SAFS-UW-1101
June 2011

2010 Annual Report

Alaska Salmon Program
University of Washington
School of Aquatic & Fishery Sciences

http://fish.washington.edu/research/alaska

SAFS-UW-1101
June 2011

Alaska Salmon Research 2010

Annual Report

Alaska Salmon Program
University of Washington
School of Aquatic & Fishery Sciences

http://fish.washington.edu/research/alaska

The recommended format for citing this report is as follows:

Alaska Salmon Program. 2011. Alaska salmon research 2010. University of Washington, School of Aquatic & Fishery Sciences, SAFS-UW-1001. Seattle.

It was not practical to list authorship for the numerous report components written by faculty and staff. The following authors contributed significantly to the report:

Faculty/Principal Investigators
D Schindler, R Hilborn, T Quinn, L Hauser

Staff
B Chasco, J Carter, H Rich, C Boatright

Cover photos:
insets: J Armstrong; background: ©2010 www.photos.com

Contents

List of Figures *iv*

List of Tables *iv*

List of Appendices *v*

List of Maps *v*

Acknowledgments *vi*

1. INTRODUCTION 1

2. FISHERIES MANAGEMENT 2
   Introduction 2
   Forecast Summary 2
   2010 Chignik Preseason Forecast 3

3. ADULT SALMON BEHAVIOR AND ECOLOGY 5
   Introduction 5
   Spawning Ground Surveys 6
   Hansen Creek Daily Runs and Bear Predation 8
   A and C Creeks 9

4. LAKE ECOSYSTEMS 16
   Introduction 16
   Environmental Conditions and Limnology 16
   Juvenile Sockeye Abundance and Size 19

5 SALMON GENETICS 23

6. STUDENT PROJECTS 25
   Graduate Student Projects 25
   2010 AREA Class Student Projects 27

7. DATA AND WEB DEVELOPMENT 28

8. FACILITIES 29

9. PUBLICATIONS 30
   In review 30
   Manuscripts in press 30
   2011 30
   2010 31
   2009 32

10. REFERENCES 34

11. GLOSSARY 36
   Acronyms 36
   Common Names, Genus and Species 36

12. APPENDICES 37

List of Figures

Figure		Page
2.1	Retrospective analysis of Black and Chignik lakes: 2000–2010.	4
2.2	Black Lake and Chignik Lake runs from 1978 to 2010 by age class.	4
3.1	Long-term average adult sockeye index counts vs. 2010 index counts for Wood River system sockeye salmon survey streams.	6
3.2	Effect of spawning run size on the kill rate by bears in Hansen Creek.	8
3.3	Number of fish entering and total fish in A and C creeks, Little Togiak Lake, for 2010.	9
4.1	Time series (1960–2010) of spring environmental indicators from the Wood River system.	18
4.2.	Time series (1962–2010) of ice break-up date for Iliamna Lake and spring air temp index from Iliamna, Alaska 1962–2010.	18
4.3	Monthly zooplankton densities in Lake Aleknagik, 1967–2009, compared with 2010.	19
4.4	Size of sockeye fry on September 1, 1962–2009 for all Wood River lakes.	20
4.5	Cumulative catch by date for 2008–2010 Wood River smolt trap operated at Mosquito Pt. at outlet of Lake Aleknagik.	21
4.6	Average smolt length by date for 2008–2010 Wood River smolt trap operated at Mosquito Pt. at outlet of Lake Aleknagik.	21
4.7	Kvichak River escapement (1961–2009), Iliamna Lake tow net index for sockeye fry catches, and sockeye fry length 1962–2010.	22

List of Tables

Table		
2.1	2010 preseason forecast (in millions) of sockeye salmon (*Oncorhynchus nerka*) returning to Bristol Bay, Alaska, by river system and age class.	2
2.2	2010 observed returns (in millions) of sockeye salmon (*Oncorhynchus nerka*) returning to the Bristol Bay, Alaska, by river system and age class.	3
2.3	Difference in millions between the 2010 preseason forecast and the observed number of sockeye salmon (*Oncorhynchus nerka*) returning to Bristol Bay, Alaska, in 2010, by river system and age class.	3
2.4	2011 preseason forecast of the number of sockeye salmon (*Oncorhynchus nerka*) in millions returning to the Bristol Bay, Alaska, by river system and age class.	3
2.5	Forecast ranges for Black Lake and Chignik Lake by age class (in thousands) for Brood Year 2011.	4
3.1	Number of bear-killed salmon and other sources of mortality combined, by sex and section of Hansen Creek, 2010.	8
4.1	Summary of environmental variables and conditions in the Wood River system in 2010, compared with the long-term average conditions (1950–2009).	17

List of Appendices

Appendix

A	Summary of ground-based spawning ground surveys of adult sockeye salmon in Wood River streams, 2010.	38
B1	Age composition of adult sockeye salmon determined by otolith sampling in Wood River spawning sites, 2010.	39
B2	Age composition of adult salmon as determined by otolith sampling in Iliamna Lake spawning sites, 2010.	41
C	Historical total peak sockeye counts for streams of lakes Aleknagik, Nerka, Little Togiak, Beverley, and Kulik, 1946–2010.	42

List of Maps

Map of the Alaska Salmon Program's three major research areas	11
Detail map of lower Wood River lakes	12
Detail map of upper Wood River lakes	13
Detail map of Iliamna Lake	14
Detail map of Chignik and Black lakes	15

Photo: J Armstrong

Acknowledgments

A project of this scope owes a great debt to a wide range of individuals and agencies. The biggest debt is to the Fisheries Research Institute (FRI) faculty and staff who founded this program, set up the data collection systems, and maintained the program until the current faculty and staff were lucky enough to inherit it. William F. Thompson, Robert "Bud" Burgner, Ole Mathisen, and Don Rogers deserve special mention. Equally important were the visionary members of the processing industry, who saw the need, found the people to do the work, and provided the majority of the funding for more than 50 years.

Our research would not be possible without the active support of the local communities and agencies, especially the communities of Aleknagik, Iliamna, Pedro Bay, and Chignik Lake, but additionally the Wood-Tikchik State Park authorities (especially Johnny Evans and Bill Berkhahn), Alaska Department of Fish and Game (especially Lowell Fair, Tim Baker, Tim Sands), Bristol Bay Science and Research Institute, Bristol Bay Native Association, Togiak National Wildlife Refuge (Patrick Walsh and Mark Lisac) and Bristol Bay Economic Development Corporation. We also thank the owners of the Fishing Bear Lodge and the Goldenhorn Lodge for assistance with field logistics in the Wood River system.

The current supporters of the teaching and research include the Bristol Bay and Chignik Salmon Processors, Chignik Regional Aquaculture Association, Gordon and Betty Moore Foundation, National Science Foundation, NOAA Fisheries, Pew Institute of Ocean Sciences, the University of Washington (School of Aquatic and Fishery Sciences, College of Environment), the H. Mason Keeler Professorship, and the Richard C. and Lois M. Worthington Professorship).

1. Introduction

The year 2010 marked the 65th year of field work in Bristol Bay for our program and marks the continued growth of both our field program and analytic work conducted at the University of Washington. In the summer of 2010, activity in our field camps remained high with over 2,500 person days. We held the undergraduate level Aquatic Ecological Research in Alaska (AERA) course for the tenth time.

The core of our program research remains focused on the biology and management of the salmon of western Alaska, but we continue to broaden the scope of the program with the work of professors Lorenz Hauser, Lisa and Jim Seeb (University of Washington), who pursue genetic studies, and the addition of a new genetics lab on-site at the UW campus in Seattle created by the Seebs. Other additions include Gunnar Knapp (University of Alaska Anchorage) and Chris Costello (University of California at Santa Barbara), both of whom conduct economic studies. We also now have ongoing research and teaching participation with Professor Milo Adkison (University of Alaska Fairbanks) and Carl Walters (University of British Columbia), and look forward to expanding our cooperative research efforts.

This report provides an overview of the research and teaching activities conducted under the umbrella of the Alaska Salmon Program—the name we use at the University of Washington to represent the various activities centered around our field facilities in Bristol Bay and the Chignik Lake system. It is organized into general themes, and within each theme, brief summaries of our activities and any major results are presented. We expect that few readers will read this report from cover to cover, but rather will read specific topics based upon their individual interests. Much of the material reported herein is also on our website, *http://safs.washington.edu/alaska*. In addition, reference maps for the general research areas and specific study sites are provided on pages 11–15.

From 1946 to 2005, our work was largely funded by the processing industry of Bristol Bay, and the program would have disappeared many years ago without their continued financial and political support. The University of Washington has also supported the program over the last 60 years through combinations of funding for facilities and staff salaries. The University of Washington support increased considerably when we began teaching the Alaska under-graduate field ecology course in 1999. We received a major increase in funding in 2005, with significant grants from the National Science Foundation, the Gordon and Betty Moore Foundation, and the Pew Institute of Ocean Sciences.

The Alaska salmon research program was initiated in 1947 under the auspices of the Fisheries Research Institute (FRI), which was originally affiliated with the UW Graduate School. In 1958, it became a department within the newly organized College of Fisheries. By the mid-1980s, FRI was a division within the School of Fisheries, and by the mid-1990s, when school divisions were eliminated, FRI as an institutional unit ceased to exist. However, we continue to use the term FRI in our relationships with outside organizations for our Alaskan salmon work.

2. Fisheries Management

Introduction

Preseason and inseason forecasting continue to be central features of our fisheries management activities. Preseason forecasts are very important to processors and fishermen for planning their capacity for the coming season, and the conservation concerns about Kvichak have meant that the preseason forecast has special importance with regard to whether the fisheries in Naknek and Egegik operate in restricted boundaries at the beginning of the season. We have a number of projects associated with escapement goals, run reconstruction, and we are working closely with the Alaska Department of Fish & Game (ADFG) on methods for evaluating alternative harvest strategies and increasing the effectiveness of inseason run forecasting. While the traditional analysis of escapement goals has been concerned only with maximum harvest, the need to increase profitability in the processing and harvesting industries has caused us to explore the economic implications as well as the biological implications of harvest strategies.

Forecast Summary

B Chasco, C Boatright (research scientists), R Hilborn (adviser)

2010 Run Summary

The 2010 Bristol Bay sockeye salmon forecast was 39.75 million fish. This forecast is the sum of individual predictions for each of the four dominant age classes (1.2, 1.3, 2.2, 2.3) from all nine major river systems—Naknek, Kvichak, Alagnak, Egegik, Ugashik, Wood, Nushagak-Mulchatna, Igushik, and Togiak (Table 2.1). Table 2.2 shows the observed 2010 returns by age and river, and Table 2.3 shows the differences between the observed and predicted returns. The total return in 2010 was 40.60 million, with nearly all ages and rivers being under-forecasted.

We also produced an estimate for total harvest in 2010 of 31.38 million fish with an estimated weight of 180.51 million pounds. The ADFG reports that 28.59 million Bristol Bay sockeye were harvested in 2010, with an estimated weight of 155.95 million pounds. The number we issue each year as a preseason forecast of harvest is "potential" harvest and therefore commonly overestimates "actual" harvest by 8 to 15%.

2011 Preseason Forecast

The 2011 Bristol Bay sockeye salmon forecast is 35.85 million fish. This forecast is the sum of individual predictions for each of the dominant age classes (1.2, 1.3, 2.2, 2.3) for the nine major river systems—Kvichak, Egegik, Ugashik, Naknek, Alagnak, Wood, Nushagak-Mulchatna, Igushik, and Togiak (Table 2.4). We also produced an estimate for total harvest of 27.74 million fish with an estimated weight of 160.68 million pounds. To generate a forecast for total harvest we simply subtracted the mid point of escapement goals for each district from the predicted total return for each district and summed. To determine the harvest in pounds for

Table 2.1 2010 preseason forecast (in millions) of sockeye salmon (*Oncorhynchus nerka*) returning to Bristol Bay, Alaska, by river system and age class.

District / River	Ages 1.2	1.3	2.2	2.3	Total
Naknek/Kvichak	**3.9**	**4.6**	**1.9**	**1.6**	**11.9**
Kvichak	2.3	0.9	1.0	0.6	4.8
Naknek	1.0	2.7	0.7	0.9	5.3
Alagnak	0.6	0.9	0.2	0.1	1.8
Egegik	**1.2**	**1.3**	**4.0**	**3.8**	**10.3**
Ugashik	**3.5**	**1.3**	**0.9**	**0.8**	**6.4**
Nushagak	**5.1**	**4.7**	**0.1**	**0.1**	**10.0**
Wood	4.7	2.0	0.1	0.1	6.9
Igushik	0.2	0.6	0.0	0.0	0.9
Nushagak	0.2	2.0	0.0	0.0	2.2
Togiak	**0.2**	**0.7**	**0.0**	**0.1**	**1.0**
Totals	**13.8**	**12.6**	**6.9**	**6.3**	**39.6**

Table 2.2 2010 observed returns (in millions) of sockeye salmon (*Oncorhynchus nerka*) returning to Bristol Bay, Alaska, by river system and age class.

District	Ages				
River	1.2	1.3	2.2	2.3	Total
Naknek/Kvichak	**5.2**	**5.7**	**5.4**	**1.5**	**17.8**
Kvichak	3.1	1.7	4.1	0.6	9.4
Naknek	1.6	2.1	1.3	0.8	5.8
Alagnak	0.5	1.8	0.1	0.2	2.6
Egegik	**0.6**	**0.8**	**2.9**	**1.5**	**5.8**
Ugashik	**0.7**	**2.1**	**1.5**	**0.5**	**4.9**
Nushagak	**4.8**	**5.9**	**0.3**	**0.2**	**11.2**
Wood	4.4	3.0	0.2	0.1	7.8
Igushik	0.2	1.1	0.0	0.0	1.4
Nushagak	0.2	1.8	0.0	0.1	2.1
Togiak	**0.3**	**0.4**	**0.1**	**0.0**	**0.9**
Totals	**11.6**	**14.9**	**10.2**	**3.8**	**40.6**

Table 2.3 Difference (in millions) between the 2010 preseason forecast and the observed number of sockeye salmon (*Oncorhynchus nerka*) returning to Bristol Bay, Alaska, by river system and age class. A negative means the preseason forecast was lower than the observed returns, and vise-versa.

District	Ages				
River	1.2	1.3	2.2	2.3	Total
Naknek/Kvichak	**-1.3**	**-1.1**	**-3.5**	**0.0**	**-5.9**
Kvichak	-0.8	-0.8	-3.0	0.0	-4.7
Naknek	0.6	0.6	-0.6	0.2	-0.5
Alagnak	0.1	-0.9	0.1	-0.2	-0.8
Egegik	**0.6**	**0.5**	**1.1**	**2.3**	**4.5**
Ugashik	**2.8**	**-0.8**	**-0.7**	**0.3**	**1.6**
Nushagak	**-0.3**	**-1.3**	**-0.2**	**-0.1**	**-1.2**
Wood	0.4	-1.0	-0.2	0.0	-0.9
Igushik	0.0	-0.5	0.0	0.0	-0.5
Nushagak	0.0	0.3	0.0	0.0	-0.3
Togiak	**-0.1**	**0.3**	**-0.1**	**0.0**	**0.1**
Totals	**2.1**	**-2.4**	**-3.4**	**2.6**	**-1.0**

each age class we subtracted the escapement proportional to the age specific forecast then multiplied the forecasted catch by the long-term average weight of two or three ocean fish (5.0 lbs and 6.7 lbs respectively).

