated with Klawock Lake watershed temporary roads (n=172). Figure from Nichols et al. (2002).

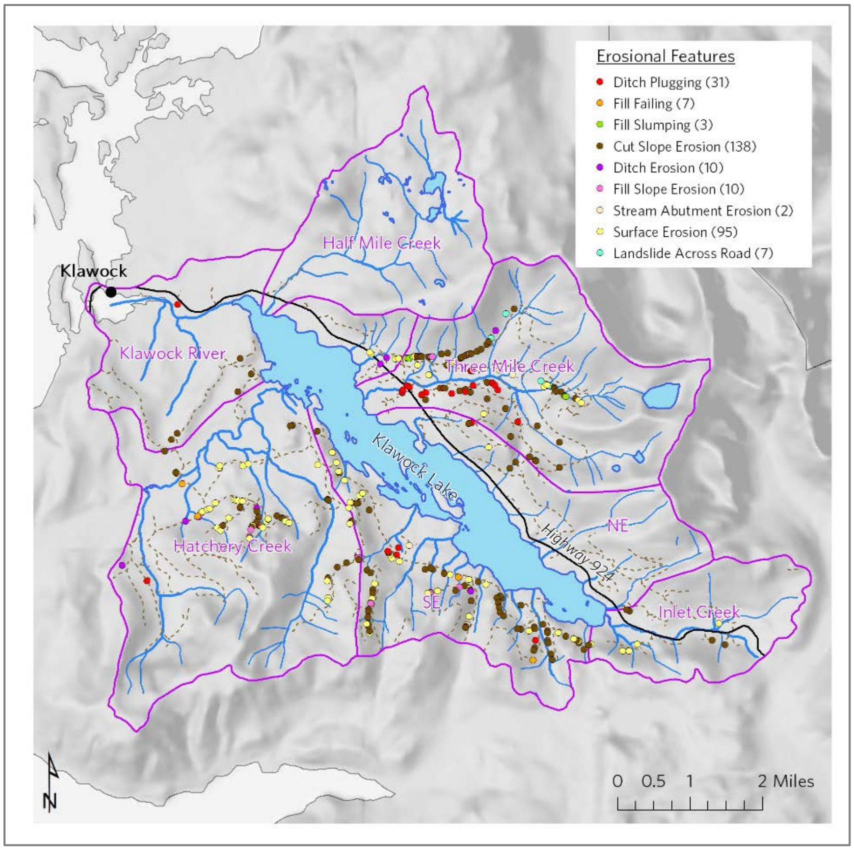

Figure 33. Location of major erosional features within the Klawock Lake watershed, Southeast Alaska (Nichols et al. 2002).

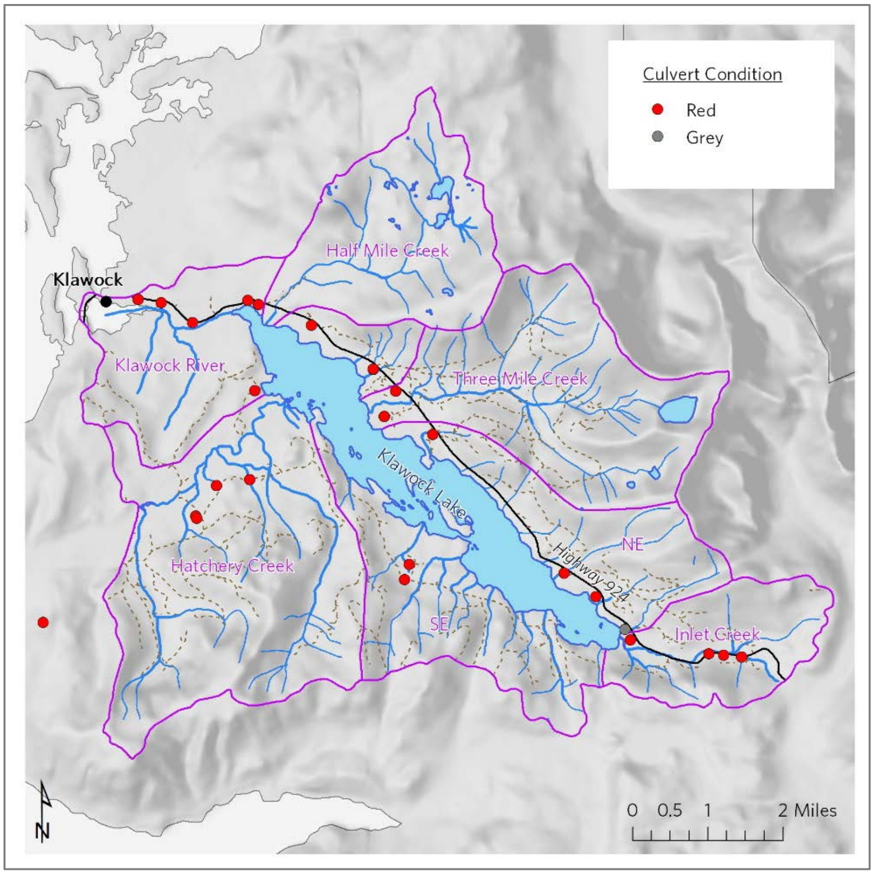

Figure 34. Location and rating (Red-Grey-Green analyses) of 31 selected culvert pipes occurring within anadromous habitat in the Klawock Lake watershed, Southeast Alaska (Nichols et al. 2002).

There was monitoring of road conditions in 2008 after several watershed restoration projects (Klawock Watershed Council 2008). Roads that had been closed (see “Habitat improvement projects”) were visually assessed for flow, erosion, and vegetative growth. At this time, water was flowing well in the ditches, water bars were functioning, and alder had taken over roadbeds. The KWC noted that in some places 4-wheelers were using closed roads and causing water bar damage, and that beavers had taken over some areas in Hatchery Creek where roads had been closed. They also surveyed the three open roads within the Half-mile watershed that are used for accessing the municipal water supply, plant and storage, and found that all three were in need of surfacing, crowning, and ditching to decrease sedimentation. In addition, one open but inactive road not closed as part of initial restoration actions, road 60000, was found to need bridge replacements, road surface work, and fixing or building of ditches to prevent runoff. The condition of the Three-mile sub-basin landslides were rated "very good", although it was suggested that these areas be reseeded every 3-4 years.

Stream discharge data were collected on four reaches of Three-mile Creek (Figure 35) from 1999-2003 and 2005-2006, when the City of Klawock was considering using this system as a water source (Figure 35; Alaska Department of Fish and Game 2006b, c, d, e). Klawock river height is also measured daily at the KRH (Figure 37; J. Lundberg, KRH, unpublished data).

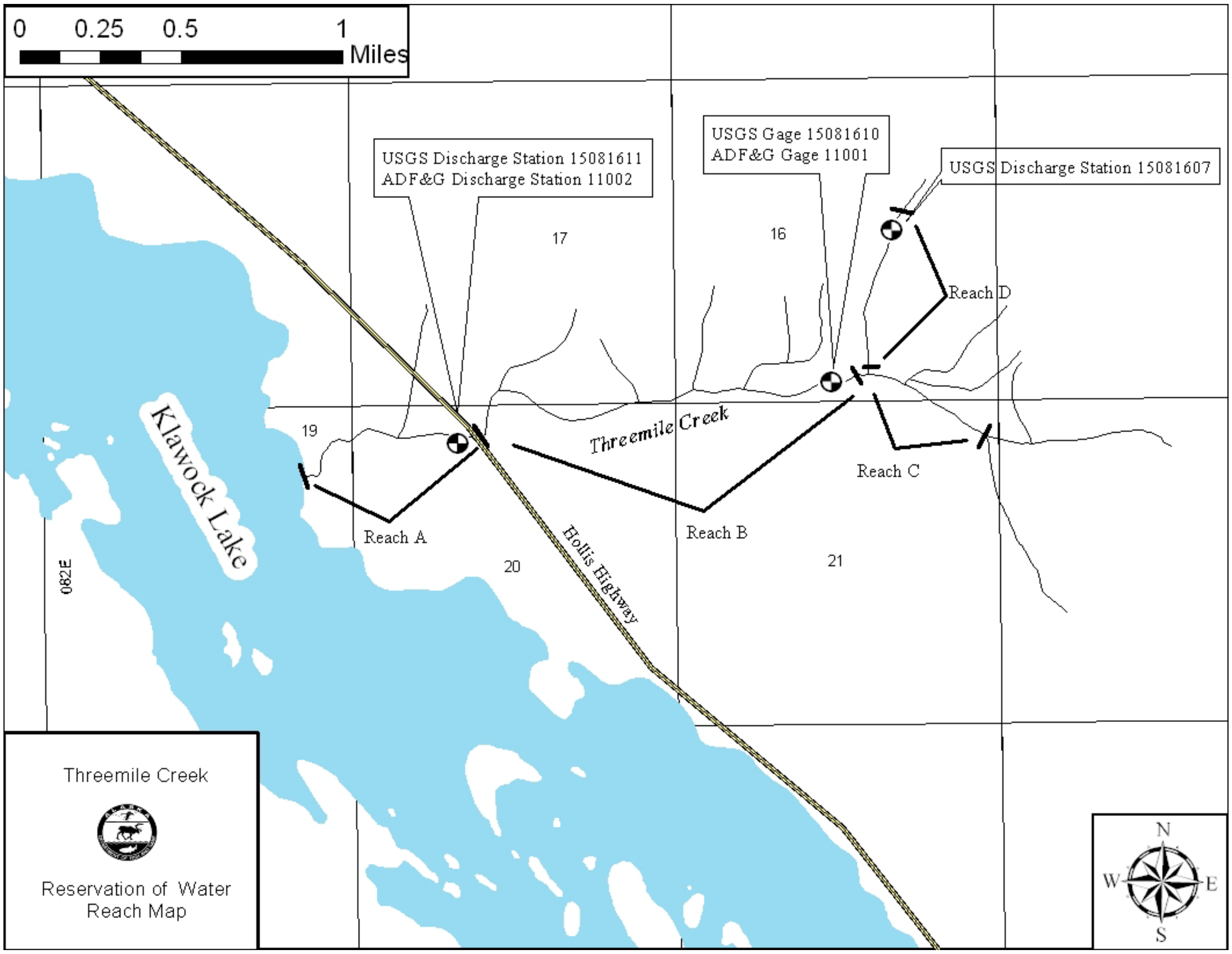

Figure 35. Stream gaging stations and reaches for which ADF&G submitted water reservation applications on Three-mile creek. Figure from ADF&G (2006b).

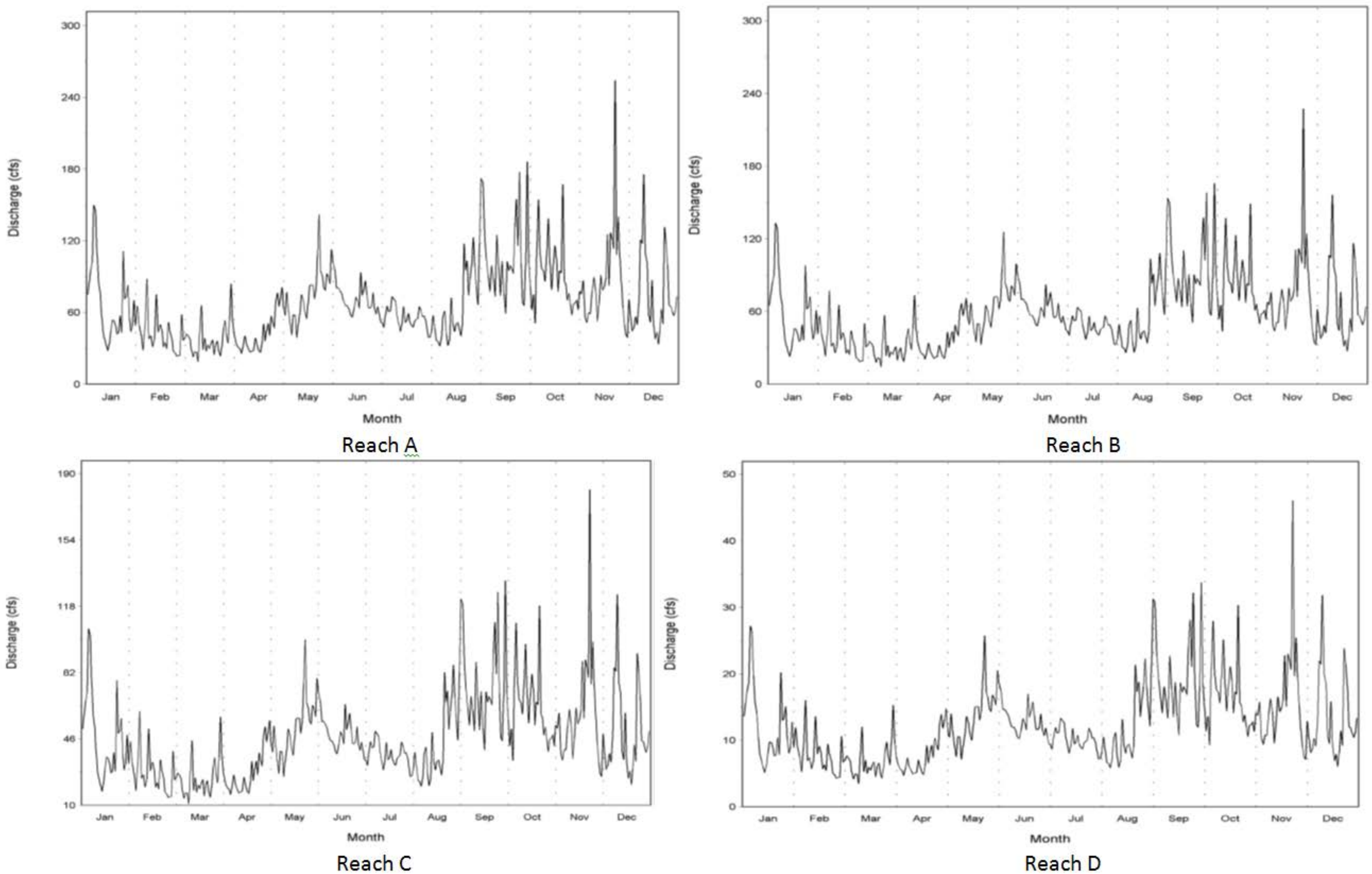

Figure 36. Annual hydrographs of estimated mean daily flows (cfs) for Reach A, B, C, and D, based on complete water years of record from three stream gages on Three-mile Creek from 1999-2003 and 2005-2006. Figures from ADF&G (2006b, c, d, e).

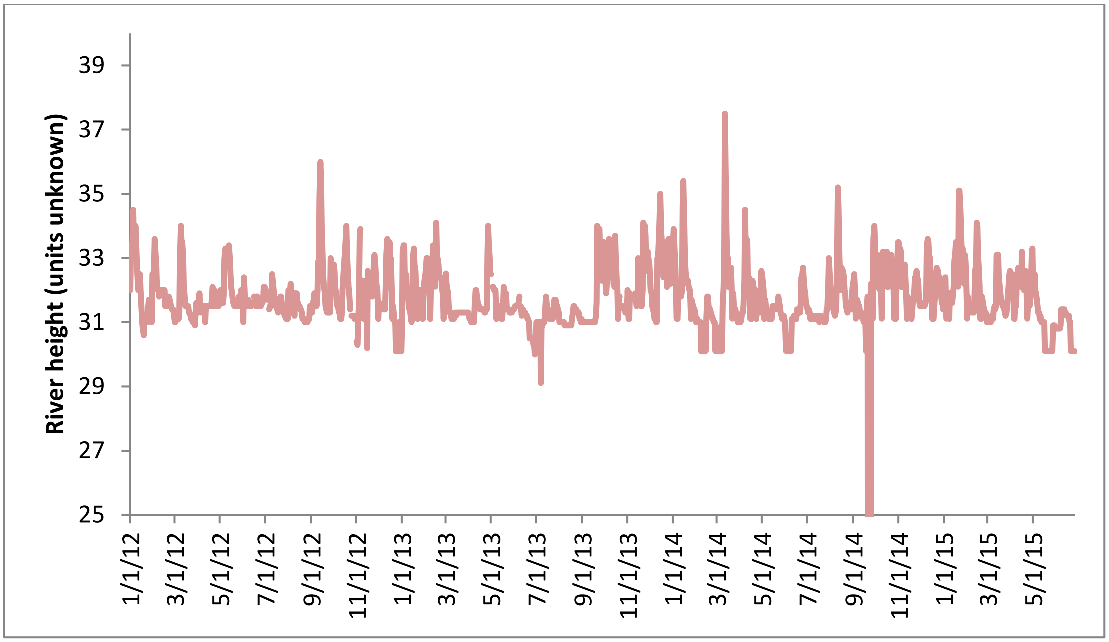

Figure 37. River height at the KRH from 2012 through current day (J. Lundberg, KRH, unpublished data).

The KWC conducted a stream monitoring program (Klawock Watershed Council 2008) during and after the majority of the restoration projects that were implemented during the 2000s (see "Habitat improvement" section). Stream temperature and dissolved oxygen from 13 streams was monitored from May to November 2007 (Appendix B; Figure 38; Figure 39). Water temperatures followed temporal trends consistent with other streams on Prince of Wales Island, and no data showed values higher than those known to cause chronic stress in salmon. Inlet Creek generally had the warmest temperatures in mid to late summer, while Three-mile Creek was generally the coldest. Dissolved oxygen saturation values easily met minimum water quality standards, with Blue Water Creek having some of the highest saturation values. Blue Water Creek had DO values well above 100% from late August until October. The high DO values are possibly incorrect, as equipment and calibration records were not included in reports. However, it is possible that DO in at least Blue Water Creek is higher than other streams because of excessive algal growth during the summer. Field visits in July 2014 showed substrate in Blue Water Creek was covered by a dense algal mat throughout the stream that was not observed in other streams (A. Prussian, personal observation). Samples were sent to the University of Alaska's Environment and Natural Resources Institute but could not be identified (Dan Bogan, UAA-ENRI, personal communication).

