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Data Review of the Sockeye Salmon Declines in Chilkat and Chilkoot Lakes, Southeast Alaska

Submitted to:
Haines Borough
103 Third Avenue South
P.O. Box 1209
Haines, Alaska
99827

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1.0 INTRODUCTION

The Chilkat and Chilkoot River watersheds are the 2 largest producers of sockeye salmon (*Oncorhynchus nerka*) in the Lynn Canal area of southeast Alaska (Eggers et al. 2009), near the community of Haines (Figure 1). There are 2 populations of sockeye salmon in Chilkat Lake based on run-timing: an early run and a late run (McPherson 1990). The late run is typically more abundant than the early run. Early run sockeye emigrate from freshwater primarily as age-1 fish that have spent one winter rearing in freshwater whereas the late run emigrates primarily as age-2 fish that have spend 2 winters in freshwater (Halupka et al. 2000). Chilkoot Lake also has an early run and late-run population, and the late run is also more abundant than the early run (McPherson 1990). Spawning occurs primarily in small tributaries for the early run, and in the mainstem of the Chilkoot River and on lake beaches for the late run (McPherson 1990). For both runs, the majority of fish spend 1 winter rearing in freshwater and emigrate as age-1 fish (Halupka et al. 2000). Chilkoot Lake sockeye emigrate from freshwater at relatively smaller sizes (65-75 mm) than Chilkat and other populations of sockeye, but use Lutak Inlet as a secondary rearing area, which is likely important to the high productivity of Chilkoot sockeye (MacPherson 1990; Halupka et al. 2000).

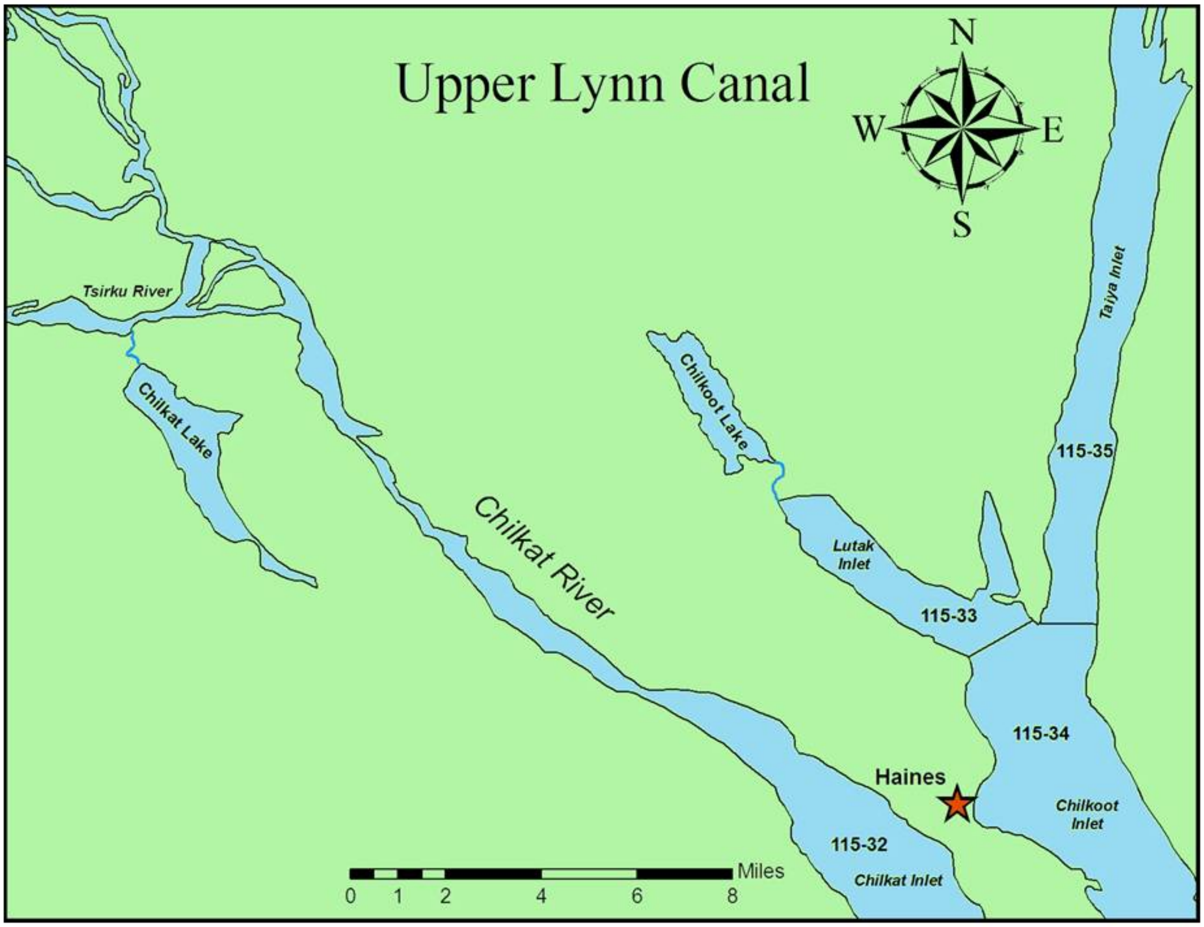

Figure 1: Upper Lynn Canal area in southeast Alaska including Chilkat and Chilkoot lakes. Figure is from Bachman (2011).

Sockeye salmon are an economically and socially important species in southeast Alaska. Commercial fisheries in the Lynn Canal area have existed since 1878, with a peak in harvest between 1900 and the 1920s. Currently, commercial fisheries for Chilkat and Chilkoot sockeye occur primarily in the Lynn Canal area by the commercial drift gill-net fishery (Eggers et al. 2009, 2010). Some Chilkat and Chilkoot sockeye salmon are caught before reaching Lynn Canal by purse seine fisheries targeting pink salmon (*Oncorhynchus gorbuscha*) (Davidson et al. 2012). Chilkat and Chilkoot Lake sockeye also support valuable sport fisheries and subsistence fisheries (Smith 2003; Eggers et al. 2009).

Returns of adult sockeye salmon to both Chilkat and Chilkoot lakes have declined substantially compared to historical records. For instance, catches of Chilkat sockeye salmon averaged 480,000 during 1900-1925 compared to 85,000 from 1975-2007 (Geiger and McPherson 2004). Returns of sockeye salmon to Chilkoot Lake have declined drastically since the early 1990s while other populations of sockeye salmon in the vicinity did not suffer as sharp a decline during the same time period (Riffe 2006). A number of management initiatives have aimed to rebuild sockeye salmon stocks, including fry stocking in Chilkat Lake, reduction in commercial fishing effort, and establishment of biological escapement goals. Despite these efforts, returns of sockeye salmon to the Chilkat and Chilkoot rivers have failed to rebound to historical levels.

In response to concern about the failure of sockeye salmon populations to recover, members of the fishing community and other stakeholders in Haines, Alaska became interested in the causes of declines of Chilkat and Chilkoot sockeye salmon and possible management alternatives. Golder Associates Ltd. (Golder) conducted the following independent review of the declines in Chilkat and Chilkoot sockeye salmon based on existing data and published reports. The main objectives of this data and literature review were:

- To assess trends in limnological data, including water chemistry, primary productivity, zooplankton, and sockeye salmon abundance.
- To identify factors contributing to declines in the abundance of sockeye salmon and rank these factors in terms of likelihood based on trends in the Chilkat/Chilkoot data, and supporting literature and comparative studies from other regions.
- To identify enhancement and management options that could help the recovery of sockeye salmon populations, and discuss their success/failure in other regions and factors that may limit their effectiveness.
- To evaluate the sufficiency of existing data to identify the causes of decline and effectively manage fisheries, and identify key data gaps.

2.0 APPROACH AND METHODS

The analysis included compiling and reviewing reports and published data concerning the abundance of sockeye salmon and limnology of Chilkat and Chilkoot lakes, including water chemistry, primary productivity, and zooplankton. The main data source was the Alaska Department of Fish & Game's (ADFG) publications. Background information from peer-reviewed and "grey" literature concerning fisheries management and enhancement options were also reviewed. Literature searches used the ADFG electronic library, as well as academic search engines and online search engines (e.g., Google Scholar). Data were also obtained directly from the ADFG, which included data from published reports and some previously unpublished data.

Data from the review were used to assess trends in sockeye salmon abundance, primary and secondary productivity, and limnology over time. Trends in total escapement and productivity of sockeye salmon in Chilkat and Chilkoot lakes were assessed and compared to other populations of sockeye salmon to help discern whether marine or freshwater factors were more likely limiting production. Limnological and fisheries data were graphed and assessed visually for trends. Linear regression was used to assess relationships between continuous variables.

Possible causes of sockeye salmon declines and limitations to recovery were identified and ranked in terms of likelihood, based on trends in the Chilkat/Chilkoot data, and supporting literature and comparative studies from other regions. Enhancement and management options that could help the recovery of sockeye salmon populations were identified. The success of enhancement and management options in other regions were discussed, as well as factors that may limit their effectiveness.

3.0 RESULTS AND DISCUSSION

3.1 Review of Limnology Data

Limnology data obtained from published reports and from the ADFG included water chemistry, zooplankton, and sockeye salmon data. Years for which different types of limnology data were collected and available for analysis in this report are shown in Table 1.

Table 1: Summary of years that limnological data were available for Chilkat and Chilkoot lakes.

Type of Data	Chilkat Lake	Chilkoot Lake
Physical	1987-1991,2004-2011	1987-1991,2001-2011
Water Chemistry	1987-1988, 1990-1991, 1994-2003	1987-1991,1997*,2001-2003
Zooplankton	1987-1991,1994-2010	1987-1991, 1995-2010
Juvenile Sockeye Abundance (Fry)	1987-1991, 1994-1995, 1997-2002	1987-1991, 1995-2011
Juvenile Sockeye Abundance (Smolt)	none	1989-1990,1994-2004
Adult Sockeye Abundance	1976-2011	1976-2011

* Only chlorophyll *a* analysed in 1997

3.1.1 Trends in Physical Data

The primary physical variable of interest assessed in this report was the euphotic zone depth (EZD), which is the depth below which photosynthesis functionally ceases. As such, the EZD is an indicator a lake's capacity for photosynthetic production. The EZD is conventionally defined as the depth at which the amount of incident light measured directly below water surface is attenuated to 1%. EZD values from Chilkat and Chilkoot lakes were obtained from the ADFG for 2004-2011, from Riffe (2006) for 2001-2004 (Chilkoot only), and from Barto (1996) for 1987-1991. Means of the 2 sampling stations and all sampling dates are presented here. Standard errors were calculated for 2005-2011 but were not available for mean values presented in summary reports for earlier years (Barto 1996 and Riffe 2006).

Water temperature was measured at each meter of depth in the water column between the surface and 50 m at 2 locations and several sampling dates during the ice-free season in Chilkat and Chilkoot lakes. These temperature profile data were obtained from the ADFG for 2004-2011. To summarize temperature data, the mean of all measurements during July through September at a depth of 1.0 m are presented here. Graphs of temperature isopleths were provided in Barto (1996) and Riffe (2006) but raw data or mean values were not presented, so these data were not assessed in the present report.

Discharge data for flows into and out of Chilkat and Chilkoot lakes were not found during our literature review.

Chilkat Lake

Mean EZD varied between 15 and 25 m from 2004-2011 with no apparent trend over time. Mean EZD values in 1987 were slightly lower (~14-18 m; Figure 2). Mean temperature (mean of July to September at both stations) ranged from 14°C to 17 °C (Figure 2). However, differences in mean temperature could be related to differences in sampling dates rather than changes in the temperature profile of the lake. A more detailed analysis of the temperatures at all depths and throughout the sampling season would be necessary to identify any changes in temperature regime of the lake over time. In depth analysis of temperature profiles was beyond the scope of the present report.

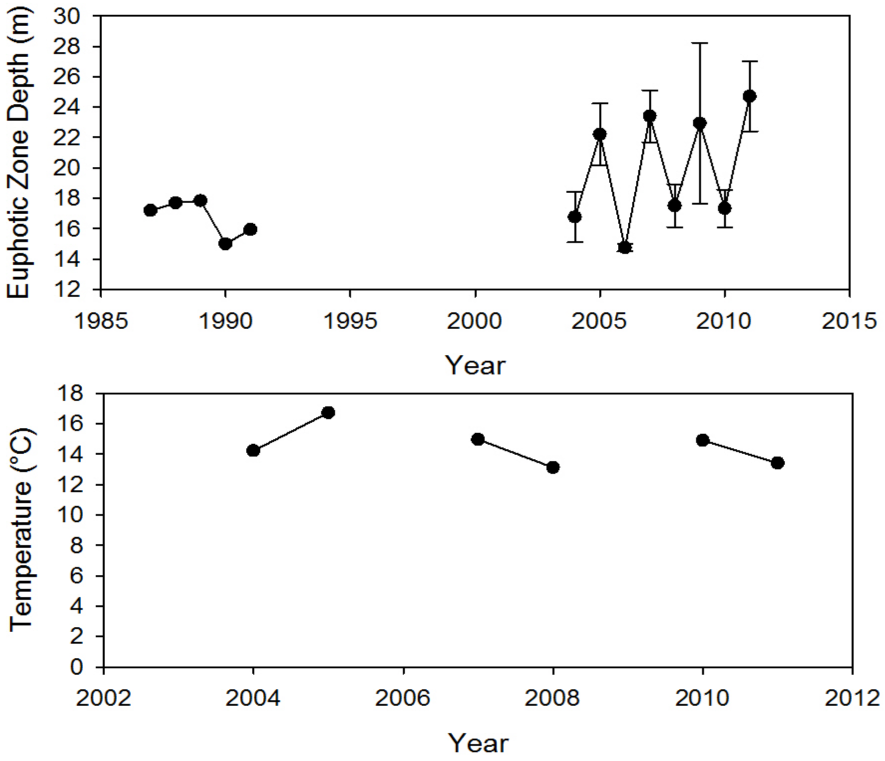

Figure 2: Euphotic zone depth (EZD) and mean temperature at 1.0 m depth in Chilkat Lake. EZD values are means of all sample dates and stations and error bars represent standard error (standard error not available for means before 2005 which were obtained from published reports). Temperature values are means from July through September at both sampling stations.

Chilkoot Lake

Mean EZD was greatest in 2006 then declined sharply from 2007-2009, and remained low in 2010 and 2011 (Figure 3). The very shallow EZDs observed in recent years could be related to increases of glacial silt, because large inputs of glacial silt that increase turbidity and decrease light penetration in Chilkoot Lake have been reported in previous years (e.g., 2004; Riffe 2006).

Mean temperature measured at 1.0 m in depth during July through September was relatively consistent from 2005-2011 (Figure 3). A more detailed analysis of the temperatures at all depths and throughout the sampling season would be necessary to identify any changes in temperature regime of the lake over time. In depth analysis temperature profiles was beyond the scope of the present report.

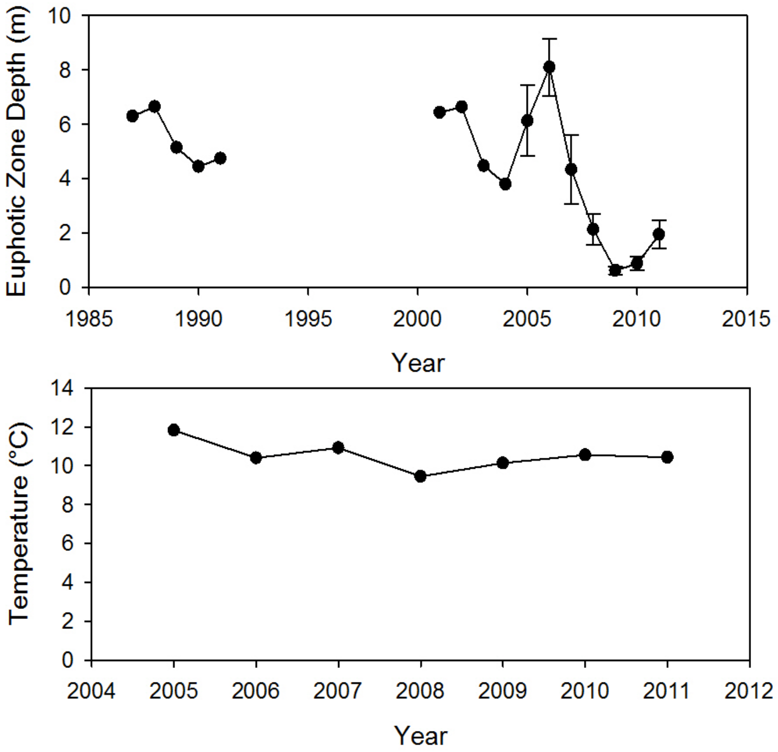

Figure 3: Euphotic zone depth (EZD) and mean temperature at 1.0 m depth in Chilkoot Lake. EZD values are means of all sample dates and stations and error bars represent standard error (standard error not available for means before 2005 which were obtained from published reports). Temperature values are means from July through September at both sampling stations.

3.1.2 Trends in Water Chemistry

Water chemistry data from limnological investigations were obtained from ADFG (Steve Heinl, personal communication). Water chemistry data for Chilkat Lake were available from 1987-2003, except in 1989, 1992 and 1993. In Chilkoot Lake, water chemistry data were available from 1987-1991, 1997 (algae only), and 2001-2003. To our knowledge, water chemistry data have not been collected after 2003 in either lake. Results of limnological investigations have been published for Chilkoot Lake for study years 2001-2003 (Riffe et al. 2006) and for study years 1987-1991 for Chilkat and Chilkoot lakes (Barto 1996). Analysis or summaries of data from all other years when data were collected has not been published, based on our literature search and review. Water chemistry variables included in the data-set provided by ADFG were: conductivity, pH, alkalinity, turbidity, color, calcium, magnesium, iron, total phosphorus, total filterable phosphorus, filterable reactive phosphorus, total Kjeldahl nitrogen, ammonia, nitrate, reactive silicon, particulate carbon, chlorophyll *a*, and phaeophytin. For both Chilkat and Chilkoot lakes, water samples and measurements were taken at 2 sample sites on the lake, and at 2-4 water depths (one sample in the epilimnion at 1.0 m and 1-3 other depths up to 50 m depending on the year). Sampling was conducted between late April and November and the number of sampling sessions varied from 2 to 7. Details of sampling protocols and laboratory methods are provided in Barto (1996) and Riffe et al. (2006).

In order to assess trends in the productive capacity of the lakes over time, our analysis focused on the following key variables:

1) **Turbidity** – Turbidity, measured in nephleometric turbidity units (NTU), affects how light penetrates the water and the depth of the euphotic zone. Turbidity is affected by suspended inorganic particles, such as silt, and organic particles like algae (Koenings et al. 1987).