Table 2.4 2011 preseason forecast of the number of sockeye salmon (*Oncorhynchus nerka*) (in millions) returning to Bristol Bay, Alaska, by river system and age class.

District	Ages				
River	1.2	1.3	2.2	2.3	Total
Naknek/Kvichak	**3.3**	**5.3**	**2.0**	**2.0**	**12.6**
Kvichak	1.5	1.5	0.9	0.7	4.5
Naknek	1.2	3.2	0.9	1.3	6.5
Alagnak	0.6	0.7	0.2	0.1	1.5
Egegik	**1.1**	**1.2**	**5.4**	**2.0**	**9.8**
Ugashik	**1.4**	**1.0**	**1.7**	**0.8**	**4.8**
Nushagak	**2.6**	**4.5**	**0.4**	**0.2**	**7.7**
Wood	2.2	2.6	0.3	0.1	5.2
Igushik	0.2	0.7	0.0	0.0	1.0
Nushagak	0.2	1.2	0.0	0.0	1.6
Togiak	**0.2**	**0.6**	**0.0**	**0.1**	**0.9**
Totals	**8.5**	**12.6**	**9.6**	**5.0**	**35.8**

2011 Chignik Preseason Forecast

B Chasco (research scientist), R Hilborn (adviser)

The 2011 Chignik Lakes forecast (Table 2.5) was made using models based on sibling regressions and recruits-per-spawner analysis, and a process known as model averaging. The total forecast for 2011 is between 1.56 and 3.00 million sockeye, the model average of 2.24 million is similar to last year's observed total run of 2.39 million. The forecasted run to Chignik Lake is between 0.82 and 1.40 million with a model average of 1.00 million, and the Black Lake run is forecasted to be between 0.74 and 1.60 million with a model average of 1.24. Figure 2.1 shows the total runs to each lake over the last 11 years, as well as what our forecasts would have been in those years. The observed numbers of fish returning to each lake have been closer to the lower range of our forecasts in recent years—with the exception of last two years. The ranges for the forecasts do not represent confidence or probability intervals, but rather they are the range of forecasts from all of the different sibling regression and spawner-recruit models.

After several years of declining runs starting in 2005, 2009 and 2010 have seen a welcomed increase in the number of sockeye returning to the Chignik Lakes (Figure 2.1). During the last two years both Black Lake and Chignik Lake have seen increased runs; however, some trends in the returns-by-age are still cause for concern. As stated in last year's report, the reason for the declining numbers between 1999 and 2010 can be attributed to the decline in 1.3 fish returning to Black Lake and the 2.3 fish returning to Chignik Lake (Figure 2.2). While there appears to be immediate increases in these age classes over the last couple of years, the overall trend appears to still exist through 2010.

Table 2.5 Forecast ranges for Black Lake and Chignik Lake by age class (in thousands) for Brood Year 2011.

Lake	lower	model average	upper
Black Lake	0.82	1.00	1.40
Chignik Lake	0.74	1.24	1.60
Total	1.56	2.24	3.00

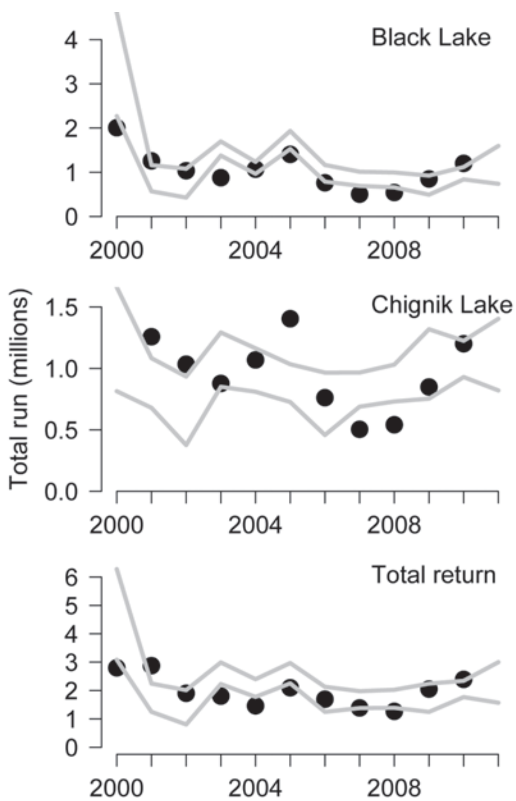


Figure 2.1 Retrospective analysis (2000–2010) of the Black Lake (upper panel), Chignik Lake (middle panel), and combined forecasts (lower panel) using this year's model structure. The grey lines are the upper and lower limits of the forecast and do not represent confidence intervals. The dots are the observed run size.

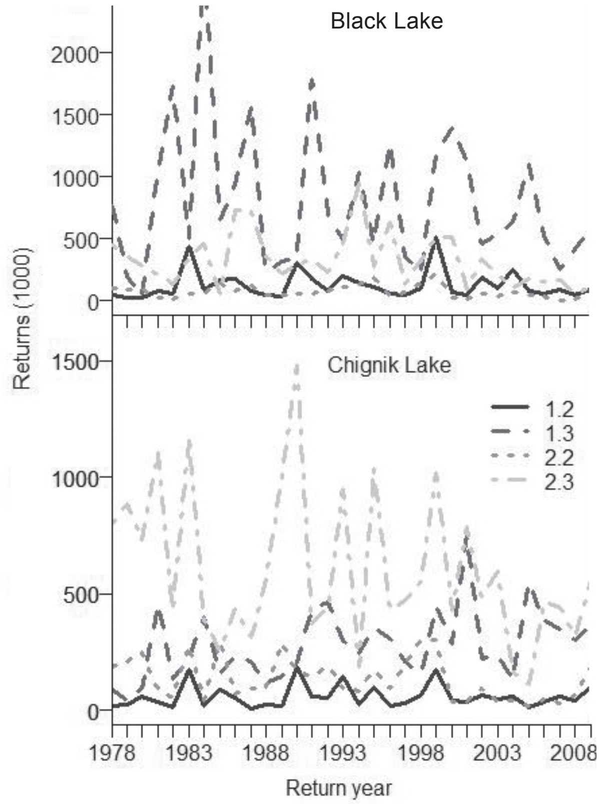


Figure 2.2 Black Lake (upper panel) and Chignik Lake (lower panel) runs from 1978 to 2010 by age class.

3. Adult Salmon Behavior and Ecology

Introduction

Research on behavior and ecology has been a key component of the overall program of investigations on western Alaska sockeye salmon since the inception of the program. The numerous long- and short-term studies being conducted on adult and juvenile salmon are designed to address pressing questions related to management and also broader questions related to the functioning of the ecosystem and the evolution of the fishes and other organisms that occupy it.

We have recently investigated processes that affect (or correlate with) the timing of return migration of sockeye salmon (Hodgson et al. 2006), describing the general tendency for runs in the northern part of the range to be early after a warm spring, and the opposite pattern in southern areas. We have also studied the extent to which the fisheries in Bristol Bay (with emphasis on Egegik and Ugashik) have been selective for timing. The exploitation rate tends to be higher at the end than at the beginning of the run, and evidence indicates that the escapements, and indeed the runs as a whole, may be getting earlier over the years (Quinn et al. 2007a).

These projects motivated the large-scale tagging study in 2006 that revealed differences in timing of sockeye salmon in the Wood River that spawn in streams compared to larger rivers (Doctor et al. 2010). In 2007, we extended this line of research to investigate the extent to which arrival date on the spawning grounds is linked to spawning site selection and body size variation within a single population (Doctor and Quinn 2009). We are also examining variation in run timing among components of the Nushagak district run and long-term changes in timing of the run to the Nushagak River itself.

We have studied the patterns of reproductive success and natural and sexual selection that salmon experience on the spawning grounds. Striking variation in longevity (days alive in the stream) has been shown among populations, and this variation has been linked to the intensity of bear predation on newly arrived salmon (Carlson et al. 2007). We have also demonstrated that populations differ in the balance between selective predation by bears on large salmon and greater reproductive success of large salmon if they are not killed (Carlson et al. 2009). These differences in selection intensity seem to result in the variation in life-history traits seen among populations. In some cases, notably Hansen Creek, the selective effects of predation are augmented by selection from stranding at the shallow mouth of the creek. This stranding is most prevalent and also most size-selective when lake levels are low (Carlson and Quinn 2007).

Efforts to study processes on the spawning grounds have also included work on the extent to which females are able to spawn completely under conditions of high density. This work—comparing Wood River, Iliamna, and Alagnak populations—documented extremely high rates of egg retention (incomplete spawning and total spawning failure for some females) in some cases, especially in the Alagnak system, where spawning densities were very high. However, it appears that elevated water temperatures also affect prespawning mortality (Quinn et al. 2007b).

We have been investigating the movements of adult sockeye salmon on the spawning grounds, looking at the interface between homing and spawning-site selection. Results have shown limited movements by adult salmon, including males, and remarkably fine-scale homing to the natal site (Rich et al. 2006, Quinn et al. 2006, and Quinn et al. in review). The spawning behavior of adult and jack sockeye salmon has also been investigated and drawn special interest from a number of our researchers (Carlson et al. 2004, Allen et al. 2007).

These studies on the behavior of the salmon themselves have been complemented with research on the ramifications of digging by salmon and carcass decomposition for the flux of nutrients in small streams. This research has revealed that adult salmon not only import nutrients from the ocean to the stream but also dislodge insects and organic material from the sediment, causing them to drift downstream. In addition, there is evidence for adaptation by the aquatic insects to emerge and avoid the disturbance caused by the salmon (Moore and Schindler, 2010).

Spawning Ground Surveys

Wood River System

The Fisheries Research Institute's (FRI) Bristol Bay research program began with spawning ground surveys in the Wood River Lakes in 1946 to determine the number and distribution of sockeye salmon spawning in this system. During the early 1950s, methods were established to enumerate and sample the commercial catches, escapements (through the use of observation towers), and the number of smolts produced. By the late 1950s, we had established several important measurements, which have been maintained to the present, to characterize each year's environment for spawning adults and rearing juveniles. To characterize the fine-scale population variability among individual spawning sites, we have surveyed about 25 small stream populations to monitor year-to-year changes in spawner densities, age composition, sex ratios, and predation rates by bears for several decades now. Historically, these surveys were integrated across all habitat within small streams and were sub-sampled with index reaches on the larger streams. Periodically we survey many of our historical sites on multiple occasions within a season to evaluate whether spawning run timing has changed over the last few decades.

We also began mapping the spatial distributions of spawning sockeye on finer spatial scales by estimating abundance in each stream in successive 200-m sections. In 2008, we also began using a continuous counting system that enables us to monitor stream habitat use continuously along each spawning stream; each fish location is associated with a GPS position. By monitoring population dynamics at fine spatial scales, we aim to evaluate how habitat use changes with population density, and to improve our understanding of habitat quality in sites throughout the Wood River system.

The Wood River had an above average escapement of 1.8 million sockeye in 2010. Heavy rain in August had produced very high water levels in the streams, making surveys difficult, and counts were probably biased low. In particular, dead salmon were often difficult to enumerate as many were buried or washed out of streams.

As in previous years, this escapement was not distributed randomly across the landscape of habitat in the Wood River system. Tributary streams of Lake Aleknagik had spawning densities that were generally similar to the long term average (Figure 3.1). The number of adult sockeye salmon in Happy Creek was the second lowest observed in the last 20 years, a period over which returns have been very strong to this site. The return to Hansen Creek was high, coinciding with returns from an especially large escapement to the Wood River in 2006. The population cycle that has become established may be undergoing a shift as a result. The return to Ice Creek was about 1/3 of the long-term mean, but this count was certainly low due to high water.

Escapements to streams in Lake Nerka were substantially smaller than the long-term averages. Aside from the Stovall Creek population which was about four

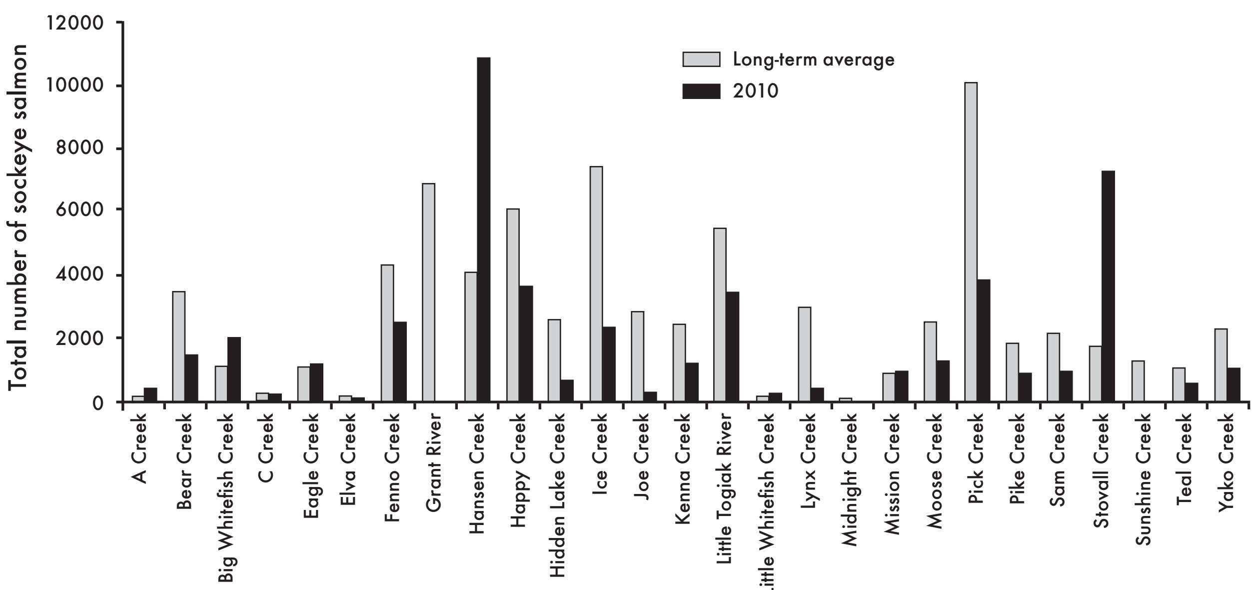


Figure 3.1 Long-term average adult sockeye index counts vs. 2010 index counts for Wood River system sockeye salmon survey streams.

times higher than the long-term average, returns to Nerka streams were only about 40% of the long-term average (Figure 3.1). Returns to A and C creeks on Little Togiak were about the long-term average. The return to Moose Creek on Lake Beverley was about half the long-term average, and to Grant River on Lake Kulik was slightly above the average. We also surveyed Uno Creek on the North Shore of Lake Beverley, a site that had not been surveyed in the recent past. The stream has substantial spawning habitat and an early-spawning population. Only a couple thousand fish were observed here in 2010.

We performed an aerial survey on Aug. 24, 2010 to assess the relative strength of escapement to the rivers and beaches throughout the Wood River system. Returns to beaches, especially in Lake Beverley and Lake Kulik, were particularly strong compared to returns to the large rivers. The age composition of these fish indicated that they were produced from the exceptionally large escapement to these lakes in 2006 (i.e., they were 1.2 fish). Over the entire Wood River system, we estimate that about 73% of sockeye returned to the beaches, which is above the 5-year average of 59%. Including fish spawning in streams, rivers and beaches, we estimate that about 36% of the sockeye salmon escapement to the Wood River system returned to Lake Kulik, 27% to Lake Beverly, 24% to Lake Nerka, and 12% to Lake Aleknagik. About 1% of the total Wood escapement was observed in Little Togiak Lake.