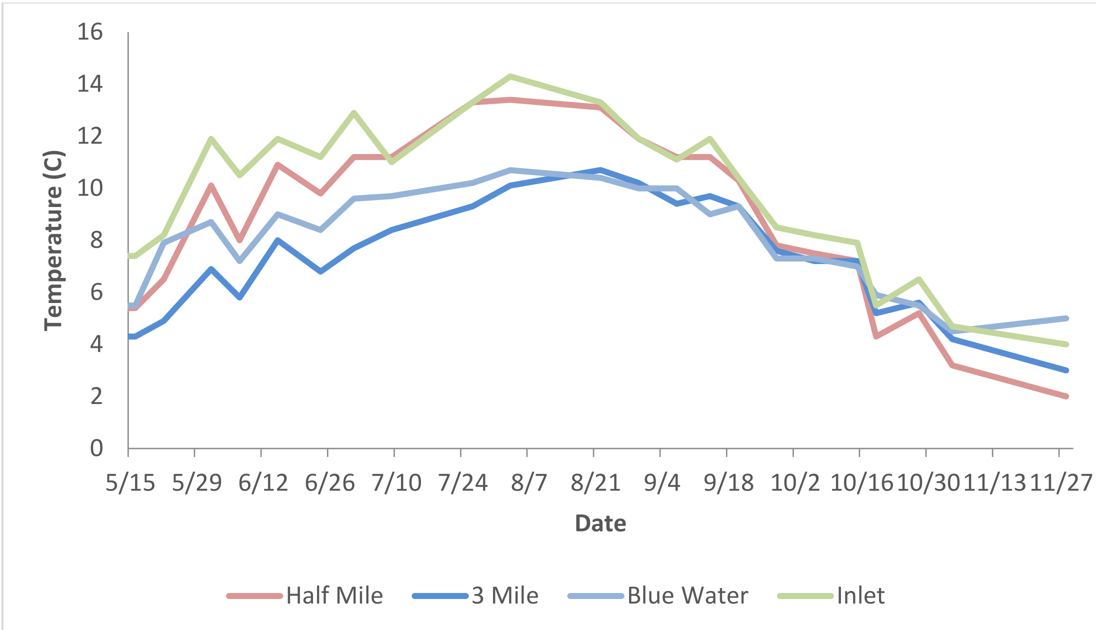

Figure 38. Daily stream temperature measured by the KWC in 2007 in select tributaries of Klawock Lake. Temperatures of other tributaries can be found in Appendix BV/

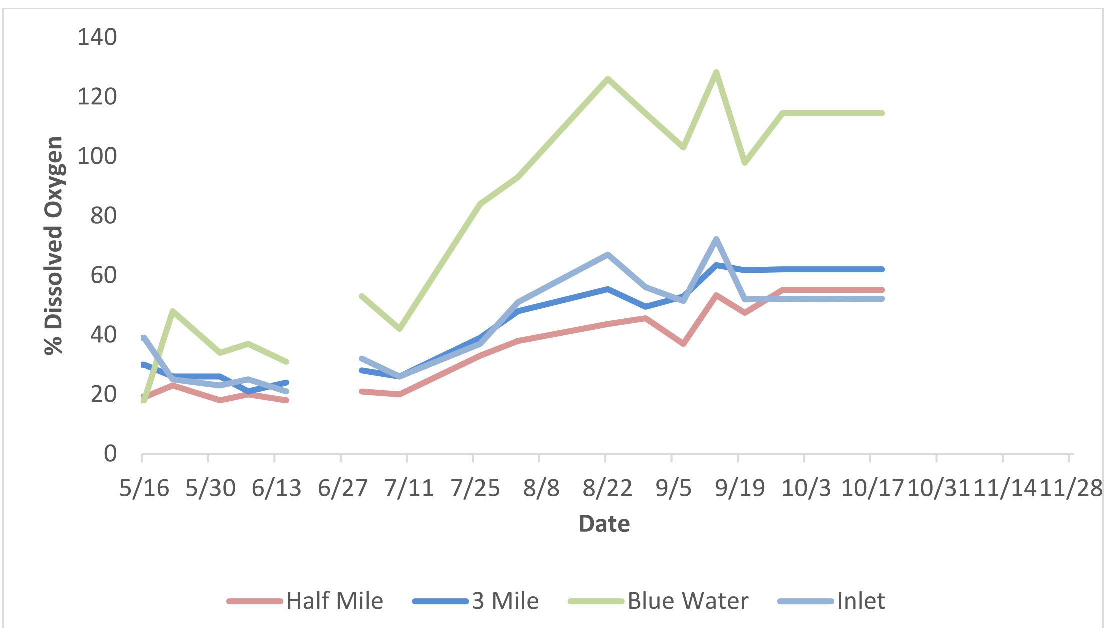

Figure 39. Dissolved oxygen in select tributaries of Klawock Lake measured by the KWC in 2007 (Klawock Watershed Council 2008).

Figure 40. Photograph of algae covered substrate from Blue Water Creek from 2014 (A. Prussian, personal observation).

Local residents interviewed in 2002 had differing responses about the potential impacts that logging had had on stream condition and sockeye salmon declines in Klawock Lake (Ratner et al. 2006). Some mentioned that it must have impacts, including debris blocking fish passage and increases in stream temperature and runoff. Other concerns related to stream habitat include comments from biologists and residents about the potential impacts of the sub-division built in the 1970s within the Three-Mile Creek alluvial fan, including ongoing riparian alterations by residents, to streambed scour (J. Conitz, ADF&G, personal communications; M. Cartwright, personal communications, S. Jacobson, USFS, personal communications; Central Council Tlingit and Haida Tribes of Alaska & US Forest Service 2002). In addition, some have acknowledged concern about the influence of water removals for the city water supply from Half-mile Creek on spawning and egg survival (J. Conitz, personal communication). Two regional assessments have highlighted the Klawock Lake watershed as being a high priority for restoration work because of likely impaired freshwater habitat condition (Albert et al. 2008; Prince of Wales Watershed Association 2014).

Klawock Estuary and Klawock Bay habitat

Little study has been done on the habitat condition of the Klawock Estuary and Klawock Bay for salmon. A study conducted in 2011 as part of the Klawock causeway restoration (see “Habitat improvement projects”) mapped eelgrass beds and other benthic habitats using aerial imagery and field-based surveys (The Nature Conservancy 2012).

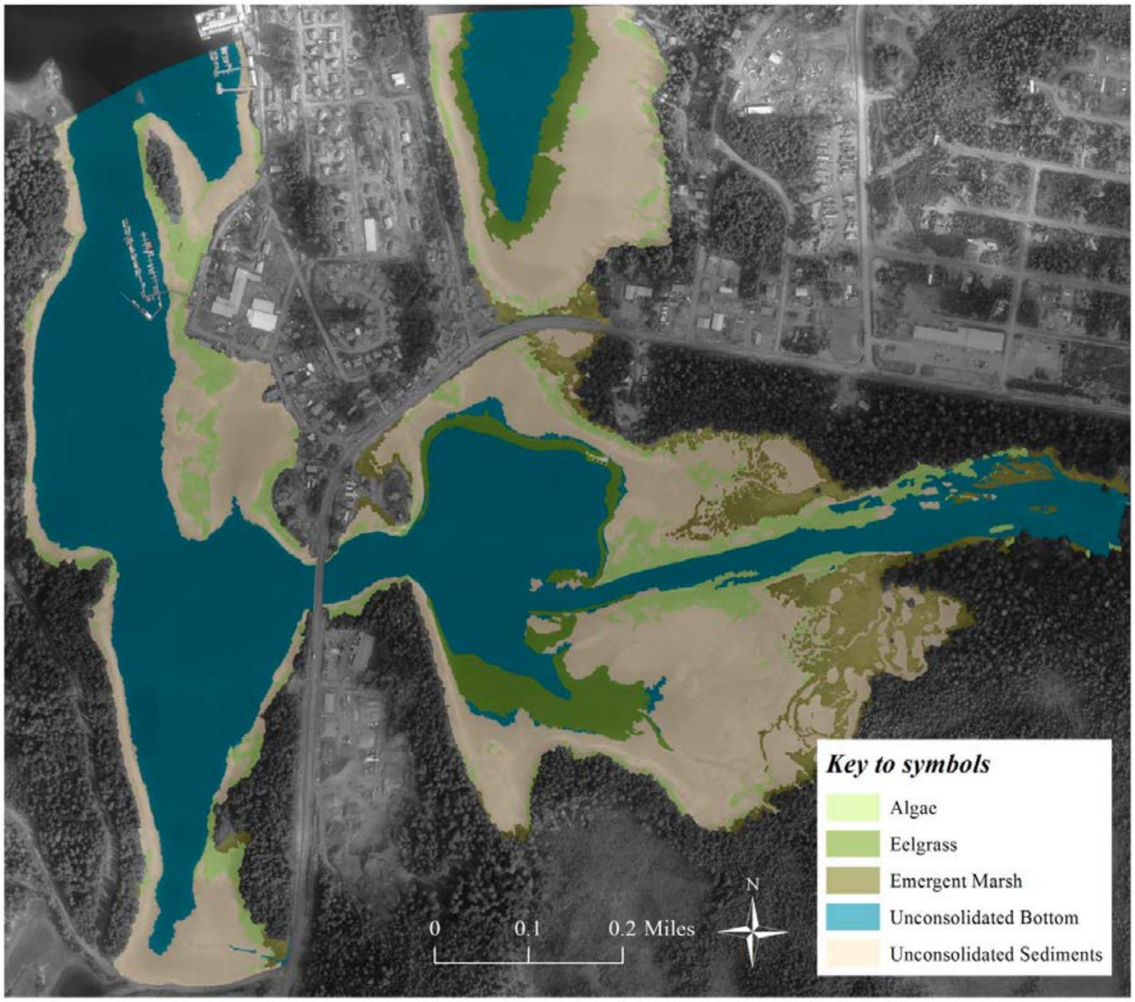

Figure 41. Benthic habitat map of Klawock Bay and Estuary created in 2011 (The Nature Conservancy 2012).

Pollution from charter boats and sewage has been suggested by local residents as impacting salmon habitat in these areas (Ratner et al. 2006).

Review of records from the Alaska Department of Environmental Conservation as part of the Prince of Wales unified watershed assessment (2014) found 15 contaminated sites in the Klawock Lake watershed, many at the mouth of Klawock River within the community of Klawock, and at least 20 spill records for the community of Klawock, much of which is situated at the mouth of the Klawock River. At the time of the Prince of Wales unified watershed assessment, only 2 contaminated sites had not been cleaned up, both of which were petroleum spills.

Habitat improvement projects

The majority of the Klawock Lake watershed habitat improvement projects were initiated as a result of the watershed condition assessment (Central Council Tlingit and Haida Tribes of Alaska & US Forest Service 2002), the road condition assessment (Nichols et al. 2002), and the resulting restoration plan (Keta Engineering 2003). Beginning in 2003 the KWC began applying for funding through the Alaska

Sustainable Salmon Fund (AKSSF) and other sources to implement a series of actions aimed at limiting sediment transport to spawning streams and improving spawning and rearing habitats. These projects were mostly implemented by the KWC, KHC, Klawock Cooperative Association, Shaan-Seet Corporation, and Craig Tribal Association, and focused on reducing erosion through road closure and revegetation, riparian thinning to increase recruitment of large wood into streams, and improving fish passage. In the end, over 52 stream miles were identified as improved (Klawock Watershed Council 2008). Major projects are summarized below, but details on specific methods can be found in the Klawock Watershed restoration master plan (Keta Engineering 2003), the 2008 master restoration plan update (Klawock Watershed Council 2008), and resulting AKSSF grant reports (Craig Community Association 2006a, b, c, 2007a, b; Klawock Cooperative Association 2007a, b, 2009).

Erosion control

The primary mechanism for erosion control in the watershed was road closure. The restoration plan called for closing the majority of roads in Three-mile Creek and Hatchery Creek basin, all roads in the Southeast basin minus one access road, and complete closure of roads in the Inlet Creek basin (Keta Engineering 2003). Road closure included installing water bars and removing drainage structures. By 2008, over 91 miles of road had been closed, including nearly all roads closed in the Half-mile and Hatchery Creek basins, and all roads closed in the Three-mile Creek and Inlet Creek basins except for the Klawock-Hollis Highway (Klawock Watershed Council 2008). According to the 2008 master restoration plan update, 309 culverts were removed, 42 bridges were removed, and 442 erosion control structures were constructed. Although the 2008 master restoration plan update only listed the location of 109 removed structures (show in Figure 42), it is likely that all of the most problematic structures were removed as part of this effort. Most of these structures were removed from the Three-mile watershed.

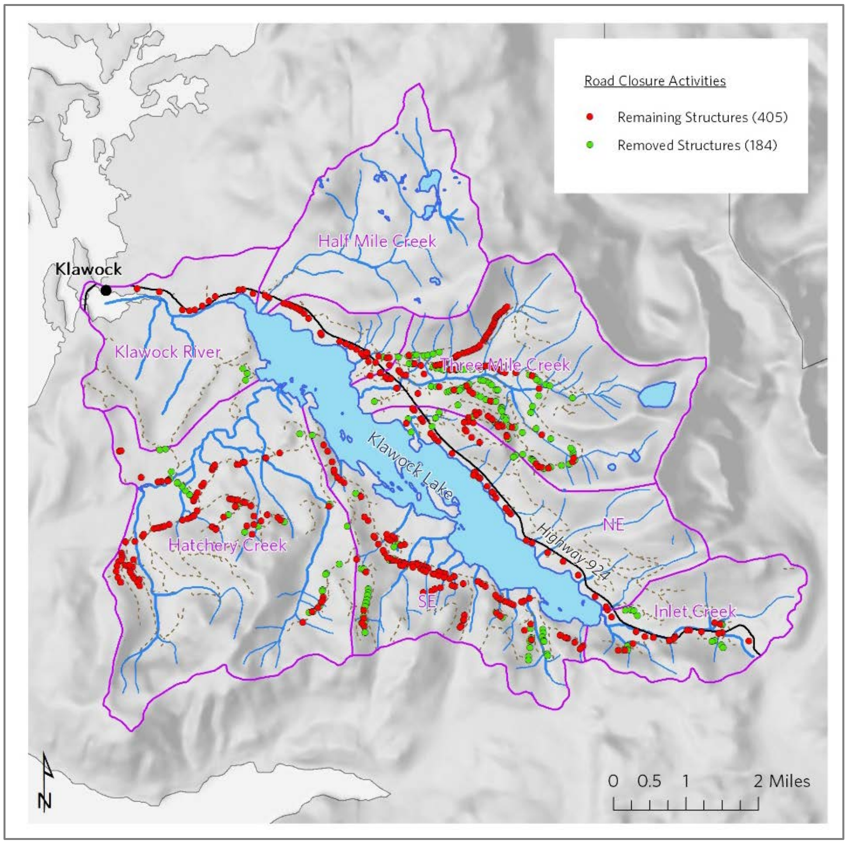

Figure 42. Structures that are known to have been removed as a result of road closure activities (Klawock Watershed Council 2008).

Erosion control was also accomplished through erosion control structures such as erosion control netting and broadcast seeding (Keta Engineering 2003). Three landslide areas in the Three-mile sub-basin were seeded in 2005 and 2008 (Klawock Watershed Council 2008).

Further details about specific erosion control measures can be found in the original restoration plan (Keta Engineering 2003) and the resulting AKSSF grant reports.

Fish passage

Because fish passage was identified as an issue in the watershed assessment (Central Council Tlingit and Haida Tribes of Alaska & US Forest Service 2002), a series of fish passage projects were proposed in the restoration plan (Keta Engineering 2003). Three culverts in the Hatchery Creek sub-basin were replaced in 2003 by the Craig Community Association, with financial support from the U.S. Fish and Wildlife Service's Tribal Grants Program (see Appendix C for details). In 2012 and 2013, 6 culverts on the Klawock-Hollis Highway that were identified as red culverts in the road condition survey were replaced by the Alaska Department of Transportation (M. Minnillo, ADF&G, personal communication). The locations of these replaced culverts are shown in Figure 41.

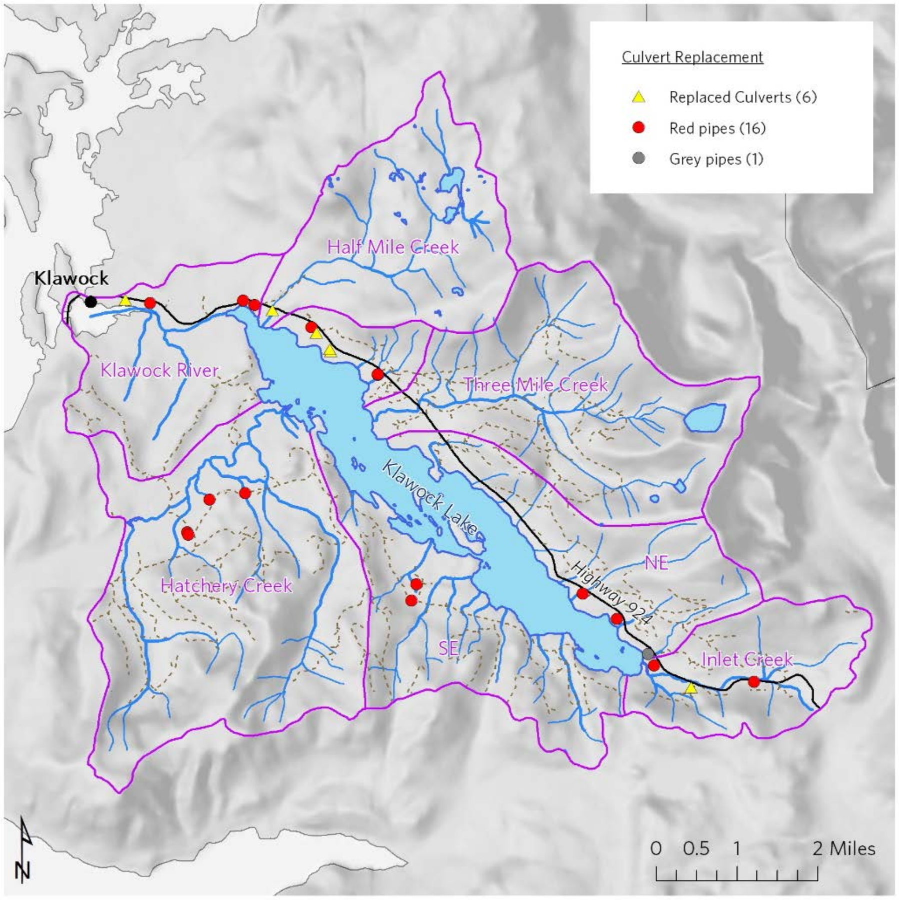

Figure 43. Replaced culverts that were initially identified as red pipes (M. Minnillo, ADF&G, personal communication; Nichols et al. 2002).

The other major fish passage project was associated with the Klawock-Hollis highway causeway in Klawock. Historically, a narrow isthmus connecting Klawock to the main Prince of Wales Island was inundated at high tides (Figure 44). This high-tide channel was a secondary migration corridor for juvenile salmon from Klawock Lake allowing them passage to lagoon habitat rich in eel grass and offering additional estuarine rearing areas. In 1964, the Klawock-Hollis Highway was constructed over this isthmus, resulting in only a single exit for the Klawock River to flow into Klawock Inlet. The causeway restoration project reconstructed passage for migrating salmon through the isthmus by installing an 18 foot by 100 foot cast concrete culvert under the road in 2011 (The Nature Conservancy 2012).

Figure 44. Aerial photo of Klawock showing the location and pre-existing condition of the Klawock River estuary and causeway area (stated as “Project Site”).