2) **Total phosphorus (TP)** – Phosphorus is the limiting macronutrient in most lakes (Schindler 1977), and is expected to be correlated to primary productivity. Soluble reactive phosphorus usually makes up a small component of TP but is the form that is most readily for uptake by algae (Koenings et al. 1987). However, inorganic particulate forms (e.g., from silt) can also be a source of phosphorus for organisms (Smith and Mayfield 1977; Koenings et al. 1989).

3) **Total nitrogen (TN)** – Nitrogen can become the limiting macronutrient under certain circumstances, which can result in large blooms of cyanobacteria (blue-green algae) that can fix their own nitrogen, and are inedible to zooplankton.

4) **Nitrogen to phosphorus molar ratio (N:P ratio)** – This ratio is important for assessing whether phosphorus or nitrogen may be limiting productivity. A molar ratio of 16:1, called the Redfield ratio, was developed from the makeup of marine phytoplankton and has also been applied as a guideline for freshwater ecosystem, although the stoichiometric composition of phytoplankton and ratio at which phosphorus may become limiting varies significantly among ecosystems (Hecky et al. 1993).

5) **Chlorophyll *a*** – Concentration of chlorophyll *a* is used to quantify the standing crop of phytoplankton, and is therefore a surrogate for primary productivity.

Because different depths were sampled across years, for consistency, only measurements from a depth of 1.0 m were used. The mean and standard error was calculated for each of the five variables, pooling sample stations and all measurements from May through September.

Our assumption was that the data set provided by the ADFG was already quality controlled and measurement or other errors had been removed.

Chilkat Lake

Turbidity was fairly consistent in most years, fluctuating between 0.6 NTU and 1.3 NTU (Figure 4). High mean turbidity (2.25 ± 1.3 NTU) in 2001 was related to very high turbidity (6.2 NTU) at one station in September and other values were between 0.6 NTU and 1.3 NTU. Turbidity values were consistent with the classification of clear water coastal lakes in Alaska (<5 NTU), as opposed to glacial water lakes, which have turbidity > 5 NTU (Koenings and Edmundson 1991). Turbidity within a given year was relatively stable between May and September (Appendix A, Figure A-1).

Mean annual TP concentrations were slightly greater in 1987 to 1991 (means of 5-10 µg/L) than between 1994 and 1999 (means of 5-7 µg/L; Figure 4). The values were higher in 2000-2002 (means of 9-10 µg/L) but decreased in 2003 (5.6 µg/L). In all years, values of TP were consistently within the range expected for clear water oligotrophic lakes in coastal Alaska (Koenings and Edmundson 1991). Barto (1996) indicated that concentrations of TP in Chilkat Lake (~5-10 µg/L) were in the median to high range for Alaskan sockeye nursery lakes.

TN fluctuated between 180 µg/L and 280 µg/L between 1987 and 2003, with no clear trends over this time period (Figure 4). TN decreased during the growing season in all years (Appendix A, Figure A-2). N:P ratios were high (~20:1 to 100:1) in Chilkat Lake throughout the growing season (Appendix A, Figure A-3) and suggest that the lake is primarily phosphorus limited and not likely nitrogen limited (Healey and Hendzel 1980). Stockner and Shortreed (1985) also found high N:P ratios in coastal sockeye salmon nursery lakes in British Columbia (mean N:P ratio of 89 for 17 lakes studied).

The mean concentration of chlorophyll *a* measured in the epilimnion of Chilkat Lake was similar in most years (~1 µg/L) except for higher values in 2000 (2.0 µg/L) and 2001 (3.4 µg/L). High concentration of chlorophyll *a* in 2000 and 2001 coincided with high TP (Figure 4). However, over all years, there was not a significant relationship between chlorophyll *a* and TP (*P*=0.1; Appendix A, Figure A-4).

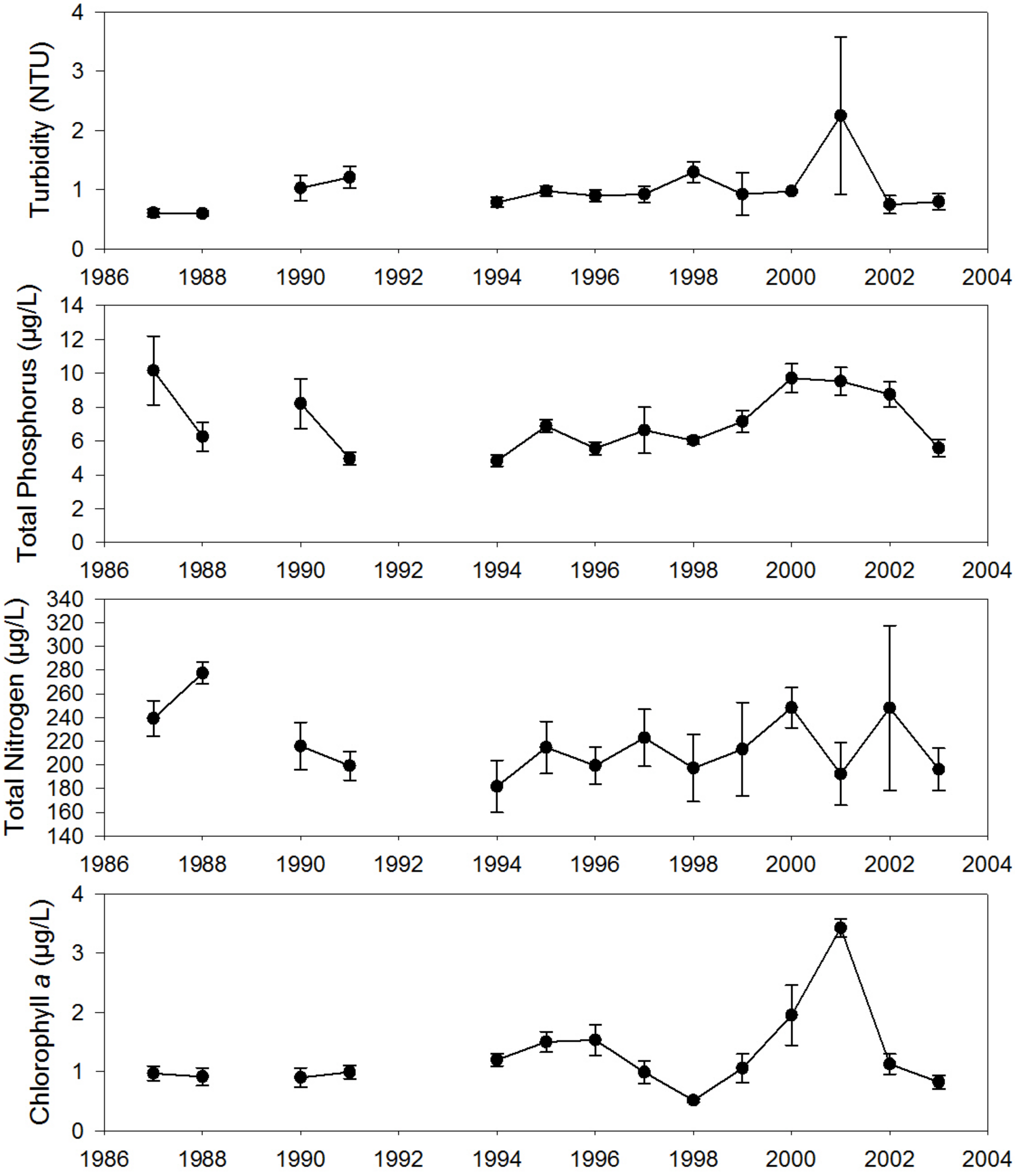

Figure 4: Key water chemistry variables in Chilkat Lake 1987 to 2003. Values are means±standard error.

Chilkoot Lake

Turbidity, TP and TN were only measured in 1987-1991 and 2000-2003. Mean turbidity ranged from 4 to 12 NTU in all years except in 2003 when turbidity was considerably higher (24 NTU; Figure 5). Turbidity values were greater than the 5 NTU limit used to classify Alaska lakes as glacial (Koenings and Edmundson 1991). However, Chilkoot Lake receives less glacial influence than other Alaskan glacial lakes, which have a mean turbidity of 33 NTU (Barto 1996). Turbidity increased throughout the summer in all years, with the greatest seasonal increase in 2003 (Appendix A, Figure A-5). Increased turbidity and corresponding decrease in euphotic depth during the summer was likely caused by glacially influenced stream run-off, which introduced large quantities of silt and inorganic particles into the lake (Barto 1996). Greater turbidity in 2003 may have been related to greater volume of glacial run-off into Chilkoot Lake although Chilkoot River discharge data or local air temperatures were not available for across year comparisons to test this hypothesis.

There was no consistent trend in TP over time, with relatively higher TP in 1989, 1990 and 2003 (24-28 µg/L), and lower TP in 1987, 1988 and 1991 (11-17 µg/L; Figure 5). TP increased between May and September each year (Appendix A, Figure A-5), which was likely related to glacial run-off because 80-90% of TP in Alaskan glacial lakes is inorganic particulate phosphorus from glacial silt (Koenings et al. 1987; Barto 1996). There was no clear trend in TN over time, although TN was slightly higher in 1987-1991 than in 2000-2003 (Figure 5). TN decreased between May and September each year (Appendix A, Figure A-6). The N:P ratio in Chilkoot Lake decreased between May and July, and remained relatively low through September (Appendix A, Figure A-7). Monthly mean N:P ratio (mean of 2 sample stations) in the epilimnion in July, August and September was less than 10:1 in many years and as low as 3.8:1 (Appendix A, Figure A-7). N:P ratio was lowest at station 2 but also sometimes less than 16:1 at station 1 (data not shown). A study in Scandinavia found that there was nitrogen limitation in lakes with a N:P ratio of <13 (Ryding 1980), whereas Flett et al. (1980) reported nitrogen fixing cyanobacteria only in experimental lakes in Canada with N:P of <10. In Chilkoot Lake, the consequences of the drop in N:P ratio in late summer are unclear but based on the N:P ratios observed and previous studies on nutrient limitation, nitrogen limitation of primary production in late of summer of some years is possible.

Mean chlorophyll *a* was stable between 1987 and 1991 (0.8-1.3 µg/L), lower in 1997 (0.4 µg/L), and then decreased from 1.8 µg/L in 2001 to 0.7 µg/L in 2003. The substantial decrease in chlorophyll *a* in 2003 compared to the previous 2 years was likely related to the large increase in turbidity that year (Figure 5), which would have decrease the euphotic zone depth in the lake and consequently, primary productivity. In phosphorus limited oligotrophic lakes, a correlation between chlorophyll *a*, an indicator of primary productivity, and TP would be expected. In Chilkoot Lake, however, there was no significant relationship (P=0.1; Figure A-8), possibly because increases in TP were mostly related to inputs of inorganic particulate phosphorus from glacial run-off, which increased turbidity and reduced euphotic depth and could have decreased primary productivity. Filterable reactive phosphorus, a form of phosphorus that is more biologically available also did not have a significant relationship with chlorophyll *a* (P=0.2; data not shown). Inorganic particulate phosphate from glacial run-off (rock phosphate) can be a source of phosphorus for bacteria and algae and in oligotrophic lakes may be an important source of the nutrient in the long-term (Smith and Mayfield 1977). Although glacial silt can be as source of phosphorus that could increase productivity in the long-term, the associated increase in turbidity reduces euphotic zone depth and thus productivity (Koenings et al. 1989), which is what was likely observed in Chilkoot Lake in 2003.

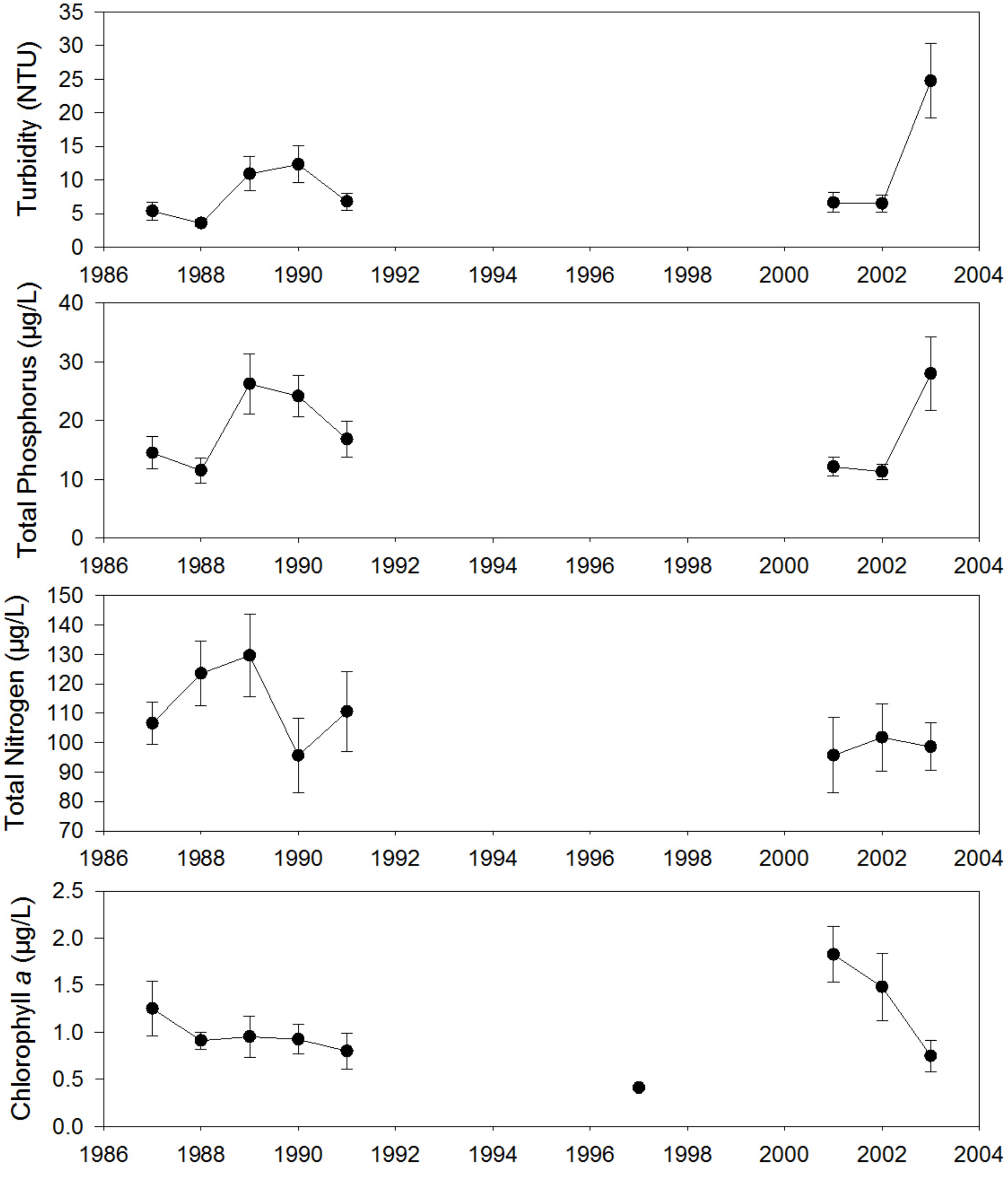

Figure 5: Key water chemistry variables in Chilkoot Lake, 1987 to 2003. Values are means±standard error.

3.1.3 Trends in Zooplankton

Zooplankton are an indicator of secondary productivity and are the key forage for juvenile sockeye salmon. Zooplankton abundance was monitored using tow-net sampling and data were obtained from the ADFG. We assume sampling and laboratory methods followed Koenings et al. (1987) and Barto (1996).

Chilkat Lake

Density of zooplankton was measured in 1987-1991 (2 sample stations) and in 1994 to 2010 (3 sample stations), once a month between May and November (sampling ended in October some years). Annual mean zooplankton density (all stations and months) was substantially greater in 1987 to 1995 than in 1996 to 2010. Zooplankton densities increased slightly from 2004 to 2010, compared to 1995 to 2003. In addition to changes in total zooplankton density, the community composition changed markedly in 1996. The zooplankton community was dominated by copepods prior to 1996 and dominated by cladocerans since 1996. A zooplankton community with few or very small sized cladocerans can be indicate heavy predation pressure (Koenings et al. 1987).

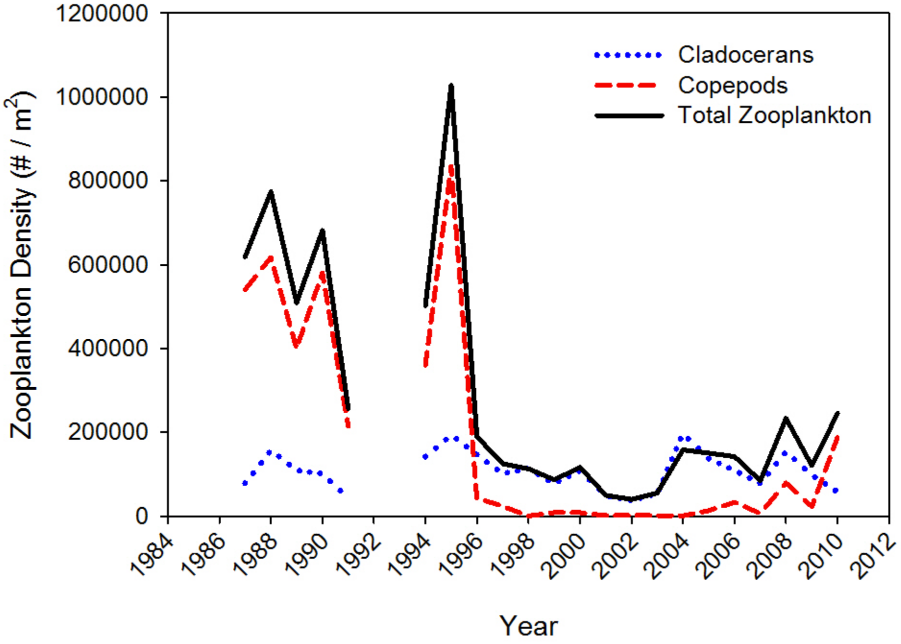

Figure 6: Density of zooplankton in Chilkat Lake, 1987-2010.

Chilkoot Lake

Density of zooplankton was measured in 1987-1991 and in 1995 to 2010. From 1987-1991 and 2008-2010, 2 stations were sampled, and in 1995-2007 4 stations were sampled. Sampling was conducted once a month between May and November most years (sampling ended in October some years). Annual mean zooplankton density declined sharply between 1987 and 1991 (Figure 7). On average, zooplankton densities were lower from 1995 to 1999 (mean=28,042/m^2) than from 2000 to 2010 (mean=61,533/m^2), although density fluctuated widely among years within these time periods. Raw zooplankton data obtained from the ADFG included taxonomic identification but densities were not summarized by taxa, and summarizing many years of data was beyond the scope of our analysis. Therefore, total zooplankton density but not community composition is presented here.