The age composition of spawners in the Wood River system in 2010 was dominated by a age 1.2 (i.e., one freshwater year of growth and 2 marine years of growth) and 1.3 fish, (Appendix B). There was a general tendency for populations in the upper lakes of the system (Kulik, Beverley) and for stream populations on Lake Aleknagik to be strongly biased towards age 1.2 fish. This was particularly true for Lake Beverley and Lake Kulik where a distinct majority of fish were age 1.2. These are the 1.2 returns from the huge escapement in 2006 to these populations. Age compositions observed in Lake Nerka streams were more balanced between 1.2s and 1.3s than in other sites in the system. The very large return of fish to Stovall Creek in 2010 was dominated by 1.2 fish. Interestingly, very few fish returning to the large rivers were 1.2 fish suggesting that a large return of 1.3 fish (from the 2006 brood year) may be seen in 2011.

Proportions of males that were jacks (i.e., 1.1 age fish) in Wood River spawning sites were highly variable among populations. Populations spawning in Aleknagik streams had higher incidences of jacks compared to other sites throughout the Wood River system, except for Teal Creek on Nerka which had the highest proportion of jacks in the system (>30% of males, although the sample size was small).

Kvichak River System

Each year since 1956, we have collected scales or otoliths from spawned-out sockeye salmon from several major spawning grounds in the Kvichak River system. In most years, aerial surveys have been conducted to estimate the relative distribution of the escapement among the various spawning grounds. Aerial surveys of a subset of the spawning grounds were conducted by ADFG in 2010 and accounted for almost 36% of the 4.2 million fish in the total escapement.

The vast majority of the spawners seen were recorded from the Iliamna River (26.4%), Gibraltar Creek (19.3%), Copper River (25.8%), and Knutson Bay (9.9%). These locations accounted for ~81% of all fish seen in the surveys, and match our core collection locations for age composition. The complex of populations spawning on island beaches were not counted via aerial survey, so our annual survey by boat gave us the only information on these spawning populations. Large numbers of spawners were present on NW Woody Island beaches, Porcupine Island, Cottonwood Point, and Fuel Dump Island beach. Additional large groups of spawners were present on the Flat Island spawning beaches (Flat Is No. 2, and No. 3). Surprisingly, no fish were present on Triangle Island, and few fish used E-2 Island. Notably, numbers were the highest we have ever seen this year in the Pedro Pond complex during our foot surveys, and the aerial counts confirm this, with the highest survey tally since 1974.

Fortunately, our ground surveys for otolith collection coincided well with the peak distribution of spawners for the Iliamna Lake populations. Otolith collection continued at sites we have sampled annually: Copper River, Gibraltar Creek, and Chinkelyes Creek (larger river and creeks), two representative island beaches (Woody and Fuel Dump islands), the mainland beach at Knutson Bay, and a system of spring-fed ponds in Pedro Bay. Additionally, we were able to collect samples from the mainland beach at Finger Bay. Age composition determined by otoliths revealed some variation in ages across the different populations in 2010—about 60% of both males and females were 4 year old fish, and about 40% were 5 year old fish, with the majority of the five year olds being of the 2.2. age class. The mainland beach at Knutson Bay, the Woody and Fuel Dump Island spawning beaches, and the Pedro Ponds system were dominated by the 1.2 age class (+90% of all fish in each population). Five year old fish (mostly 2.2 age class) were found in good numbers in Gibraltar Creek, Copper River, and Chinkeleyes Creek (76%, 67%, 48% respectively), with 1.3's present at Copper River, Finger Bay beach and Chinkelyes Creek. The Kvichak system saw another relatively strong return year of 2.2 age class (~43% of the escapement), and last year's escapement was ~45%

2.2s; these are the highest 2.2 returns seen since the 2004 escapement (69% 2.2s). Cooler spring conditions since 2006 likely played a role in increased smolts leaving as 2-checks, and we expect this trend to continue.

Hansen Creek Daily Runs and Bear Predation

H Rich (research scientist), C Cunningham (graduate student) T Quinn (adviser)

Hansen Creek, a small tributary to Lake Aleknagik, has been the focus of long-term research on sockeye salmon spawning behavior, life history, ecology and evolution, with special emphasis on bear predation. This stream has shown a clear, 4-yr cycle of abundance, with large runs in 1987, 1991, 1995, 1999, 2003, and 2007. However, the 2006 'pre-peak' run of 20,440 spawners was significantly larger than the 7,850 fish that returned in the "peak" year of 2007. The 2010 run to Hansen Creek of 14,375 was large for a pre-peak year, although the 4 year old fish (1.2 age class- 94% of the Hansen run), returning in 2010 were from the anomalously large run of 2006, which was a record escapement to the Wood River system as a whole, and may not be indicative of a shift in the cycle. Off-peak year's run sizes are typically in the 3,000–4,000 spawner range, with a larger pre-peak run, followed by a larger still peak run. A large number of jacks seen in the creek in 2009 (5.9% of males) suggested a large pre-peak year was coming in 2010. Interestingly, 5% of the males in 2010 were also jacks, indicating another strong year class on the way for the scheduled "peak" year run.

In 2010, the average size of female sockeye salmon was 401 and 456 mm for ages 1.2. and 1.3 respectively (mid-eye to hypural plate), and for male sockeye was 283, 406, and 470 mm for ages 1.1, 1.2, and 1.3 respectively. Both males and females were dominated by the 1.2 age class. The sex ratio was ~33% male in 2010, down from 2009 (53%), but in line with what we had seen over the last 3 years (~35%).

Predation by bears is density-dependent on an inter-annual basis, and predation rate by bears in 2010 was 55% (run size 14,375), consistent with the trend seen in previous years, but slightly higher than expected (Figure 3.2). Predation in Hansen Creek and elsewhere in the system (e.g., Pick and Bear creeks) is size-selective—larger fish are more vulnerable than smaller fish (Quinn and Buck 2001). In addition, males are generally more likely to be killed than females, and this is true again this year (59.7% of males killed vs. 52.6% of females; Table 3.1). The detailed studies at Hansen Creek are being applied to the more extensive, but less intensive sampling that we conduct in association with the annual creek surveys throughout the system. These data demonstrate that the level of predation is a decreasing function of stream size (especially width), and the age structure and morphology of sockeye salmon are clearly related to habitat and predation (Quinn et al. 2001a; Quinn et al. 2001b; Carlson et al. 2009).

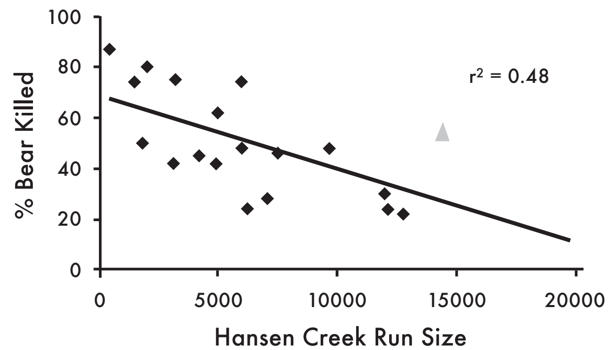


Figure 3.2 Effect of spawning run size on the kill rate by bears in Hansen Creek (modified from Rogers et al. 2003). The gray triangle denotes 2010 run size.

Table 3.1 Number of bear-killed salmon and other sources of mortality combined, by sex and section of Hansen Creek, 2010.

Section	Status	Female	Male	Total
Mouth	Bear	171	152	323
	Other	112	123	235
Lower	Bear	1750	1095	2845
	Other	1105	348	1453
Middle	Bear	1237	604	1841
	Other	1261	541	1802
Pond	Bear	117	100	217
	Other	550	222	772
Upper	Bear	1237	547	1784
	Other	1042	455	1497
Total	Bear	4512	2498	7010
	Other	4070	1689	5759
% Bear Killed		52.6	59.7	54.9

A and C Creeks

D Peterson (graduate student), L Hauser and R Hilborn (advisers)

A and C creeks, located in Little Togiak Lake, are two of the smallest salmon runs we regularly monitor, and are at the extreme of several dimensions of adaptation, including depth of water (shallow), intensity of bear predation (high), and life expectancy after stream entry (short). Since 1996, we have attempted to monitor these streams daily, marking every individual fish and recording its location in the creeks. In the last several years, graduate students have been using these systems for their research: Jocelyn Lin has studied genetic differentiation between lake and creek spawning fish (Lin et al. 2008a), and Stephanie Carlson used the data in her analysis of senescence rates (Carlson et al. 2007). A new graduate student, Daniel Peterson, started a project this year to examine how yearly variation in predation pressure and dispersal behaviors affects the number and reproductive success of migrants between subpopulations. Dispersers mix genetic material between the beach populations and the two creeks, thus affecting the ability of the metapopulation of salmon to evolve to novel selection pressures as well as the susceptibility of individual sub-populations to the negative effects of inbreeding.

A major objective is to pedigree the populations: that is, to determine who the parents were for each individual returning in a generation. This will allow us to determine how many individuals, and what habitats, produce successful offspring, and calculate several factors important to genetic differentiation, such as the effective population size. In addition, we should be able to calculate the heritability of phenotypic traits, both morphology and behavior, from pedigree data. We first obtained near-complete genetic samples in 2003, and we continued genetic sampling in 2004–2010, collecting samples from between 87% and 100% of the population. In 2010, the offspring of fish that spawned in 2005 and 2006 returned, and we sampled 99% of the population in both A and C creeks. If we can continue to sample at such high levels in 2011 we should be able to assign parentage to most of the 2006 fish (See Lin et al. 2008a for further information on the genetics of A and C Creeks).

A and C creeks are normally characterized by extremely intense bear predation—A Creek in particular often being completely cleaned out by bears several times in the season. 2010 was a classic case of this, with the bears killing almost every fish in A creek on several occasions, resulting in 97% of the deaths being bear kills with another 3% killed by gulls. Similarly the bears killed 84% of the dead fish in 2009 and 83% in 2008. In C Creek bear kills constituted 96% of fish that died, but probably due to habitat differences between the creeks, it never wiped out all of the fish until close to the end of the run. Prior to 2004, there was a beaver dam on C Creek about 200 m from the lake. This dam broke down during the 2004 season and, since then, we have seen a number of fish colonize the area above the dam, providing excellent data on how quickly new habitats are colonized. In 2009 and 2010 the fish moved further up into new habitat than they had before. Despite the increased habitat there were fewer total fish in C creek (294) than in A Creek (457). Figure 3.3 shows the number of fish entering, and the number of fish still alive in A and C creeks for 2010.