Monitoring after the project included installing an underwater camera for identifying and counting migrating adult and juvenile salmon transiting the culvert, as well as water quality sampling and eel grass surveys in the newly accessible lagoon. Passage of adult and juvenile fish has been documented through the culvert. Sampling for changes in water quality and density of fish and eel grass in the newly accessible lagoon has so far been inconclusive, and mapping eel grass locations is planned in the future.

Riparian thinning

Riparian thinning projects were implemented in order to promote rapid growth of remaining trees, both opening forests to promote browse and aiding in the recruitment of LWD in streams (Keta Engineering 2003). In 2007, KWC was funded approximately $65,000 by AKSSF to thin 103 acres of riparian forest in eight sub-watersheds of Klawock Lake. According to thinning inspection reports from July 30, 2007, 90 acres were thinned, which covered over 20,000 lineal feet of stream along 23 separate tributaries (Table 12; Klawock Cooperative Association 2007a). Maps of the treated areas could not be found.

Table 12. Areas of riparian forest and total length of stream thinned in select sub-basins of the Klawock Lake watershed (Klawock Cooperative Association 2007a).

Sub-basin	Acres thinned	Length of stream
Hatchery Creek	18	4,030
Swamp Creek	5	1,000
Chutes and Ladders	18	3,950
Alder Creek	9	1,900
Arrow Creek	2	880
7-Mile	7	1,500
Deadhead	2	500
Three-mile	29	6,400
Total	90	20,160

Riparian thinning prescriptions from the USFS (P. Tierney, USFS, unpublished data) were used for these projects, and are described in more detail in Appendix D. The treatment was designed to leave approximately 40% of the alder canopy. Conifers were generally thinned to an 18x18 foot spacing resulting in about 134 trees per acre. All red alder were removed within a 20 foot radius of any desired conifer. Larger alder were girdled rather than cut down to avoid placing too much slash on the ground at once. No-cut streamside buffers of 5-15 feet were also left and specified for each section of the stream. Finally, red alder was thinned to a 25x25 foot spacing (70 trees per acre) to maintain some stand diversity and provide some protection for conifers from wind, snow, and ice. There has been no known monitoring of these thinned areas post inspection.

Discussion and recommendations

Despite the inconsistency and inaccuracy in which sockeye salmon abundance has been monitored over the years, it is likely that modern day abundance is far from what it was in previous centuries. The Klawock Lake drainage has been subject to extensive study with many diverse and interested land management, regulatory, and funding organizations playing important roles in its management and use. Moving forward, this work is extremely valuable as a basis to better address sockeye salmon declines on Klawock Lake. In order to synthesize the major findings of these studies and their implications, we will address the most commonly-cited factors thought to be responsible for the historical and recent sockeye salmon declines in Klawock Lake.

Spawning habitat degradation

Timber harvest within riparian areas of streams has long been recognized as having profound impacts on the natural functions of freshwater systems (e.g., Murphy 1995). Previous assessment by Central Council Tlingit and Haida Tribes of Alaska and USFS (2002) suggested that timber harvest practices during the 1970s-1990s, before the implementation of riparian buffer setbacks along stream corridors, severally impaired the natural functions of many streams within the Klawock Lake watershed. Natural stream functions including sediment transport, erosion control, and flow regulation are extremely important for ensuring natural spawning conditions and adequate egg to fry survival for salmonids of all species, including sockeye salmon (Hall & Lantz 1969; Hicks 1989; Tiegs et al. 2008). Because timber harvest within riparian areas have been documented as influencing these processes, and the condition of suitable and available spawning habitat for adult salmon, it is likely that historical timber harvest practices in the Klawock Lake watershed have negatively impacted sockeye salmon abundance in this system.

The extent and magnitude of this negative impact, however, is difficult to assess at this time. With the exception of the anadromous cataloging nominations from the late 1970s and early 1980s, of which little is known about the extent sampled and methodologies used, historical extent of sockeye salmon habitat is not documented. Even less has been recorded about the spatial abundance of spawning sockeye at that time, or whether lake shore spawning habitat existed or exists. Three-mile Creek and Inlet Creek were identified as the largest producers of sockeye during the 1990s and 2000s, and it is likely they were significant producers historically as well, given the geomorphology of these watersheds and historical accounts from the cannery. Three-mile Creek was also identified as being in functional-at-risk condition, and thus this may be the most likely location for significant negative impacts on sockeye abundance. It is also possible that Hatchery Creek produced more sockeye salmon historically and that it has been adversely impacted by beaver activity.

To date, there have been significant investments in restoration activities in the Klawock Lake watershed, including considerable amount of work to reduce sediment contributions to streams, improve fish passage through roads, close logging roads, and improve riparian conditions along lake tributaries. It is likely that most of these activities have improved stream function, although some restoration actions, such as forest thinning in riparian areas, may take many years to result in improved function. It is likely that these projects have improved salmon habitat, especially in regards to fish passage. However, there are potential restoration efforts originally proposed that were never completed, including sediment re-introduction in Half-mile Creek to replace sediment that is no longer transported downstream due to the water impoundment. A field evaluation of some of the highest priority restoration projects, including those fish passage projects on major sockeye pawning tributaries, would be useful to determine how successful they have been and if they are continuing to function as designed. Finally, it may be possible that restoration actions targeted specifically at current or historic sockeye spawning areas, as opposed to those designed to improve watershed function more generally, may yield beneficial results.

Because traditional use of sockeye included collection of spawning or spawned out sockeye, it is possible that knowledge around historical extent and abundance of sockeye spawning still exists with Native Alaskan elders. Research focused on collecting such traditional ecological knowledge could be valuable for identifying, evaluating and prioritizing potential restoration activities. Likewise, better understanding of current spatial patterns of sockeye spawning in the Klawock Lake would be valuable to better understand habitat preferences of Klawock Lake sockeye. Characterizing the habitat conditions of these current and historical spawning areas, specifically with regard to habitat characteristics considered vital to egg-to-fry survival of sockeye salmon, including hyporheic flow, and sediment transport and stability, will be necessary in order to determine if and to what extent improvements can be made to spawning areas in streams.

Ultimately, the best way to quantify the condition and productivity of current spawning habitat for sockeye abundance would be to quantify the relationship between spawners entering particular tributaries, and the fry exiting these tributaries. Given the expense of such research, it may be best to focus on spawning habitat assessment and restoration efforts in the areas most likely to support sockeye productivity, and measure the results in changes in habitat conditions.

CLIMATE AND LAKE AND OCEAN PRODUCTIVITY

Large-scale climate indices have been shown to be linked to salmon productivity (e.g., Mantua et al. 1997). Specifically, sea surface temperatures and the Pacific Decadal Oscillation are correlated with long-term trends in sockeye productivity, likely through processes tied to both marine and freshwater survival. However, meta-analysis of sockeye populations over long time scales have suggested that individual systems can display significant variability over time and that any temporal patterns of individual systems can often be very different from nearby, similar systems (Rogers & Schindler 2011; Rogers et al. 2011).

Sockeye systems are often thought to be limited by freshwater productivity and the amount of food available to juveniles that spend one to three years in lakes (e.g., Edmundson & Mazumder 2001; Hyatt et al. 2004; Hyatt & Stockner 1985; Milovskaya et al. 1998; Rich et al. 2009). However, nutrient and food web dynamics within sockeye lakes are complex and often vary among lakes (Gregory-Eaves et al. 2004; Gregory-Eaves et al. 2009; Mazumder & Edmundson 2002; Selbie et al. 2009; Selbie et al. 2007; Sweetman & Finney 2003), making it difficult to understand just how these bottom-up processes can impact sockeye production overtime, especially without long-term, consistent datasets examining climate, water quality, nutrient availability, phytoplankton populations, zooplankton communities, and sockeye salmon production at the juvenile and adult life stages.

Thus, the assumptions drawn from various intermittent studies conducted by ADF&G between 1987 and 2007 looking at water quality, nutrient availability, phytoplankton populations, zooplankton communities, and sockeye salmon juvenile and smolt about whether or not Klawock Lake is or was at the time a food-limited system were likely premature. As these researched acknowledged (M. Cartwright, personal communications; Conitz 2009), only with a systematic, long-term approach to monitoring and analyzing these factors can robust conclusions be drawn. Doing this would involve long-term funding mechanisms and commitments from multiple partners.

Data collected as part of the paleolimnologic sampling in 2002 does provide a more useful long-term dataset of nutrient and zooplankton communities over long-period of times. This effort to fully understand food web dynamics and how they impact sockeye productivity was hindered by its inability to reconstruct historical sockeye salmon abundance due to high flushing rates, an issue since identified in Klawock Lake and other similar systems (M. Cartwright, unpublished data; Gregory-Eaves et al. 2009; Holtham et al. 2004). However, this work does showcase that, over time, the food base for sockeye salmon within Klawock Lake has varied largely, suggesting that sockeye salmon in this system have also likely been subject to large, natural variances. Looking at the food base using these techniques over the last 15 years may provide more insight into recent trends in sockeye productivity, especially given the accurate escapements monitored over that time period.

Many sockeye systems have been augmented by lake fertilization efforts in the past in attempt to boost productivity. If climatic and lake productivity issues were identified as factors influencing Klawock Lake sockeye productivity, fertilization could potentially be an option to address it. Meta-analyses looking at the impacts of fertilization on sockeye populations has been found to be successful in the majority of systems (Hyatt et al. 2004; Hyatt & Stockner 1985); however, it has been stressed that given the complexity and variability of sockeye-lake systems, not all systems subjected to fertilization will see positive effects (Gregory-Eaves et al. 2004; Hyatt et al. 2004; Mazumder & Edmundson 2002; Selbie et al. 2007). Systems with high flushing rates, such as Klawock Lake, would most likely be least responsive to fertilization efforts (Scharf 1999).

Many factors in the nearshore and marine environment, including coastal upwelling, water temperature, prey availability, and predation can impact salmon abundance (e.g., Kruse 1998). It is logical that impacts on sockeye salmon in the nearshore environment would be shared among nearby sockeye systems with similar migration patterns. Figure 45 illustrates sockeye salmon escapement patterns for the previous 10 years from other sockeye salmon systems. Hetta, McDonald, and Hugh Smith Lake all seem to follow similar patterns in escapement, whereas Klawock Lake is often very different. Given the complexities inherent in sockeye systems and the individual system variation documented in previous meta-analysis of sockeye systems (Rogers & Schindler 2011; Rogers et al. 2011), it is unsurprising that similarities are not detectable.

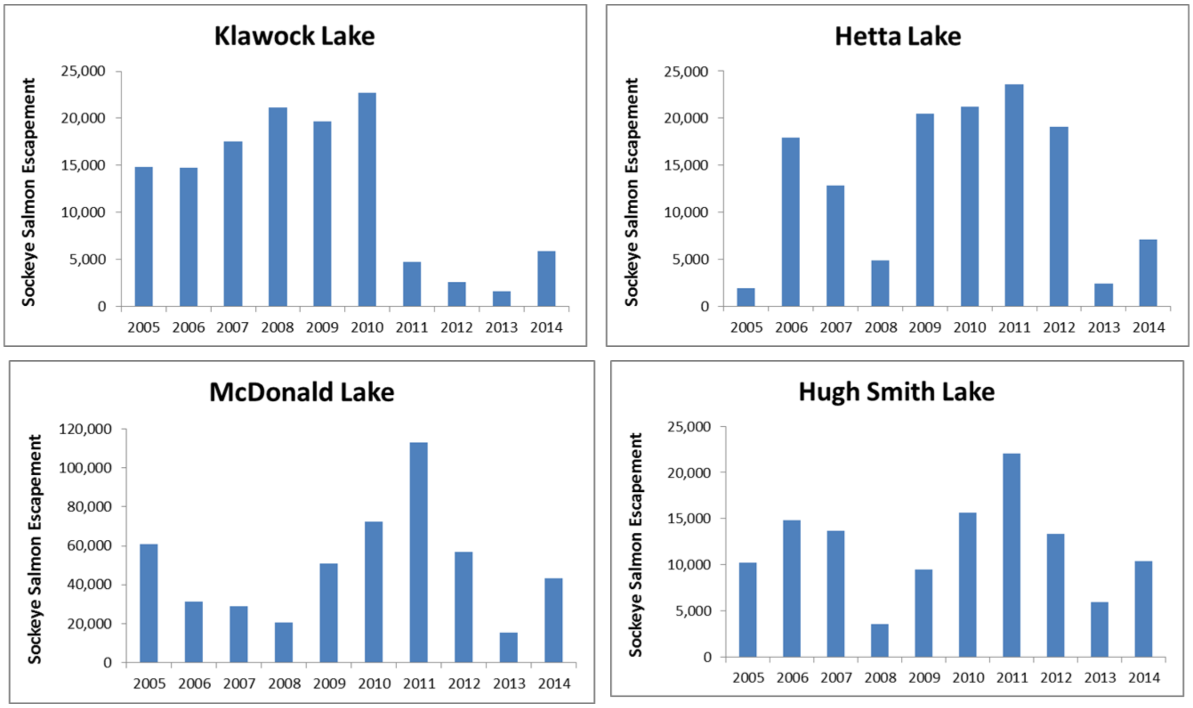

Figure 45. Sockeye salmon escapements for the last 10 years for Klawock Lake and nearby sockeye salmon systems. Data and graphs from S. Heinl (unpublished data).

Further comparison to other similar systems besides these four may be useful for understanding relationships between climate and Klawock Lake sockeye salmon, but given the relatively short length of time in which there are reasonable escapement numbers in this system, and the inability to reconstruct historical production of sockeye using paleolimnology, it is unlikely that this relationship will be fully understood anytime soon. However, ensuring a management system (see "Harvest management") that can respond to changing climatic conditions that influence productivity year to year and decade to decade is essential.

PREDATION AND HATCHERY ISSUES

The aforementioned criticism of the hatchery by Klawock residents and subsistence fishers (C. Woll, personal observation; Langdon 2006; Ratner et al. 2006) is most likely a result of insufficient weir procedures under previous management. Education to the public about the importance of the weir for monitoring sockeye escapement, and the safety measures in place to adequately pass fish, are important steps in improving the relationship between the hatchery and the community. However, even weirs with safety protocols have the potential to harm or injure passing fish.

However, various concerns about predation, both by hatchery-reared coho, and by other natural predators in the lake have been raised over the years as well (M. Cartwright, personal communications; Alaska Department of Fish and Game 2006a; Lewis & Zadina 2001; Ratner et al. 2006). Bioenergetics models and predation studies looking at other natural and hatchery-influenced sockeye systems have demonstrated that predation by steelhead smolt, rainbow trout, coho salmon, and cutthroat trout can have impacts on sockeye fry and smolt survival (Beauchamp 1995; Cartwright et al. 1998; McCart 1967; Ricker 1941; Ruggerone & Rogers 1992). Looking specifically at juvenile coho as predators, it is assumed that they can consume prey up to about 50% of their body length, although the majority of prey are smaller (Pearsons & Fritts 1999; Riley et al. 2003). Spatial and temporal overlap in combination with prey and predator size, are likely the most important determinants of potential impacts of juvenile coho and coho smolt on sockeye salmon fry and smolt (Naman & Sharpe 2012; Riley et al. 2003).

Previous studies within Klawock Lake looking at predation on sockeye fry and juveniles were only exploratory (M. Cartwright, unpublished data; Alaska Department of Fish and Game 2006a), but demonstrate that salmonids do make up a significant portion of cutthroat trout diet. These studies were inconclusive about the feeding habitats of hatchery coho. However, since 2011, a portion of coho smolt have been released into the lake in May, which was earlier than in previous years, presenting potential overlap within the lake with sockeye fry entering the lake. Studies looking at the residency time of hatchery coho, in combination with the development of a bioenergetics model looking at predation on sockeye fry and juveniles by coho, cutthroat, and other fish species, would be particularly informative on these potential impacts on sockeye productivity.

Very little is known about Klawock Lake sockeye salmon within the Klawock estuary. Lake-type juvenile sockeye, sockeye smolt, or coho smolt are not known to frequently utilize estuarine habitats, although it has been suggested that estuarine use by salmonids is often variable and related to the physical characteristics of individual estuaries (Simenstad et al. 1982; Thorpe 1994). Thus, a preliminary investigation into the spatial distribution throughout time of sockeye and coho smolt in Klawock estuary may be beneficial. Although it is unlikely that hatchery coho smolt could predate on Age-2 sockeye smolt due to the size restrictions, it is possible that large coho smolt could predate on small Age-1 sockeye smolt if their spatial distribution overlapped for extended lengths of time.

Depending on the results of these studies looking at the potential impacts of predation by juvenile coho and coho smolt on sockeye fry and juvenile sockeye, management actions including reducing the spatial and/or temporal overlap of hatchery coho and sockeye and management of coho escapement could be implemented. Predation by cutthroat trout could also be curtailed through trout population management if deemed necessary.

Salmon Harvest management

The State of Alaska's policies for the management of salmon fisheries is meant to employ a precautionary approach that sustains yield in perpetuity. Estimating the appropriate level of sustainable yield, as well as managing harvest, whether by the subsistence or commercial fishery, requires accurate, in-season estimates of escapement and harvest. ADF&G's efforts in 2000-2008 to validate modern weir counts of sockeye salmon were successful, and it is thought by some that accurate weir counts continue (J. Reeves, USFS, personal communications). Periodic efforts to validate these counts will likely result in even more confidence, and better management of harvest. ADF&G's efforts to provide in-season estimates of subsistence harvest in 2001 – 2008 showcased that evaluation of permits considerably underestimate subsistence harvest; although these studies have allowed for better estimation of subsistence harvest, in-season reporting of subsistence harvest or more study resulting in even better estimation of annual harvest would also be beneficial. Finally, a targeted study looking at estimating harvest in the commercial fishery would provide information to fill an obvious data gap and potentially address user group conflicts.

It is likely that sockeye salmon run timing into the Klawock Lake watershed has moved later in the year over time. It has also been shown that the subsistence fishery occurs early in the run, almost always before the median run date. Annual run timing of sockeye salmon populations in southeast Alaska has been shown to have shifted, on average, later in the year since the 1970s (Kovach et al. 2015). These authors suggested that this may be a result of selection to adapt to warming water temperatures in mid-summer. However, it should be noted that the rate of change of median spawning date in Klawock Lake (0.51 days/year) is larger than that of other locations in southeast Alaska (0.15 days/year). Directional selection by fisheries has been shown to influence the timing of sockeye salmon migrations (Quinn et al. 2007), and it is possible that this may have had or is currently having impacts on run timing in Klawock lake. Run timing is a heritable trait in salmon and genetic diversity of salmon has been shown to be the primary driver of salmon's adaptability and resilience (Hilborn et al. 2003; Schindler et al. 2010). Although it is unlikely that directional selection by fisheries harvest has significantly impacted sockeye salmon productivity in Klawock Lake, maintaining as much genetic diversity in the Klawock Lake run as possible is a worthwhile endeavor given the likelihood of other additional factors depleting Klawock sockeye stocks. Allowing and/or encouraging harvest more evenly distributed throughout the Klawock Lake sockeye salmon run may accomplish this goal, as well as allow for easier voluntary management of the subsistence fishery in the event of years of low runs and higher subsistence yields in the event of years of high runs.