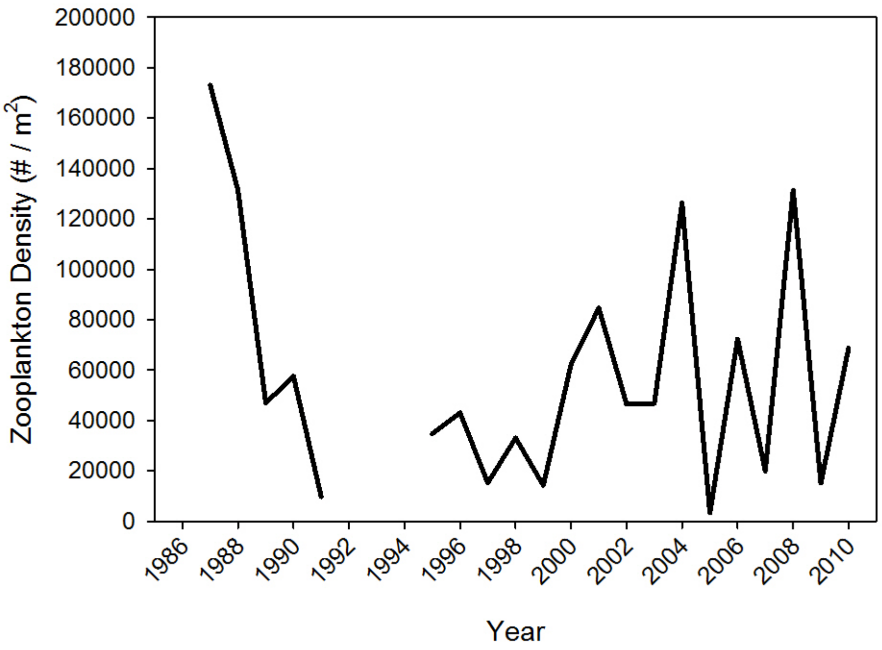

Figure 7: Density of zooplankton in Chilkoot Lake, 1987-2010.

3.1.4 Trends in Sockeye Salmon

Chilkat Lake

Juvenile Sockeye Salmon

The abundance of juvenile sockeye salmon in Chilkat Lake was estimated using hydroacoustic surveys coupled with tow-net surveys to estimate species composition in the fall of 1987-1991 and 1994 to 2002 and these data were obtained from the ADFG. A large population of three-spine stickleback (*Gasterosteus aculeatus*) in Chilkat Lake makes hydroacoustic and tow-net sampling problematic, which may be why this sampling has not been conducted since 2002 (Steve Heinl, ADFG, personal communication). The percent composition of stickleback in the tow-net catch between 1987 and 2002 varied from 10% to 97%, with a mean of 49% (Table 2.) There was no consistent trend in juvenile sockeye salmon abundance based on hydroacoustic estimates between 1987 and 2002, with greatest abundance in 1989 and 1994, and very low abundance in 2001 and 2002 (Figure 1). Because of the apparent difficulties caused by large stickleback abundances for the hydroacoustic surveys, conclusions drawn from these data should be limited.

Juvenile sockeye salmon in Chilkat Lake were also enumerated during emigration from the lake at the Chilkat weir during 1989 to 1990 and 1994 to 2004. Estimates were based on mark-recapture methods where juveniles were captured by incline plane trap, marked, and released upstream (Eggers et al. 2010). A subsample of the juveniles was also sampled for scales to determine age and otoliths were collected to estimate the proportion of hatchery-reared fish, which had thermally marked otoliths. Abundance of juvenile sockeye salmon was fairly consistent across years, except for very low abundance in 2002 (Figure 9).

Based on limnological investigations in the 1980s (Koenings and Burkett 1987; Barto 1996), production of sockeye salmon in Chilkat Lake was thought to be limited by the amount of spawning area, and the lake was capable of supporting more rearing juveniles than were produced naturally (Eggers et al. 2010). Consequently, managers stocked Chilkat Lake with sockeye fry in 1994 to 1997 and 2001. In addition, incubation boxes were installed next to Chilkat Lake. In 1989 to 1998 and in 2003, the incubation boxes were seeded with sockeye salmon eggs, which then were released into the lake in the spring. The percentage of juveniles that were from stocked fry ranged from 20% to 36% from 1995 to 1999 and was 0.4% to 3.8% in 2002 to 2003 (Eggers et al. 2010; Table A-1).

There was a significant positive relationship between the number of smolts emigrating from Chilkat Lake in the spring and zooplankton density in the previous year (*P*=0.002; Figure A-9). Abundance of juvenile sockeye is expected to be positively related to zooplankton abundance, but at very high abundance of sockeye, zooplankton abundance can decrease due to predation by sockeye, resulting in a trophic cascade (e.g., Schmidt et al. 1998).

There was no evidence of a predation induced "trophic cascade" on zooplankton by sockeye salmon in Chilkat Lake during the years where both variables were measured, as sockeye and zooplankton abundance continued to increase together over the range of values observed (Figure A-9).

Table 2: Estimated abundance and species composition of sockeye salmon, stickleback and other fish species from hydroacoustic surveys and tow-net sampling in Chilkat Lake.

Year	% Species Composition			Numbers of Fish		
	% Sockeye	% Stickleback	% Other	# Sockeye	# Stickleback	# Other
1987	16%	83%	1%	842,710	4,257,905	444
1988	23%	77%	1%	685,972	2,332,304	274
1989	78%	18%	4%	2,751,343	628,878	1,376
1990	49%	51%	0%	1,191,612	1,247,360	
1991	49%	51%	0%	1,335,991	1,381,025	
1994	42%	54%	4%	3,802,308	4,869,623	3,780
1995	31%	68%	1%	1,570,389	3,437,079	593
1997	37%	61%	2%	1,388,891	2,333,716	756
1998	78%	21%	1%	1,927,203	518,862	247
1999	90%	10%	0%	1,893,717	210,413	
2000	44%	52%	4%	2,296,800	2,714,400	2,088
2001	2%	97%	1%	93,290	4,851,065	466
2002	5%	94%	1%	199,478	3,409,254	363
Mean	49%	49%	1%	1,739,014	2,121,716	1,067

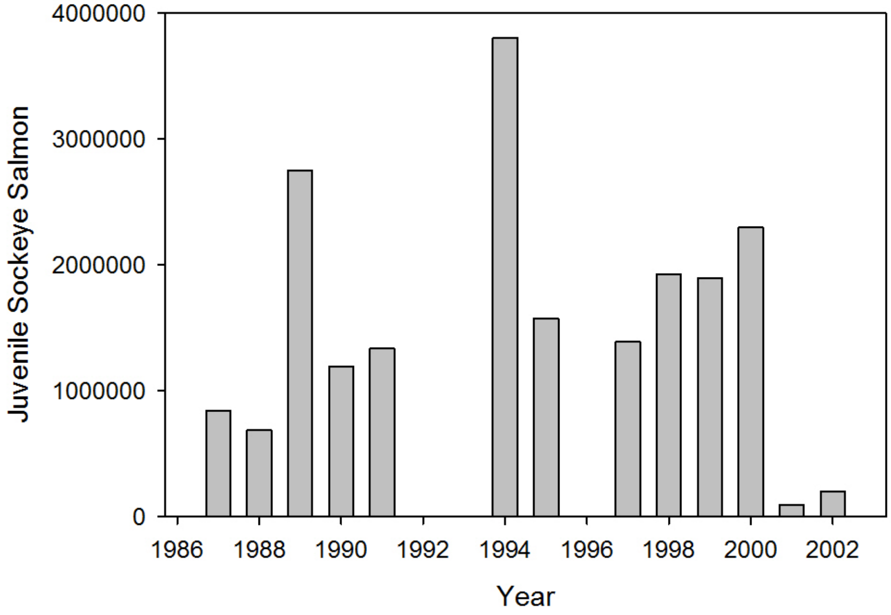

Figure 8: Abundance of juvenile sockeye salmon in Chilkat Lake estimated from hydroacoustic surveys in the fall.

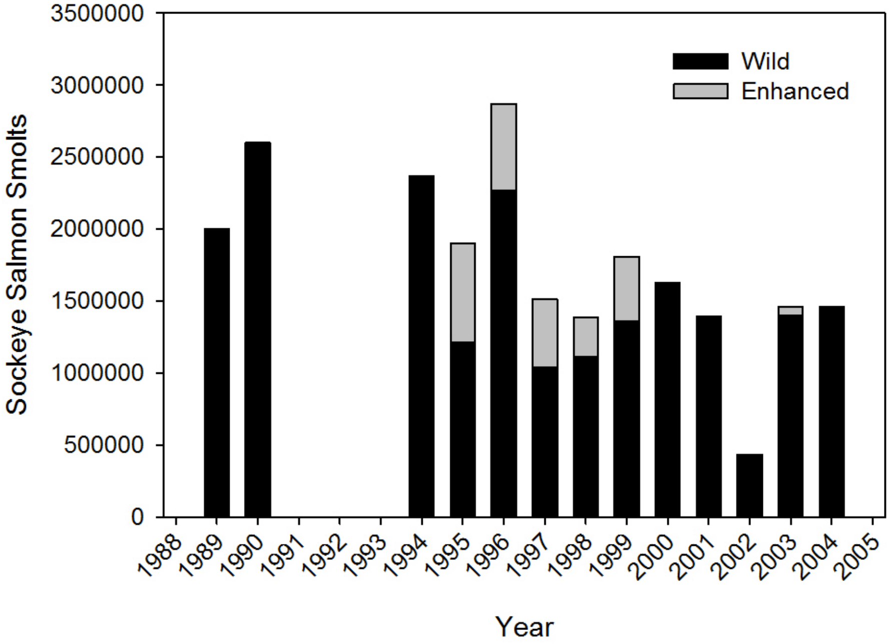

Figure 9: Abundance of sockeye salmon smolts emigrating from Chilkat Lake in the spring estimated from mark-recapture methods.

Adult Sockeye Salmon

Escapement of Chilkat sockeye is currently assessed using dual-frequency identification sonar (DIDSON), which replaced the weir count and mark-recapture methods used prior to 2008 (Eggers et al. 2010). Escapement of sockeye presented in Table A-2 (Appendix A) are based on DIDSON estimates for 2008-2011, mark-recapture estimates or 1995-2007, and corrected weir counts, based on the relationship between mark-recapture and weir count estimates, for 1976-1994. This time series provides the most accurate estimate of sockeye salmon escapement to Chilkat Lake (Eggers et al. 2010). The biological escapement goal for Chilkat sockeye salmon is 70,000 to 150,000 spawners and is determined to achieve maximum sustained yield of the population (Eggers et al. 2010). Escapement has met or exceeded the lower escapement goal in most years between 1975 and 2011 (Figure 10). Escapement was very low in 1984 to 1990, except for a high abundance year in 1988, and did not meet the lower escapement goal in 1985 and 1987. Escapement increased and exceeded the upper escapement goal in 1992 to 1999, followed by a decline from 2000 to 2011. Escapement was below or near the lower escapement goal in 2006-2008, 2010, and 2011. Chilkat sockeye salmon abundance data including total return, harvest, and escapement, as well as juvenile and productivity data, are provided in Table A-2 (Appendix A). While reviewing the data in published reports, some inconsistencies in the escapement and recruitment data were observed (Eggers et al. 2010; Bachman 2011). Therefore, up-to-date and quality-controlled escapement and recruitment data from the ADFG were obtained and used for this report (Steve Heinl, ADFG, personal communication), and these time-series do not exactly match the data previously published.

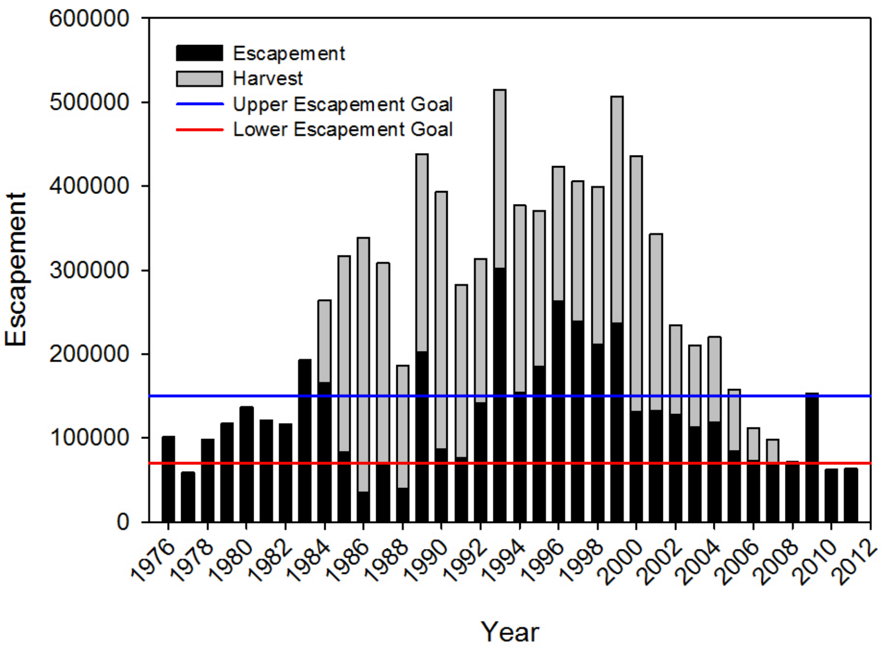

Figure 10: Harvest and escapement compared to upper and lower escapement goals for Chilkat sockeye salmon, 1976-2011 (return years). Harvest data were not available for 1975-1983 and 2008-2011.

Productivity

Productivity of a salmon population is typically assessed by the number of returning adults that are available for harvest or escapement (sometimes called 'recruits') that are produced by spawners in a particular brood year, which is referred to as the returns per spawner. The number of returns per spawner assesses survival of all stages of the life-cycle and their associated environments combined. If the abundance of juveniles (fry or smolts) is estimated for a population, the number of juveniles produced per spawner ('juveniles per spawner') can be calculated to assess survival and productivity in the early part of the life-cycle in freshwater. The number of returning adults produced per juvenile ('returns per juvenile') is a measure of survival and productivity during the marine phase of the life cycle (and the later portion of the freshwater stage, depending on when and where juveniles were enumerated). Comparisons of trends in productivity in the freshwater stage, marine stage, and the total life-cycle can be used to help identify the life-stage and environment that most affects productivity of the population (Peterman and Dorner 2011).

Returns per spawner for Chilkat sockeye was calculated using recruitment and escapement data obtained from the ADFG and provided in Table A-2 (Appendix A). Returns per spawner increased from 1983 to 1988, decreased from 1988 to 1995, and remained below the replacement level (i.e., 1 return per spawner) through 2002. Returns per spawner, on average increased slightly from 2002 to 2006. The majority of Chilkat sockeye salmon return to spawn at 4-6 years of age, and a much smaller percentage of individuals return at 3 or 7 years. Because of the 3-7 year time lag for recruits from a given brood year to return, 2006 was the most recent year of recruitment data available (imputed values based on the average proportion of age classes were used for 6 and 7 year olds for 2005 and 2006 in the ADFG data set).

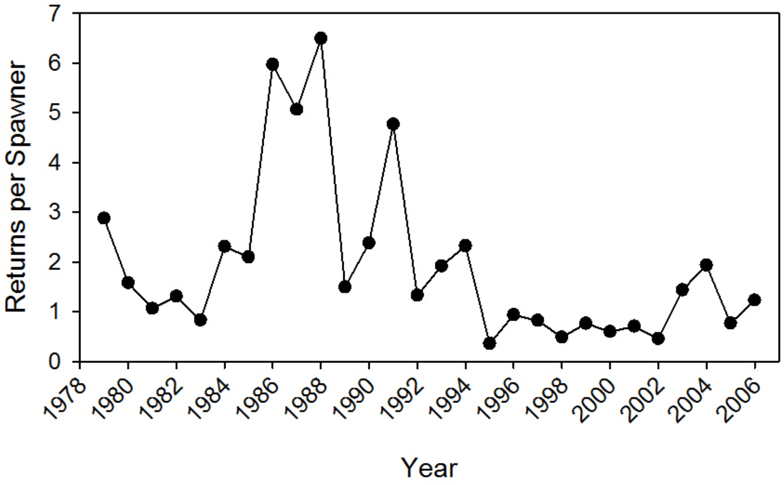

Figure 11: Returns per spawner for Chilkat sockeye salmon, 1979-2006 (brood years).

For Chilkat sockeye, both smolt counts and hydroacoustic estimates of juveniles in the lake were available to calculate the number of juveniles per spawner, which was used as an index of survival during the early freshwater life-stage. Juveniles per spawner for Chilkat sockeye was calculated as the number of juvenile sockeye estimated by hydroacoustic surveys one year after the escapement brood year divided by the escapement that brood year. A one year time lag between the brood year and juvenile abundance was used to assess survival from emergence until the fall after the first summer of growth, assuming most sockeye in the surveys were age-0 fish (although age-1 sockeye that did not migrate to sea would also be included). Smolts per spawner was calculated as the recruitment of smolts (age-1, age-2, and age-3) that were produced by a particular brood year (obtained from Table 7 of Eggers et al. [2010]), divided by the escapement that brood year.

Juveniles per spawner decreased between the late 1980s and 2001 (Figure 12). Smolts per spawner was relatively stable between 1992 and 2001 with only small increases or decreases (Figure 12). Smolts per spawner and juveniles per spawner were both very high for the 1988 brood year because of an exceptionally large production of juveniles and a smaller than average escapement.

The returns per juvenile was calculated using juvenile hydroacoustic estimates, as well as smolt estimates, as a measure of marine and late-freshwater stage survival (Figure 12). Returns per juvenile was calculated as the adult returns produced by a particular brood year divided by the number of juvenile sockeye from hydroacoustic estimates one year after the brood year. Returns per smolt was calculated as the adult returns produced by a particular brood year divided by the number of smolts produced by that brood year (age-1, age-2 and age-3 smolts from Table 7 of Eggers et al. [2010]). Returns per juvenile declined between from 1987-1999, followed by a large increase in 2000-2001 (Figure 12). Returns per smolt declined between the early 1990s and the late 1990s, following a similar trend as returns per juvenile during that time period. Because of the difficulties with hydroacoustic estimates in Chilkat Lake (see Juvenile Sockeye Salmon section above), the smolt data were considered more reliable than juvenile data, and the sharp increase in returns per juvenile in 2000-2001 could be a sampling artefact or due to other unknown causes.