Photo: H Rich

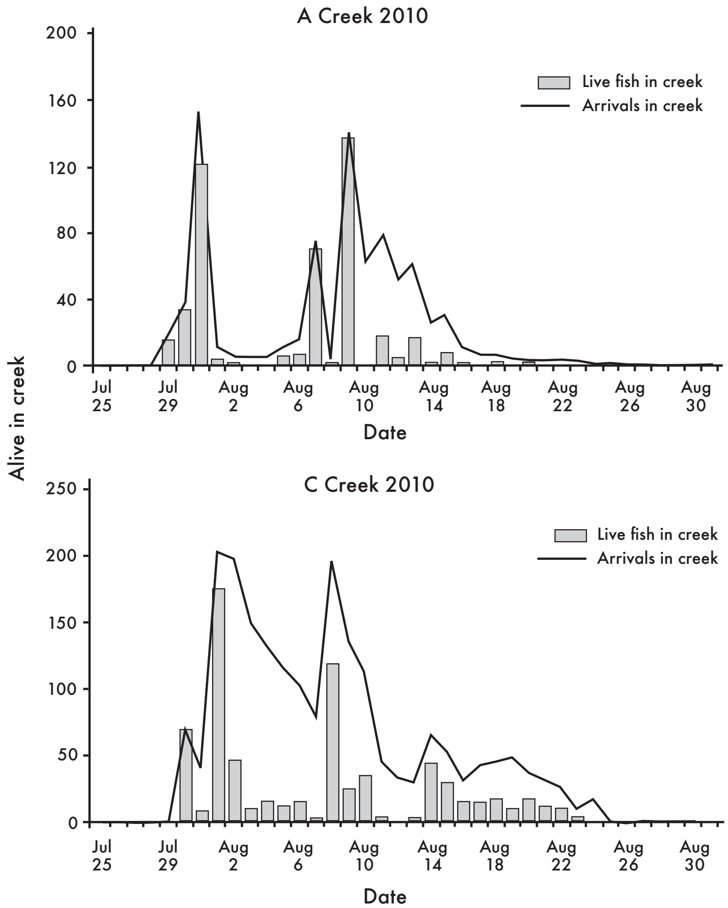
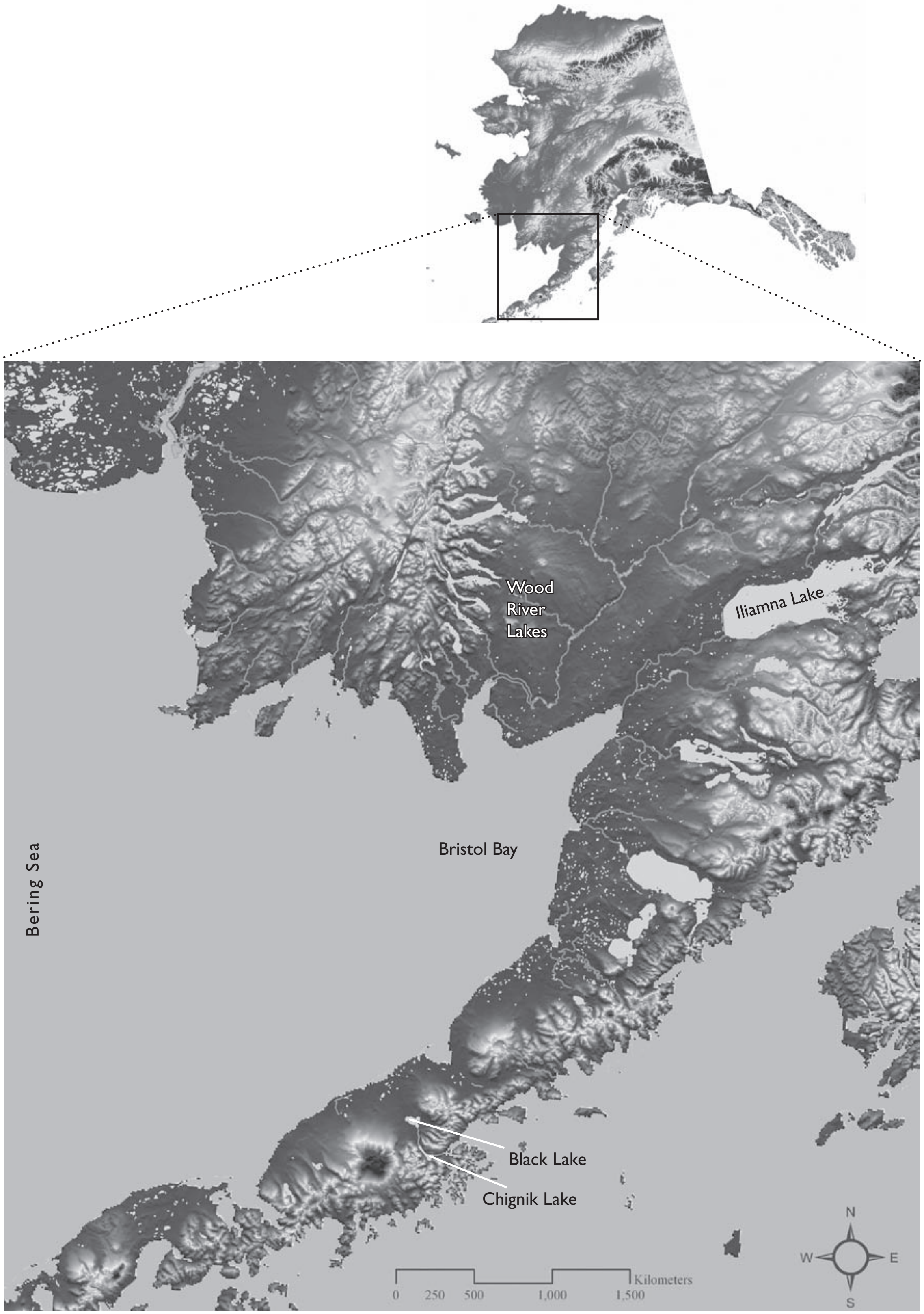
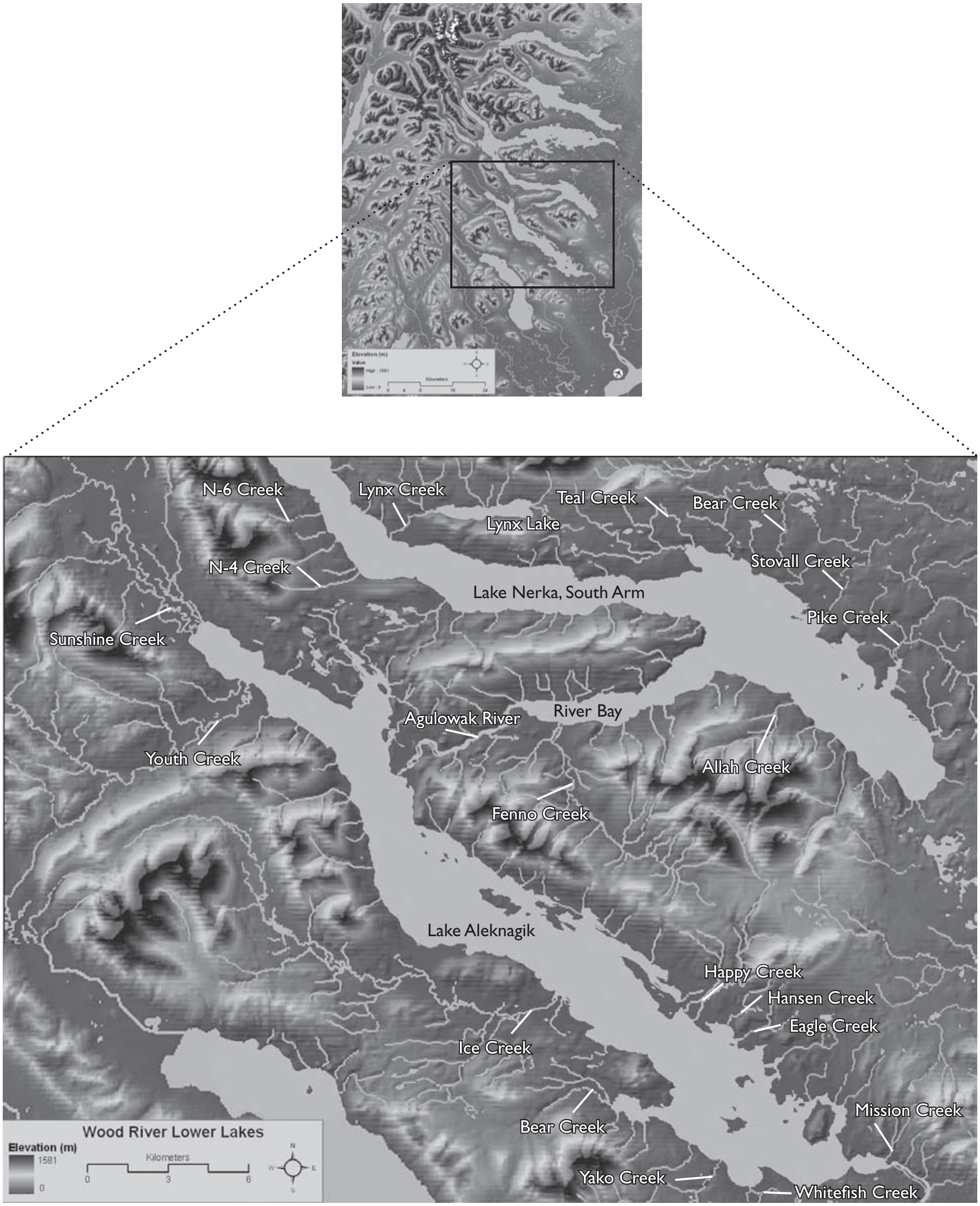


Figure 3.3 Number of fish entering (gray bars) and total fish (black line) in A and C creeks, Little Togiak Lake, for 2010.

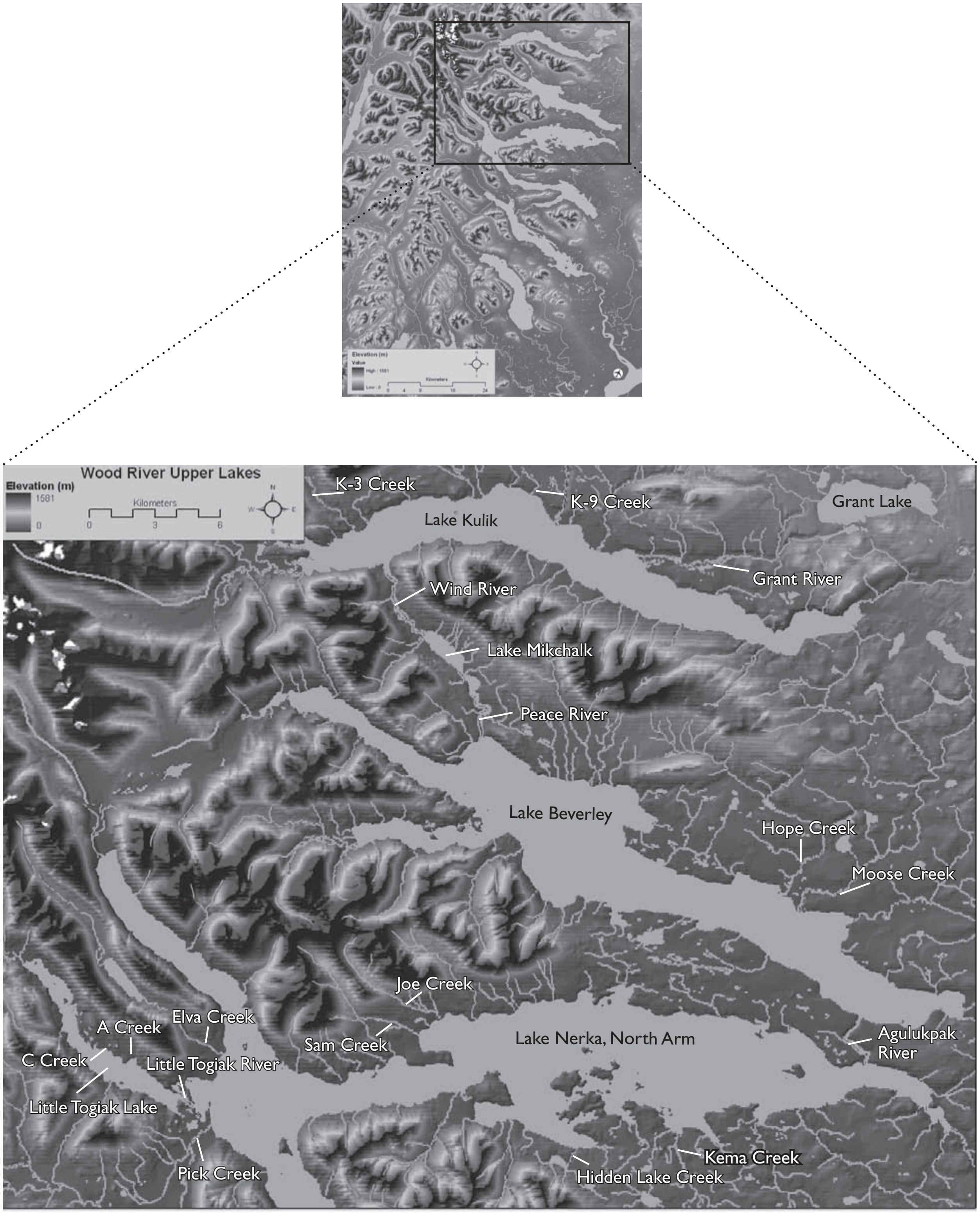
Maps



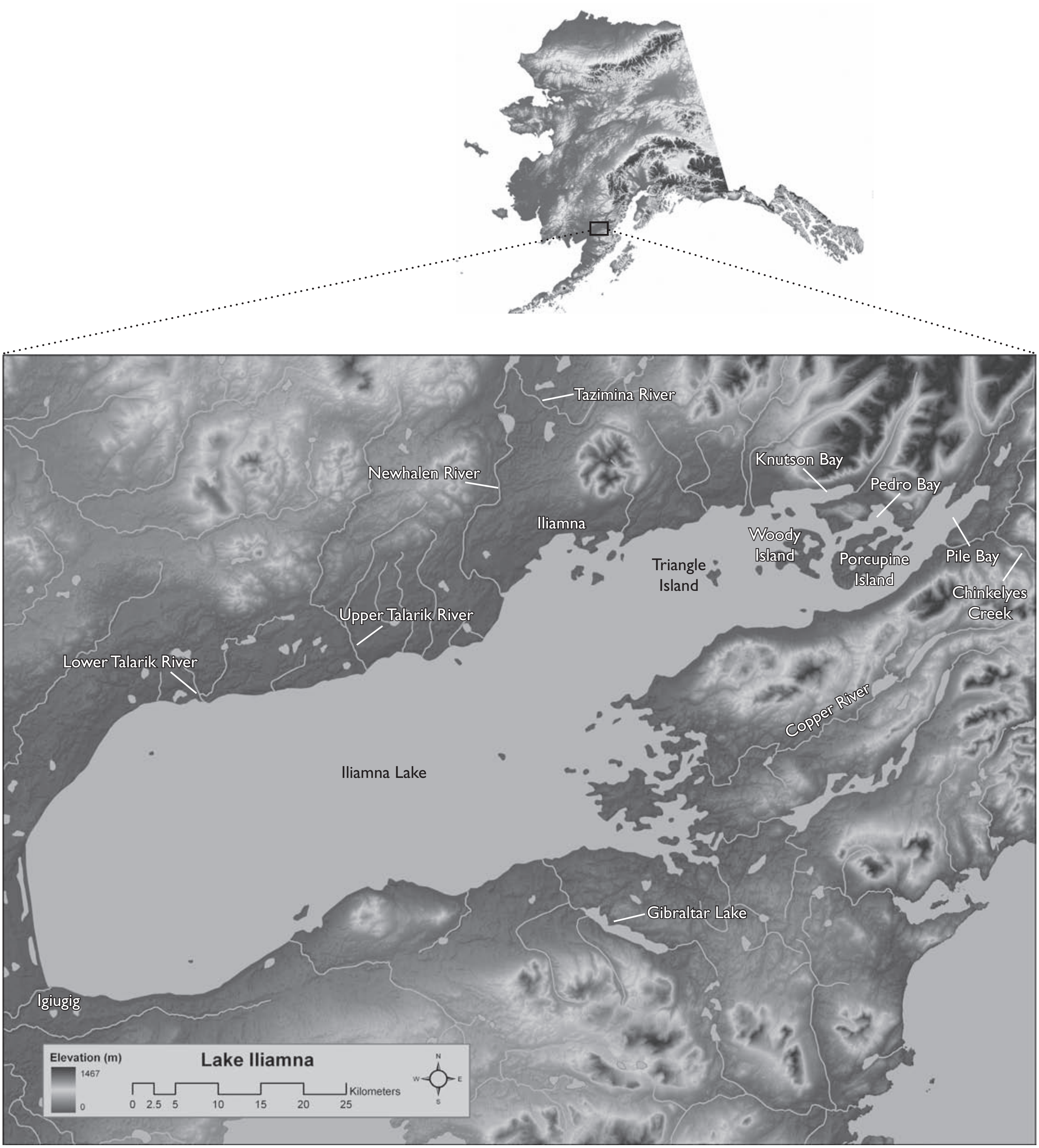
Map of the Alaska Salmon Program's three major research areas: Wood River lakes, Iliamna Lake, and the Chignik Lake system.



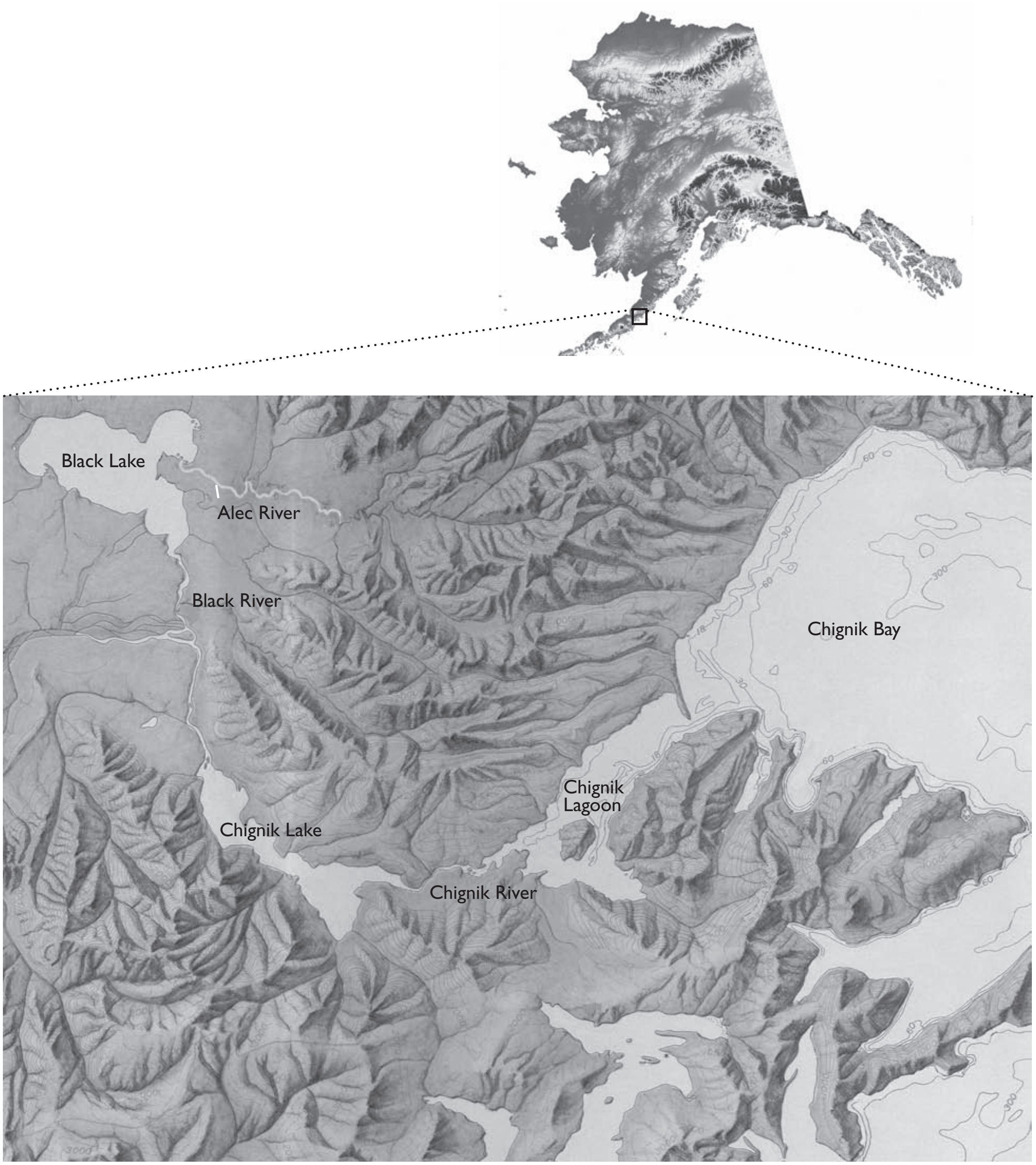
Detail map of lower Wood River lakes.