Ultimately, a collaborative approach to management may allow for a conservation-based approach, especially in years with poor sockeye returns. A collaborative approach between stakeholders and agencies could result in such measures as adjustment of timing of the subsistence harvest, better self-reporting of harvest, use of other systems during poor sockeye salmon returns, selective harvest practices, or the pooling of a community fishery to ensure meeting the community needs. These changes could be regulatory or non-regulatory in nature, but would require consensus and trust among fishers, managers, and biologists to accomplish their goals.

Conclusions

It is clear from this retrospective analysis that there are likely to be multiple factors, natural and human-induced, impacting sockeye productivity in the Klawock Lake watershed. Without prior long-term datasets or the ability to accurately reconstruct historic sockeye salmon abundance and the inherent natural complexities of sockeye salmon productivity cycles, it is difficult at this time to tease out the most important factors contributing to sockeye salmon declines.

In order to truly understand these complexities into the future, a holistic research approach that investigates multiple factors over long-time scales would be necessary. The continued monitoring of harvest and escapement and an effort to monitor smolt abundance could help determine whether the primary mechanisms impacting productivity are isolated to the fresh or salt water environments. Coupling these with datasets looking at climate, water quality, and prey and predator bases would be necessary to fully understand all of the mechanisms in play.

However, given the long-term commitments (financially and institutionally) that a research program like this would require, focusing on understanding the major data gaps may be a better first step. These data gaps include better estimates of the commercial and subsistence harvest, the role of predation on juvenile sockeye, and a fine-scale understanding of current and historical sockeye spawning habitats. In addition, focusing on management actions likely to have positive impacts on sockeye productivity, especially in times of naturally low periods of productivity, is critical. These may include restoration efforts in key sockeye salmon spawning areas and a collaborative harvest management system that involves the local community and allows for a more robust conservation approach.

Ultimately, ongoing research and management activities will require a collaborative approach between multiple stakeholder groups to ensure lasting results.

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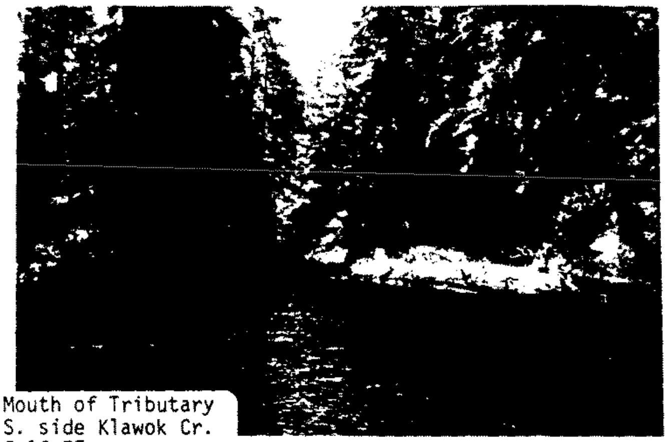
APPENDIX A: HISTORICAL STREAM HABITAT MAPS

The following maps have been directly transferred from Edgington and Larson (1979).



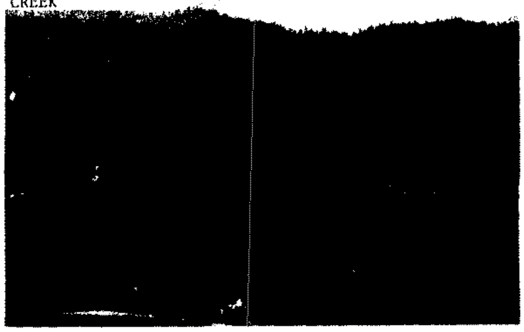
Mouth of Tributary
S. side Klawok Cr.
5-16-77

103-60-47

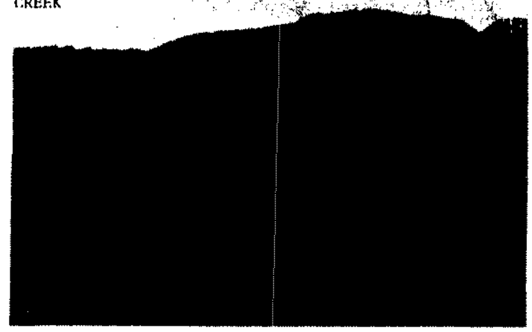
Klawok Creek falls
upper intertidal.
5-16-77

- 452 -

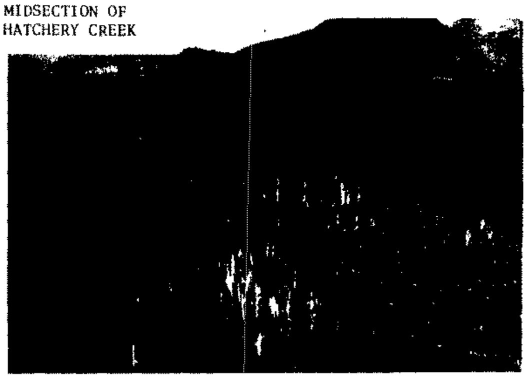
103-60-47 8/77
MOUTH OF HATCHERY CREEK



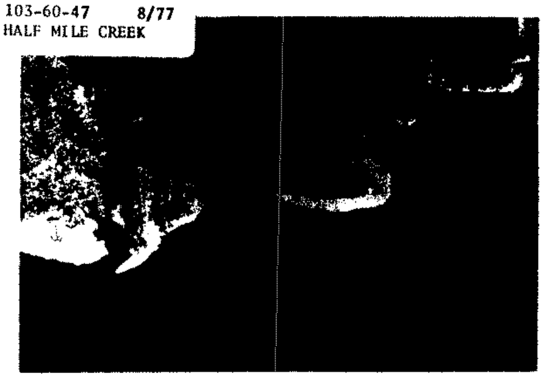
103-60-47 8/77
MOUTH OF HATCHERY CREEK

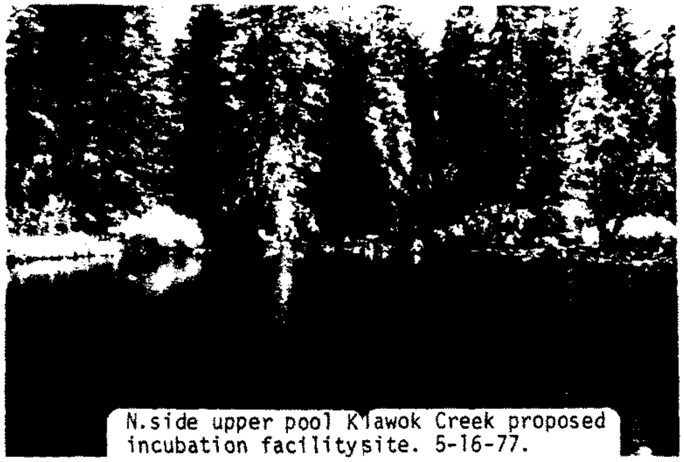


MIDSECTION OF HATCHERY CREEK



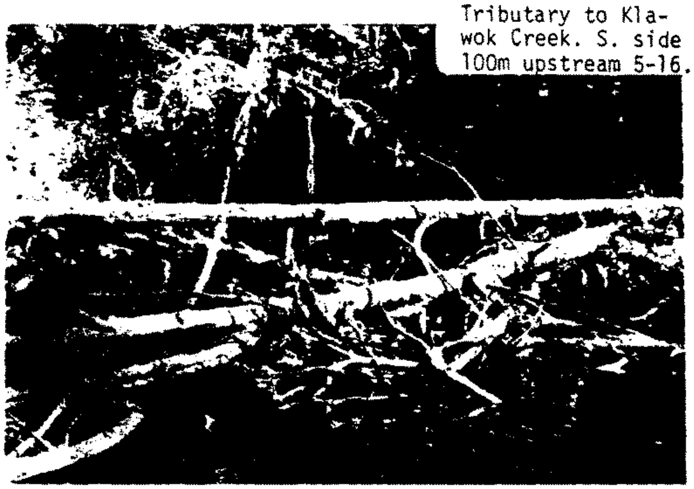
103-60-47 8/77
HALF MILE CREEK





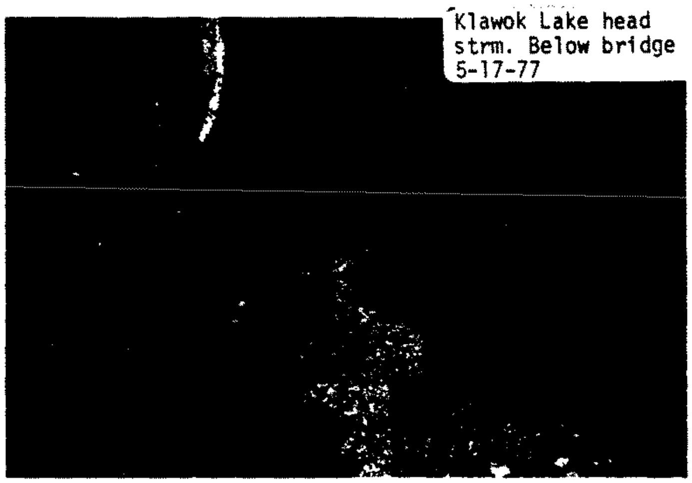
N.side upper pool Klawok Creek proposed incubation facilitysite. 5-16-77.

103-60-47

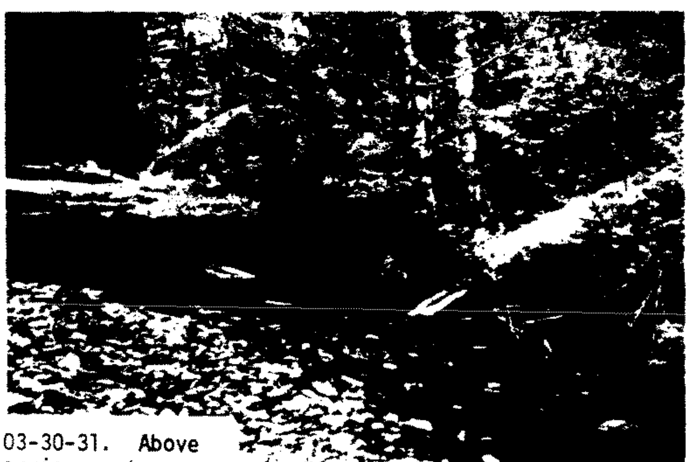


Tributary to Klawok Creek. S. side 100m upstream 5-16.

Klawok Lake head
strm. Below bridge
5-17-77



103-60-47

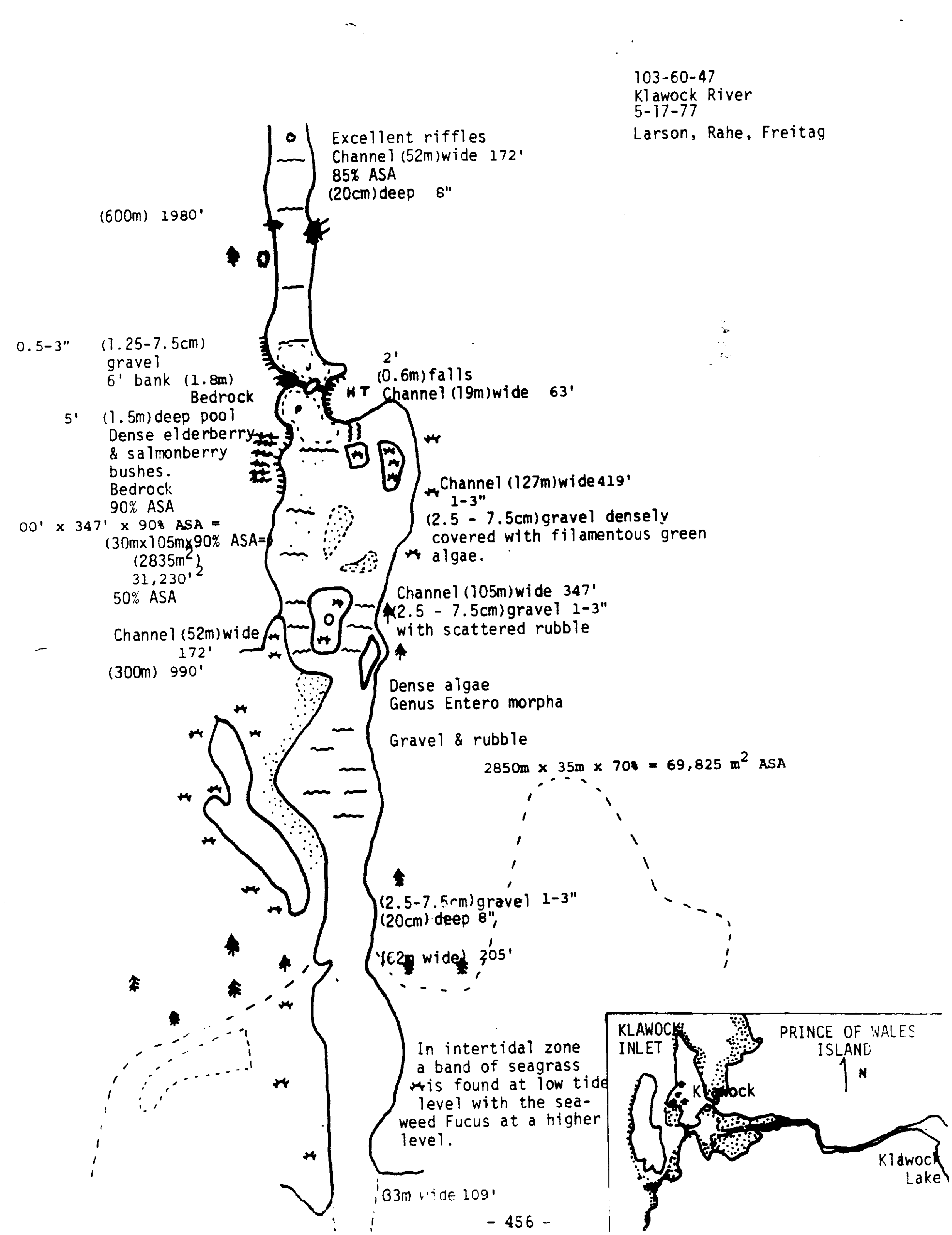


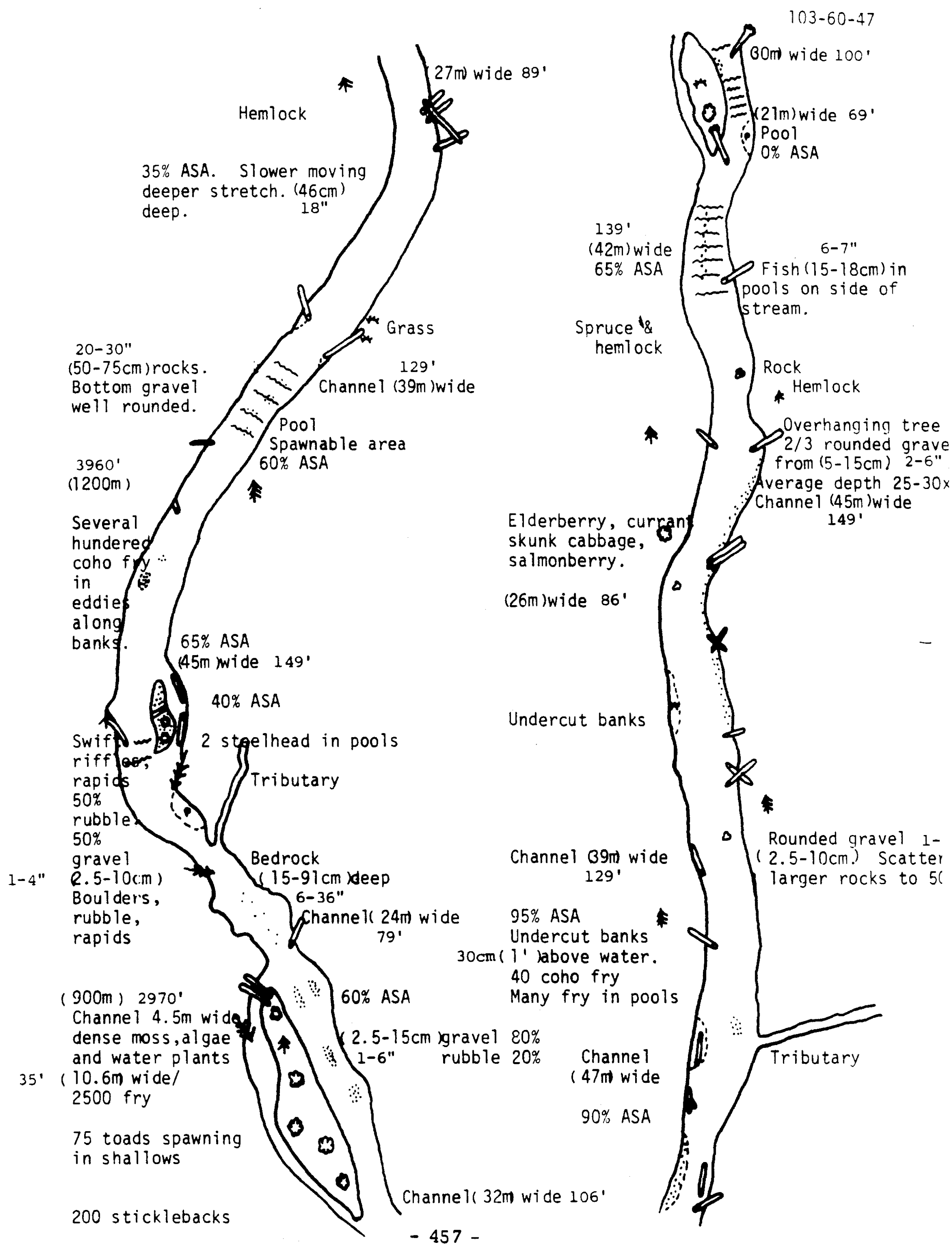
103-30-31. Above
barrier upstream.