A sharp decline in overall productivity of sockeye salmon occurred in Chilkat Lake starting in 1987. This decline coincided with a decline in smolts per spawner (Figure 12), as well as a decline in the zooplankton population (Section 3.1.3), suggesting that decreased survival during the freshwater phase of the life-cycle played a large part in the decrease in overall productivity between 1987 and 1991. Although returns per juvenile decreased along with overall productivity, returns per smolt did not decrease during this time period. This discrepancy could be explained if juvenile sockeye experienced high mortality during their first winter in the lake, which was after the fall hydroacoustic surveys but before smolt counts during emigration from the lake. Thus, trends in both the early freshwater productivity index and marine/late-freshwater index are consistent with the notion that declines in productivity in 1987-1991 were more related to changes freshwater survival than marine survival.

The continued decline in overall productivity of Chilkat sockeye from 1993-2002 may have been influenced more by a decline in marine survival than freshwater survival because smolts per spawner was stable, but returns per smolt consistently declined over this time period. Trends in productivity and comparisons to other regions and populations of sockeye salmon are discussed in Section 3.2.

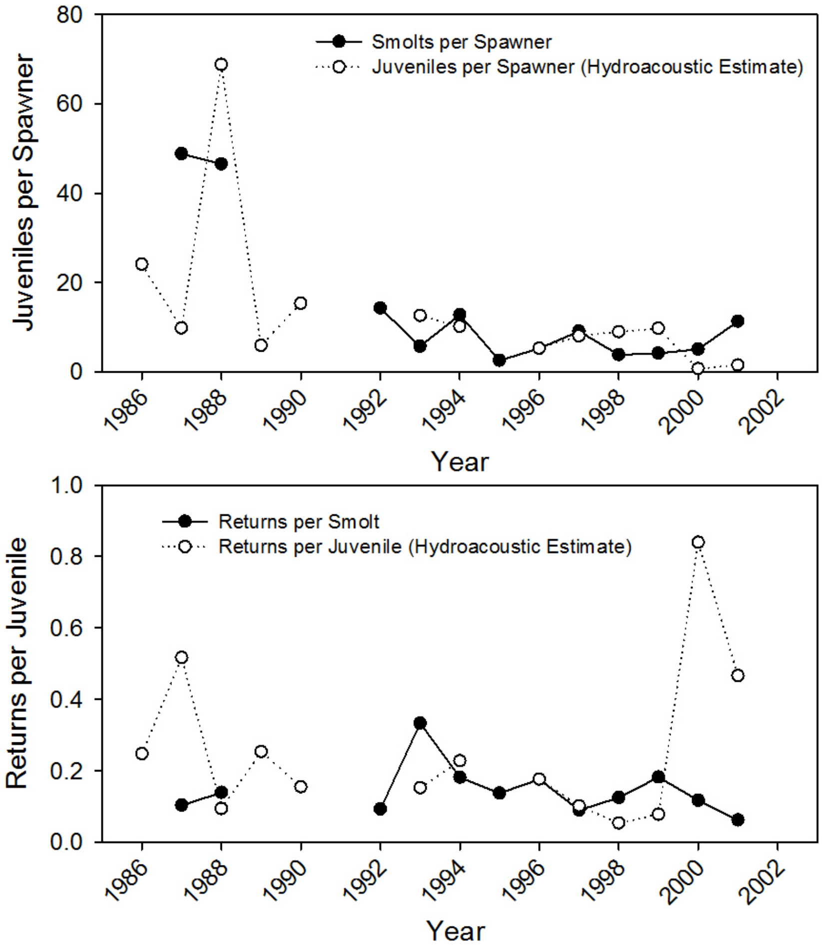

Figure 12: Productivity for different life-cycle stages of Chilkat sockeye salmon, as assessed by the number of juveniles per spawner and the number of returns per juvenile, 1986-2001 (brood years).

Chilkoot Lake

Juvenile Sockeye Salmon

Juvenile sockeye salmon abundance was estimated in Chilkoot Lake from hydro-acoustic surveys coupled with tow-net surveys to estimate species composition in 1987-1991 and 1995-2010 (Bachman 2011) and these data were obtained from the ADFG. Species composition of tow-net samples was dominated by sockeye salmon juveniles, with few stickleback or other fish species in most years (Table 3). Abundance of juvenile sockeye salmon fluctuated between 300,000 and 1,500,000 in most years (Figure 13). Abundance of juveniles decreased in the early 1990s and was low again in 2005-2007. The large decrease in the abundance of juvenile sockeye from 1988-1991 coincided with a large decrease in zooplankton density (Figure A-10, Appendix A). Bachman (2003) previously noted the decrease in juvenile abundance that coincided with a crash in the zooplankton population during the late 1980s and early 1990s. Eggers et al. (2009) suggested that productivity in Chilkoot Lake appeared to be improving compared to the early 1990s, which is supported by the data in

Figure A-10 (Appendix A), although inter-annual variability in both zooplankton and juvenile sockeye abundance was high. For years when both juvenile sockeye salmon and zooplankton data were collected, linear regression was used to test for a relationship between juvenile sockeye abundance and zooplankton abundance in the previous year (because high zooplankton densities may lead to better overwinter survival and greater sockeye abundance the following year). Within the multiple years of data collected, there was not a significant relationship between juvenile sockeye salmon abundance and zooplankton abundance from the previous year (*P*=0.1)

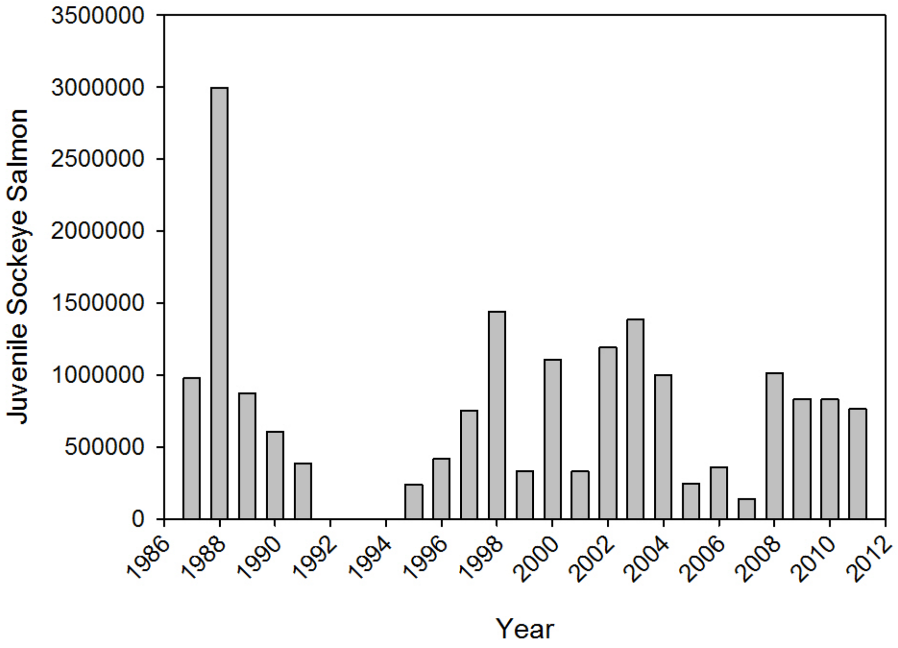

Figure 13: Abundance of juvenile sockeye salmon in Chilkoot Lake estimated from hydroacoustic surveys in the fall.

Table 3: Estimated abundance and species composition of sockeye salmon, stickleback and other fish species from hydroacoustic surveys and tow-net sampling in Chilkoot Lake.

Year	% Species Composition			Numbers of Fish		
	% Sockeye	% Stickleback	% Other	# Sockeye	# Stickleback	# Other
1987	73%	21%	6%	977,516	284,242	83,193
1988	98%	0%	2%	2,993,974	0	72,144
1989	100%	0%	0%	870,608	4,186	0
1990	99%	0%	1%	602,826	0	5,066
1991	81%	19%	0%	384,369	91,035	0
1995	91%	7%	2%	238,250	17,499	5,048
1996	99%	0%	1%	415,749	0	2,403
1997	99%	0%	1%	748,606	0	6,454
1998	99%	0%	1%	1,438,485	0	8,251
1999	94%	4%	2%	330,478	15,278	5,340
2000	93%	0%	7%	1,105,666	0	85,051
2001	48%	38%	15%	330,885	262,426	102,689
2002	100%	0%	0%	1,192,560	0	4,141
2003	n/a	n/a	n/a	1,384,754	n/a	n/a
2004	94%	2%	4%	996,046	21,306	42,612
2005	100%	0%	0%	247,283	0	0
2006	100%	0%	0%	356,957	0	0
2007	100%	0%	0%	140,237	0	0
2008	99%	0%	0%	1,014,655	1,911	3,822
2009	100%	0%	0%	832,991	0	0
2010	100%	0%	0%	830,394	0	0
2011	100%	0%	0%	763,541	0	0
Mean	94%	4%	2%	827,129	33,232	20,296

Adult Sockeye Salmon

Escapement of Chilkoot sockeye is assessed by weir counts. Calibrations of the weir counts to mark-recapture population estimates have been inconsistent; therefore, uncorrected weir counts are used to estimate escapement, although these estimates are likely conservative (Eggers et al. 2009). Escapement (1976-2011) and recruitment data (1979-2006) were obtained from the ADFG and total return data (1980-2010) were obtained from Bachman (2011). Harvest data were obtained from the ADFG (1987-2010) or calculated by the difference between total return and escapement (1980-1986). Chilkoot sockeye salmon abundance data including total return, harvest, and escapement, as well as juvenile and productivity data, are provided in Table A-3 (Appendix A).

The escapement goal for Chilkoot sockeye is 38,000 to 86,000 spawners, as enumerated by weir counts (Eggers et al. 2009). The escapement goal for Chilkoot sockeye is a “sustainable escapement goal”, which aims to conserve a population over a five to ten year period, and is set instead of a “biological escapement goal” in cases where stock-specific abundance data are not available (Carroll 2005). In the case of Chilkoot sockeye, a sustainable escapement goal was set because of uncertainty in escapement based on weir counts

(Eggers et al. 2009). Separate escapement goals were previously set for early and late run-timing groups of Chilkoot sockeye (McPherson 1990; Geiger and McPherson 2004) but the current escapement goal encompasses the entire historical run-timing, because the timing of migration and spawning overlapped between the groups and there was not a sound biological reason to manage the timing groups as 2 separate populations (Eggers et al. 2009).

Escapement exceeded the current escapement goals in almost all years from 1976 to 1991, but was near or less than the lower escapement goal from 1994 to 1999 (Figure 14). Escapements were greater than the lower goal from 2000-2007, less than the lower goal in 2008 and 2009, then greater than the lower goal in 2010. Of years where escapement goals were not met, total returns of sockeye were less than the lower escapement goal in 1994, 1995 and 1999. However, in 2007 and 2008, total returns exceeded the lower escapement goal by a small margin, but harvest resulted in escapement goals not being met.

Productivity

Returns per spawner was calculated for 1979-2006 using escapement and return data obtained from the ADFG. Returns per spawner data indicated a decrease in productivity during the mid-1980s to mid-1990s, increased but variable productivity from 1995-1999, and decreased productivity in 2000-2006 (Figure 15).

Juveniles per spawner for Chilkoot sockeye was calculated as the number of juvenile sockeye estimated by hydroacoustic surveys one year after the brood year divided by the escapement that brood year. A one year time lag between the brood year and juvenile abundance was used to assess survival from emergence until the fall after the first summer of growth, assuming most sockeye in the surveys were age-0 fish (although age-1 sockeye that did not migrate to sea would also be included). Juveniles per spawner was greater, on average, between brood years 1995 and 1999, than in 1986-1994, and 2000-2010 (Figure 16). This was a similar trend to returns per spawner data, for years that both indices were available (i.e., brood years 1986-2003).

Returns per juvenile was calculated as the total adult returns that were spawned in a particular brood year divided by the number of juveniles estimated by hydroacoustic surveys one year after the brood year. Juveniles were enumerated in the fall when individuals that emerged that spring were age-0, and the majority of these fish emigrate to the ocean either the following spring at age-1, or the spring after that at age-2. Therefore, this measure of returns per juvenile assesses not only marine productivity, but also the later stage of freshwater productivity, including the first winter in the lake for age-1 smolts and 2 winters in the lake for age-2 smolts. Returns per juvenile followed similar trends as returns per spawner and juveniles per spawner, with a decrease in productivity from brood years 1986-1990, relatively higher but variable productivity from brood years 1995-2000, and a decrease in productivity after 2000 (Figure 16). However, returns per spawner consistently increased from 2003-2006 whereas juveniles per spawner and overall productivity did not.

The finding that all three indices of productivity followed fairly similar trends over time does not support the idea that a decline in productivity at a particular life-stage was primarily responsible for overall trends in productivity. For example, if juveniles per spawner decreased over time along with decreases in abundance, but returns per juvenile stayed relatively stable over the same time period, it would suggest that some causal factor during the early freshwater life-stage was contributing to declines. This was not the case for Chilkoot sockeye over the time period assessed, as trends in early freshwater productivity, marine productivity (which included the later part of the freshwater stage), and total productivity were similar. Comparisons among productivity in Chilkat, Chilkoot, and other populations of sockeye salmon are discussed in Section 3.2.

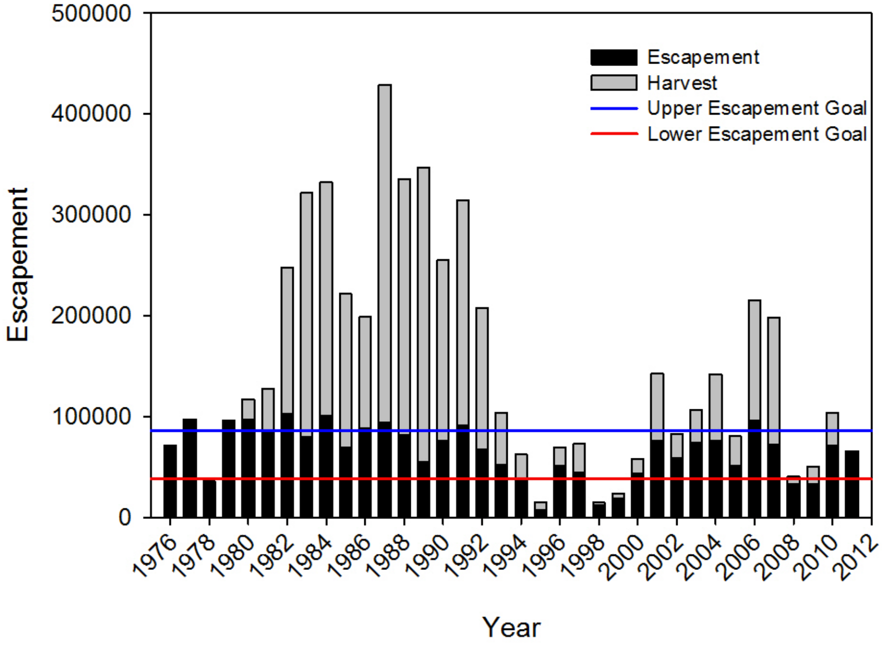

Figure 14: Harvest and escapement compared to upper and lower escapement goals for Chilkoot sockeye salmon, 1976-2011 (return years). Harvest data were not available for 1976-1979 and 2011.

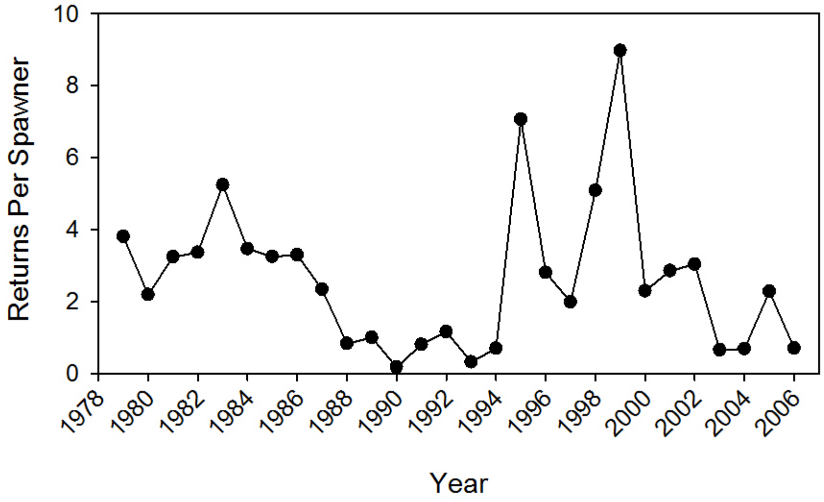

Figure 15: Returns per spawner for Chilkoot sockeye salmon, 1979 to 2006 (brood years).

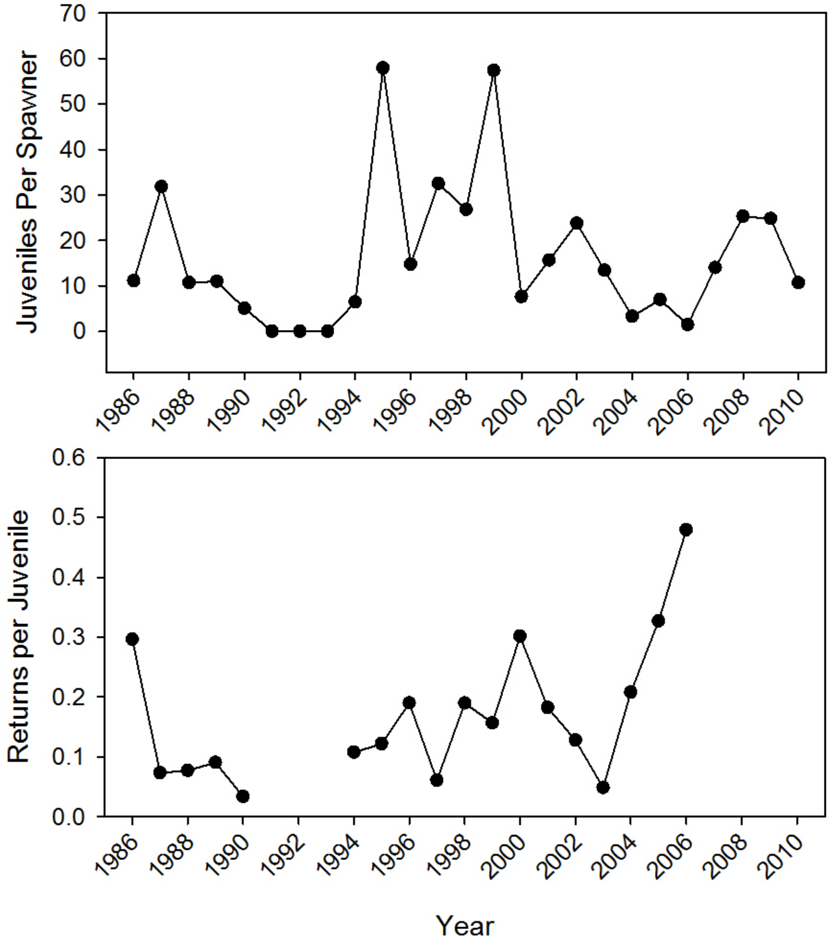

Figure 16: Productivity for different life-cycle stages of Chilkoot sockeye salmon, as assessed by the number of juveniles per spawner and the number of returns per juvenile, 1986-2010 (brood years).