Detail map of upper Wood River lakes.



Detail map of Iliamna Lake.



Detail map of Chignik and Black lakes.

4. Lake Ecosystems

Introduction

Our limnological and environmental records from the Wood River system and Iliamna Lake are now continuous for spring and summer seasons for more than 50 years, and we have made extending these valuable records a programmatic priority. One striking feature of these long-term records is the large change in environmental conditions associated with climate warming during the last century. Climate warming has been especially notable throughout Alaska, and it appears to be having a wide array of effects on the physical and biological aspects of the spawning and nursery habitats of salmon and other aquatic species. Some of these responses are described in more detail in the research descriptions in this section.

The summer of 2010 was relatively cool and characterized by heavy rainfall in July and August. The thermal conditions were quite similar to the long-term average conditions observed in the last 50 years, but were among the coldest observed in the last 15 years (Table 4.1, Figures 4.1, 4.2). These cool conditions followed the similarly cool conditions observed since 2007. In addition to maintaining our routine environmental and limnological monitoring, we have continued our paleolimnological research to reconstruct historical sockeye salmon escapement densities over the last several centuries. This research is enabling us to better understand the responses of sockeye populations to long-term variation in climatic and ocean conditions.

Environmental Conditions & Limnology

Thermal Conditions: Wood River

Bristol Bay was relatively cold in 2010 compared with the last decade and, therefore, was an anomaly from the long-term warming trend observed over our period of records. The springs of 2002–2005 were substantially milder than average as reflected by the timing of spring ice break-up and spring water temperatures. In general, the date of spring ice break-up has advanced considerably and is about 10 days earlier now than it was in 1962. However, in 2010, spring ice break-up occurred on May 30 and May 19 in lakes Aleknagik and Iliamna, respectively.

Statistical time-series analyses of the long-term changes in spring break-up date on Lake Aleknagik (Figure 4.1) show that the Pacific Decadal Oscillation and a long-term warming trend associated with global warming have contributed about equally to the trend towards earlier ice break-up dates (Schindler et al. 2005). Conditions in 2006–2010 were clearly an anomaly from this trend and were about average considering the long-term record. This shift in ice breakup timing that is more similar to the long-term average has been coincident with declining intensity of the Pacific Decadal Oscillation in the last few years. Spring lake temperatures are strongly correlated with the timing of spring ice break-up. In 2006–2010, water temperatures were generally colder than those observed for most of the last 17 years. Between 1993 and 2005, spring water temperatures in all but one year (1999) were warmer than average. However, substantially warmer spring conditions do not carry over directly into equally warmer summer conditions. In fact, surface water temperatures in July and August of 2003–2005 were only subtly warmer than the long-term averages in Lake Aleknagik. From 2006–2010, water temperatures were on target or slightly colder than the 50-year average conditions in Lake Aleknagik (Table 4.1, Figure 4.1). Water temperatures in 2010 were approximately average in June and July but then about 1° C colder than the 50 year average in August.

Water transparency in Lake Aleknagik in 2010, as measured by Secchi depth, was slightly lower than the long-term average, supporting the recent trend towards lower transparencies observed in the last few years (Table 4.1).This decreased transparency was particularly noticeable in August and September, coincident with heavy rainfall late in the summer. Water conductivity during recent years has not varied much from long-term average conditions (Table 4.1).

Table 4.1 Summary of environmental variables and conditions in the Wood River system in 2010 compared with long-term average conditions (1950–2010).

	Year	Date							
1. Date of ice break-up 1949–2010	2010	5.30							
	average (1949–2009)	5/28							
	range (1949–2009)	4/28-6/17							
		25-Jun	**14-Jul**	**2-Aug**	**31-Aug**				
2. Water surface temperature 0-20m 1958–2010	2010	6.8	9.3	10.5	10.7				
	average (1958–2009)	6.2	9.0	11.2	11.6				
	range (1958–2009)	3.8–13.7	8.1–18.0	9.4–18.8	9.7–16.0				
3. Water transparency Secchi depth (m) 1962–2010	2010	6.2	7.1	8.8	6.9				
	average (1962–2009)	7.6	8.2	9.4	9.2				
	range (1962–2009)	4.8–10.5	4.7–12.3	6.3–10.9	5.8–12.1				
4. Water conductivity (micromhos/cm) 1968–2010	2010	40	40	40	40				
	range (1968–2009)	39.1	39.4	38.1	39.1				
	range (1968–2009)	31.1–52.1	32.0–42.6	32.5–40.5	32.2–47.9				
		June 1–15	**June 16–30**	**July 1–15**	**July 16–31**	**Aug. 1–15**	**Aug. 16–31**	**Sept. 1–15**	**Sept. 16–30**
5. Lake level (cm) of Lake Nerka 1952–2010	2010	147	141	120	100	126	153	108	
	average (1952–2009)	149	152	130	104	87	81	81	91
	range (1952–2009)	84–227	97–218	74–199	52–172	34–173	30–184	29–161	76–102
		June		**July**		**August**		**September**	
6. Total Zooplankton Density 0-60m (100s of animals/m2) 1967–2010	2009	1108		1663		1470		1635	
	average (1967–2008)	1562		1910		2509		2764	
	st dev (1967–2008)	313		483		524		449	

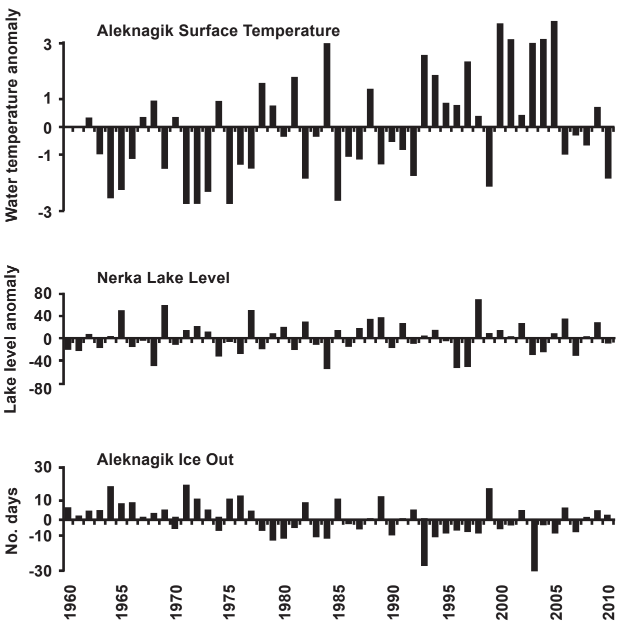


Figure 4.1 Time series (1960–2010) of spring environmental indicators from the Wood River system. Spring (June 22–25) water temperatures are given as the anomaly from the long-term mean (6.4° C). Water level at Lake Nerka is given as the anomaly from the long-term spring (June 6–30 mean [151 cm]). Ice break-up date is given as the number of days before/after May 28.

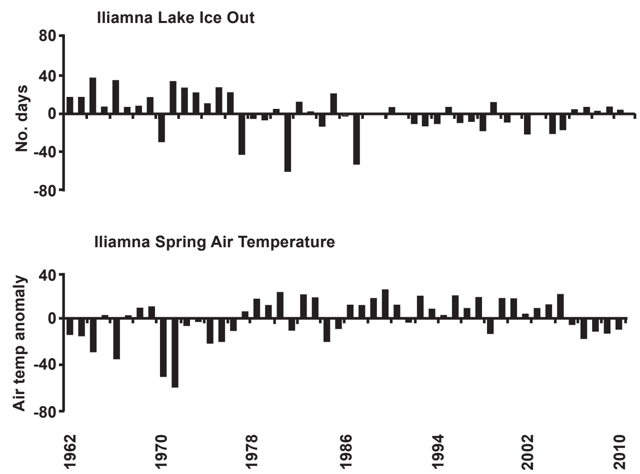


Figure 4.2. Top: Time series (1962–2010) of ice break-up date for Iliamna Lake given as the number of days before/after the long term average date of May 18. Bottom: Spring air temp index (difference from mean March–June) from Iliamna, Alaska 1962–2010.

Lake Level

We have used the lake level in Lake Nerka as our integrated measure of hydrology throughout the Wood River System. Lake level was slightly below average throughout June and July (Figure 4.1) due to little residual snowpack and low rainfall during the early part of the summer. However, by early August, heavy rainfall brought lake levels to above average conditions which were maintained through the end of August (Table 4.1). Lake levels remained high into September.

Thermal Conditions: Iliamna Lake

Thermal conditions in the Iliamna Lake system have also shown a steady warming trend over the last five decades that parallels the observed increases in spring environmental conditions in the Wood River system. In the Iliamna Lake system we also have a long-term record of ice-free data, which have been collected each year by FRI and ADFG personnel. In 2010, we saw an ice free date of May 19, which was similar to the later dates we have seen over the last four years, and about three days later than the long-term average (Figure 4.2).

After the cool spring air temperatures—which were the 16th coldest on record over the 49 year time series (1962-2010, Figure 4.2)—summer conditions in 2010 were cool and wet again. July 2010 was the wettest July on record, with over 7 inches of rainfall recorded. The mean 2010 August air temperature at Iliamna was 11.9° C, cooler than the long-term average of 12.4° C (since 1960). Daily water temperature measurements at Woody Island in the eastern end of Iliamna Lake recorded by our HOBO sensors showed cooler summer temperatures (July 1 to August 11) in 2010 (mean 8. 5° C), cooler than in 2008, 2009 (9. 8°, 9.7° C) and much cooler than the very warm summer of 2005 (mean 13.2° C).

Zooplankton and Aquatic Insects

We have monitored zooplankton abundance in Lake Aleknagik since 1967 as a means for assessing temporal trends in the primary prey for juvenile sockeye salmon and their competitors (e.g., sticklebacks). The observed warming trend in water temperatures is strongly and positively associated with enhanced zooplankton densities throughout the summer (Carter 2010). In 2003–2005, total crustacean zooplankton densities were substantially higher than the long-term averages, and these differences were most pronounced late in the season (August and September) when sockeye fry are located in pelagic habitats and feeding almost exclusively on zooplankton. The taxa that appear to be benefiting most from this warming trend are the cladocerans Eubosmina and Daphnia, which are important prey for sockeye throughout their range (Schindler et al. 2005). These taxa are found at relatively low densities in the spring and reach peak densities in August and September (Figure 4.3). In 2003–2005, Eubosmina and Daphnia densities were approximately double the long-term means for August and September. Both cyclopoid and calanoid copepods, which are generally more abundant early in the summer, were found at densities comparable with the long-term means in Lake Aleknagik (Figure 4.3).

In 2010, zooplankton densities showed some substantial departures from the long-term averages (Figure 4.3). The zooplankton community continues to be dominated by cyclopoid copepods and bosminids. However, both Daphnia and calanoid copepods (preferred prey for juvenile sockeye) had substantially lower than average densities in 2010, coincident with the cool water temperatures which constrain zooplankton production in this system (Carter 2010). Eubosmina had substantially higher than average population densities throughout the summer of 2010.

Juvenile Sockeye Abundance and Size

Wood River

We have sampled juvenile sockeye fry in the Wood River system in August of each year since 1958 by tow netting at night. The resulting data are collected to monitor growth of juvenile sockeye during their freshwater residency. An analysis of this dataset showed that the climate warming trends evident in the ice break-up dates and in water temperatures have effected enhanced growing conditions for juvenile sockeye from 1962 to 2002 (Schindler et al. 2005). The specific mechanisms accounting for the enhanced growing conditions have not been pinpointed yet, but they appear to be a combination of a longer grow-

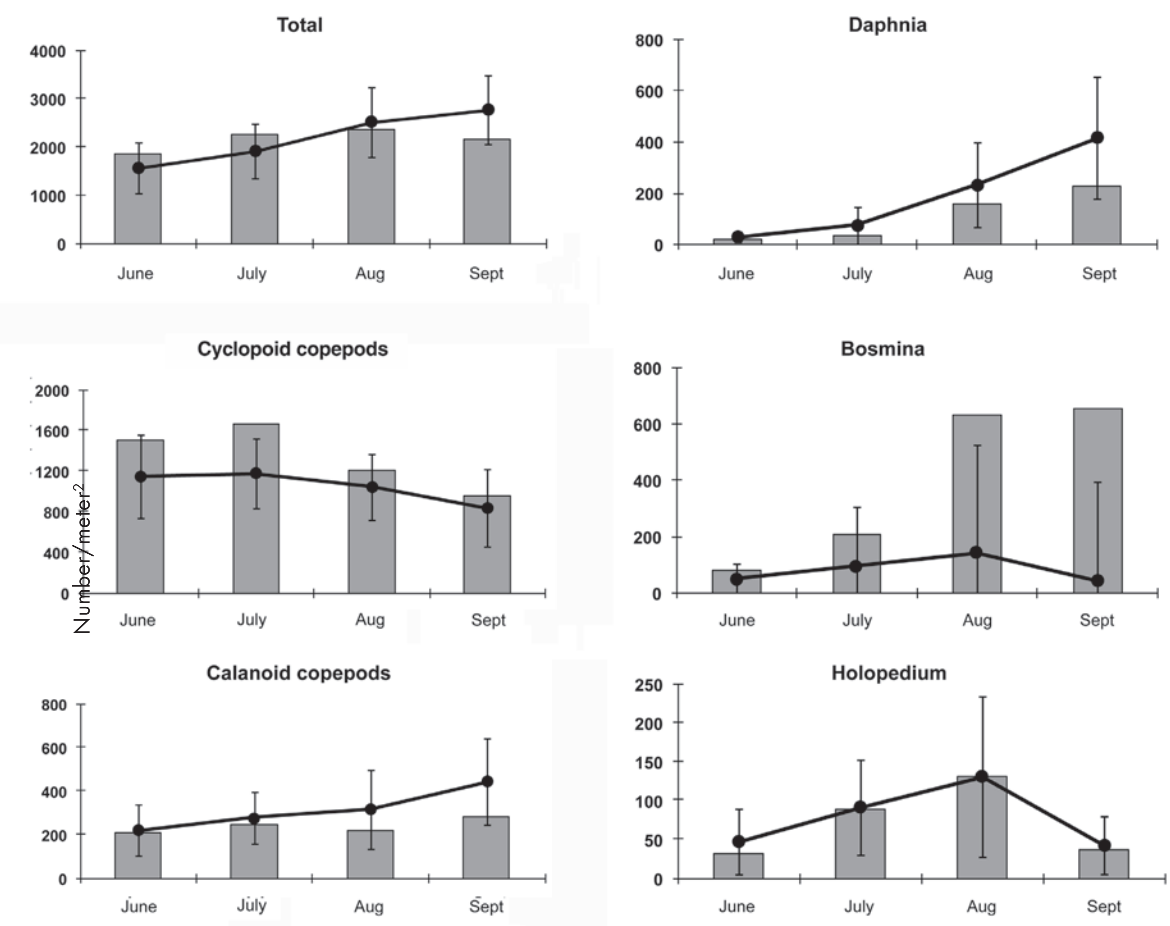


Figure 4.3 Monthly zooplankton densities in Lake Aleknagik from 1967 to 2009 (lines with standard deviations) compared with densities observed in 2010.

ing season, increased water temperatures, and increased zooplankton abundance—all of which should yield higher growth of juvenile sockeye in lakes. These improved growing conditions for juvenile sockeye are associated with the long-term population buildup in the Wood River since the 1960s. As escapements have increased during this time period, there has also been increased competition among juvenile sockeye in the Wood River system, a process that partially obscures the positive effects of a warmer climate (Schindler et al. 2005).