Klawok Lake. 3 Mile Cr. upstream from bridge. 5-17-77

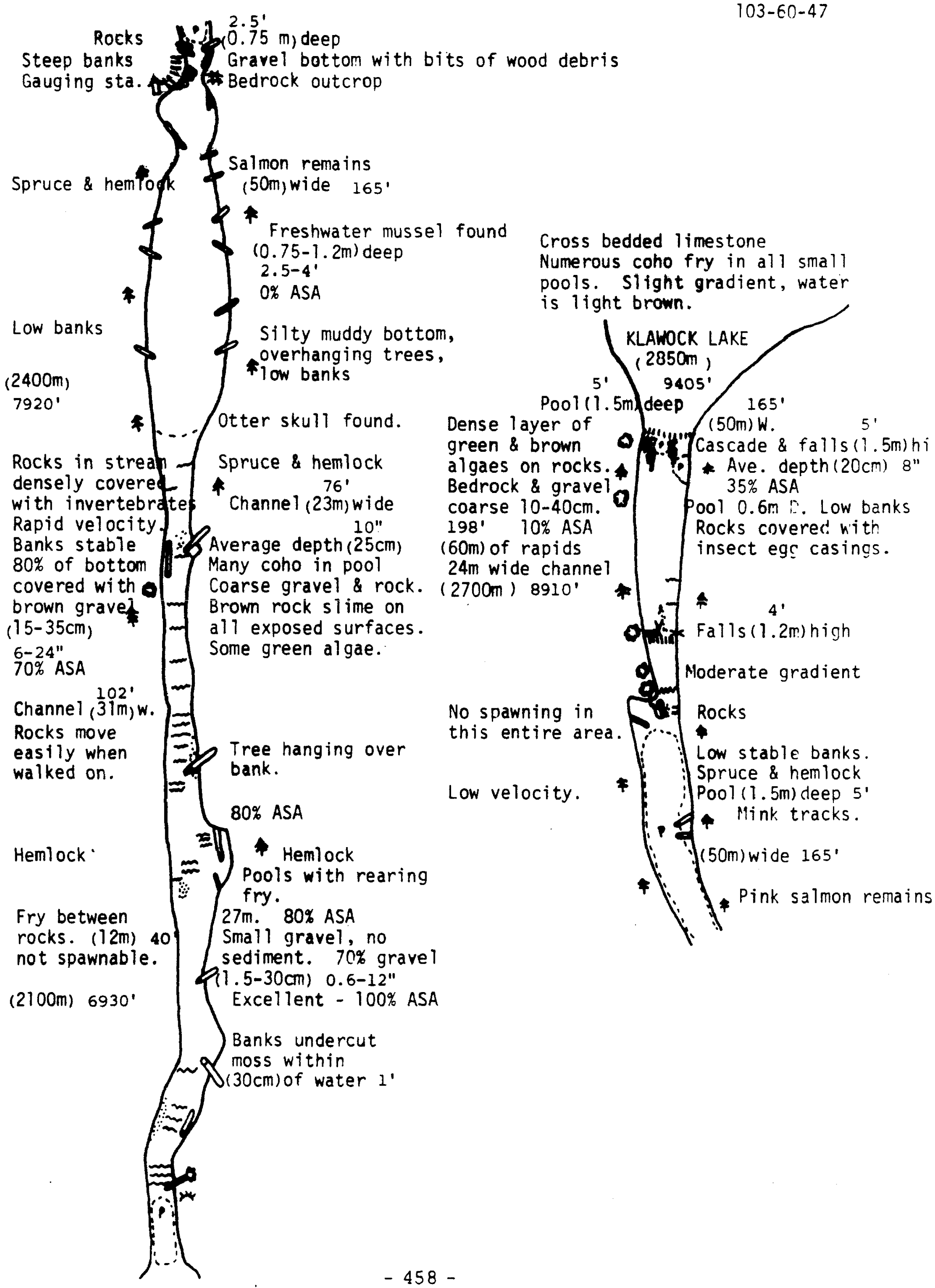
103-60-47

Klawok Creek. Upper IT. Looking down-stream from falls.

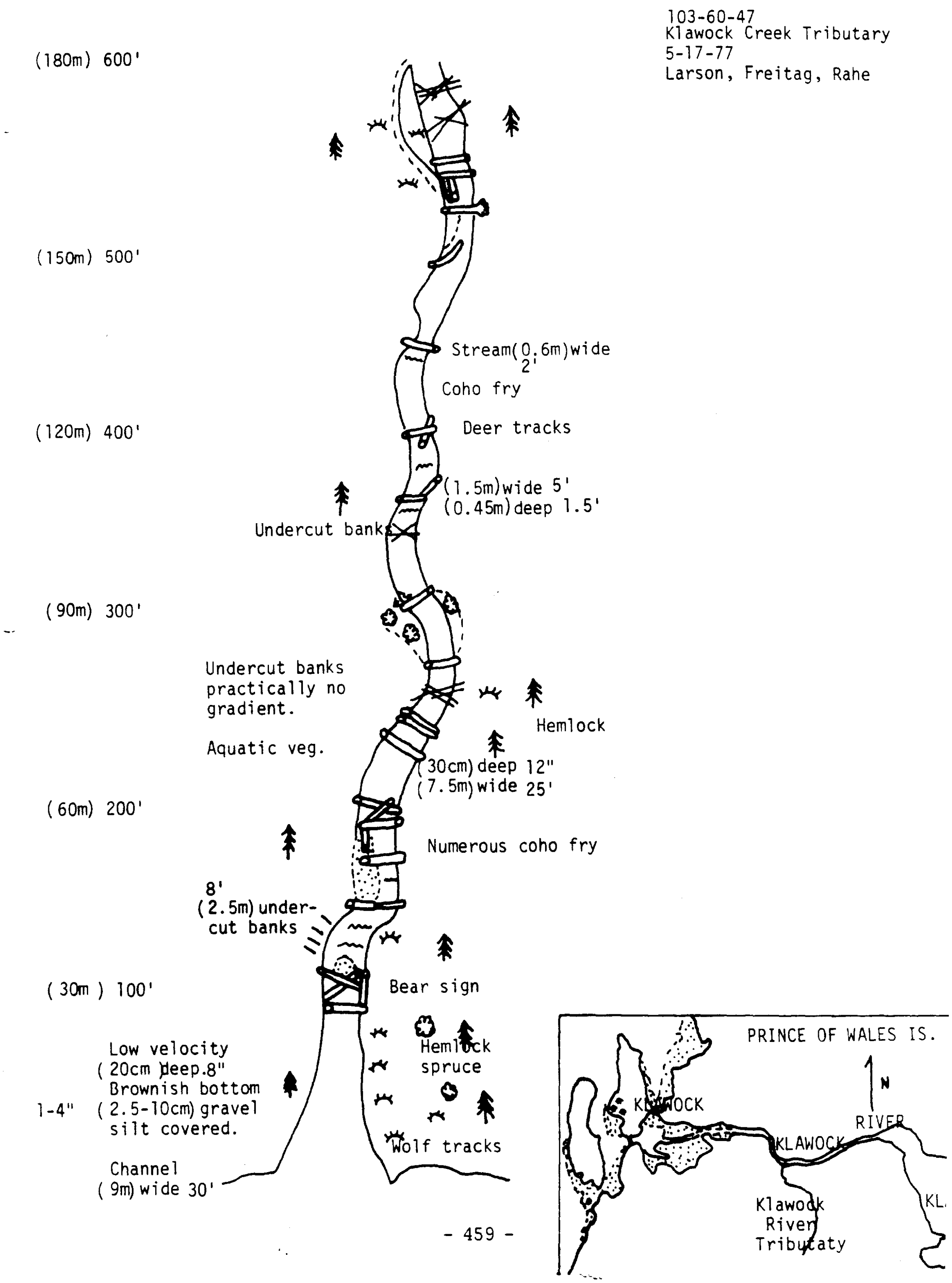

103-60-47
Klawock River
5-17-77
Larson, Rahe, Freitag
Excellent riffles
Channel (52m) wide 172'
85% ASA
(20cm) deep 8"
(600m) 1980'
0.5-3" (1.25-7.5cm)
gravel
6' bank (1.8m)
Bedrock
2'
(0.6m) falls
HT Channel (19m) wide 63'
5' (1.5m) deep pool
Dense elderberry
& salmonberry
bushes.
Bedrock
90% ASA
00' x 347' x 90% ASA =
(30mx105mx90% ASA=
(2835m²)
31,230'²
50% ASA
Channel (127m) wide 419'
1-3"
(2.5 - 7.5cm) gravel densely
covered with filamentous green
algae.
Channel (105m) wide 347'
(2.5 - 7.5cm) gravel 1-3"
with scattered rubble
Channel (52m) wide
172'
(300m) 990'
Dense algae
Genus Entero morpha
Gravel & rubble
2850m x 35m x 70% = 69,825 m² ASA
(2.5-7.5cm) gravel 1-3"
(20cm) deep 8"
(62m wide) 205'
In intertidal zone
a band of seagrass
is found at low tide
level with the sea-
weed Fucus at a higher
level.
63m wide 109'
KLAWOCK
INLET
PRINCE OF WALES
ISLAND
N
Klawock
Klawock
Lake


103-60-47
(27m) wide 89'
Hemlock
35% ASA. Slower moving deeper stretch. (46cm) deep. 18"
Grass
20-30" (50-75cm) rocks. Bottom gravel well rounded.
129' Channel (39m) wide
Pool
Spawnable area
60% ASA
3960' (1200m)
Several hundered coho fry in eddies along banks.
65% ASA
(45m) wide 149'
40% ASA
2 steelhead in pools
Swift riffles, rapids
50% rubble
50% gravel
1-4" (2.5-10cm)
Boulders, rubble, rapids
Tributary
Bedrock (15-91cm) deep 6-36"
Channel (24m) wide 79'
(900m) 2970'
Channel 4.5m wide dense moss, algae and water plants
35' (10.6m) wide/
2500 fry
75 toads spawning in shallows
200 sticklebacks
60% ASA
(2.5-15cm) gravel 80% 1-6" rubble 20%
Channel (32m) wide 106'
(30m) wide 100'
(21m) wide 69'
Pool
0% ASA
139' (42m) wide
65% ASA
6-7" Fish (15-18cm) in pools on side of stream.
Spruce & hemlock
Rock
Hemlock
Overhanging tree
2/3 rounded grave from (5-15cm) 2-6"
Average depth 25-30x
Channel (45m) wide 149'
Elderberry, currant skunk cabbage, salmonberry.
(26m) wide 86'
Undercut banks
Rounded gravel 1- (2.5-10cm.) Scatter larger rocks to 5(
Channel (39m) wide 129'
95% ASA
Undercut banks
30cm (1') above water.
40 coho fry
Many fry in pools
Channel (47m) wide
90% ASA
Tributary