3.2 Factors Affecting the Abundance and Productivity of Sockeye Salmon

Factors potentially contributing to changes in the abundance and productivity of Chilkat and Chilkoot sockeye were reviewed and presented in this section. The list of factors is not comprehensive of all possible contributing factors but reflects the most likely causes of changes in productivity based on the data reviewed in this report, hypotheses presented by other authors for these stocks, and literature about other sockeye stocks that had declines during the same time period. The factors were ranked in terms of their likelihood (unlikely, possible, likely, or very likely) of being a primary factor affecting the productivity of Chilkat or Chilkoot sockeye. In addition, the uncertainty in the classification of their likelihood was ranked as high, medium or low, based on the quantity and quality of the data and literature used to make these judgements. The Cohen Commission, a recent inquiry into the causes of declines in sockeye salmon in the Fraser River, BC, Canada, suggested that combinations of different factors at different life stages were likely responsible for changes in productivity, and these interactions likely vary in complex and often unknown ways across time and stocks (Marmorek et al. 2011). We acknowledge that this is also likely the case for Chilkat and Chilkoot sockeye, where different combinations of factors and their interactions may affect changes in productivity over time. The likelihood and uncertainty of the factors identified are summarized in Table 4.

Changes in ocean conditions and marine survival

Overall productivity of Chilkat sockeye declined sharply starting in 1987 and remained low through 2006 when the most recent recruitment data were available. Based on the data reviewed, productivity declines for Chilkat sockeye in the late 1980s to early 1990s were more likely to be primarily driven by changes in early freshwater survival, whereas subsequent declines and continued low productivity from 1993-2002 were more likely driven by decreases in marine or late-freshwater survival.

For Chilkoot sockeye, trends in early freshwater productivity, marine/late-freshwater productivity, and total productivity were similar. Productivity declined from brood years 1986-1990, was higher in 1994-2000, and then declined after 2000. The very similar patterns of the three indices of productivity suggest that declines in both marine and freshwater survival could have been associated with productivity declines.

As part of the Cohen Commission's investigation into the cause of the declines of Fraser River sockeye salmon, the productivity of salmon populations from the Fraser River and elsewhere on the Pacific coast was compared to assess similarities and differences in trends (Peterman and Dorner 2011). One of the key findings of the report was that most Fraser River populations and many non-Fraser populations, including populations in southeast Alaska, northern British Columbia, and Washington state, showed consistent declines in productivity since the late 1990s, and or since the late 1980s in many cases (Figure A-11, Appendix A). Of particular interest to the present report was that other sockeye populations in southeast Alaska, including McDonald Lake, Redoubt Lake and Chilkat Lake had similar, though not identical, declines in productivity. Because of the consistent declines in productivity over the same time period in many regions of the Pacific coast, Peterman and Dorner (2011) suggested that a shared causal mechanism may exist across a large spatial extent. Although some shared large scale factor may be related to productivity declines in Alaska, British Columbia and Washington, Peterman and Dorner (2011) also pointed out that local factors also were likely contributing to productivity trends, which explains variation in productivity observed during the general declines since the late 1980s. Indeed, the difference in productivity trends between Chilkat and Chilkoot sockeye suggests that some unknown local factors likely influenced productivity differently between these 2four stocks. Chilkat sockeye had a consistent decline in productivity since the late 1980s whereas the productivity of Chilkoot sockeye declined staring in the late 1980s, but increased in the mid-1990s to 2000, before continued decline after that.

Our assessment of different productivity indices and Peterman and Dorner's (2011) study showing the large spatial extent of declines in sockeye productivity provide some support for the possibility that marine survival is an important factor in the declines of Chilkat and Chilkoot sockeye. However, a longer time series and more reliable productivity data (based on more accurate juvenile assessments) would be necessary to strongly support the conclusion that marine survival is primary driver of declines in Chilkat and Chilkoot sockeye. To our knowledge, no information is available about specific causes of declines in marine survival for Chilkat and Chilkoot sockeye.

Some information is available about the marine survival of other stocks of sockeye salmon and their correlation with oceanographic conditions. Peterman and Dorner (2011) found that for most stocks (7 of 9) of Fraser River sockeye for which juvenile abundances were available, post-juvenile (late freshwater and marine phase) survival decreased consistently with declines in overall productivity, whereas only one stock had declines in productivity in the early freshwater stage. Marmorek et al. (2011) concluded that marine conditions and climate change effects on early coastal and ocean migration were both "likely" contributors to the decline of Fraser sockeye productivity since the 1980s. A persistent shift in oceanographic conditions in the North Pacific Ocean began in 1992, including increased sea surface temperature and salinity, which are factors that have been associated with lower productivity for Fraser sockeye stocks (McKinell et al. 2011). The productivity of many Fraser sockeye stocks recovered for broods that reared in the ocean in the winter of 1998/1999, when there were la Ninã climate conditions that are often associated with greater marine survival for many sockeye stocks (McKinell et al. 2011). The winter of 1998/1999 corresponds with the 1995 brood year for age-2 smolts, and overall and marine productivity of the 1995 brood year for Chilkoot sockeye was substantial higher than previous years. Thus, it is plausible that the recovery of productivity of Chilkoot sockeye starting in 1995 was related to marine survival and improved ocean conditions starting in the 1998/1999 la Ninã. The causes of the rapid increase in returns per juvenile of Chilkoot sockeye from 2003-2006 are unknown and this trend was not also widely observed in other stocks reported in Peterman and Dorner (2011).

The degree to which studies of linkages between oceanographic conditions and marine survival of Fraser River stocks are relevant to Chilkat and Chilkoot sockeye is not known. However, in general, sockeye salmon from Washington, British Columbia, and Alaska are known to share habitat in the North Pacific Ocean and encounter similar oceanographic conditions (Marmorek et al. 2011). The timing of changes in Chilkat and Chilkoot sockeye productivity roughly correspond to changes in oceanographic conditions that have been linked to lower marine productivity in Fraser sockeye. That is, a general decline in productivity occurred from the early late 1980s to the early 2000s (Chilkat, Chilkoot and Fraser), which has been linked to changes in oceanographic conditions (Fraser River stocks), and productivity recovered in the mid-1990s for some populations (Chilkoot and some Fraser stocks).

Based on our assessment of productivity indices and similarities to Fraser River and other stocks, **marine survival is ranked as a factor *likely* to have affected the productivity of Chilkat sockeye salmon.**

For Chilkoot sockeye, both marine and freshwater productivity fluctuated with overall productivity, and the trend in overall productivity differed somewhat from the general trend observed in many stocks of sockeye salmon across a large spatial extent. The increase in productivity in the mid-1990s was also observed in other sockeye stocks, which may be linked to large-scale climate patterns. Therefore, **marine survival is ranked as a factor *likely* to have affected the productivity of Chilkoot sockeye salmon.**

Estimates of juvenile abundance were available for both Chilkat and Chilkoot sockeye which allowed comparison of productivity during the early-freshwater and marine life-stages to overall productivity. However, the time-series were relatively short and the reliability of hydroacoustic estimates has been questioned. Correlations between oceanographic conditions and productivity may be similar to those identified for Fraser sockeye but have not been specifically assessed for Chilkat or Chilkoot stocks. For these reasons, **uncertainty in the likelihood of marine conditions affecting productivity is ranked as medium for both Chilkat and Chilkoot sockeye.**

Lake conditions and freshwater productivity

In Chilkat Lake there was evidence of changes in freshwater rearing conditions and sockeye salmon productivity over time. In 1987-1991 the decline in the zooplankton abundance corresponded with a decline in sockeye productivity, which could be related to the declining food source for sockeye. The change in community composition and severe decline in abundance of zooplankton (mainly copepods) in 1996 may have been caused by the large number of sockeye juveniles in the lake, partly from stocking of hatchery fry during 1994-1997, which suggests top-down (predatory) influences on the zooplankton population. Juveniles per spawner and overall productivity subsequently declined during the mid-nineties (Figure 11 and Figure 12). Trends in nutrients and chlorophyll *a* did not correlate with sockeye salmon productivity or abundance from 1994-2003, when water quality data was last collected in Chilkat Lake. Overall, the data reviewed suggest that lake conditions were likely related to declines in productivity during the late 1980s and early 1990s, and possibly during a brief period in the mid-nineties after fry stocking. However, lake conditions after the mid-nineties to present do not seem to correspond to productivity trends. **Lake conditions and freshwater productivity are ranked as a factor possible to have affected the productivity of Chilkat sockeye salmon. The uncertainty in this ranking was medium.**

The decline in sockeye salmon productivity from 1987 to 1991 was likely related to the sharp decline in zooplankton abundance in Chilkoot Lake, as has been suggested by others (Barto 1996). Nutrients also decreased, on average, during this time period, which provides additional evidence that lake conditions may have affected sockeye productivity during the late 1980s and early 1990s. Trends in early-freshwater, late-freshwater/marine, and overall productivity followed similar trends from the 1990s-2002, suggesting that both freshwater and marine survival may have affected overall productivity. Trends in zooplankton abundance did not correlate with juvenile abundance or productivity from the 1990s-2002 and water quality data were only collected in a few years during this time, which increases the uncertainty about the influence of lake conditions on productivity. **Lake conditions and freshwater productivity are ranked as a factor possible to have affected the productivity of Chilkoot sockeye salmon. The uncertainty in this ranking was high because of limited water quality data.**

Glacial silt and flow reversals

One particular factor that can affect lake productivity is the quantity of glacial silt in the water, which affects light penetration and primary productivity. In Chilkat Lake, flow reversal occurs when lake levels drop below the level of Tisirku River, causing the river to flow into the lake. Flow reversal can cause a decrease in light penetration and reduced euphotic zone depth in Chilkat Lake due to the high concentration of glacial silt in the Tisirku River water (Barto 1996). There was no significant change in turbidity in Chilkat Lake from 1987-2003, and changes in zooplankton or sockeye did not correspond to changes in turbidity. Koenings and Edmundson (1989) suggested that additions of silt from flow reversals were unlikely to drastically elevate turbidity in Chilkat Lake and may result in a long-term benefit to production (because of phosphorus additions). **Therefore, glacial silt from flow reversals was ranked as a factor unlikely to have affected the productivity of Chilkat sockeye salmon. The uncertainty in this ranking was low.**

Chilkoot Lake is a glacial lake and the quantity of silt from glacial run-off may have an influence on lake productivity. Summers with hotter air temperatures result in increased glacial run-off into Chilkoot Lake, resulting in increased turbidity, decreased light penetration and decreased euphotic volume. Some authors have hypothesized that inputs of glacial silt to Chilkoot Lake have increased since the 1990s, causing reduced light penetration and primary productivity, and reduced sockeye salmon productivity through bottom-up effects (Riffe 2006; Eggers et al. 2009; Bachman 2011). Eggers et al. (2009) noted that lower zooplankton densities from 1988-1998 corresponded with a period of slightly higher average air temperatures in June and July (their Figure 5). However, there did not appear to be a consistent strong relationship between zooplankton and air temperature, as both variables increased together from 2001-2004. Measurements of euphotic zone depth and turbidity were only available for 1987-1991 and 2001-2003.

EZD data for Chilkoot Lake were available from 1987-1991 and 2001-2011. Trends in EZD did not appear to correspond well with juvenile sockeye abundance, based on visual assessment, which does not support the idea that glacial silt was a primary driver of sockeye productivity changes. For instance, EZD was greatest in 2006 (Figure 3), but juvenile sockeye abundances were some of the lowest on record in 2006 and 2007 (Figure 13). After 2006, EZD decreased drastically and was very low in 2008-2011 but these years did not correspond with a decrease in juvenile sockeye salmon abundance compared to the previous 10 years (Figure 13). Because EZD, turbidity or warm temperatures (a surrogate for glacial melt) appeared to correlate with lake productivity in some years but not in others, and limited data were available to test the glacial silt hypothesis, **glacial melt and siltation were ranked as factors <u>possible</u> to be primary factors influencing the productivity of Chilkoot sockeye salmon, and the uncertainty was ranked as <u>high</u>.**

Stickleback

Three-spine stickleback compete with juvenile sockeye salmon for food and large populations of stickleback can reduce sockeye salmon growth rates and survival (O’Neill 1986; Hyatt et al. 2004). Barto (1996) reported that there was overlap in the diets of stickleback and juvenile sockeye in Chilkat Lake. Although stickleback and sockeye salmon compete for resources to their mutual disadvantage, pelagic stickleback may be displaced from limnetic areas by large numbers of sockeye juveniles (Barto 1996 and references therein).

Chilkat Lake has a large population of stickleback. Stickleback comprised 10% to 97% of the catch during tow-net surveys from 1987-2002, with a mean of 49%. There was no clear trend over time in percent of composition of stickleback. However, percent composition of stickleback was highest and dominated the catch in the last 2 years sampled (97% in 2001 and 94% in 2002; Table 2). The large catches of stickleback are partly due to their abundance but also likely related to sampling bias because stickleback are more easily caught by tow-nets and juvenile sockeye salmon may be more able to avoid capture in Chilkat Lake (R. Bachman, ADFG, personal communication). The population of stickleback in Chilkoot Lake is relatively smaller, comprising an average of 4% of the catch in tow-net surveys (Table 3). The percentage of stickleback in these surveys has not appeared to change over time. However, it is not known whether or not the percent composition in tow-net surveys is a good indicator of overall abundance of stickleback over time in Chilkoot Lake.

There is limited information about the abundance of stickleback or their influence on sockeye salmon. Based on percent composition data and stickleback-sockeye interactions in other lakes, **stickleback are ranked as a factor <u>possible</u> to have affected the productivity of Chilkat sockeye salmon. The uncertainty in this ranking was <u>medium.</u>** Because of the relatively small population of stickleback in Chilkoot Lake, **stickleback are ranked as a factor <u>unlikely</u> to have affected the productivity of Chilkoot sockeye salmon. The uncertainty in this ranking was <u>low.</u>**

Harvest and Fisheries Management

Chilkat and Chilkoot sockeye salmon are harvested primarily in the drift gill-net fishery in Lynn Canal, as purse seine fisheries in the Icy Strait and northern Chatham Strait are closed during most of the sockeye salmon season (Eggers et al. 2009, 2010). However, some Chilkat and Chilkoot sockeye salmon are caught before they reach Lynn Canal by the purse seine fishery that targets primarily pink salmon in the Icy Strait and surrounding areas. The total number of Chilkat and Chilkoot sockeye salmon caught by purse seine fisheries has not been accurately monitored in the past and is unknown. For instance, in 2011 the purse seine fishery in Hawk Inlet in District 12 caught 20,240 wild sockeye salmon of which 13% were of Chilkoot Lake origin and 17% were of Chilkat Lake origin, based on scale pattern analysis (Davidson et al. 2012). Scale pattern analysis to discern stocks is effective in the Lynn Canal but likely inaccurate for fish caught in the Icy Strait (R. Bachman, ADFG, personal communication), such that catch composition of Chilkat and Chilkoot stocks in the Icy Strait was referred to as “qualitative”. The purse seine fishery in the Homeshore area (#114-25) of District 14 in the Icy Strait caught 11,000 sockeye salmon in 2011 but stock composition was not assessed so it is not known what proportion were from the Chilkat or Chilkoot populations. Purse seine fishery openings in Districts 12 and 14 are often controversial because the northern seine management plan intends to restrict by-catch of sockeye salmon, and the perception by the drift gill-net fleet in upper Lynn Canal is that many of the sockeye caught in Districts 12 and 14 could be from Chilkat or Chilkoot populations (Davidson et al. 2012). Purse seine fisheries for pink salmon in the Icy Strait and northern Chatham Strait are highly constrained by efforts to reduce sockeye salmon by-catch, and consequently there are often few purse seine openings in certain sections of these districts even in years with very large abundances of pink salmon. Although some Chilkat and Chilkoot sockeye salmon are caught by purse seine fisheries, escapement goals for these stocks have been met in most years, and therefore purse seine by-catch of sockeye salmon is primarily an issue of harvest allocation among gear types, and is unlikely to have driven long-term trends in abundance. To address the uncertainly about the number of Chilkat and Chilkoot sockeye salmon caught by purse seine fisheries, the ADFG plans to conduct sampling for genetic stock identification in Districts 12 and 14 in 2013 (R. Bachman, ADFG, personal communication).

Escapement for Chilkat sockeye salmon is currently estimated using DIDSON, and stock-recruit analyses were used to set a biological escapement goal, meaning that the goal is a scientifically defendable estimate intended to produce maximum sustained yield (MSY) for the stock (Eggers et al. 2010). Estimates of escapement of Chilkoot sockeye salmon based on weir counts are less reliable (likely conservative); therefore a sustainable escapement goal intended to produce 90% of MSY was set to account for the uncertainty (Eggers et al. 2009). Escapement goals were met for Chilkat and Chilkoot sockeye in most years since the mid 1970s, but there were a few years when goals were not attained for both stocks (see Section 3.1.4). Harvest of Chilkat and Chilkoot sockeye salmon in the drift gill-net fishery is quantified using scale pattern analysis to estimate the percent composition of the catch for each stock (Eggers et al. 2009, 2010). Overall, the methods used for stock assessment and harvest management appear to be adequate to monitor returns and manage harvest. Our review of the data did not identify any serious deficiencies in the management system or evidence that over-harvest was a primary driver of productivity declines. Consequently, harvest and fisheries management are ranked **as factors unlikely to have affected the productivity of Chilkat and Chilkoot sockeye salmon. The uncertainty in this ranking was low.**

Table 4: Summary of potential factors contributing to changes in abundance and productivity of Chilkat and Chilkoot sockeye, their likelihood, and the uncertainty associated with these judgements.