In 2010, sizes of sockeye fry in all lakes of the Wood River system were very close to the average seen on September 1 across the period of record (Figure 4.4). The notable exception to this general observation is that sizes of fry from Lake Aleknagik were larger than average again in 2010, continuing a trend in this lake that has been consistent for the last decade. The depressed growth rates observed in Lake Beverley during 2007–2008 reflecting the exceptionally high sockeye escapement in 2006, have apparently recovered to approximately average rates in 2009 and 2010.

Wood River Sockeye Smolts

In 2008, we re-initiated the FRI sockeye smolt sampling program at the outlet of Lake Aleknagik (Mosquito Point) and continued this sampling in 2009 and 2010. We used the same sampling design and similar gear (fyke net) described by Burgner (1962) to evaluate changes in migration timing, sizes and age composition of smolts. In addition, we used genetics stock identification techniques to assign the population of origin of fish migrating over the course of the season (McGlauflin et al. in press).

In general, sockeye smolt migration timing in 2008–2010 was later and more protracted than estimated for the 1950s by Burgner (1962), who showed a relatively strong positive relationship between the date of Aleknagik ice break-up and the smolt migration timing. Smolts were caught between June 1 and August 14 in 2008, from June 2 until September 4 in 2009, and from June 10 until August 28 in 2010. Smolt migration timing was later in 2010 than observed in 2008 and 2009 (Figure 4.5). The timing of ice break-up in 2008 was about average (May 28) and the timing of the 20th percentile of the smolt migration

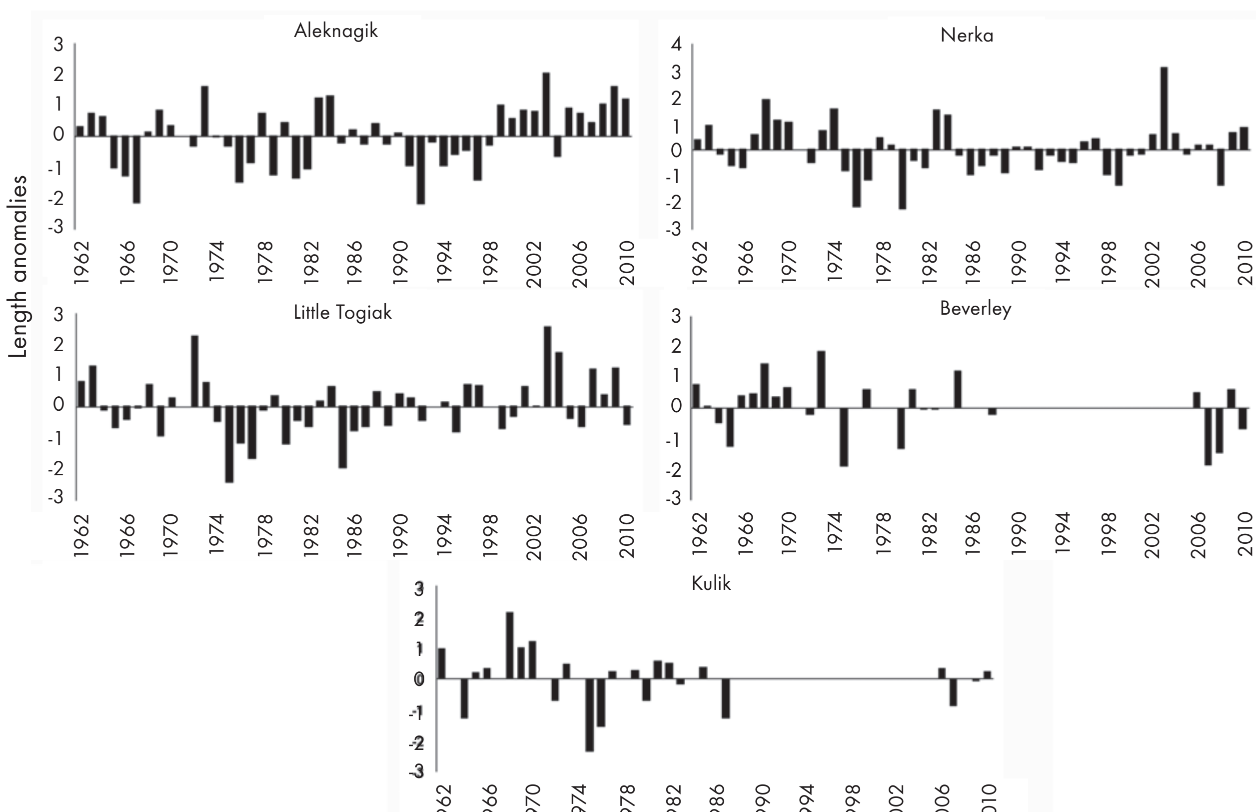


Figure 4.4 Size of sockeye fry on September 1, 1962–2010 for all Wood River lakes. All fish were sampled with night tow net surveys. Annual length anomalies (measured as fork length, mm) are based on the long-term average (Aleknagik, 55.47; Nerka, 56.27: Little Togiak, 52.69; Kulik, 54.20; and Beverley, 54.60). Kulik sockeye in 1967 were 10.9 mm larger than the average.

was June 27. Ice break-up occurred on June 1 in 2009 and the 20th percentile of the smolt migration was about June 27 again. In 2010, ice breakup was on the 30th of May and the 20th percentile of the smolt run occurred on July 8. In contrast, in 1953, 1954, and 1957 the ice break-up occurred between May 26–28, but the 20th percentile of the smolt run occurred between June 2 and June 12. This delay in the smolt migration timing may be a reflection of larger contributions of fish from lakes Beverley and Kulik, which have had strong escapements in recent years. In general, smolts from Beverley and Kulik are thought to migrate later in the season than fish from the lower lakes of the Wood River system (Burgner 1962).

There was wide variation in the size of smolts leaving the Wood River between 2008 and 2010, characterized by a strong upward trend in average smolt size from about 75mm (3 g) in early June to 95mm (7.5 g) by the end of July. Smolt sizes were largest in 2010, and smallest in 2008, when comparing among years from 2008-2010. By the end of August (2010) average smolt sizes were over 110mm fork length (Figure 4.6).

Kvichak

We have sampled sockeye salmon fry and yearlings in August of each year since 1962 (1961 brood year) by tow netting at night in Iliamna Lake (similar monitoring was done in Lake Clark until 1995). These tow net catches are used to generate an index of relative abundance for fry each year. The index value for fry abundance in 2010 was the highest on record, and is the third year in a row with higher-than-average index values (Figure 4.7), indicating good survival from the 2.3 million parent escapement in 2009. Catch rates of sockeye fry in August tow netting surveys had been consistently lower than average from 1997–2007, coincident with the lower escapements to the Kvichak River during this time period (Figure 4.7). The parent escapement from 2009 (2.3 million spawners) was smaller than the long-term average, and fry production was much higher than would be expected from this escapement; interestingly, we also saw relatively high catches of age-1 (yearling) sockeye salmon. This may reflect slow growth of that cohort caused by cool spring temperatures in 2009 and coincidently high fry production, resulting in a larger fraction of the brood remaining in the lake rather than leaving as smolts at age-1.

Fry size at the end of the first growing season is largely influenced by temperatures experienced shortly after emergence. The adjusted mean length of fry caught in 2010 Iliamna Lake tow net operations (47 mm) reflects the pattern of cooler springs and resulting smaller fry. The 2010 adjusted mean length was 10 mm smaller than the long-term average (57 mm). The smaller size of fry this year match smaller sizes we have seen since the 2006 calendar year, and all of those cohorts also experienced cold spring temperatures similar to this year's cohort. The small fry seen this year, were smaller than temperature alone would explain. Fry length has also been shown to be effected by both inter- and intra-brood density, in addition to spring temperatures (Rich et al. 2009). The intra-brood densities were much higher than average, and the additional higher prevalence of age-1 yearling sockeye from the 2008 brood (inter-brood) must also have contributed to slower growth seen in this year's fry cohort.

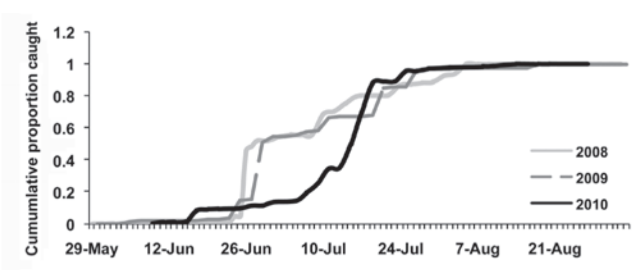


Figure 4.5 Cumulative catch by date for 2008–2010 Wood River smolt trap operated at Mosquito Pt. at outlet of Lake Aleknagik.

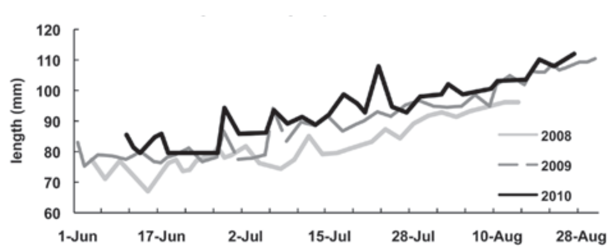


Figure 4.6 Average smolt length by date for 2008–2010 Wood River smolt trap operated at Mosquito Pt. at outlet of Lake Aleknagik.

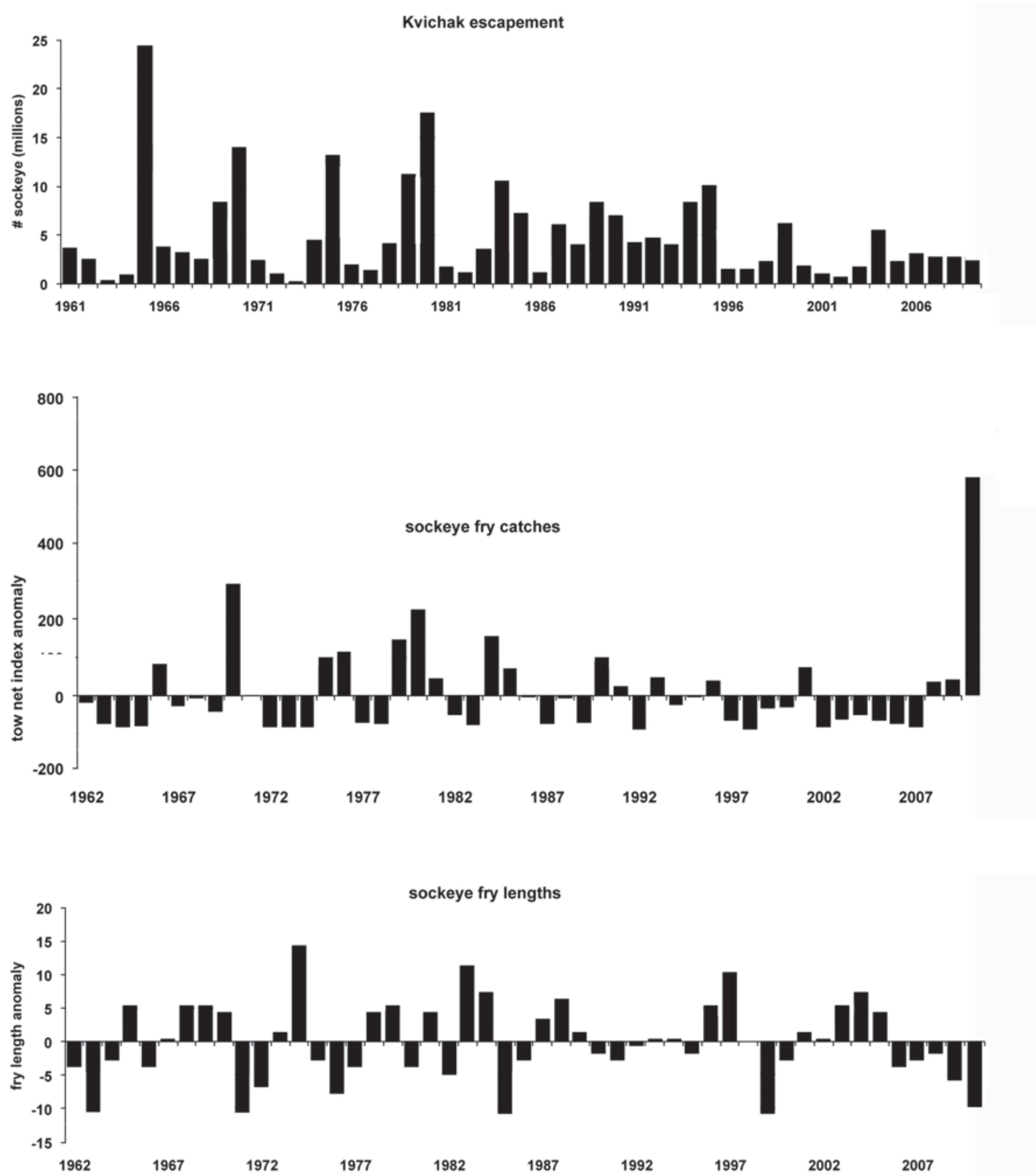


Figure 4.7 Kvichak River escapement (1961–2009), Iliamna Lake tow net index for sockeye fry catches (deviation from mean), and sockeye fry length (deviation from mean) 1962–2010.