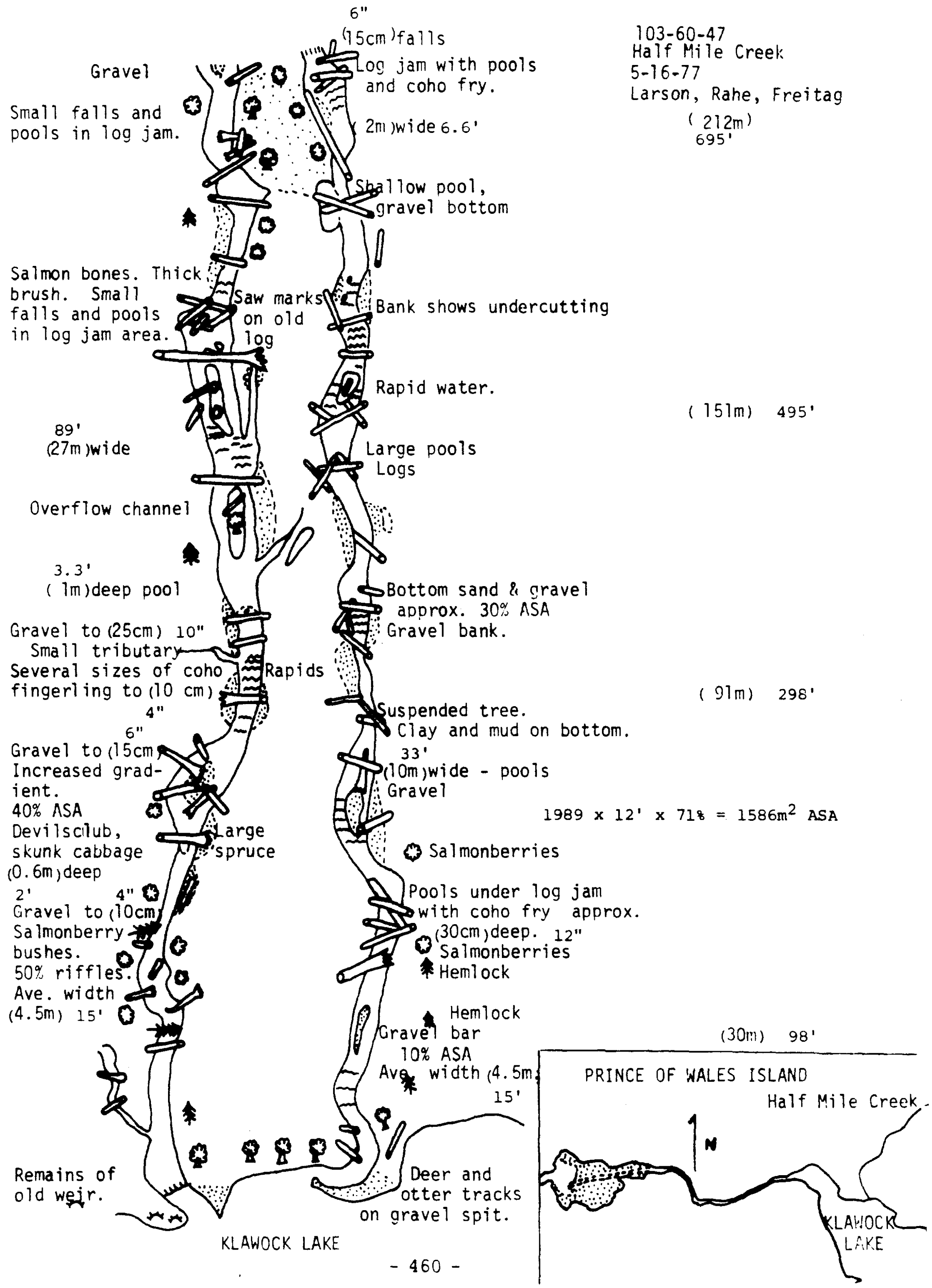
103-60-47

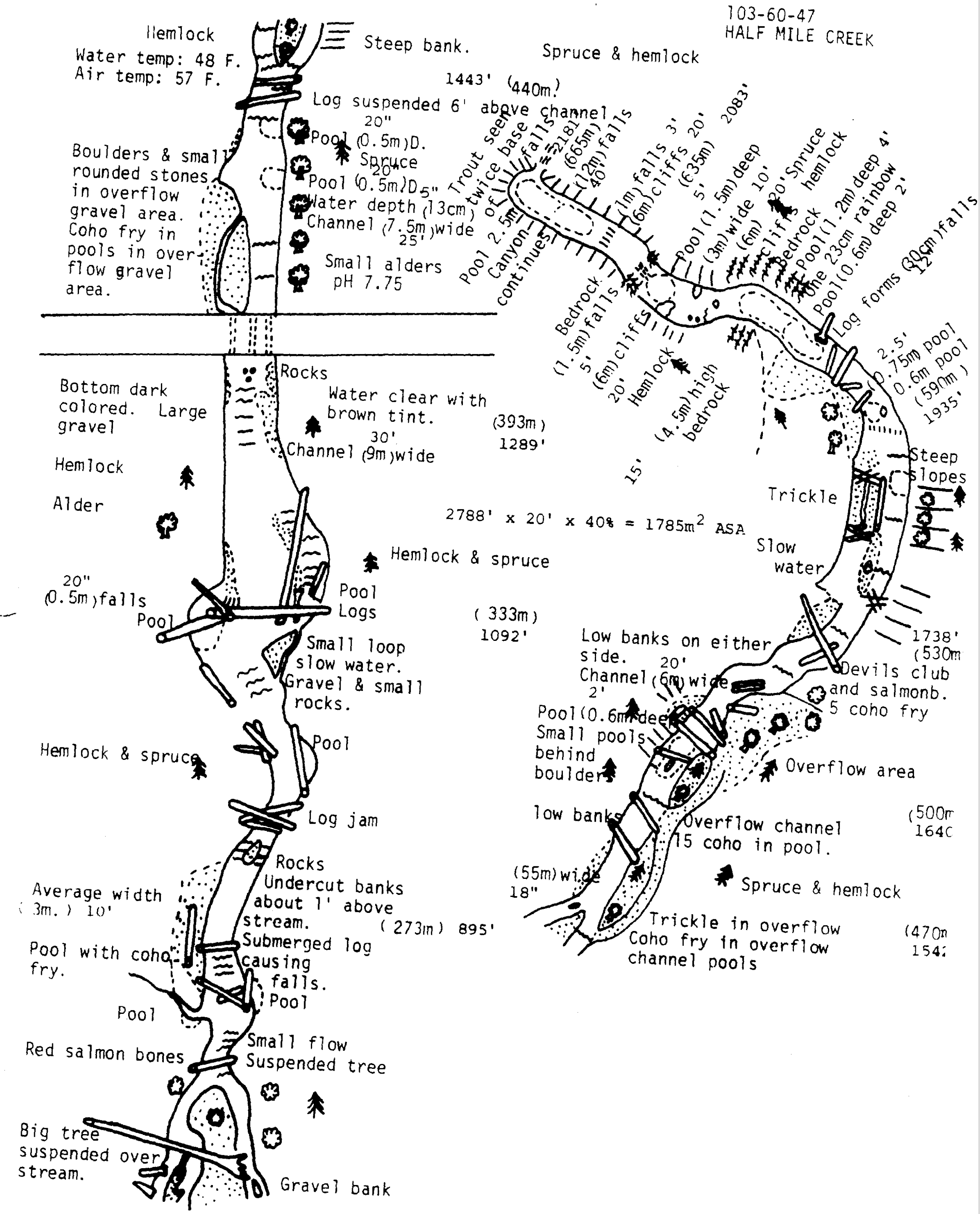


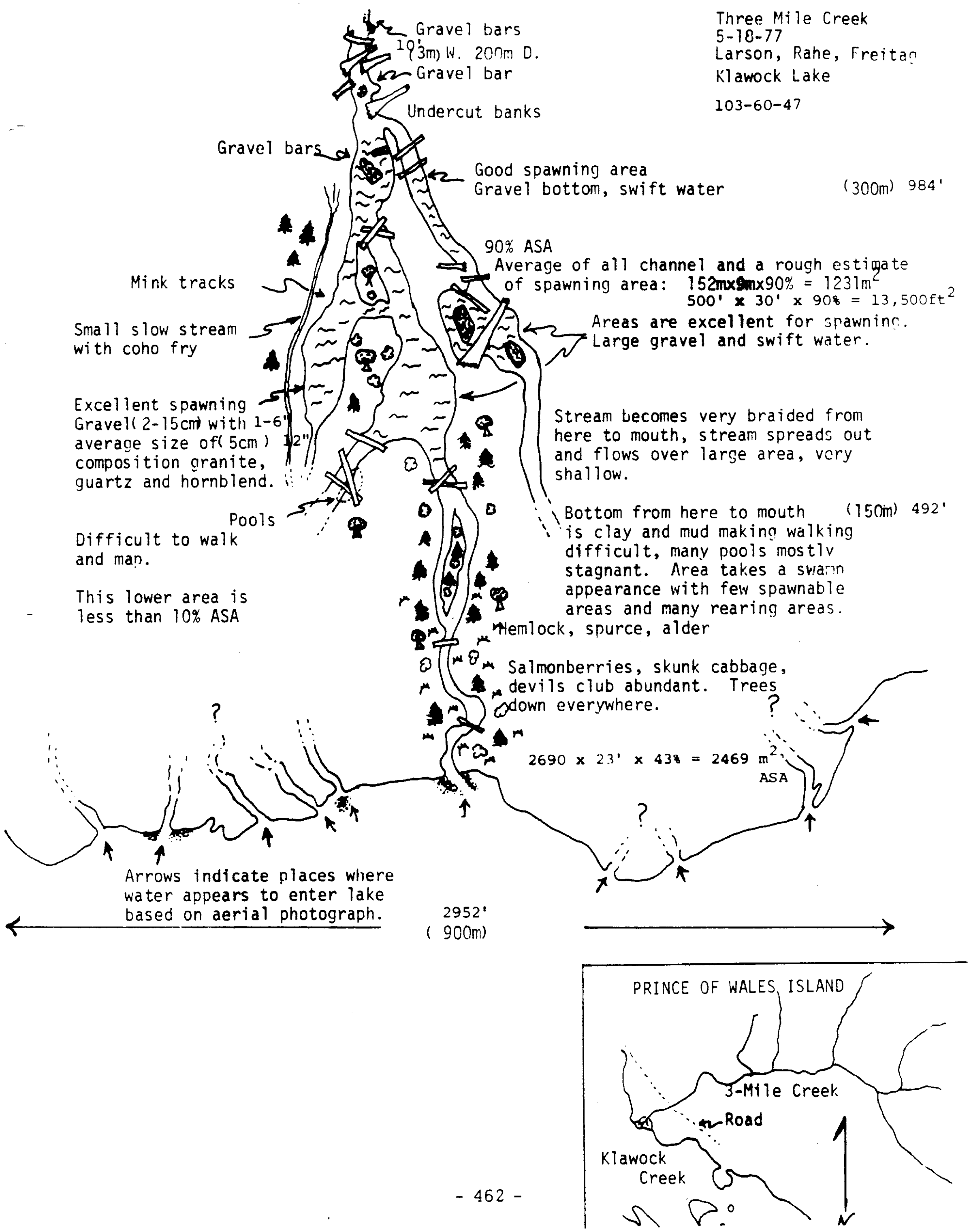
Rocks
Steep banks
Gauging sta.
2.5'
(0.75 m) deep
Gravel bottom with bits of wood debris
Bedrock outcrop
Salmon remains
(50m) wide 165'
Spruce & hemlock
Freshwater mussel found
(0.75-1.2m) deep
2.5-4'
0% ASA
Low banks
Silty muddy bottom,
overhanging trees,
low banks
(2400m)
7920'
Otter skull found.
Rocks in stream
densely covered
with invertebrates
Rapid velocity.
Banks stable
80% of bottom
covered with
brown gravel
(15-35cm)
6-24"
70% ASA
Spruce & hemlock
76'
Channel (23m) wide
10"
Average depth (25cm)
Many coho in pool
Coarse gravel & rock.
Brown rock slime on
all exposed surfaces.
Some green algae.
102'
Channel (31m) w.
Rocks move
easily when
walked on.
Tree hanging over
bank.
80% ASA
Hemlock
Hemlock
Pools with rearing
fry.
Fry between
rocks. (12m) 40'
not spawnable.
27m. 80% ASA
Small gravel, no
sediment. 70% gravel
(1.5-30cm) 0.6-12"
Excellent - 100% ASA
(2100m) 6930'
Banks undercut
moss within
(30cm) of water 1'
Cross bedded limestone
Numerous coho fry in all small
pools. Slight gradient, water
is light brown.
KLAWOCK LAKE
(2850m)
9405'
5'
Pool (1.5m) deep
165'
(50m) W.
5'
Cascade & falls (1.5m) hi.
Ave. depth (20cm) 8"
35% ASA
Dense layer of
green & brown
algaes on rocks.
Bedrock & gravel
coarse 10-40cm.
198' 10% ASA
(60m) of rapids
24m wide channel
(2700m) 8910'
Pool 0.6m D. Low banks
Rocks covered with
insect egg casings.
4'
Falls (1.2m) high
Moderate gradient
No spawning in
this entire area.
Rocks
Low stable banks.
Spruce & hemlock
Pool (1.5m) deep 5'
Low velocity.
Mink tracks.
(50m) wide 165'
Pink salmon remains.

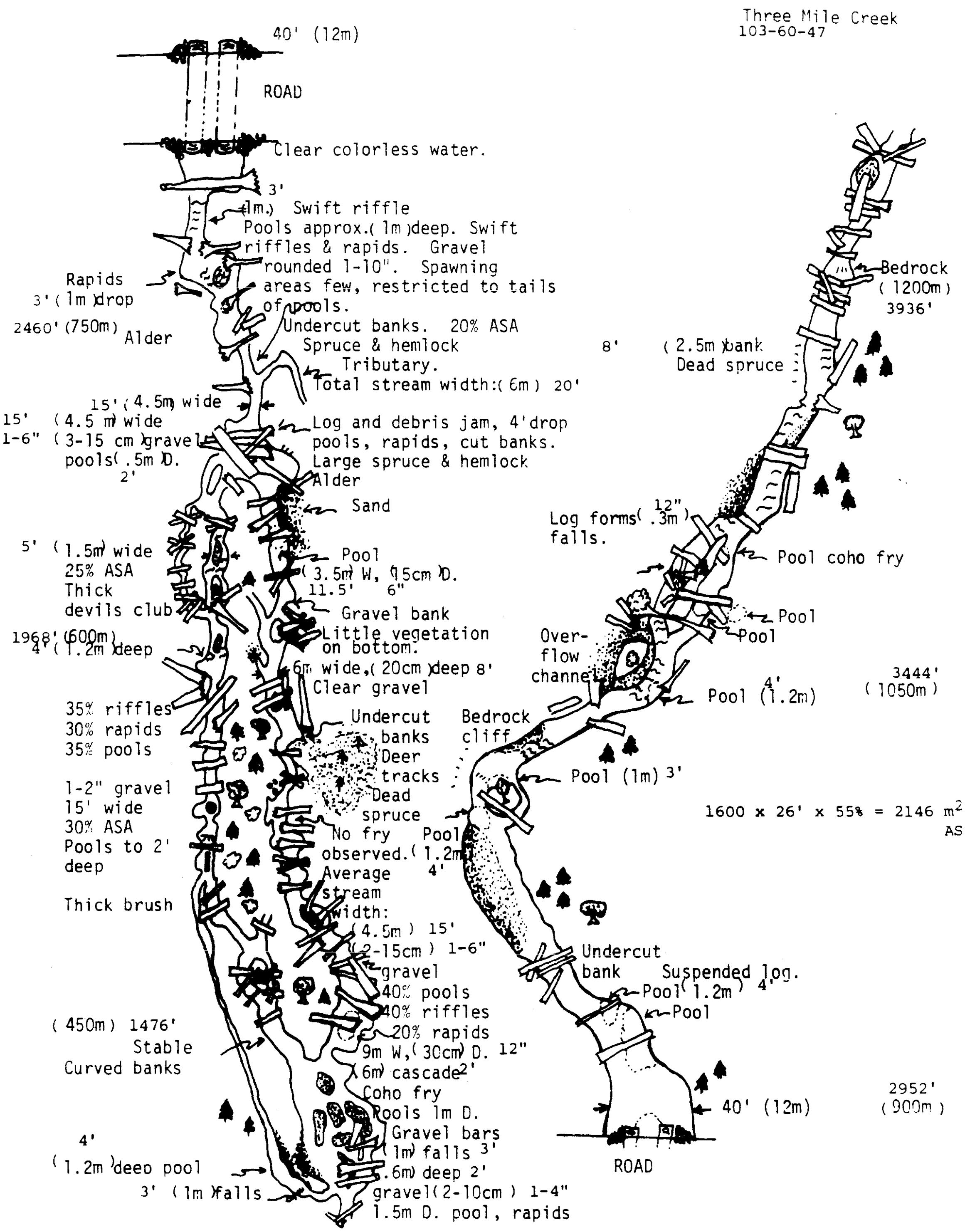


103-60-47
Klawock Creek Tributary
5-17-77
Larson, Freitag, Rahe
(180m) 600'
(150m) 500'
Stream(0.6m)wide 2'
Coho fry
(120m) 400'
Deer tracks
(1.5m)wide 5'
(0.45m)deep 1.5'
Undercut banks
(90m) 300'
Undercut banks practically no gradient.
Aquatic veg.
Hemlock
(30cm)deep 12"
(7.5m)wide 25'
(60m) 200'
Numerous coho fry
8' (2.5m) under-cut banks
(30m) 100'
Bear sign
Low velocity
(20cm deep.8"
Brownish bottom
1-4" (2.5-10cm) gravel
silt covered.
Channel
(9m) wide 30'
Hemlock
spruce
Wolf tracks
PRINCE OF WALES IS.
N
KLAWOCK
RIVER
KLAWOCK
Klawock River Tributaty

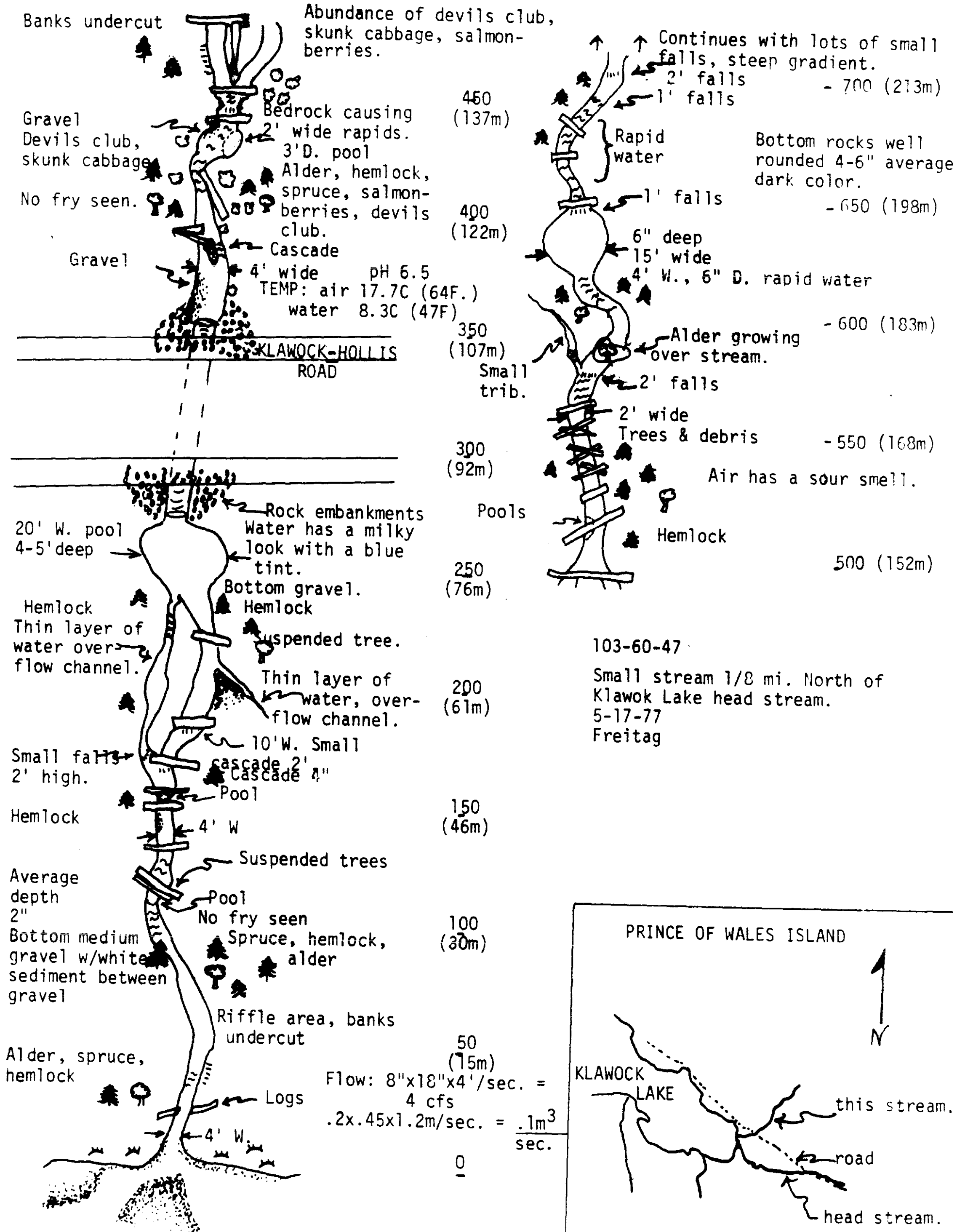

103-60-47
Half Mile Creek
5-16-77
Larson, Rahe, Freitag
(212m)
695'
6"
(15cm) falls
Log jam with pools
and coho fry.
Gravel
Small falls and
pools in log jam.
(2m) wide 6.6'
Shallow pool,
gravel bottom
Salmon bones. Thick
brush. Small
falls and pools
in log jam area.
Saw marks
on old
log
Bank shows undercutting
Rapid water.
(151m) 495'
89'
(27m) wide
Large pools
Logs
Overflow channel
3.3'
(1m) deep pool
Bottom sand & gravel
approx. 30% ASA
Gravel bank.
Gravel to (25cm) 10"
Small tributary
Several sizes of coho
fingerling to (10 cm)
4"
Rapids
(91m) 298'
Suspended tree.
Clay and mud on bottom.
6"
Gravel to (15cm
Increased grad-
ient.
40% ASA
Devilsclub,
skunk cabbage
(0.6m) deep
33'
(10m) wide - pools
Gravel
1989 x 12' x 71% = 1586m2 ASA
Large
spruce
Salmonberries
2'
4"
Gravel to (10cm
Salmonberry
bushes.
50% riffles.
Ave. width
(4.5m) 15'
Pools under log jam
with coho fry approx.
(30cm) deep. 12"
Salmonberries
Hemlock
Hemlock
Gravel bar
10% ASA
Ave. width (4.5m
15'
(30m) 98'
Remains of
old weir.
Deer and
otter tracks
on gravel spit.
KLAWOCK LAKE
PRINCE OF WALES ISLAND
Half Mile Creek
N
KLAWOCK
LAKE


103-60-47
HALF MILE CREEK
Hemlock
Water temp: 48 F.
Air temp: 57 F.
Steep bank.
Spruce & hemlock
1443' (440m)
Log suspended 6' above channel
20" (0.5m) D.
Pool
Spruce
20" (0.5m) D.
Pool
5" (13cm)
Water depth
25' (7.5m)
Channel wide
Small alders
pH 7.75
Boulders & small rounded stones in overflow gravel area.
Coho fry in pools in overflow gravel area.
Trout seen twice base of falls
Pool 2.5m
Canyon continues
Rocks
Bottom dark colored. Large gravel
Water clear with brown tint.
30' (9m)
Channel wide
(393m)
1289'
Hemlock
Alder
2788' x 20' x 40% = 1785m² ASA
Hemlock & spruce
20" (0.5m) falls
Pool
Pool
Logs
(333m)
1092'
Small loop slow water.
Gravel & small rocks.
Pool
Hemlock & spruce
Log jam
Rocks
Undercut banks about 1' above stream.
Submerged log causing falls.
Pool
(273m) 895'
Average width (3m.) 10'
Pool with coho fry.
Pool
Small flow
Suspended tree
Red salmon bones
Big tree suspended over stream.
Gravel bank
Steep slopes
Trickle
Slow water
1738' (530m)
Low banks on either side.
20' (6m)
Channel wide
2' (0.6m)
Pool deep
Small pools behind boulder
Devils club and salmonb.
5 coho fry
Overflow area
low banks
Overflow channel
15 coho in pool.
18" (55m) wide
Spruce & hemlock
Trickle in overflow
Coho fry in overflow channel pools
(500m 164
(470m 154
Hemlock
(4.5m) high bedrock
15'
Log forms
2.5' (0.75m) pool
(590m) 1935'


Three Mile Creek
5-18-77
Larson, Rahe, Freitag
Klawock Lake
103-60-47
Gravel bars
10'(3m) W. 200m D.
Gravel bar
Undercut banks
Gravel bars
Good spawning area
Gravel bottom, swift water
(300m) 984'
90% ASA
Average of all channel and a rough estimate of spawning area: 152mx9mx90% = 1231m²
500' x 30' x 90% = 13,500ft²
Mink tracks
Small slow stream with coho fry
Areas are excellent for spawning. Large gravel and swift water.
Excellent spawning Gravel(2-15cm) with 1-6" average size of(5cm) 2" composition granite, guartz and hornblend.
Stream becomes very braided from here to mouth, stream spreads out and flows over large area, very shallow.
Pools
Difficult to walk and map.
This lower area is less than 10% ASA
Bottom from here to mouth is clay and mud making walking difficult, many pools mostly stagnant. Area takes a swamp appearance with few spawnable areas and many rearing areas.
(150m) 492'
Hemlock, spurce, alder
Salmonberries, skunk cabbage, devils club abundant. Trees down everywhere.
2690 x 23' x 43% = 2469 m² ASA
?
?
?
Arrows indicate places where water appears to enter lake based on aerial photograph.
2952' (900m)
PRINCE OF WALES ISLAND
3-Mile Creek
Road
Klawock Creek
N