Factor	Chilkat		Chilkoot	
	Likelihood	**Uncertainty**	**Likelihood**	**Uncertainty**
Marine conditions and survival	Likely	Medium	Likely	Medium
Lake conditions and freshwater productivity	Possible	Medium	Possible	High
Glacial Silt	Unlikely	Low	Possible	High
Stickleback	Possible	Medium	Unlikely	Low
Harvest and fisheries management	Unlikely	Low	Unlikely	Low

3.3 Data Gaps and Sufficiency of Existing Information

Data collected to monitor sockeye salmon and their habitats in Chilkat and Chilkoot lakes included water quality, indices of primary and secondary productivity, and abundance of juvenile and adult sockeye salmon. However, for some of these variables, the data are thought to be inaccurate (e.g., Chilkat juvenile sockeye abundance, Chilkoot sockeye escapement), data were not collected in some years, or monitoring programs have stopped being conducted (e.g., water quality). These deficiencies make it difficult for managers to identify what life-stages and habitats may be limiting production of sockeye salmon, and the specific factors that may be reducing survival. The most important data gaps identified in this review were:

- Failure to collect water quality data since the 2003 means it is no longer possible to monitor nutrient levels, turbidity, and chlorophyll *a*, which are important indicators of general productivity and the sockeye rearing capacity of the lake.
- The abundance of juvenile sockeye salmon in Chilkat Lake has not been assessed since 2002. It is important to monitor the abundance of juveniles (rearing fry or emigrating smolts) in order to identify the portion of the life-cycle where productivity declines occur so that management efforts can focus on the appropriate life-stage and environment. One of the key recommendations of Peterman and Dorner's (2011) assessment of Fraser sockeye salmon productivity was to collect high-quality, long-term juvenile data for as many stocks on the Pacific coast as possible, while recognizing that juvenile abundance is often logistically difficult to monitor and many monitoring programs stopped in the last 10 years due to budgetary constraints.
- Chilkat Lake also has the issue of high densities of stickleback. Introduction of fry to "outcompete" stickleback in the past has apparently led to a decline in the copepod zooplankton population and an overall decrease in productivity, as measured by juvenile production. The assumption that lake productivity is not limiting should be re-examined, and, possibly, alternative methods to decreasing stickleback could be considered (see Section 3.4). Therefore, background information and the feasibility of potential management options are also information gaps. Nutrient levels of phosphorus and nitrogen do not appear to be depressed compared to historical levels, so are unlikely a factor for decreased production.

- Changes in marine conditions and survival were ranked as factors likely and possible to have affected productivity of Chilkat and Chilkoot sockeye salmon, respectively. Our literature review did not reveal any information about the ecology of Chilkat or Chilkoot sockeye during the marine phase of the life-cycle. Information about the spatial distribution, migration routes, and survival rates during different phases of the marine life-stage is necessary to understand productivity of sockeye in the marine environment. The problem of very limited information about the sockeye salmon in the marine environment is not unique to Chilkat and Chilkoot stocks, and has also been identified as a key information gap for Fraser River and other stocks (Peterman and Dorner 2011). Because there are no management options to address marine productivity, other than regulation of escapements to meet freshwater productivity demands, understanding marine productivity issues are of most value to help understanding of how much of the adult return variability is are related to management of harvests and freshwater habitat.

3.4 Management Options to Help Sockeye Recovery

Published literature was reviewed to identify potential management options that have been implemented elsewhere to help the recovery of sockeye salmon populations. Where applicable, the success of these management options for other populations, as well as the factors that influence the effectiveness, are discussed. Any of the management options discussed would require a significant amount of research to assess their feasibility for Chilkat or Chilkoot sockeye, as well as on-going effectiveness monitoring programs.

Hatchery Enhancement

Modern hatchery enhancement of sockeye populations has been conducted throughout Alaska since the 1960s and 1970s (Heard 2003). Because hatchery and wild origin salmon are subjected to the same marine conditions, hatchery enhancement is typically aimed at improving survival during the early fresh-water stage, relative to wild-reared fish (Heard 2003). Previous enhancement of sockeye salmon in Chilkat Lake included stocking fry in 1994-1997 and 2001 and incubation boxes seeded with sockeye salmon eggs in 1989-1998 and in 2003. In the years following fry stocking, managers observed decreased smolt size, increased smolt age (greater proportion of age 2 and age-3 smolts) and a slight decline in the number of hatchery and wild smolts emigrating from Chilkat Lake (Eggers et al. 2010). In addition, the timing of fry stocking also corresponded roughly with a change in community composition and sharp decline in zooplankton in 1996. Based on this information and stock-recruit analyses, Eggers et al. (2010) concluded that fry stocking had depressed wild smolt production and that production of Chilkat sockeye was likely limited by the rearing capacity of the lake. This was in contrast to the previous notion that Chilkat sockeye were spawning-area limited and that Chilkat Lake had the capacity to rear more sockeye juveniles than were produced naturally (Eggers et al. 2010), which led to the implementation of the stocking program in the 1990s. Based on the most recent assessment of the effects of fry stocking, hatchery enhancement is unlikely to be a recommended management option for Chilkat sockeye salmon.

The Chilkoot sockeye salmon stock has no history of hatchery enhancement. Our literature search did not reveal any recent studies assessing the carrying capacity of Chilkoot Lake for rearing juvenile sockeye salmon. However, in recent years fisheries managers have directed harvests for Chilkoot sockeye in years of low zooplankton abundance, to avoid potentially exceeding the carrying capacity of the lake (Eggers et al. 2009). In addition, the policy in southeast Alaska is not to have hatcheries in systems with large, wild runs of salmon to avoid potential hatchery interactions with wild stocks (Heard 2011). Hatchery enhancement of Chilkoot sockeye salmon is not a likely to be a recommended management option, although there is considerable uncertainty because of limited recent information about the lake carrying capacity.

Lake Fertilization

Fertilization of sockeye salmon nursery lakes by the addition of nutrients has been used as a management strategy in many lakes in British Columbia and Alaska. The premise behind fertilization programs was that many lakes had reduced inputs of carcass-derived nutrients from salmon because of the removal of salmon by the commercial fishery, which resulted in lower productivity and carrying capacity in the nursery lake (Hyatt et al. 2004). If a lake is limited by nutrient availability (“bottom-up control”), then the addition of nutrients can increase primary productivity (algal production), and in turn, secondary productivity (zooplankton), and the carrying capacity for juvenile sockeye salmon. A summary of Alaskan sockeye salmon nursery lake fertilization programs indicated consistent increases in primary productivity that often, but not always, resulted in increases in secondary productivity and sockeye salmon productivity (Edmundson et al. 1999). A review of sockeye lake fertilization in British Columbia and Alaska found that all fertilization programs resulted in greater primary and secondary productivity, and in nearly all cases this was associated with greater smolt size and biomass of juvenile sockeye salmon (Hyatt et al. 2004). The review also indicated that fertilization rarely results in undesirable outcomes, such as blooms of blue-green algae or diatoms, or limited benefits to sockeye salmon because of interactions or competition with mysids (large invertebrate planktivores) or stickleback (Hyatt et al. 2004). The risk of large blooms of blue-green algae or diatoms that have occurred in some fertilized lakes can typically be managed and avoided by in-season monitoring of the N:P ratio and adjusting fertilizer inputs accordingly. Large populations of stickleback that compete with sockeye salmon for food resources can limit the effectiveness of energy transfer in the food web and reduce the benefits of fertilization. For example, Long Lake in British Columbia developed such a large population of stickleback that juvenile sockeye growth rates stopped responding positively to fertilization (Hyatt et al. 2004). Although the benefits achieved through nutrient additions vary, none of the fertilization programs in British Columbia have resulted in any harmful effects. Whether or not fertilization results in increases in adult returns is variable and difficult to assess, because of the large influence and variability of marine survival.

In order to assess the feasibility and potential effectiveness of fertilization of Chilkat and Chilkoot lakes, collection of limnology data, including water quality and primary production, for several years (at minimum) would be required, as these data have not been monitored since 2004. The previous data collected from these lakes indicates that phosphorus levels are not low compared to other sockeye systems in southeast Alaska. The benefits of fertilization would need detailed cost-benefit investigations to determine if such a program is warranted.

Biocontrol of Stickleback

Stickleback were ranked as a factor possible to have affected productivity of Chilkat sockeye salmon. Three-spine stickleback are a native fish species in Chilkat Lake and make up a large portion of the limnetic fish population sampled in tow-net surveys. Stickleback are known to compete with juvenile sockeye and reduce the bottom-up benefits of increases in primary productivity to sockeye. On the other hand, several Alaskan lakes (Hugh Smith, Packers, Karluk and McDonald lakes) have had large increases in juvenile sockeye populations in response to large escapements or nutrient enrichment, despite the presence of large populations of stickleback (Barto 1996). Whether the large population of stickleback is an important factor limiting Chilkat sockeye remains uncertain. One solution that has been used to address declining sockeye salmon populations in the presence of large stickleback populations is biocontrol by introducing stickleback predators. Sterilized 25-cm cutthroat trout (*Oncorhychus clarki)* were introduced into Walheach Lake, British Columbia, to increase predation on stickleback and reduce the effects of interactions between kokanee (landlocked sockeye salmon) and stickleback (Hyatt et al. 2004). Stickleback abundance in Walheach Lake increased five-fold after nutrient enrichment, but decreased by 96%, in a part due to predation, after stocking of cutthroat trout (Perrin et al. 2006). Chilkat Lake already has a large population of cutthroat trout (R. Bachman, ADFG, personal communication) and the potential effectiveness of stocking additional cutthroat trout as stickleback predators is unknown. A considerable amount of background information and feasibility studies would be required to determine whether stickleback are limiting sockeye production, and whether biocontrol might be an effective management solution in Chilkat Lake. A food habits study and a detailed sampling program of abundance of both juvenile sockeye and stickleback would most likely be required, along with the determination of policy constraints on introducing or enhancing abundance of potential predators. Stickleback make up a small portion of the limnetic catch in Chilkoot Lake and are unlikely to be an important factor influencing sockeye salmon productivity.

3.5 Summary and Response to Haines Borough Queries

Haines Borough requested that the following five objectives (listed below in bold text) be addressed in this report. Our responses to these issues are given below (in regular text).

1) **Review current and past Alaska Department of Fish & Game (ADFG) data to assess the underlying cause of declining Sockeye salmon stocks returning to both Chilkoot Lake and Chilkat Lake, including low escapement, poor lake condition, and interception.**

   This objective has been addressed through the data review in Section 3.0 and the discussion of underlying causes of declines in Section 3.2.

2) **Determine whether a historic level of production can be reached once again given current lake conditions.**

   Because historical levels of production are based on a combination of marine survival and freshwater survival, current lake conditions are only some of the potential factors that influence observed adult returns. The productivity trends identified in the existing data have high uncertainty because of data limitations, but certainly are reversible, both by natural changes and lake rehabilitation programs. Unlike many lake systems, the available data do not provide clarity as to the cause of the decline, possibly because there may have been multiple factors that change over time and limited data. Continued collection of data and possibly short term interventions using rehabilitation strategies, such as those identified here, may provide clarity and assist in determining if historic production can be restored cost effectively.

3) **Determine whether current available data is sufficient for accurate analysis and, if not, then what data is needed for this and future studies of both systems.**

   The sufficiency of existing data and important data gaps are discussed in Section 3.3.

4) **Assess the benefits of genetic testing in Icy Straits as opposed to current scale sampling to determine percentage of Sockeye salmon bound for Lynn Canal.**

Based on the previous review, the data do not suggest that escapements have been a factor in changing productivity levels of the fishery. The historical level of sampling of productivity within the lakes suggests mechanisms related to in-lake processes may be a significant factor and these estimates are independent of development of precise return per spawner estimates for each of the lakes, the primary benefit of achieving higher precision in stock identification of the harvests. The comparison of productivity changes among lakes in the region also suggests overall return rates are generally highly related to marine survival, which is common over multiple clear water sockeye lakes in southeast Alaska. As with freshwater productivity estimates, potential biases in stock identification would only have minor influences on the estimates of marine survival. Although precise estimates of returns are always beneficial, and may be achieved by genetic analysis of the catch, it is unlikely that these data would provide any improved insight as to the causes of decline in productivity of Chilkat and Chilkoot lakes. The current scale pattern analysis in Lynn Canal is sufficient to reach the conclusions identified in this report, as expected improvements with more precise methods would not change any conclusions. Genetic stock identification to determine stock composition of purse seine catches in the Icy Strait is planned for 2013 and will help improve fisheries management of Chilkat and Chilkoot sockeye salmon.

5) **Provide alternative fishery management plan amendments to mitigate declining fish stocks.**

Management options are discussed in Section 3.4.

3.6 Conclusion

The causes of declines in productivity in Chilkat and Chilkoot sockeye are likely complex and may be changing over time. Here we have identified some of the most likely factors that may been influencing the productivity of these sockeye stocks, based on review of available limnological and stock assessment information, and published literature. There does not seem to be any evidence that escapement levels have been inadequate or that harvest policies have adversely affected the productivity of the systems. However, we have not examined in detail, the information on harvest rates of local stocks among areas, but only the relationship of productivity of the lakes to published escapement levels. Much of the variation in returns to these systems parallels other sockeye salmon lakes in southeast Alaska, particularly the returns to Chilkat Lake, suggesting weather in the marine environment that is associated with climatic cycles is likely a major factor in recent declines in abundance. However, some in-lake issues are clearly identified, such as the precipitous decline in copepods, which may be related to stocking levels and stickleback competition. The information gaps and limitations of existing data that were identified in this report represent the key research needs required if stakeholders or managers wish to reduce the uncertainty about the factors influencing the productivity of Chilkat and Chilkoot sockeye, and assess the feasibility of different management options aimed at helping stocks recover.

GOLDER ASSOCIATES LTD.

ORIGINAL SIGNED

ORIGINAL SIGNED

Dana Schmidt, Ph.D., R.P.Bio.
Senior Fisheries Biologist, Limnologist

David Roscoe, M.Sc.
Fisheries Biologist

DR/DS/cmc

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APPENDIX A

Supplementary Data

Table A-1: Summary of sockeye salmon enhancement in Chilkat Lake, including the number of fry stocked and % of emigrating smolts that were of enhanced (hatchery) origin. Data are from Eggers et al. (2010).

Year	Fry stocked	Total Smolt Outmigration	Wild Smolts	Enhanced Smolts	% Enhanced
1989	0	2,000,000	2,000,000	0	0
1990	0	2,600,000	2,600,000	0	0
1994	4,400,000	2,367,891	2,367,891	0	0
1995	2,393,558	1,897,413	1,210,977	686,436	36.17747
1996	2,691,311	2,869,160	2,269,741	599,419	20.89179
1997	2,806,858	1,515,859	1,039,634	476,225	31.41618
1998	0	1,386,118	1,115,700	270,418	19.50902
1999	0	1,809,273	1,362,342	446,931	24.70224
2000	0	1,629,883	1,629,883	0	0
2001	2,698,874	1,398,802	1,389,802	0	0
2002	0	434,411	432,608	1,803	0.415045
2003	0	1,458,025	1,401,462	56,563	3.879426
2004	0	1,457,990	1,457,990	0	0

Table A-2: Chilkat sockeye salmon abundance data.

Year	Total Returns[1]	Harvest[2]	Escapement[3]	Recruits[3]	R/S[4]	Smolts[5]	Juveniles[6]
1976			101,000				
1977			59,000				
1978			98,000				
1979			117,000	336,486	2.88		
1980			137,000	216,625	1.58		
1981			121,000	128,422	1.06		
1982			116,000	151,581	1.31		
1983			193,000	160,303	0.83		
1984	264,231	98,231	166,000	383,865	2.31		
1985	316,598	233,598	83,000	174,023	2.10		
1986	338,728	303,728	35,000	208,890	5.97		
1987	308,430	238,430	70,000	354,476	5.06		842,710
1988	186,466	146,466	40,000	259,644	6.49		685,972
1989	437,683	235,683	202,000	301,752	1.49	2,000,000	2,751,343
1990	393,195	306,195	87,000	207,063	2.38	2,600,000	1,191,612
1991	282,775	206,775	76,000	362,554	4.77		1,335,991
1992	312,865	171,865	141,000	186,924	1.33		
1993	514,817	212,817	302,000	578,900	1.92		
1994	377,030	223,030	154,000	357,691	2.32	2,367,891	3,802,308
1995	370,608	185,608	185,000	65,907	0.36	1,210,977	1,570,389
1996	422,872	159,872	263,000	245,454	0.93	2,269,741	
1997	405,603	166,603	239,000	196,218	0.82	1,039,634	1,388,891
1998	399,503	188,503	211,000	101,667	0.48	1,115,700	1,927,203
1999	506,712	270,712	236,000	179,821	0.76	1,362,342	1,893,717
2000	435,672	304,672	131,000	78,271	0.60	1,629,883	2,296,800
2001	343,283	211,283	132,000	92,967	0.70	1,389,802	93,290
2002	234,239	106,239	128,000	58,554	0.46	432,608	199,478
2003	210,501	97,501	113,000	162,197	1.44	1,401,462	
2004	220,346	101,346	119,000	230,090	1.93	1,457,990	
2005	158,042	74,042	84,000	64,475	0.77		
2006	111,991	38,991	73,000	89,734	1.23		
2007	98,305	30,305	68,000				
2008			71,735				
2009			153,033				
2010			61,906				
2011			63,339				

Notes:

1. Calculated as escapement plus harvest
2. From Table 4 of Eggers et al. (2010)
3. Provided by the Alaska Department of Fish and Game (ADFG)
4. R/S is the returns per spawner and was calculated by dividing recruits by escapement
5. Number of wild smolts from Table 6 of Eggers et al. (2010)
6. Juvenile sockeye estimates from hydroacoustic surveys and obtained from the ADFG

Table A-3: Chilkoot sockeye salmon abundance data.