5. Salmon Genetics

Evolution and Maintenance of Genetic and Phenotypic Diversity

A core component of biocomplexity for studies is the investigation of the current population structure of sockeye salmon and the ways in which this structure has evolved. Our investigations and those of our collaborators have spanned a range of spatial and temporal scales to consider the patterns and processes of sockeye salmon biodiversity in Bristol Bay. At a mechanistic level, we have demonstrated the restricted movements of individual adult sockeye salmon of both sexes once they settle in specific areas of a stream (Hansen Creek, flowing into Lake Aleknagik), and their tendency to return to these areas after displacement (Stewart et al. 2004, Rich et al. 2006). Most recently, experimental thermal marking of embryonic salmon otoliths allowed us to show extremely fine-scale homing to natal sites within this very small stream system (Quinn et al. 2006).

These studies of homing at fine spatial scales, combined with work on isolation of temporally discrete breeding groups within a stream conducted by collaborators (Hendry and Day 2005), open up the possibility of an exceptionally complex population structure in a single creek. We know that salmon arriving early tend to be larger than those arriving later, and that they tend to selectively settle and breed in certain areas of some creeks. We plan to combine datasets on these phenomena to shed light on the interplay between arrival timing and nest-site use in one creek.

The work on spatial and temporal aspects of homing led us to compare the genetic structure of sockeye salmon in three small streams, in close proximity within a single bay of Lake Aleknagik: Happy, Hansen, and Eagle creeks (see map, page 12). Adult sockeye salmon in Happy and Hansen creeks are similar in spawning timing but differ in size and morphology (Happy Creek fish being older, larger for their age, and deeper-bodied for their length than in Hansen Creek), whereas Hansen and Eagle creek fish are similar in size and shape but differ in timing (Eagle Creek fish spawn later than those in Happy and Hansen creeks). We collected DNA samples for microsatellite analysis from early and late fish in Happy and Hansen creeks, and fish from Eagle Creek similar in timing to the late collections from the other creeks. These data demonstrated a lack of genetic differentiation despite morphological variability, suggesting the presence of strong selection pressures maintaining phenotypic differentiation (Lin et al. 2008b).

At a somewhat broader scale, we are investigating the levels of gene flow between pairs of populations spawning in creeks and nearby beaches. Building on previous work showing that sockeye salmon (and especially males) spawning in creeks are much less deep-bodied than those spawning in beaches (Blair et al. 1993, Hamon et al. 2000, Quinn et al. 2001a), we are collecting data on size and shape in sockeye salmon spawning in two small creeks flowing into Little Togiak Lake (A Creek and C Creek), and the sockeye salmon spawning on beaches in the lake at the outlet of each creek. Data from three brood years (2002–2004) showed strong differentiation between beach and creek spawners as well as higher differentiation between the populations in the two creeks than between the beach populations (Lin et al. 2008a). More importantly, the genetic data provided evidence of considerable annual variation in straying rates, and the A Creek population showed signs of complete replacement by immigrants in 2004. In addition, we have collected similar data from creek and beach spawners in Lynx Creek in Lake Nerka, Yako Creek in Lake Aleknagik, and Knutson Creek in Iliamna Lake (see maps, pages 12–14). These samples have been screened for genetic diversity and will be analyzed to test the generality of the findings from A and C creeks in an effort to determine the relative rates of gene flow between proximate but different habitats (i.e., creek and beach) and between more distant but similar habitats (i.e., beach-to-beach and creek-to-creek; Lin et al. 2008a, 2008b).

At a still broader scale, we have been collaborating with geneticists at the ADFG who have been examining possible differences in timing of adult and smolt migrations between sockeye salmon from Lake Clark and Iliamna Lake. These scientists have had considerable success in differentiating sockeye salmon from these two lake systems, but it appears that the timing of adult and smolt migrations do not differ between these population complexes (Habicht et al. 2004). We are currently in the process of standardizing molecular genetic methods between laboratories, and hope to exchange data more readily in the near future. Such data exchange will greatly improve our genetic database, which will allow a more thorough investigation of genetic diversity of Alaskan sockeye salmon. Finally, our collections have contributed to a review of population structure of sockeye salmon across their entire distribution (Beacham et al. 2006).

Photo: T Quinn

6. Student Projects

Graduate Student Projects

Jonathan Armstrong, PhD candidate

Adviser: Daniel Schindler

Thermal heterogeneity and the energy budgets of consumer fishes

The spawning migration of Bristol Bay sockeye salmon provides a brief window of spectacular bounty, and the annual success of consumers throughout the world, ranging from humans to Arctic Terns, may depend critically on their ability to extract profit from this resource pulse. The commercial gillnetting fleet can catch fish faster than tenders can process them, which in some years leads to bottlenecks that result in lost revenue. Analogously, animals such as resident fishes, bears, and gulls may face digestive bottlenecks as they gorge on salmon eggs and flesh at rates faster than their guts can handle. For cold-blooded animals, such as fishes, water temperature strongly controls maximum rates of food-processing, and thus the ability to capitalize on pulses of salmon eggs. I study how juvenile coho salmon exploit patchiness in water temperature to reduce digestive bottlenecks and increase their energetic revenue. Many individuals binge-feed on eggs and then migrate to warmer water to accelerate digestion.

Kale Bentley

Adviser: Daniel Schindler

Influence of salmon biocomplexity on movement and growth of resident fishes

Resident fishes (i.e., rainbow trout, Artic grayling, and Arctic char) in southwest Alaska accumulate most of their annual growth during the relatively short summer season. Eggs from spawning sockeye salmon are an important component in resident fish diets and, in some years, can constitute the vast majority of energy supporting their growth. However, due to asynchronous population dynamics and variation in spawn timing in neighboring populations of sockeye salmon, this pulse of high-quality food is not evenly distributed through space and time within river systems. Within years, the staggered spawn timing of sockeye extends the time resident fish can feed on eggs from roughly 3–4 weeks to more than 2.5 months, but requires that individual consumers move between spawning locations. Among years, individuals need to migrate among sockeye spawning sites to capitalize on periodic large returns in individual sockeye populations. Therefore, we are using a combination of stream snorkel surveys and PIT-tag tracking studies to determine whether resident fishes are able to exploit and benefit from the inherent spatial and temporal variability in sockeye resources that are produced as a result of biocomplexity in sockeye salmon stocks.

Morgan Bond, PhD candidate

Adviser: Tom Quinn

Dolly Varden life-history diversity: a multi-faceted approach to explaining variation in anadromy

The focus of this study is life history diversity in Dolly Varden, particularly with respect to partial anadromy. One method for assessing life history diversity involves analyzing otolith (earbone) chemistry, a permanent record of fish habitat use. Life history reconstruction from Chignik Lakes Dolly Varden indicates a high level of life history diversity; fish exhibit a range of strategies from early life anadromy (entering marine waters in their first year) to complete residency (no migrations by age 8). These data, compiled for a large number of fish from a variety of habitats, are the first step toward building life history models and understanding potential mechanisms of variation in anadromy.

Curry Cunningham, MS student

Advisers: Tom Quinn, Ray Hilborn

Evaluating the evolutionary interaction of natural and anthropogenic selection in sockeye salmon, with predictive individual-based modeling

This project aims to facilitate a more coherent understanding of how selective pressure from a commercial gillnet fishery for sockeye salmon might affect phenotypic change in morphometric and life history traits, by accounting for the influence of co-occurring natural selection processes. The focal system for this analysis is Hansen Creek, Alaska, where an extensive time series of stream surveys have quantified the impact of natural selective pressure from predation by brown bears (*Ursus arctos*), stranding due to low water conditions at the Hansen Creek delta, and sexual processes resulting from intra-sexual competition and inter-sexual selection. Phenotypically explicit statistical approximations for these forms of selection have been derived and embedded within an individual-based simulation model for the sockeye salmon life cycle, permitting quantitative predictions of future phenotypic trends to be generated under alternative selection scenarios. It is hypothesized that this holistic approach will demonstrate the importance of natural processes in buffering against the evolutionary influence of fishery selection and permit the efficacy of alternative harvest policies to be evaluated.

Jennifer Griffiths, PhD candidate

Adviser: Daniel Schindler

Climate change and geomorphic evolution in an Alaskan watershed and implications for salmon production

This research investigates the response of salmon production in the Chignik watershed, where two lakes with different physical characteristics and geomorphic rates are experiencing the same regional climate change. A hydrodynamics model is coupled to a bioenergetics model to assess the implications of restoration alternatives for water temperature and salmon growth in the upper watershed. Historic townet records will be used to assess the important environmental and biological variables for sockeye growth in both rearing lakes. Our overall objective is to assess the future production potential of the watershed and the relative contribution of each rearing lake to total freshwater production.

Rachel Hovel, MS student

Adviser: Tom Quinn

Climate-driven habitat changes restructure northern lake fish communities

This project examines how littoral zone fish communities in large Alaskan lakes have responded to several decades of documented climate warming. Species abundance data from more than 50 years of standardized beach seining on Lake Aleknagik were analyzed along with environmental records, including water temperature and date of ice out. Analyses indicate differences in changes in relative abundance of fish of varied life history strategies, such as timing of breeding and generation time. In addition, both rate of change and extent of change were significantly different among sampling sites within the lake. These results suggest that habitat heterogeneity and the diversity of fish strategies can play an important role in evaluating community-level responses to large scale environmental change and in assessing the trajectory of community composition in the future.

Neala Kendall, PhD candidate

Adviser: Tom Quinn

Fishery selection and Pacific salmon life histories: patterns and processes

I quantified size-selective fishing on Nushagak River Chinook salmon by both commercial and recreational fisheries. The average age and lengths of most maturing fish have decreased over time. Size-selection by the commercial fishery has been highly variable over time but, overall, smaller-than-average fish have been caught. In contrast, the recreational fishery has regularly removed larger-than-average fish. Age and size at maturation trends are unlikely to have been caused solely by fishery selection and are likely also related to environmental changes affecting fish growth. In another project, I quantified size-selective fishing by nine Alaskan sockeye salmon fisheries and found that size-selectivity varied over time but on average larger fish were caught, leaving smaller fish to spawn. Also, selection was generally stronger on females than on males.

Wesley Larson, MS student
Adviser: Lisa Seeb
What drives major histo-compatibility complex diversity in Bristol Bay sockeye salmon

The major histocompatibility complex (MHC) binds pathogens that enter the body and allows the immune system to recognize them and mount a response. The genes that encode the MHC are highly polymorphic and under selection. We are attempting to characterize the manner and direction of selection on these MHC genes in the Wood River Lakes system.

Jocelyn Lin, PhD candidate
Advisers: Lorenz Hauser, Ray Hilborn
Factors affecting phenotypic and genetic diversity in Pacific salmon

I use molecular and modeling techniques to study genetic and phenotypic diversity among populations of Pacific salmon. Chapter 1 of my dissertation examines patterns of genetic and phenotypic differentiation between beach and creek spawning ecotypes of sockeye salmon, with the goal of identifying factors that impact gene flow and population divergence. Chapter 2 focuses on the population genetics of chum and Chinook salmon in the Wood River system to consider how gene flow and genetic drift may affect these small spawning aggregates. Chapter 3 is on selection and how phenotypes may affect reproductive success of wild sockeye salmon. Chapter 4 describes an individual-based, quantitative genetic model for investigating local adaptation and population viability in connected populations of sockeye salmon.

Peter Lisi, MS student
Adviser: Daniel Schindler
Watershed controls on stream thermal regimes: effects on salmon spawn timing and links to riparian communities

My research seeks to further understand how geomorphic variation translates into hydrologic variation among streams throughout a river system, and how variation in hydrology produces intraspecific diversity in the timing of a seasonal ecosystem subsidy (salmon) throughout a river system. I am currently using GIS, stable isotopes in water, and temperature loggers to determine how watershed features influence the contribution of snowmelt and rainfall to streams, how the balance of rain and snow regulates the thermal regimes of streams, and how variation in spawn timing of individual populations of sockeye salmon (*Oncorhynchus nerka*) corresponds to spatial variation in thermal conditions among streams. Finally, I will determine if variation in salmon spawn timing among streams translates into phenological variation in a riparian plant. Specifically, I will test the hypothesis that a pollinator mutualism directly ties riparian plant flower timing to the seasonal timing of an annual influx of salmon resources to streams.

Daniel Peterson, MS student
Adviser: Lorenz Hauser
Gene flow under a temporally variable predation regime in two proximate populations of sockeye salmon

The goal of this project is to quantify the effects of variation in predatory selection pressure on the level of gene flow within a metapopulation of creek- and beach-breeding sockeye salmon. We will use genetic techniques to examine how variation in strength of predation pressure affects the overall genetic impact of immigrants on recipient subpopulations as well as the relative fitness of different reproductive behavioral strategies. Our broad aim is to understand the forces that influence patterns of genetic structure in a temporally dynamic metapopulation.

2010 AERA Class Student Projects

Hannah Barrett
Predatory fish attraction to sockeye salmon tissues

Britttany Cummings
Effects of spawning salmon on the size at emergence of stream dwelling insects

Jeanelle Miller
Influence of hyporheic-surface water interactions on sockeye spawning distribution in Hansen Creek, AK

Ke'ale Louie
Analysis of tissue-specific energy loss experienced by sockeye salmon during senescence

Hannah Stapleton
The effect of the parasite *Schistocephalus solidus* on diet and feeding rate of the three-spined stickleback

Marshall Stephens
Price mediated movement of permits in Alaska's limited entry herring fisheries

7. Data and Web Development

Data Recap

J Carter (research scientist & database manager)

The Alaska Salmon Program has been collecting ecological data on Bristol Bay salmon populations and the lakes and streams in which they spawn since 1946. These data were archived as paper records, necessitating an effort to modernize by moving to a single comprehensive Alaska Salmon Program Database (ASPD). Our transition of all major long-term monitoring data from SW Alaska into a publicly accessible database is essentially complete and the functionality of the database has improved dramatically.

Significant progress with the database was made in the prior years and details can be found in the 2009 Alaska Salmon Program annual report, accessible online (see ASP website). In 2010–2011 our primary focus was to fill in any gaps in the major datasets and incorporate pertinent smaller program datasets and graduate student projects into the database. We have made substantial progress in this area and will continue to prioritize these goals.

Primary Data Goals for 2011–2012

Primary data goals for fall 2011–summer 2012 are as follows:

- To continue integrating small and short-term program datasets, as well as data from graduate student theses and dissertations and undergraduate student projects into the database.
- To create a functional ASP fish tagging database and eventually merge it into the main ASPD. Merging the tagging database will require adjustments to database design as well as identification and removal of potential overlapping data to avoid data redundancy.
- To ensure that all datasets in the ASPD have appropriate metadata noted and accessible. This is critical to guarantee all data are used correctly and will be given high priority once we return from the summer 2011 field season.

Website

The Alaska Salmon Program has maintained a website, hosted by the School of Aquatic & Fishery Sciences, since 1999. The original site primarily provided general information about the program, including a history of the research from program inception in 1946, a list of select publications with links to full-text pdfs of technical reports, facility descriptions, a photo gallery, and personnel directory. Data were limited to a table of the annual Bristol Bay salmon run forecast and links to the full report. Site content was primarily a function of the program's principal funding source and research impetus—the Bristol Bay commercial salmon fisheries.

A condition of recent program funding was to develop web-based resources for obtaining ASP datasets and associated information (e.g., publications). Funding is also supporting a dedicated web content developer to assist in developing online data resources and to redesign and expand the scope and breadth of web content and provide timely updates and maintenance. The ASP website hosts a searchable photo gallery, including photos and descriptive information on various program components—biology, environment, socioeconomics, and infrastructure.