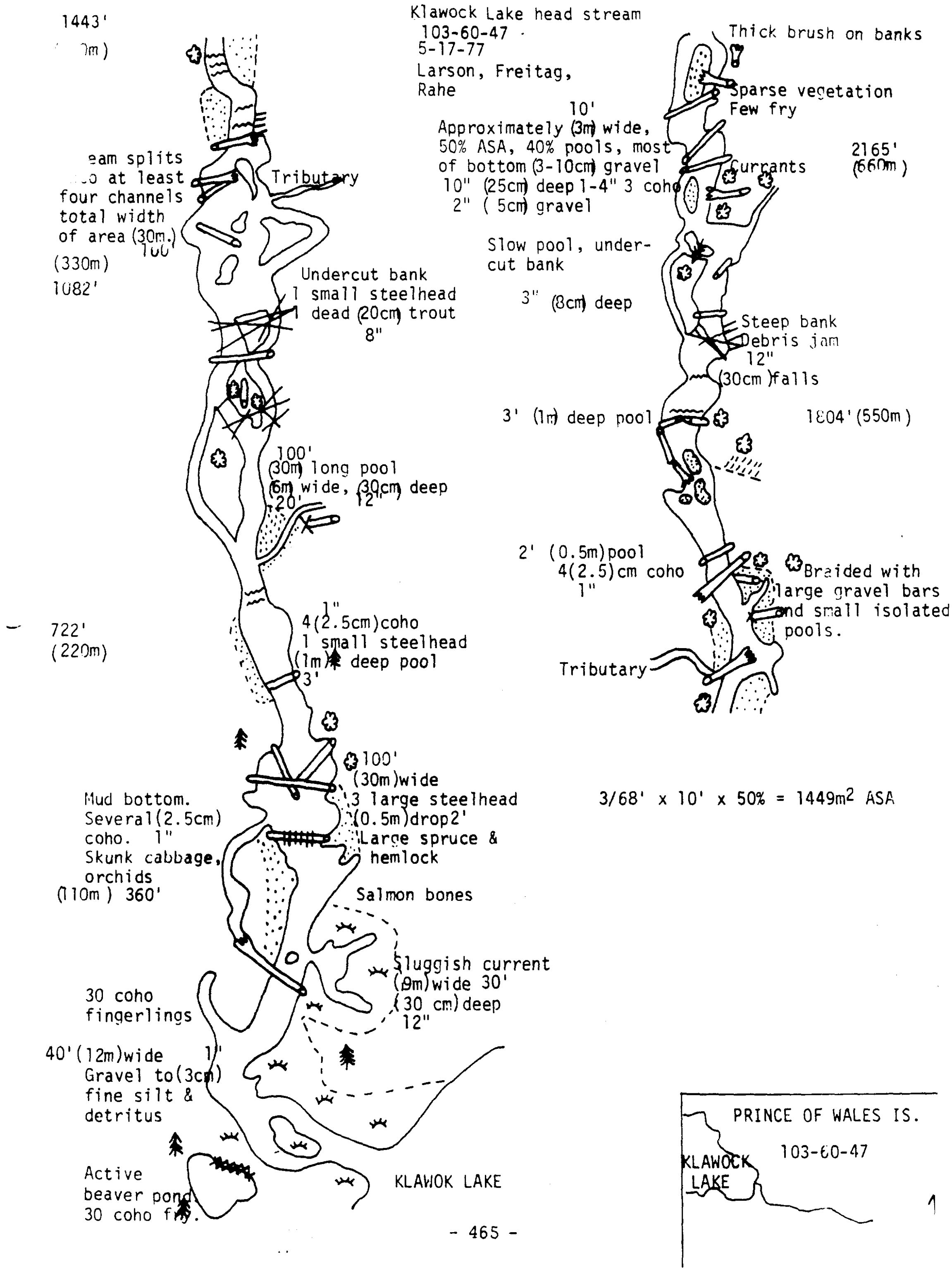


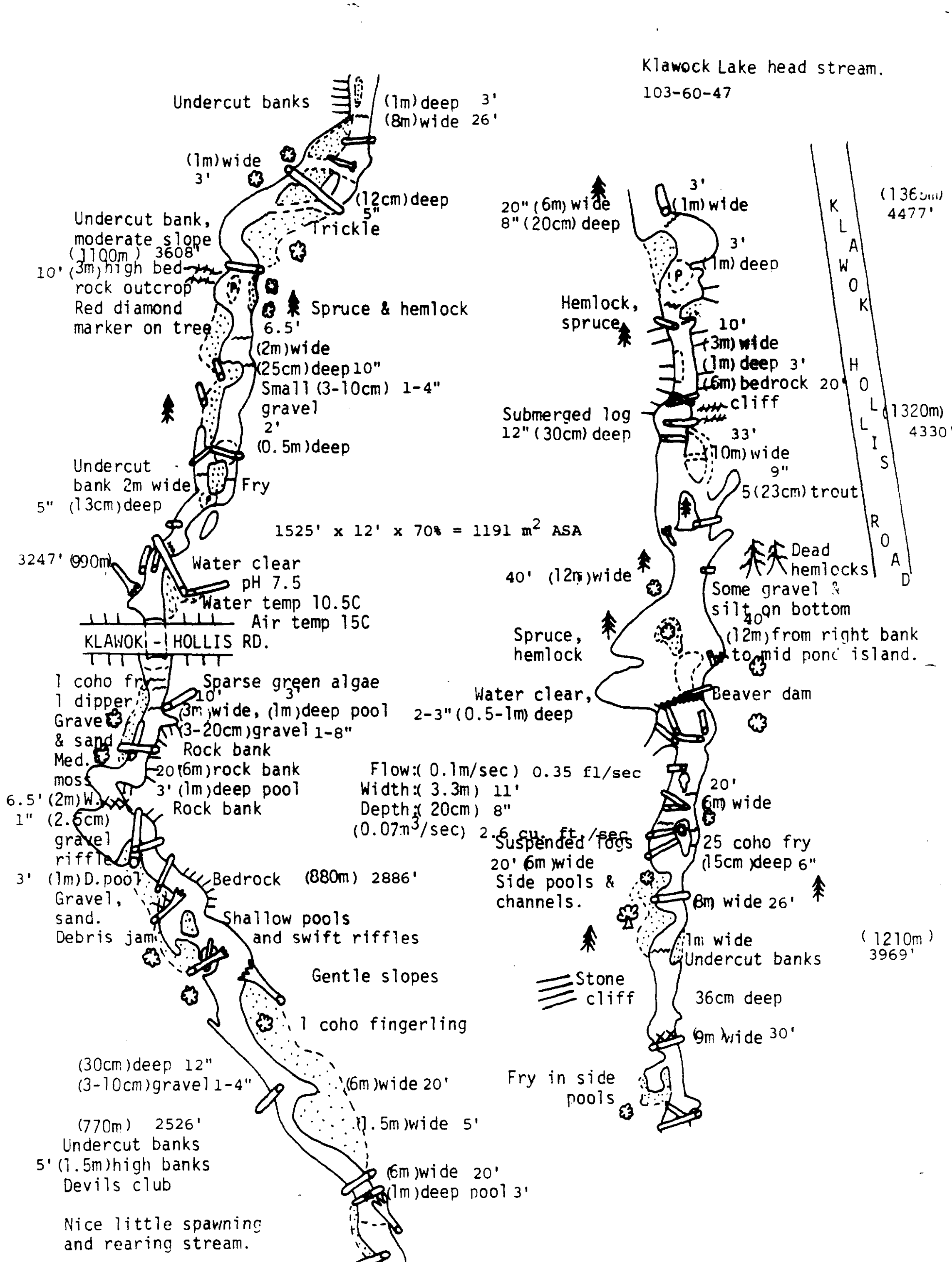
Three Mile Creek
103-60-47
40' (12m)
ROAD
Clear colorless water.
3' (1m.) Swift riffle
Pools approx.(1m)deep. Swift riffles & rapids. Gravel rounded 1-10". Spawning areas few, restricted to tails of pools.
Rapids
3' (1m)drop
2460' (750m)
Alder
Undercut banks. 20% ASA
Spruce & hemlock
Tributary.
Total stream width:(6m) 20'
15' (4.5m) wide
15' (4.5 m) wide
1-6" (3-15 cm)gravel
pools(.5m)D.
2'
Log and debris jam, 4'drop
pools, rapids, cut banks.
Large spruce & hemlock
Alder
Sand
5' (1.5m) wide
25% ASA
Thick
devils club
Pool
(3.5m) W, (15cm) D.
11.5' 6"
Gravel bank
Little vegetation on bottom.
1968' (600m)
4' (1.2m) deep
6m wide,(20cm)deep 8'
Clear gravel
35% riffles
30% rapids
35% pools
Undercut banks
Deer tracks
Dead spruce
Bedrock cliff
1-2" gravel
15' wide
30% ASA
Pools to 2' deep
Thick brush
No fry observed.
Pool (1.2m) 4'
Average stream width:
(4.5m) 15'
(2-15cm) 1-6"
gravel
40% pools
40% riffles
20% rapids
9m W,(30cm) D. 12"
(6m) cascade 2'
Coho fry
Pools 1m D.
Gravel bars
(1m) falls 3'
(.6m) deep 2'
gravel(2-10cm) 1-4"
1.5m D. pool, rapids
(450m) 1476'
Stable
Curved banks
4'
(1.2m)deep pool
3' (1m)falls
Bedrock
(1200m)
3936'
8' (2.5m)bank
Dead spruce
12"
Log forms(.3m) falls.
Pool coho fry
Pool
Pool
Over-flow channel
Pool (1.2m) 4'
3444'
(1050m)
Pool (1m) 3'
1600 x 26' x 55% = 2146 m2 AS
Undercut bank
Suspended log.
Pool (1.2m) 4'
Pool
40' (12m)
2952'
(900m)
ROAD

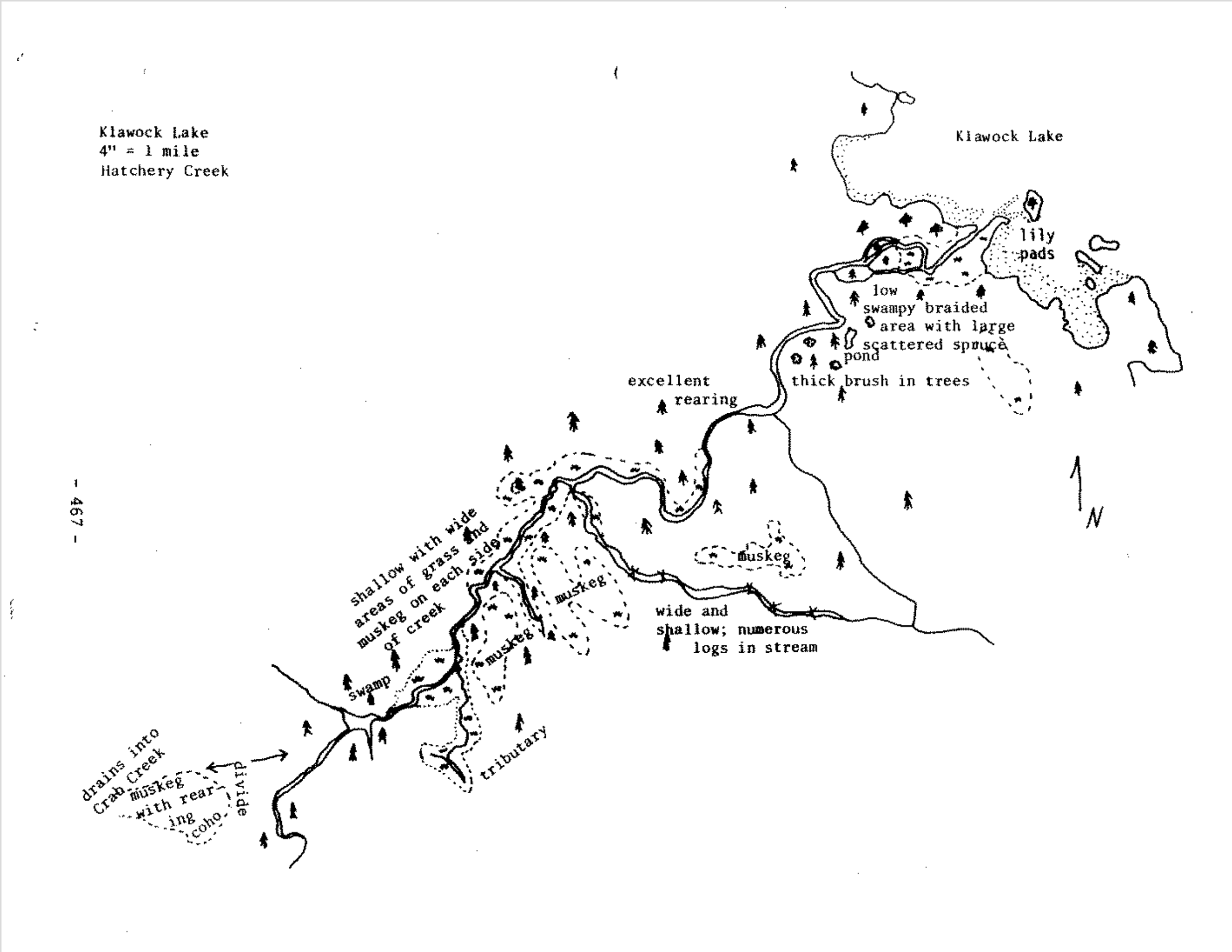


103-60-47

Small stream 1/8 mi. North of Klawok Lake head stream.
5-17-77
Freitag


Klawock Lake head stream
103-60-47
5-17-77
Larson, Freitag, Rahe
1443'
eam splits
at least four channels total width of area (30m.) 100'
(330m)
1082'
Tributary
Undercut bank
1 small steelhead
1 dead (20cm) trout 8"
10'
Approximately (3m) wide, 50% ASA, 40% pools, most of bottom (3-10cm) gravel
10" (25cm) deep 1-4" 3 coho
2" (5cm) gravel
Slow pool, under-cut bank
3" (8cm) deep
Thick brush on banks
Sparse vegetation
Few fry
Currants
2165' (660m)
Steep bank
Debris jam
12" (30cm) falls
3' (1m) deep pool
1804' (550m)
100' (30m) long pool
(6m) wide, (30cm) deep 20' 12"
2' (0.5m) pool
4(2.5)cm coho 1"
Braided with large gravel bars and small isolated pools.
Tributary
722' (220m)
1" 4(2.5cm) coho
1 small steelhead
(1m) deep pool 3'
100' (30m) wide
3 large steelhead
(0.5m) drop 2'
Large spruce & hemlock
3/68' x 10' x 50% = 1449m2 ASA
Mud bottom. Several (2.5cm) coho. 1"
Skunk cabbage, orchids
(110m) 360'
Salmon bones
Sluggish current (9m) wide 30'
(30 cm) deep 12"
30 coho fingerlings
40' (12m) wide 1"
Gravel to (3cm) fine silt & detritus
Active beaver pond. 30 coho fry.
KLAWOK LAKE
PRINCE OF WALES IS.
103-60-47
KLAWOCK LAKE

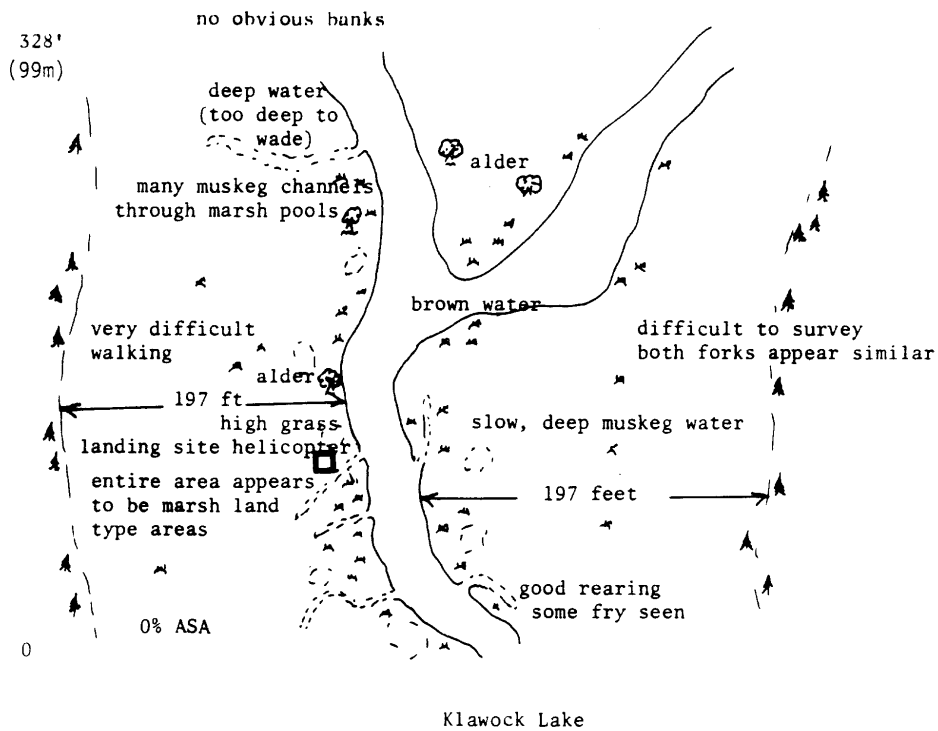

Klawock Lake head stream.
103-60-47
Undercut banks
(1m)deep 3'
(8m)wide 26'
(1m)wide
3'
(12cm)deep
5"
Trickle
Undercut bank,
moderate slope
(1100m) 3608'
10' (3m)high bed-
rock outcrop
Red diamond
marker on tree
Spruce & hemlock
6.5'
(2m)wide
(25cm)deep 10"
Small (3-10cm) 1-4"
gravel
2'
(0.5m)deep
Undercut
bank 2m wide
5" (13cm)deep
Fry
1525' x 12' x 70% = 1191 m2 ASA
3247' (990m)
Water clear
pH 7.5
Water temp 10.5C
Air temp 15C
KLAWOK - HOLLIS RD.
1 coho fry
1 dipper
Gravel
& sand
Med.
moss
Sparse green algae
10'
3'
(3m)wide, (1m)deep pool
(3-20cm)gravel 1-8"
Rock bank
20'(6m)rock bank
3'(1m)deep pool
Rock bank
6.5'(2m)W.
1" (2.5cm)
gravel
riffle
3' (1m)D.pool
Gravel,
sand.
Debris jam
Bedrock
(880m) 2886'
Shallow pools
and swift riffles
Gentle slopes
1 coho fingerling
(30cm)deep 12"
(3-10cm)gravel 1-4"
(6m)wide 20'
(770m) 2526'
(1.5m)wide 5'
Undercut banks
5'(1.5m)high banks
Devils club
(6m)wide 20'
(1m)deep pool 3'
Nice little spawning
and rearing stream.
20" (6m) wide
8" (20cm) deep
3'
(1m) wide
3'
(1m) deep
Hemlock,
spruce
10'
(3m) wide
(1m) deep 3'
(6m) bedrock 20'
cliff
Submerged log
12" (30cm) deep
33'
(10m) wide
9"
5(23cm) trout
KLAWOCK HOLLIS ROAD
(1365m)
4477'
(1320m)
4330'
40' (12m)wide
Dead
hemlocks
Some gravel &
silt on bottom
40'
(12m) from right bank
to mid pond island.
Spruce,
hemlock
Water clear,
2-3"(0.5-1m) deep
Beaver dam
Flow: (0.1m/sec) 0.35 ft/sec
Width: (3.3m) 11'
Depth: (20cm) 8"
(0.07m3/sec) 2.6 cu. ft./sec
20'
(6m) wide
25 coho fry
(15cm) deep 6"
Suspended logs
20' (6m) wide
Side pools &
channels.
(8m) wide 26'
(1m) wide
Undercut banks
(1210m)
3969'
Stone
cliff
36cm deep
(9m) wide 30'
Fry in side
pools



Klawock Lake
4" = 1 mile
Hatchery Creek
- 467 -
Klawock Lake
lily pads
low swampy braided area with large scattered spruce
pond
thick brush in trees
excellent rearing
shallow with wide areas of grass and muskeg on each side of creek
muskeg
muskeg
muskeg
wide and shallow; numerous logs in stream
swamp
tributary
drains into Crab Creek
divide
muskeg with rearing coho
N

Air: 80°F
Water: 70°F
pH: 7.5

Klawok Lake
103-60-47
Rahe, Freitag
8-18-77
Hatchery Creek



APPENDIX B: RESTORATION MONITORING DATA

The following data has been summarized from the Klawock Lake Restoration Update (2008).