Year	Total Returns[1]	Harvest[1]	Escapement[2]	Recruits[2]	R/S[3]	Juveniles[4]
1976			71,296			
1977			97,368			
1978			35,454			
1979			95,948	365,264	3.81	
1980	117,350	20,838	96,513	211,139	2.19	
1981	127,160	43,788	84,047	271,949	3.24	
1982	247,560	144,587	103,038	346,467	3.36	
1983	321,810	241,467	80,141	419,501	5.23	
1984	332,200	231,783	100,781	348,982	3.46	
1985	221,350	152,324	69,141	224,471	3.25	
1986	198,450	110,426	88,024	289,721	3.29	
1987	430,180	334,995	94,208	219,806	2.33	977,516
1988	335,240	253,968	81,274	67,081	0.83	2,993,974
1989	346,760	291,863	54,900	54,621	0.99	870,608
1990	252,180	178,864	76,119	12,965	0.17	602,826
1991	314,670	224,041	90,754	72,793	0.80	384,369
1992	207,790	140,719	67,071	77,530	1.16	
1993	103,250	51,424	52,080	16,297	0.31	
1994	62,830	25,414	37,007	25,637	0.69	
1995	15,155	7,946	7,177	50,663	7.06	238,250
1996	69,600	18,861	50,741	142,218	2.80	415,749
1997	73,167	28,913	44,254	87,685	1.98	748,606
1998	14,541	2,217	12,335	62,715	5.08	1,438,485
1999	23,542	4,258	19,284	173,057	8.97	330,478
2000	58,229	14,674	43,555	99,807	2.29	1,105,666
2001	143,785	66,385	76,283	217,442	2.85	330,885
2002	82,636	24,276	58,361	176,902	3.03	1,192,560
2003	106,778	32,324	74,459	48,478	0.65	1,384,754
2004	142,133	66,537	75,591	51,415	0.68	996,046
2005	80,498	29,321	51,178	116,476	2.28	247,283
2006	215,464	119,236	96,203	67,185	0.70	356,283
2007	204,889	125,303	72,561			140,237
2008	40,440	7,483	32,957			1,014,655
2009	50,584	17,038	33,545			832,991
2010	103,543	31,977	71,657			830,394
2011			65,915			763,541

Notes:

1. From Bachman (2011)
2. Provided by the Alaska Department of Fish and Game (ADFG)
3. R/S is the returns per spawner and was calculated by dividing recruits by escapement
4. Juvenile abundance estimates from hydroacoustic surveys and obtained from ADFG

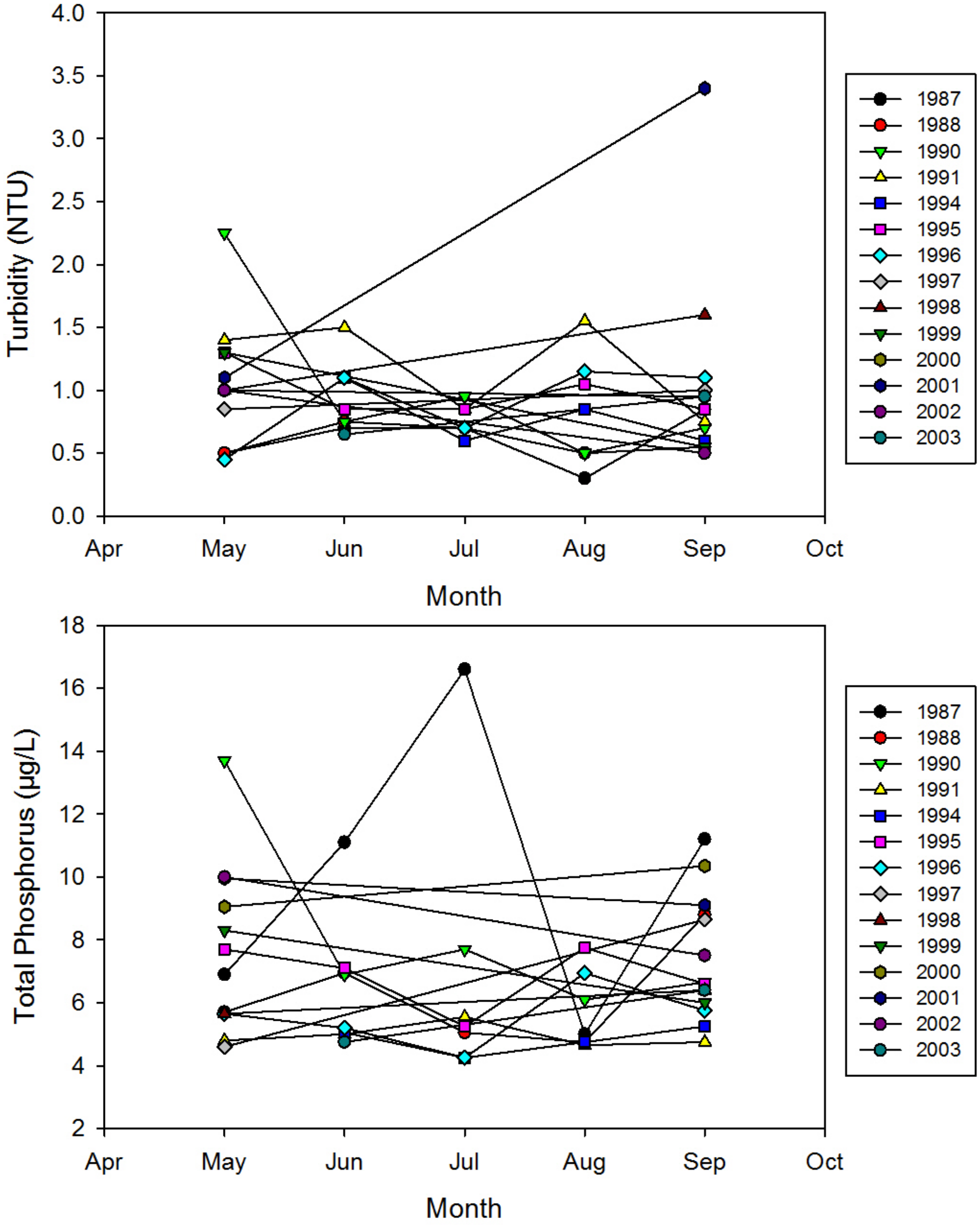

Figure A-1. Turbidity and total phosphorus in Chilkat Lake for all years measured, 1987-2003. Values are means of two sampling stations.

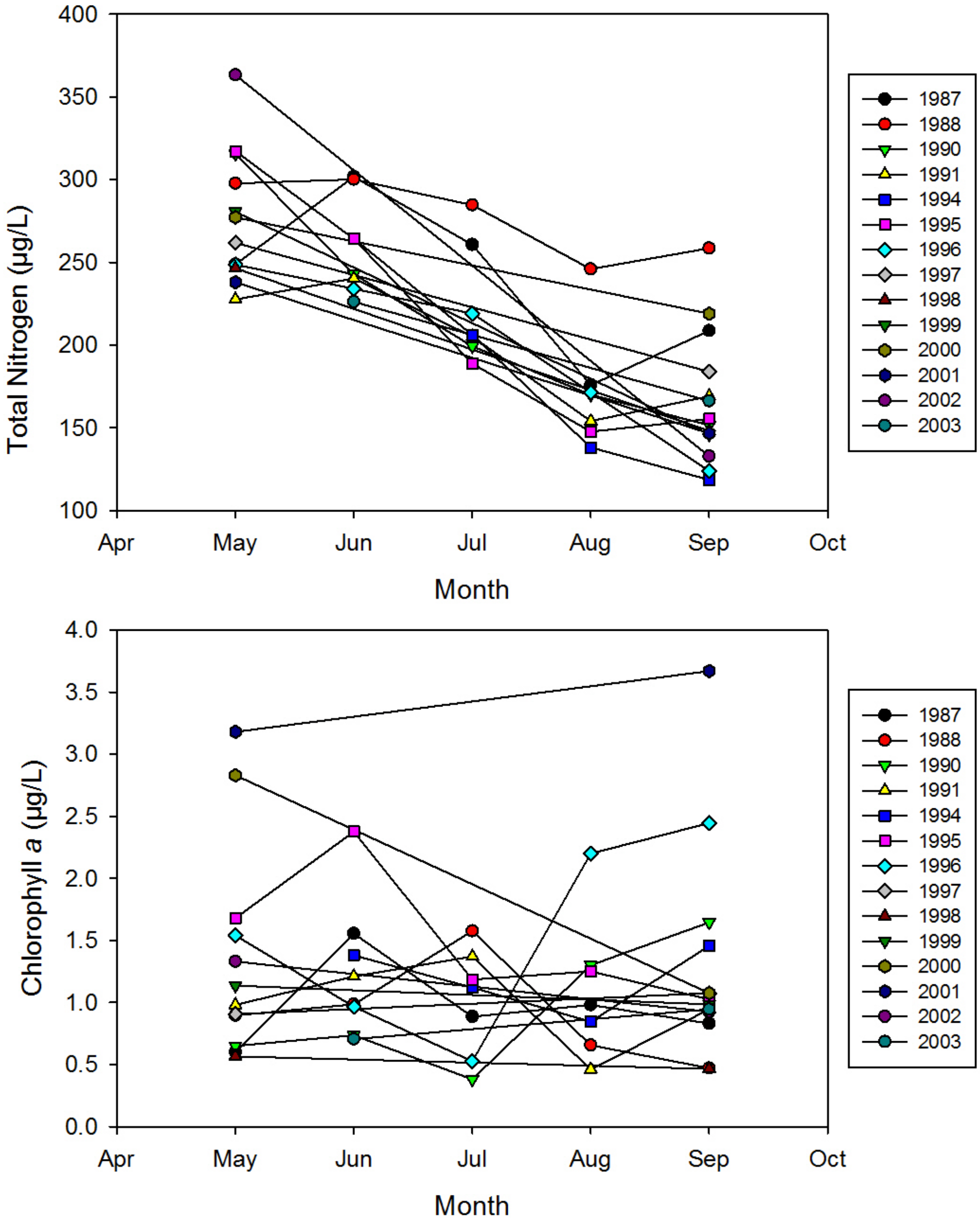

Figure A-2. Total nitrogen and chlorophyll *a* concentration in Chilkat Lake for all years measured, 1987-2003. Values are means of two sampling stations.

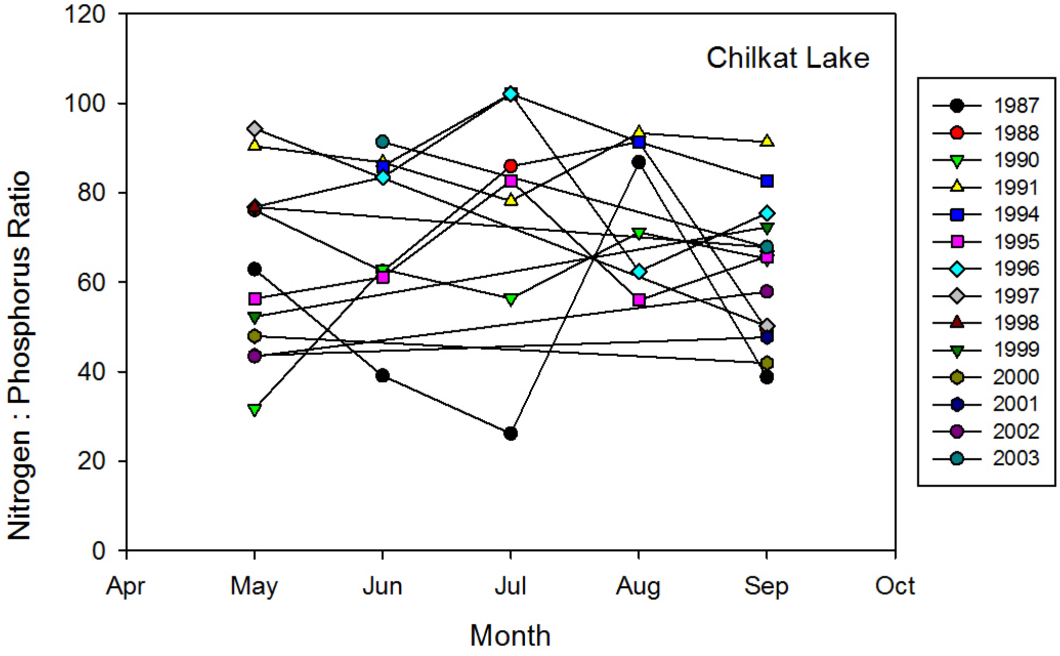

Figure A-3. Nitrogen to phosphorus ratio in Chilkat Lake for all years measured, 1987-2003.

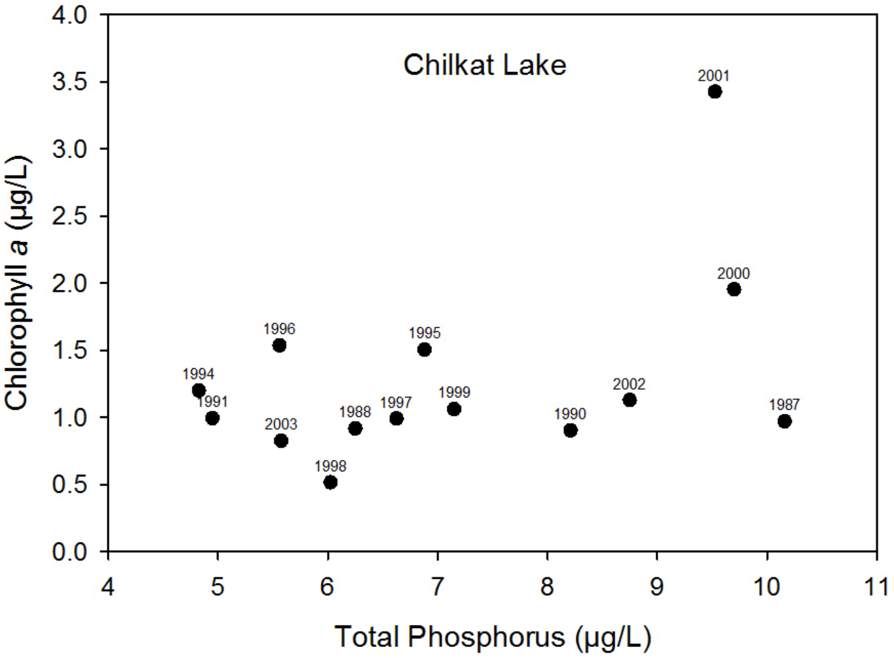

Figure A-4. Total phosphorus and chlorophyll *a* concentrations in Chilkat Lake for all years measured, 1987-2003.

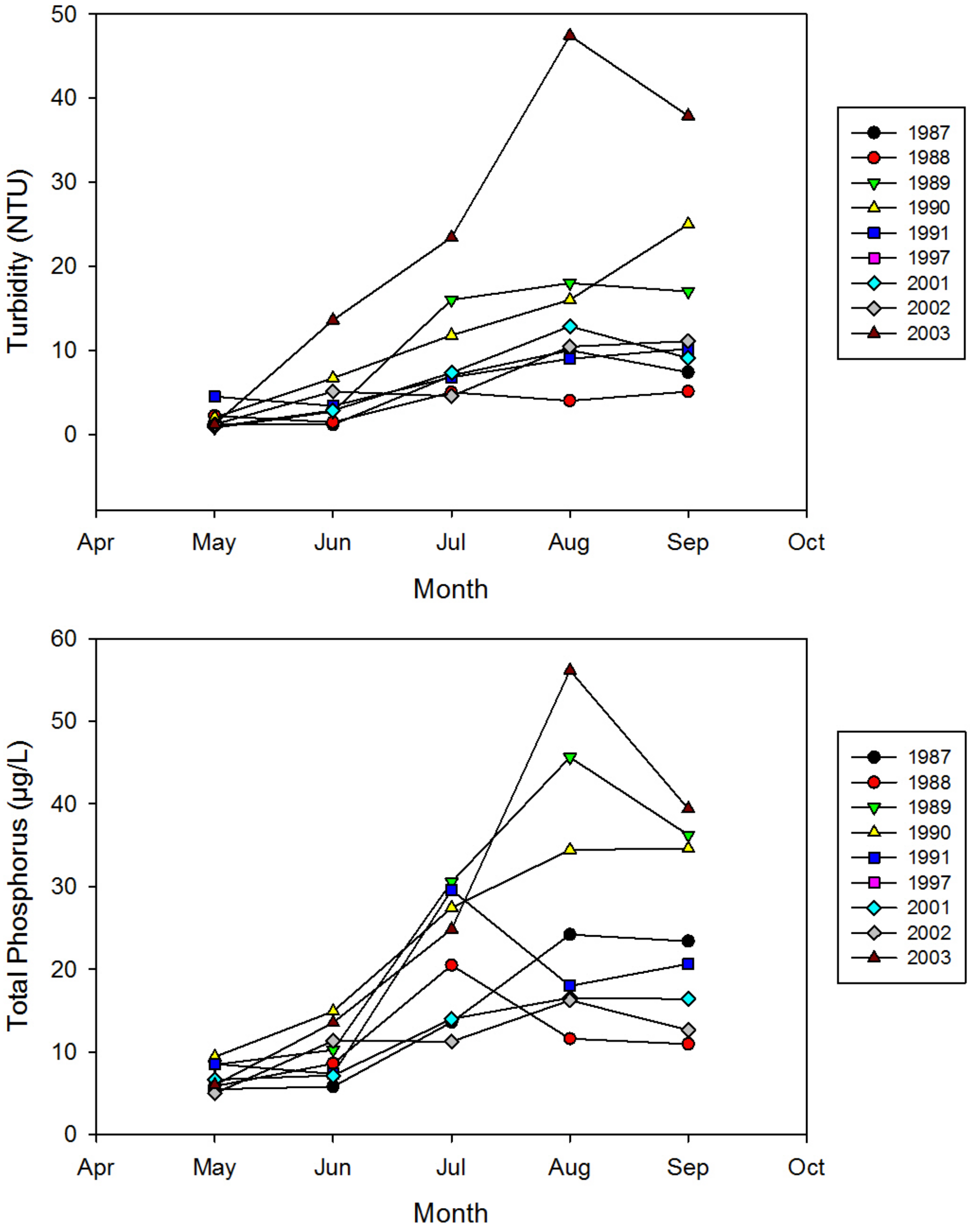

Figure A-5. Turbidity and total phosphorus in Chilkoot Lake for all years measured, 1987-2003. Values are means of two sampling stations.