Table B1. Water temperature for select tributaries of Klawock Lake in 2007 taken by the KWC.

Temperature	Half Mile	2.5 mile	3 Mile	Deadhead	7 mile	Arrow	Blue Water	Inlet	Crab	Swamp	Chutes and Ladders	Alder	Salmon Salad
5/16	5.4	5.9	4.3	9.4	8.4		5.5	7.4	5.3	5.7	4.9	7.5	7.3
22-May	6.5	5.9	4.9	5.3	5.9		7.9	8.2	7	7	7.8	6.9	8.7
1-Jun	10.1		6.9	7.6	7.7	10.7	8.7	11.9	6.2	6.6	6.1	7.4	8.5
7-Jun	8		5.8	7.7	6	9.7	7.2	10.5	7.7	9	8.2	10.6	9.2
15-Jun	10.9	7.9	8	9.8	7.3	11.4	9	11.9	9.8	9.9	9.9	12.2	9.7
24-Jun	9.8	8.1	6.8	9.7	7	10.1	8.4	11.2	8	9.2	9	10	8.6
1-Jul	11.2	8.9	7.7	8.2	11	11.6	9.6	12.9	10	10.3	10.1	9.6	11.4
9-Jul	11.2	9.2	8.4	8.4	11.3	11	9.7	11	10	10.1	10	10	10.8
8-Jan	13.8	10.8	9.5	11	13.7	13.8	11.2	15.2	11.2				
26-Jul	13.3	12.3	9.3	10.3	12.9	12.2	10.2	13.3	11.6	11.9	11.5	11.1	12.6
3-Aug	13.4	11.1	10.1	11	12.9	12.7	10.7	14.3	12.1	11.8	11.6	10.9	12.8
22-Aug	13.1	10.8	10.7	11.9	12.6	12.7	10.4	13.3	11.7	11.8	11.4	10.2	12
30-Aug	11.9	10.7	10.2	10.7	12.3	11.6	10	11.9	12.1	11.4	11.2	10.9	12
7-Sep	11.2	10.1	9.4	11.7	9.3	10.9	10	11.1	10.3	10.4	10.2	10.2	10.8
14-Sep	11.2	10.4	9.7	11.5	10.8	11	9	11.9	11.2	11.1	10.9	10.8	11.5
20-Sep	10.3	9.8	9.3	11	9.3	10.3	9.3	10.4	9.9	9.6	9.6	9.4	10
28-Sep	7.8	8.6	7.6	9.3	7.1	8.6	7.3	8.5	8.2	8.1	8.2	8.4	8.8
6-Oct	7.5	7.7	7.2	8.8	6.9	8.2	7.3	8.2		7	7.3	7.8	7.8
15-Oct	7.2	7.7	7.2	8.6	6.8	8.1	7	7.9	7.3	7.1	7.2	7.6	7.9
19-Oct	4.3	6.8	5.2	6.4	4.6	5.9	5.9	5.5					
28-Oct	5.2	6.5	5.6	6.7	5.2	6.2	5.5	6.5	6	5.3	5.7	6.2	6.2
4-Nov	3.2	5.4	4.2	5.1	3.7	4.8	4.5	4.7	4.3	4	4.3	5.1	4.7
10-Nov	3.9	5.5	4.6	5.5	4.2	5.5	5	5.1	4.5	3.9	4.1	4.7	4.7
28-Nov	2	6	3	4	4	5	5	4	1	2	1	3	3

Table B2. Dissolved oxygen values for select tributaries of Klawock Lake in 2007 taken by the KWC.

% Dissolved Oxygen	Half Mile	2.5 mile	3 Mile	7 mile	Deadhead	Arrow	Blue Water	Inlet	Crab	Swamp	Chutes and Ladders	Alder	Salmon Salad
5/16	19	17	30	22	23		18	39	36	37	50	30	37
22-May	23	36	26	47	26	33	48	25	29	21	25	23	30
1-Jun	18	36	26	28	23	38	34	23	27	22	29	31	25
7-Jun	20		21	25	24	38	37	25	21	20	24	21	25
15-Jun	18	25	24	25	17	33	31	21	25	25	30	19	31
24-Jun													
1-Jul	21	38	28	28	25	44	53	32	25	29	34	39	25
9-Jul	20	43	26	25	27	41	42	26	31	27	29	30	26
8-Jan	30	53	33	29	37	47	65	37	40				
26-Jul	33	60	39	43	54	62	84	37	51	53	62	56	41
3-Aug	38	59	48	53	60	68	93	51	56	59	72	70	43
22-Aug	43.7	67.8	55.4	74.1	64.2	84.2	126.1	67	69.2	65.8	88	86.8	63.7
30-Aug	45.6	70.8	49.5	51.3	63.3	79.9	114.4	56	75	70.8	85.2	70.1	48.8
7-Sep	37	71.5	52.9	62.1	53.8	82	103	51.4	63.5	73	79	72	55.2
14-Sep	53.3	74.5	63.5	88.5	69.2	108.8	128.3	72.2	70.5	77	80	75.2	61.2
20-Sep	47.4	66.2	61.7	60	61.8	71.3	97.9	51.9	75.5	80	86.5	80.2	54.6
28-Sep	55.1	92	62	81	64.1	91.2	114.5	52.1	88.5	72.6	87.1	74.9	60.5
6-Oct	55.1	92	62	81	64.1	91.2	114.5	52	88.5	72.6	87.1	74.9	60.5
15-Oct	55.1	92	62	81	64.1	91.2	114.5	52.1	88.5	72.6	87.1	74.9	60.5
19-Oct	55.1	92	62	81	64.1	91.2	114.5	52.1	88.5	72.6	87.1	74.9	60.5
28-Oct													
4-Nov	54.5	78.2	70.2	66	84.2	105.5	114.5	70.5	106.5	85.5	88.1	84	60.5
10-Nov	44.3	84	69.2	63	69.2	83	98.4	51.9	90	82	83	78.5	54

APPENDIX C: HATCHERY CREEK FISH PASSAGE INFORMATION

This data was provided by Neil Stichert, U.S. Fish and Wildlife Service.

Survident 1B018

42" corrugated metal pipe at 2.4% grade, was likely a velocity barrier to juvenile salmon due to its narrow diameter compared to the stream width. Replaced with a 77x52" pipe arch with stream design and natural substrate bottom at 2.0%.

Before

After

Survident 1B019

24” corrugated metal pipe with extensive rusting and pitting and perched outlet at a 4.1% grade. Replaced with 57”x38” pipe arch at 3.26% grade.

Before

After

Survident 1B011

18 inch diameter by 41 foot corrugated plastic pipe at 0.6% grade replaced with 64x43” by 43 foot pipe arch at 2.63%.

Before

After

APPENDIX D: KLAWOCK WATERSHED RIPARIAN THINNING PRESCRIPTIONS

Klawock Watershed
Riparian Thinning Prescriptions

May, 2007
Finalized June 05, 2007
By: P. Tierney

Introduction

The following prescription is intended to increase the growth rate of conifer species on the sites by reducing the conifer stocking and releasing selected conifers from competition for light by faster growing red alder. It is a conservative approach designed to leave approximately 40 percent of the alder cover in the stand to help provide for stand diversity and some protection to the selected leave conifers from wind, snow, and ice.
Items common among prescriptions:

1) Eligible conifers – Eligible conifers are described by minimum heights (two feet tall) and sometimes by a maximum diameter and/or residual classification. For riparian prescriptions where large conifers are an objective of treatment, a maximum diameter is often used to exclude larger trees from treatment. These larger trees, including old growth remnant trees should be ignored in spacing requirements. Large individual trees and patches of remnant old growth either not harvested or selectively harvested should not be treated.
2) Desirable conifers for leave trees (leave tree selection) – Leave trees should be the largest, most vigorous trees, free from disease or mechanical damage, have at least 30% live crown, be well rooted in the soil and not perched on a nurse log or stump. Height to diameter ratio should also be considered. Tall, skinny trees are not preferred leave trees because of the high height to diameter ratio. When exposed by thinning or release, these trees may bend or snap off due to weather (wind, snow and ice).
3) Conifer release – Conifer trees can be encouraged to grow by increasing sunlight to the live crown. Conifers may be released from competition for sunlight by thinning dense groups (or stands) to allow the tree crowns to expand both horizontally (crown and diameter growth) and vertically (height growth). Conifers may be overtopped by brush or broad crowned hardwoods such as red alder. Release of these conifers involves removing the overtopping vegetation that effectively cover and shade these young trees. When selecting conifers for release and there is a choice, choose overtopped conifers that are at least 5 feet tall, and meet criteria in item 2 above rather than larger conifers that appear to be competing well with surrounding alder (crown of conifer is already ½ the height or more of the surrounding alder). Other conifers thinned to an 18x18 foot spacing will benefit from selective release through edge or side-lighting once alder is removed from around the conifer selected for release.
4) Stream buffers – No treatment buffers along streams provide for several immediate and long-term objectives. Minimizing disturbance and slash deposits directly adjacent to the stream bank are paramount. Heavy slash directly adjacent to streams can inhibit and stream flows, redirect high flow waters, and can physically be carried downstream, possibly taking desired streamside vegetation along with it. All have the potential to increase sedimentation and destabilize stream banks. Small no treatment buffers (5 to 15 feet) can help protect streamside vegetation, minimize slash along the stream bank, provide for wildlife use and still provide for increased sunlight (through side-lighting).
5) Conifer spacing – target approximately 134 conifer trees per acre to be left (18x18 foot spacing) and us a wide variance of 50% in the spacing requirements to allow for the selection of the

largest, most vigorous trees of the desired species to be left. Occasionally, groups of larger (and older) conifers may be present. Generally, these trees should not be treated.

6) Girdling – Although other methods of girdling are available and may be appropriate, standard girdling calls for two circular saw cuts approximately 4 inches apart, about 1 inch deep and at least ¼ inch width that completely encircle the bole of the tree. Saw cuts must be deep enough to completely sever the live cambium under the bark but care must be taken not to cut too deeply or the trees will topple with the first windstorm. The objective of girdling is to lessen slash loading from larger trees, avoid crop tree damage during thinning operations and provide for additional snags within the riparian corridor while maintaining or increasing growth on remaining conifer trees.

General Prescriptions

Generalized prescriptions are as follows and may be applied to each stream and stream reach with certain adjustments.

a) Thin eligible conifers to approximately 134 trees per acre (18x18 foot spacing). Use a wide variance (+/- 50%) to select the largest, most vigorous trees to leave of the preferred species and with desirable characteristics (see items 1 and 2 above). Use an upper diameter limit (dbh limit for conifers) to avoid treating larger trees and remnant old growth. Do not account for these larger trees in spacing requirements.

b) Select conifers at approximately 1 chain (66 foot) spacing for release, using a wide variance (+/- 50%) to select the conifers that would benefit most from release (see item 3 above). Remove all alder within a 20 foot radius of the bole of selected conifers. To avoid excessive slash, girdle all alder above (dbh limit for alder) that would otherwise be cut.

c) Maintain a streamside buffer (5 to 15 feet from bankfull width, specified by stream) where no treatment takes place. Any slash entering the stream or buffer must be pulled back or lopped and thrown to lie outside the specified buffer.

d) Thinning of alder to approximately 70 trees per acre (25x25 foot spacing). Use a wide variance (+/- 50%) to allow for conifer spacing. Use a dbh limit so that larger alder will be girdled instead of cut to reduce slash loading.

Treatment of streams which cross the Klawock-Hollis highway may have concerns with visuals, slash and possible conflicts with utility installations along the highway. It may be advisable to consider a no treatment buffer along the Klawock-Hollis highway that extends 50 feet beyond the clearing limits for the highway and utility corridors.

<u>Hatchery Creek sub-basin:</u>

Most riparian stands identified for treatment in this sub-basin are young mixed conifer/alder stands with patchy distribution of alder and conifer stems. Some areas are dominated by conifer while others are clearly dominated by alder with at least some understory conifer.

Rx – Implement prescription a) using an 8 inch dbh limit for conifers (ignore conifers 8 inches dbh and greater).

Implement prescription b) using an 8 inch dbh limit for alders (girdle alder to be removed that is 8 inches dbh and greater).

Implement prescription c) using a 10 foot stream buffer on all stream reaches.

This prescription may be applied to all stream reaches within the sub-basin. The uppermost stream reach in the basin identified for treatment (the first reach encountered when entering along road 6000000) has few conifer dominated sites. Administration may wish to consider only the selection of overtopped conifers for release (prescription b) only as presented above).

Arrow Creek:

Riparian corridors along Arrow Creek are a mixture of conifer/alder stands with patchy distribution of both alder and conifer stems.

Rx – Implement prescription a) with a 10 inch dbh limit for conifers (ignore conifers 10 inches dbh and greater).
Implement prescription b) with a 10 inch dbh limit for alders (girdle alder to be removed that is 10 inches dbh and greater).
Implement prescription c) with a 10 foot stream buffer on all stream reaches.

7-Mile Creek:

Riparian corridors along 7-Mile Creek are a mixture of conifer/alder stands with patchy distribution of both alder and conifer stems. Tree sizes along this stream differ above and below the highway enough to adjust the prescription slightly.

Rx –

Below the highway:

Implement prescription a) with an 8 inch dbh limit for conifers (ignore conifers 8 inches dbh and greater).
Implement prescription b) with a 10 inch dbh limit for alders (girdle alder to be removed that is 10 inches dbh and greater).
Implement prescription c) with a 10 foot stream buffer on all stream reaches.

Above the highway:

Implement prescription a) with a 10 inch dbh limit for conifers (ignore conifers 10 inches dbh and greater).
Implement prescription b) with a 10 inch dbh limit for alders (girdle alder to be removed that is 10 inches dbh and greater).
Implement prescription c) with a 15 foot stream buffer on all stream reaches.

Dead Head Creek:

Riparian corridors along Dead Head Creek are a mixture of conifer/alder stands with patchy distribution of both alder and conifer stems.

Rx – Implement prescription a) with a 10 inch dbh limit for conifers (ignore conifers 10 inches dbh and greater).
Implement prescription b) with a 10 inch dbh limit for alders (girdle alder to be removed that is 10 inches dbh and greater).
Implement prescription c) with a 10 foot stream buffer on all stream reaches.

Three-Mile Creek:

Riparian corridors along Three-Mile Creek and tributaries to be treated are a mixture of conifer/alder stands with patchy distribution of both alder and conifer stems. Stand size differs significantly enough along the south side of the creek to call for a different prescription. Significant numbers of residual trees remain along this stream and some of the tributaries identified for treatment.

Rx – Implement prescription c) using a 15 foot no treatment buffer along both sides of the main stem stream. Implement a 5 foot buffer along all tributaries to Three-Mile Creek.

For the north side of the creek and tributaries along the north side:

Implement prescription a) with a 10 inch dbh limit for conifers (ignore conifers 10 inches dbh and greater).

Implement prescription b) with a 10 inch dbh limit for alders (girdle alder to be removed that is 10 inches dbh and greater).

For the south side of the stream and tributaries along the south side:

Implement prescription a) with an 8 inch dbh limit for conifers (ignore conifers 8 inches dbh and greater).

Implement prescription d) with a 10 inch dbh limit for alders (girdle alder to be removed that is 10 inches dbh and greater).

2.5 Mile Creek:

Riparian corridors along 2.5 Mile Creek are a mixture of conifer/alder stands with patchy distribution of both alder and conifer stems.

Rx – Implement prescription a) with an 8 inch dbh limit for conifers (ignore conifers 8 inches dbh and greater).

Implement prescription b) with a 12 inch dbh limit for alders (girdle alder to be removed that is 12 inches dbh and greater).

Implement prescription c) with a 10 foot stream buffer on all stream reaches.

Alder West

Riparian corridors along these stream reaches are a mixture of conifer/alder stands with patchy distribution of both alder and conifer stems.

Rx - Implement prescription a) with a 10 inch dbh limit for conifers (ignore conifers 10 inches dbh and greater).

Implement prescription b) with an 8 inch dbh limit for alders (girdle alder to be removed that is 8 inches dbh and greater).

Implement prescription c) with a 5 foot stream buffer on all stream reaches.

Alder Creek

Riparian corridors along the remaining Alder Creek stream reaches to be treated are a mixture of conifer/alder stands with patchy distribution of both conifer and alder. Some distinct patches of conifer dominated and alder dominated areas exist and tree sizes vary.

Rx - Implement prescription a) with a 10 inch dbh limit for conifers (ignore conifers 10 inches dbh and greater).
Implement prescription b) with a 12 inch dbh limit for alders (girdle alder to be removed that is 12 inches dbh and greater).
Implement prescription c) with a 10 foot buffer on all stream reaches.

<u>Chutes and Ladders/East 1/West 2 and all associated tributaries</u>
Riparian corridors along these streams are a mixture of conifer/alder stands with patchy distribution of both alder and conifer stems. Significant areas of young conifer regeneration exist especially along the West 2 stream reach and tribs. To assure diameter growth of conifers, apply conifer release (prescription b) even though some of the area may have little alder present.

Rx - Implement prescription a) with a 10 inch dbh limit for conifers (ignore conifers 10 inches dbh and greater).
Implement prescription b) with an 8 inch dbh limit for alder (girdle alder to be removed that is 8 inches dbh and greater).
Implement prescription c) with a 10 foot buffer on all stream reaches.

<u>Chutes and Ladders/West 1</u>
Riparian corridors along this stream are a mixture of conifer/alder with somewhat patchy distribution of conifer and alder stems.

Rx – Implement prescription a) with a 10 inch dbh limit for conifers (ignore conifers 10 inches dbh and greater).
Implement prescription b) with a 12 inch dbh limit for alder (girdle alder to be removed that is 12 inches dbh and greater).
Implement prescription c) with a 10 foot buffer on all stream reaches.

<u>Swamp Creek</u>
Riparian corridors along these stream reaches are a mixture of conifer/alder with some larger conifer and intermittent alder. Patchy distribution was observed.

Rx - Implement prescription a) with a 12 inch dbh limit for conifers (ignore conifers 12 inches dbh and greater).
Implement prescription b) with an 8 inch dbh limit for alder (girdle alder to be removed that is 8 inches dbh and greater).
Implement prescription c) with a 10 foot buffer on all stream reaches.

In the event that additional streams or stream reaches are selected for treatment to attain stated riparian objectives, the following prescription may be applied.
Prescription a) using an 8 inch dbh limit for conifers.
Prescription b) using a 10 inch dbh limit for alder.
Prescription c) using a 10 foot buffer width.

Questions may be directed to:
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