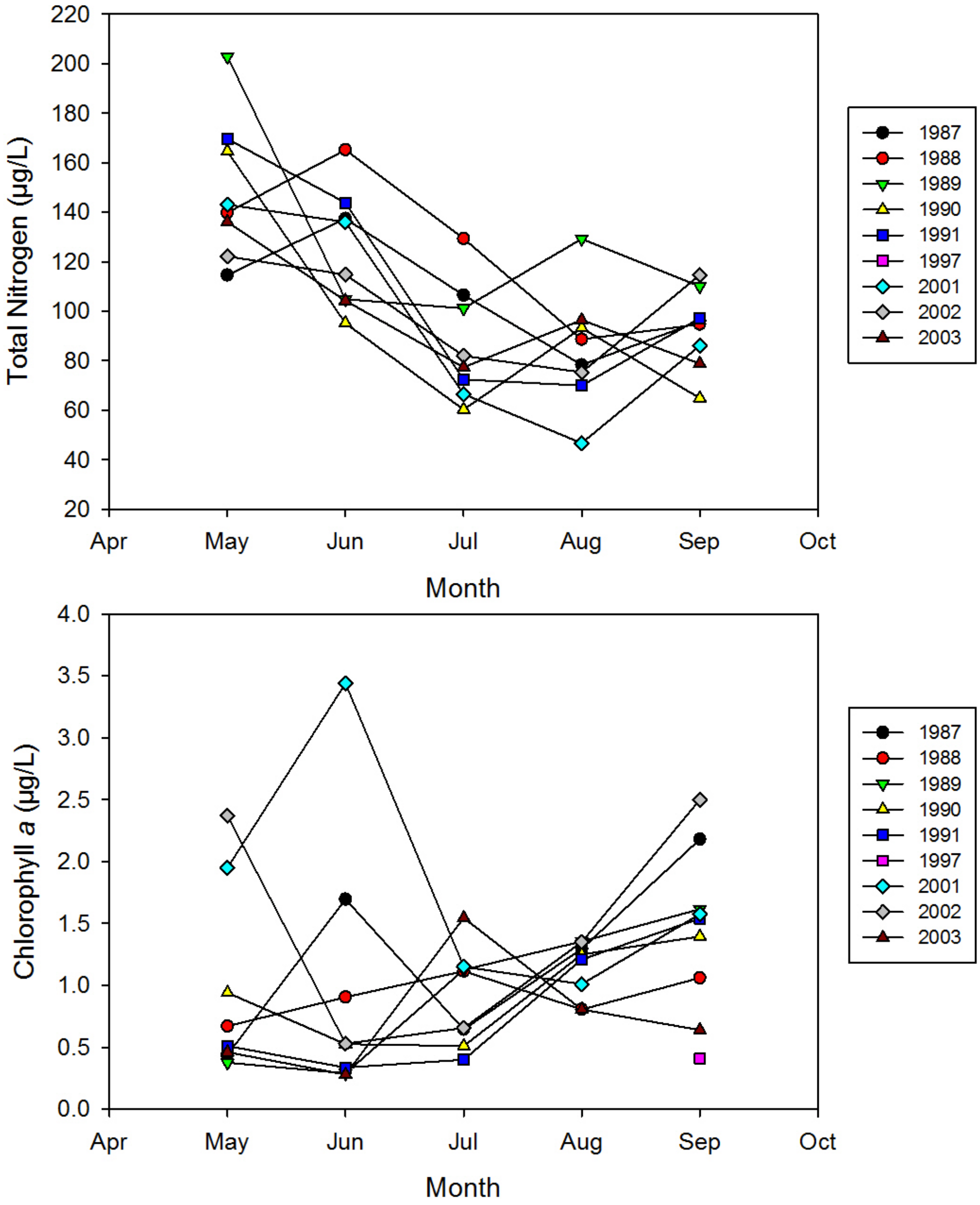

Figure A-6. Total nitrogen and chlorophyll *a* concentration in Chilkoot Lake for all years measured, 1987-2003. Values are means of two sampling stations.

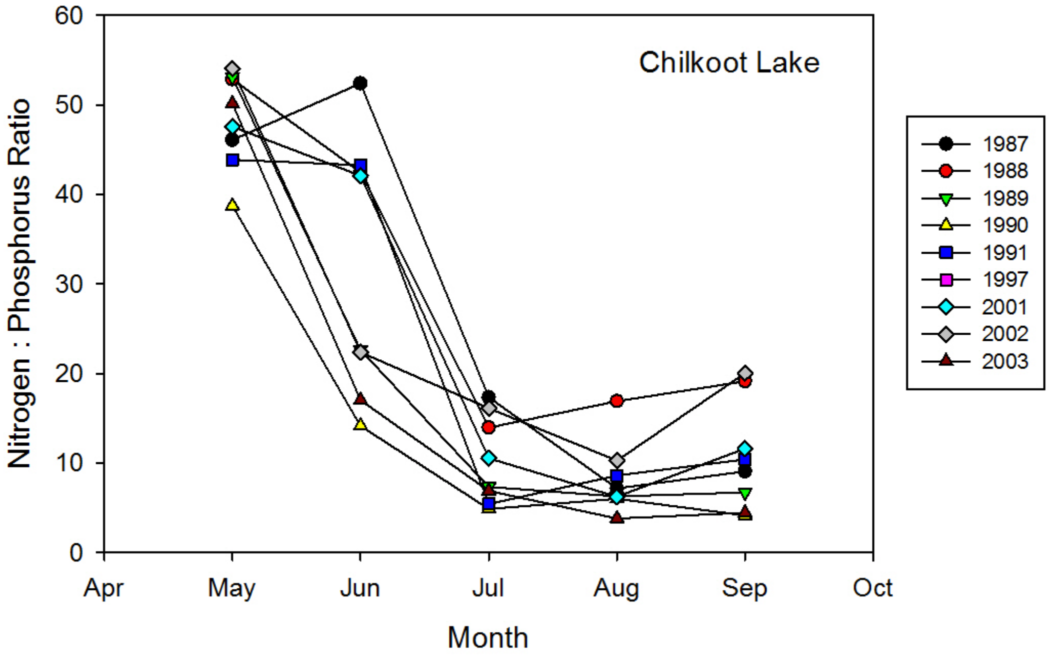

Figure A-7. Nitrogen to phosphorus ratios in Chilkoot Lake for all years measured, 1987-2003.

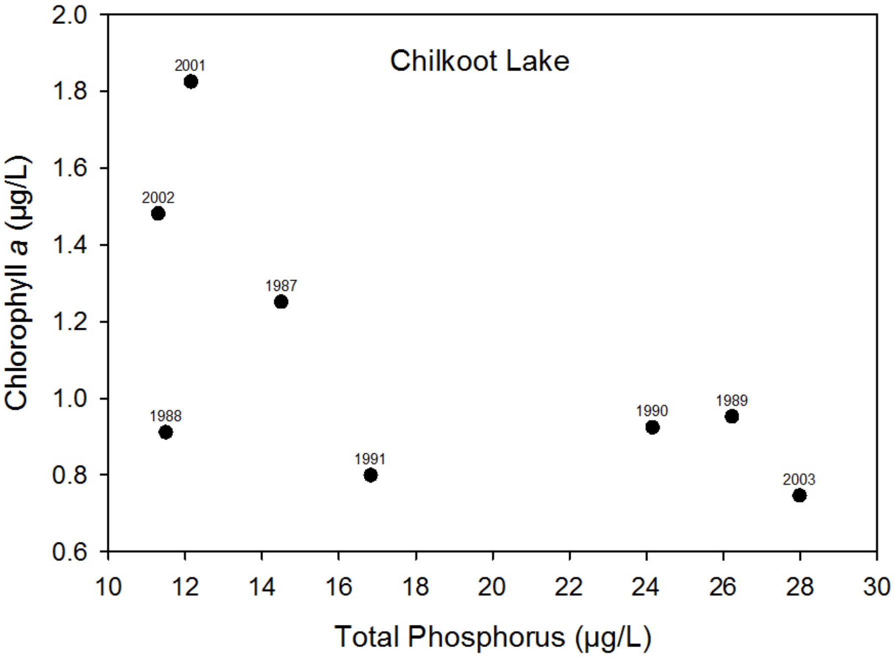

Figure A-8. Total phosphorus and chlorophyll *a* concentrations in Chilkoot Lake for all years measured, 1987-2003.

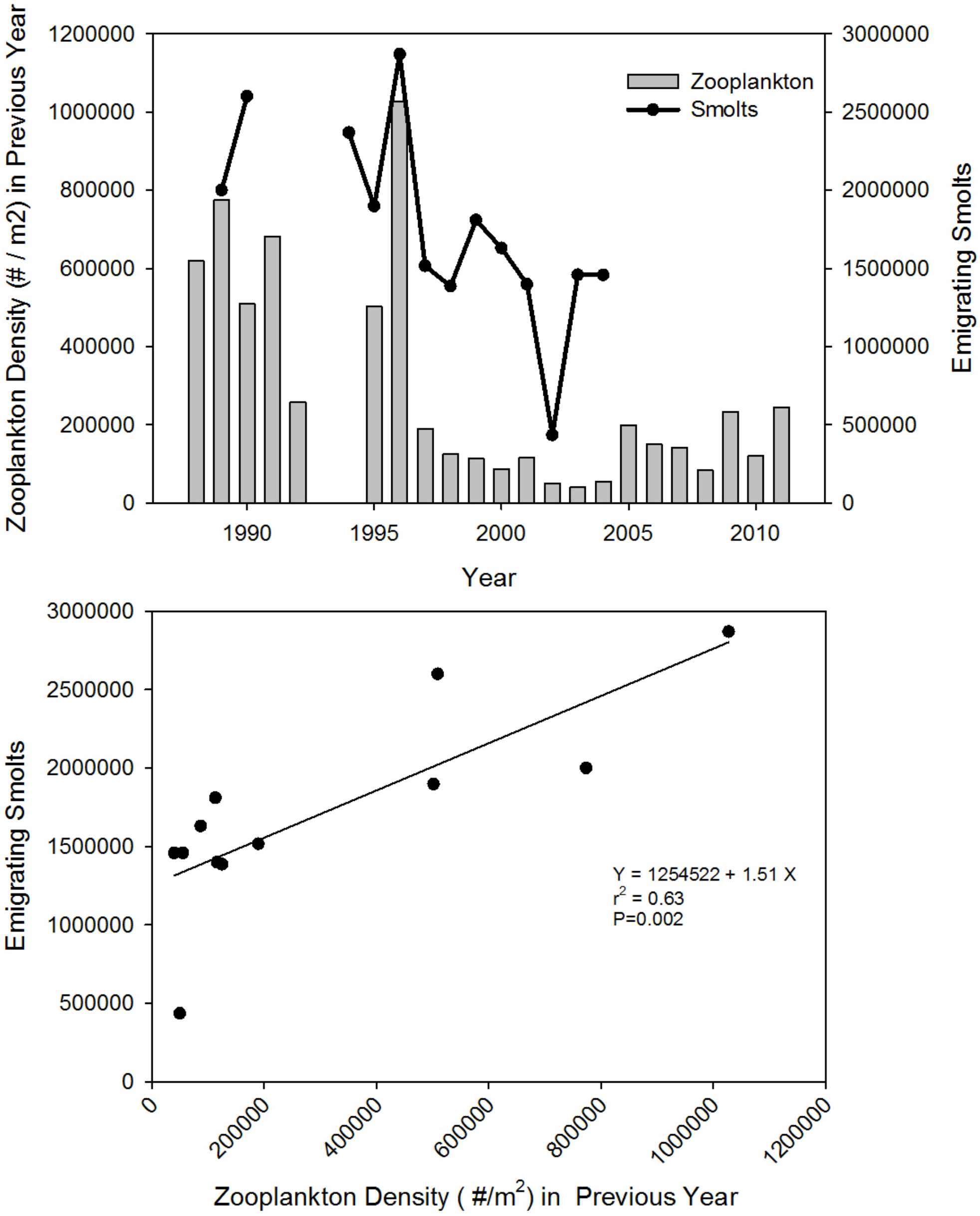

Figure A-9. **Relationship between the number of smolts emigrating from Chilkat Lake and zooplankton density in previous year.**

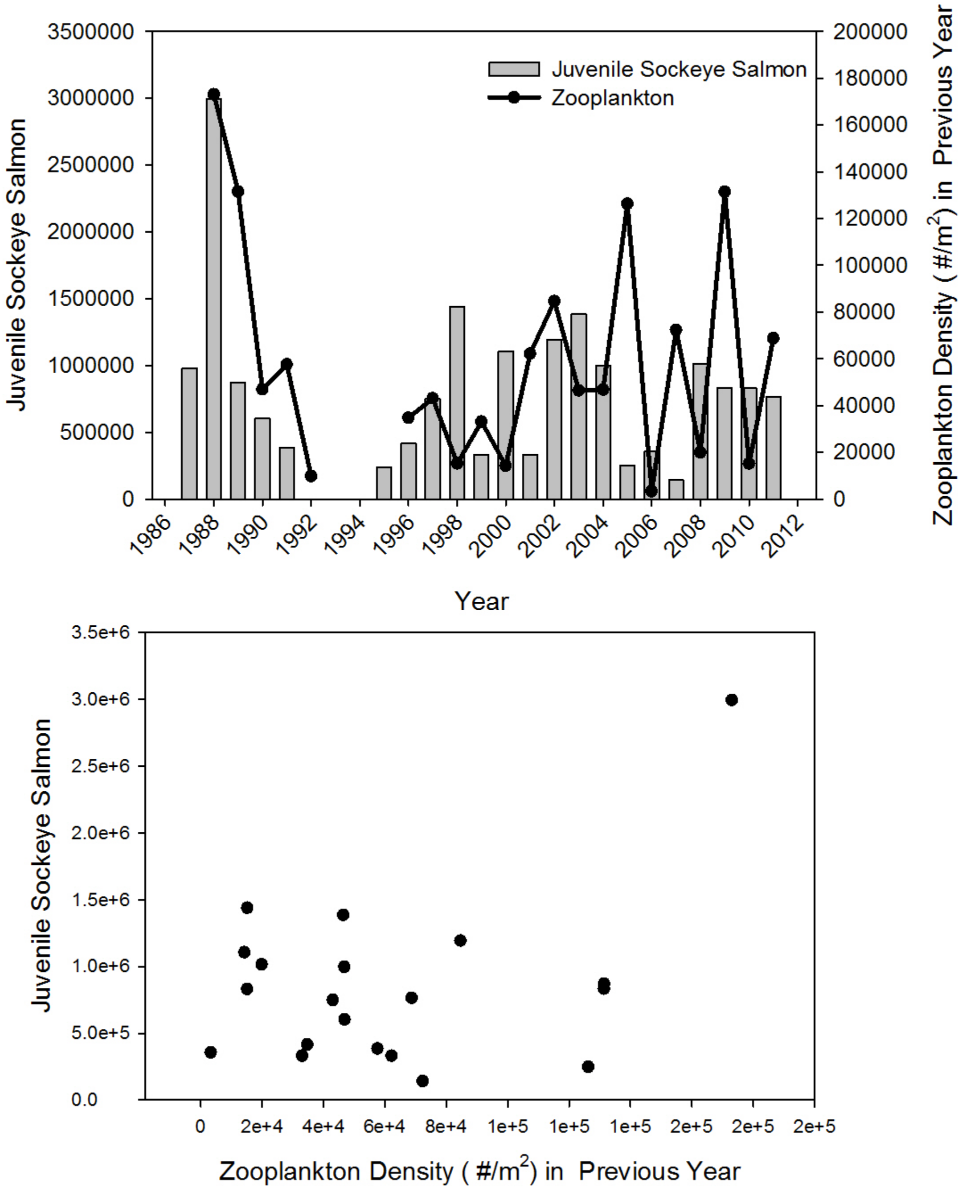

Figure A-10. Relationship between the number of juvenile sockeye salmon in Chilkoot Lake estimated by hydroacoustic surveys and zooplankton density in previous year.

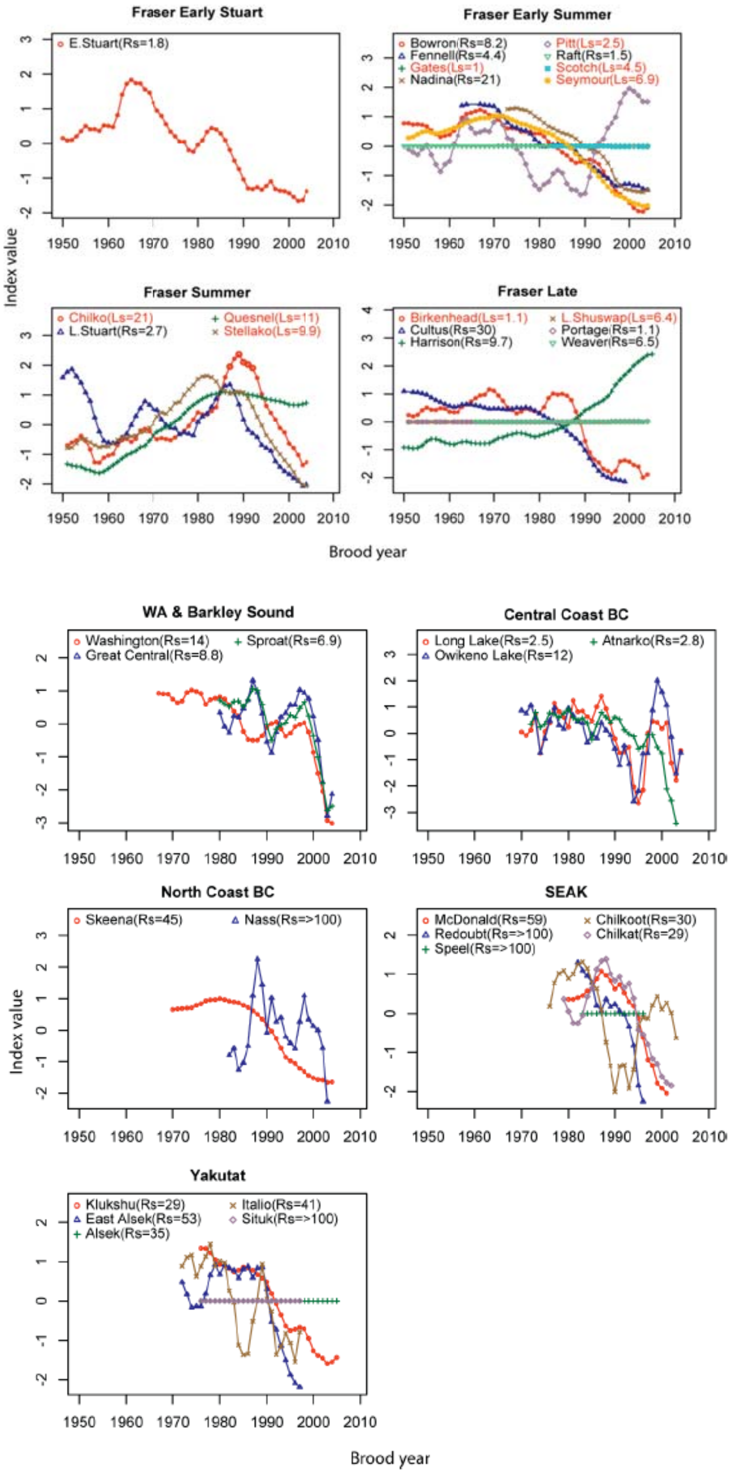

Figure A-11. Productivity trends in sockeye salmon stocks in Washington, British Columbia and Alaska from Figures 9 and 10 of Peterman and Dorner (2011). Productivity units are from a scaled Kalman filter time series and are shown in standard deviation units from their means.

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solutions@golder.com
www.golder.com

Golder Associates Ltd.
201 Columbia Avenue
Castlegar, British Columbia, V1N 1A8
Canada
T: +1 (250) 365 0344

Golder
Associates