Datasets in the ASPD that have been error checked and verified are available via our website (*http://fish.washington.edu/research/alaska/data.html*). The following information is presented for each dataset: 1) a summary graphic showing an example time-series trend for each dataset, 2) summary data available for download, 3) metadata, and 4) an opportunity to request data beyond the summary using our online request form.

These web-based resources will be expanded during 2010 to include new datasets as they become available both through historical data entry and data collection during the 2010 field season.

8. Facilities

The following facilities upgrades and maintenance projects were undertaken and completed in 2010:

- The Panabode workshop structure on Porcupine Island, originally built in 1961, had settled into the ground and had several rotten log courses. The building was jacked up and a new foundation built underneath, a pony wall and floor were added, thus raising the height of the structure by about three feet. A new roof was added as well.
- The Iliamna Village cabin was given some overdue maintenance: repairs were made to the rotting entry, a new floor was installed throughout the cabin, and the interior walls were painted.
- The bunk house facility at the Lake Nerka camp was jacked up, a new foundation was put in place, a new porch was built, and some of the old windows were replaced.

Photo: H Rich

9. Publications

In Peer Review

Carter JL Schindler DE. Responses of zooplankton populations to four decades of climate warming in lakes of southwestern Alaska. *Freshwater Biology*.

Costello C, Deacon RT, Parker DP. Overcoming the common pool problem through voluntary cooperation: the rise and fall of a fishery cooperative. *Journal of Political Economy*.

Griffiths JR, Schindler DE. Metabolic costs of changing climate and geomorphology for juvenile sockeye salmon in a shallow Alaskan lake. *Freshwater Biology*.

Johnson SP, Schindler DE. Marine trophic diversity in an anadromous fish is linked to geomorphic variation in freshwater. *Proceedings of the Royal Society of London B*.

Kendall NW, Dittman AH, Quinn TP. Comparative maturation schedules of two Columbia River sockeye salmon, *Oncorhynchus nerka*, populations. *Endangered Species Research*.

Lin JE, Hilborn R, Hauser L. Population sinks or harbingers of range expansion: chum (*Oncorhynchus keta*) and Chinook salmon (*O. tshawytscha*) in the Wood River system. *Molecular Ecology*.

Pess GR, Quinn TP, Schindler DE, Liermann MC. Spatial distribution and dynamics of pink, chum, and Chinook salmon in a watershed dominated by sockeye salmon: insights into the processes of straying and colonization. *Canadian Journal of Fisheries and Aquatic Sciences.*

Quinn TP, Kendall NW, Rich HB, Jr, Chasco BE. Diel vertical movements, and effects of infection by the cestode Schistocephalus solidus on daytime proximity of three-spine sticklebacks *Gasterosteus aculeatus* to the surface of a large Alaskan lake. *Oecologia.*

Quinn TP, Rich HB, Jr, Gosse D, Schtickzelle N. Population dynamics and asynchrony at fine spatial scales: A case history of sockeye salmon population structure in Alaska. *Canadian Journal of Fisheries and Aquatic Sciences.*

Ruff CP, Schindler DE, Armstrong JB, Bentley K, Brooks GT, Holtgrieve GW, McGlauflin MT, Torgersen CE, Seeb JE. Temperature-associated population diversity in salmon confers benefits to mobile consumers. *Ecology.*

Manuscripts in press

Ackerman MW, Habicht C, Seeb LW. Evaluating the information content of SNP loci influenced by selection for use in mixed stock analyses of sockeye salmon in southcentral Alaska. *Transactions of the American Fisheries Society.*

Armstrong JB, Schindler DE. No guts, no glory, the digestive physiology of living in a patchy world. *Nature.*

Costello C, McGough B, Plantinga A. Optimally managing a stochastic renewable resource under general economic conditions. *BE Journal of Economic Analysis and Policy.*

Creelman E, Hauser L, Simmons R, Templin WD, Seeb LW. Temporal and geographic genetic divergence: Characterizing sockeye salmon populations in the Chignik watershed, Alaska, using single nucleotide polymorphisms. *Transactions of the American Fisheries Society.*

Kendall NW, Quinn TP. In press. Length and age trends of Chinook salmon in the Nushagak River, Alaska related to commercial and recreational fishery selection and exploitation. *Transactions of the American Fisheries Society.*

Kroksek M, Hilborn R, Peterman R, Quinn TP.. Cycles, stochasticity, and density dependence in pink salmon population dynamics. *Canadian Journal of Fisheries and Aquatic Sciences.*

McGlauflin MT, Schindler D, Habicht C, Seeb LW, Seeb JE. Influences of spawning habitat and geography: Population structure and juvenile migration timing of sockeye salmon in the Wood River lakes, Alaska. *Transactions of the American Fisheries Society.*

Seeb LW, Grau ED, Farley EV, Habicht C, Seeb JE, Utter FM. Patterns of nearshore juvenile migration of sockeye salmon in the eastern Bering Sea. *Transactions of the American Fisheries Society.*

2011

Baker MR, Kendall NW, Branch TA, Schindler DE, Quinn TP. 2011. Selection due to non-retention mortality in gillnet fisheries for salmon. *Evolutionary Applications* 4:429-443. DOI: 10.1111/j.1752-4571.2010.00154.x

Bentley KT, Burgner RL. An assessment of climate change effects on parasite infestation rates of sockeye salmon in southwest Alaska. *Environmental Biology of Fishes.* DOI 10.1007/s10641-011-9830-2

Chen G, Saulnier-Talbot E, Selbie DT, Brown E, Schindler DE, Bunting L, Leavitt PR, Finney BP, Gregory-Eaves I. Salmon-derived nutrients drive diatom beta-diversity patterns in Alaskan lakes. *Freshwater Biology.* 56(2):292–301.

Everett MV, Grau ED, Seeb JE. 2011. Short reads and non-model species: Exploring the complexities of next generation sequence assembly and SNP discovery in the absence of a reference genome. *Molecular Ecology Resources* (Suppl. 1), 93–108.

Gomez-Uchida D, Smith MJ, Habicht C, Seeb JE, Quinn TP, Seeb LW. Single nucleotide polymorphisms mirror geographic and ecological complexity among Alaskan sockeye salmon populations. *BioMedCentral Evolutionary Biology.* 11(48).

Griffiths JR, Schindler DE, Balistrieri LS, Ruggerone GT. 2011. Effects of simultaneous climate change and geomorphic evolution on thermal characteristics of a shallow Alaskan lake. *Limnology and Oceanography*. 56(1):193–205. DOI:10.4319/lo.2011.56.1.0193

Hauser L, Baird M, Hilborn R, Seeb LW, Seeb JE. 2011. An empirical comparison of SNPs and microsatellites for parentage and kinship assignment in a wild sockeye salmon (*Oncorhynchus nerka*) population. *Molecular Ecology Resources.* 11 (Suppl 1), 150–161.

Holtgrieve GW, Schindler DE. Marine-derived nutrients, bioturbation, and ecosystem metabolism: reconsidering the role of salmon in streams. *Ecology.* 92(2):373–385.

Seeb JE, Carvalho G, Hauser L, Naish K, Roberts S, Seeb LW. 2011. Single-nucleotide polymorphism (SNP) discovery and applications of SNP genotyping in nonmodel organisms. *Molecular Ecology Resources.* 11 (Suppl 1), 1–8.

Seeb LW, Templin WD, Sato S, Abe S, Warheit KI, Seeb JE. In review. Single nucleotide polymorphisms across a species' range: implications for conservation studies of Pacific salmon. *Molecular Ecology Resources.* 11 (Suppl 1), 195–217.

Seeb JE, Pascal CE, Grau ED, Seeb LW, Templin WD, T. Harkins T Roberts SB. 2011. Transcriptome sequencing and high-resolution melt analysis advance single nucleotide polymorphism discovery in duplicated salmonids. *Molecular Ecology Resources* 11:335-348.

Smith M J, Pascal CE, Grauvogel Z, Habicht C, JSeeb JE, Seeb LW. In review. Multiplex preamplification PCR allows accurate single nucleotide polymorphism (SNP) genotyping of historical fish scales. *Molecular Ecology Resources*. 11 (Suppl 1), 268–277.

Templin WD, Seeb JE, Jasper JJ, Barclay AW, Seeb LW. In review. Genetic differentiation of Alaska Chinook salmon: the missing link for migratory studies. *Molecular Ecology Resources.*11 (Suppl 1), 226–246.

2010

Armstrong JB. 2010. comment: Egg consumption in mature Pacific salmon (*Oncorhynchus* spp.) *Can J Fish Aq Sci.* 66(9):1546–1533.

Armstrong JB, Schindler DE, Omori KL, Ruff CP, Quinn TP. 2010. Thermal heterogeneity mediates the effects of pulsed subsidies across a landscape. *Ecology.* 91(5):1445–1454 DOI:10.1890/09-0790.1

Branch TA. 2010. Reply to the comment by Francis on "Differences in predicted catch composition between two widely used catch equation formulations". *Canadian Journal of Fisheries and Aquatic Sciences* 67:766–768. DOI:10.1139/F10-024

Branch T, Hilborn R. 2010. A general model for reconstructing salmon runs. *Canadian Journal of Fisheries and Aquatic Sciences* 67:886–904. DOI: 10.1139/F10-032

Carlson SM, Quinn TP, Hendry AP. 2010. Eco-evolutionary dynamics as influenced by selection within a generation: a consideration in Pacific salmon. *Heredity* 106:438–447. DOI:10.1038/hdy.2010.163

Denton KP, Rich HB, Jr., Moore JW, Quinn TP. 2010. The utilization of a Pacific salmon *Oncorhynchus nerka* subsidy by three populations of charr *Salvelinus* spp. *Journal of Fish Biology* 77:1006-1023. DOI:10.1111/j.1095-8649.2010.02746.x

Doctor KK, Hilborn R, Rowse M, Quinn TP. 2010. Spatial and temporal patterns of upriver migration by sockeye salmon, *Oncorhynchus nerka*, populations in the Wood River system, Bristol Bay, Alaska. *Transactions of the American Fisheries Society* 139:80–91. DOI: 10.1577/T08-227.1

Greene CM, Hall JE, Guilbault KR, Quinn TP. 2010. Improved viability of populations with diverse life history portfolios. *Biology Letters* 6:382–386. DOI: 10.1098/rsbl.2009.0780

Habicht C, Seeb LW, Myers KW, Farley EV, Seeb JE. 2010. Summer-fall distribution of stocks of immature sockeye salmon in the Bering Sea as revealed by single-nucleotide polymorphisms (SNPs). *Transactions of the American Fisheries Society* 139:1171–1191. DOI: 10.1577/T09-149.1

Hilborn R, Stokes K. 2010. Defining overfished stocks: have we lost the plot? *Fisheries.* 35:113-120. DOI: 10.1577/1548-8446-35.3.113

Holtgrieve GW, Schindler DE, Gowell CP, Ruff CP, Lisi PJ. 2010. Stream geomorphology regulates the ecosystem engineering and nutrient enrichment effects of Pacific salmon on benthic biota. *Freshwater Biology* 55(12):2598–2611. DOI: 10.1111/j.1365-2427.2010.02489.x

Holtgrieve GW, Schindler DE, Branch TA, A'mar ZT. 2010. Simultaneous quantification of aquatic ecosystem metabolism and re-aeration using a Bayesian statistical model of oxygen dynamics. *Limnology & Oceanography* 55:1047–1063 DOI: 10.4319/lo.2010.55.3.1047

Kendall NW, Rich HB, Jr. Jensen LR, Quinn TP. 2010. Climate effects on inter-annual variation in growth of the freshwater mussel, *Anodonta beringiana*, in Iliamna Lake, *Alaska. Freshwater Biology* 55:2339–2346. DOI:10.1111/j.1365-2427.2010.02447.x

Moore J.W., and D.E. Schindler. 2010. Convergent phenologies of spawning salmon and emerging aquatic insects. Proc. Roy. Soc. London B 277:1695–1703. DOI: 10.1098/rspb.2009.2342

Moore, JW, McClure M, Rogers LA, Schindler DE. 2010. Synchronization and portfolio performance in a threatened salmon stock. *Conservation Letters* 3(5):340–348. DOI: 10.1111/j.1755-263X.2010.00119.x

Olsen JB, Beacham TD, Wetklo M, Seeb LW, Smith CT, Flannery BG, Wenburg JK. 2010. The influence of hydrology and waterway distance on population structure of Chinook salmon *Oncorhynchus tshawytscha* (Walbaum) in a large river. *Journal of Fish Biology* 76:1128–1148. DOI: 10.1111/j.1095-8649.2010.02554.x

Reed TE, Waples RS, Schindler DE, Hard JJ. Kinnison MT. 2010. Phenotypic plasticity and population viability: the importance of environmental predictability. *Proceedings of the Royal Society B: Biological Sciences.* Online Early: DOI: 10.1098/rspb.2010.0771

Reed TE, Schindler DE, Waples RS. 2010. Interacting effects of phenotypic plasticity and evolution on population persistence in a changing climate. *Conservation Biology.* Online Early: DOI: 10.1111/j.1523-1739.2010.01552.x

Reed TE, Martinek G, Quinn TP. Lake-specific variation in growth, migration timing, and survival of juvenile sockeye salmon, *Oncorhynchus nerka*: separating environmental from genetic influences. J*ournal of Fish Biology* 77:692–705. DOI: 10.1111/j.1095-8649.2010.02711.x

Schindler DE, Hilborn R, Chasco, RB Boatright CP, Quinn TP, Rogers LA, Webster MS. 2010. Population diversity and the portfolio effect in an exploited species. *Nature* 465:609–613. DOI:10.1038/nature09060

Sethi SA. 2010. Risk management for fisheries. *Fish and Fisheries* 11(4):341–365. DOI: 10.1111/j.1467–2979.2010.00363.x

Westley PAH, Schindler DE, Quinn TP, Ruggerone GT, Hilborn R. 2010. Natural habitat change, commercial fishing, climate, and dispersal interact to restructure an Alaskan fish metacommunity. *Oecologia* 163:471–484. DOI 10.1007/s00442-009-1534-3

Woody CA, Hughes RM, Wagner EJ, Quinn TP, Roulson LH, Martin LM, and K Griswold. 2010. The Mining Law of 1872: Change is overdue. 2010. *Fisheries* 35(7):321–331. DOI: 10.1577/1548-8446-35.7.321

2009

Baker MR, Schindler DE. 2009. Unaccounted mortality in salmon fisheries: non-retention in gillnets and effects on estimates of spawners. *Journal of Applied Ecology* 46:752–761. DOI: 10.1111/j.1365–2664.2009.01673.x

Baker MR, Schindler DE, Holtgrieve GW, St. Louis VL. 2009. Bioaccumulation and transport of contaminants: migrating sockeye salmon as vectors of mercury. E*nvironmental Science and Technology* 43:8840–8846. DOI:10.1021/es901798f CCC

Branch TA. 2009. Differences in predicted catch composition between two widely used catch equation formulations. *Canadian J of Fisheries and Aquatic Sciences* 66:126–132. DOI:10.1139/F10-024

Carlson SM, Rich HB, Jr, Quinn TP. 2009. Does variation in selection imposed by bears drive divergence among populations in the size and shape of sockeye salmon? *Evolution* 63:1244–1261. DOI:10.1111/j.1558-5646.2009.00643.x

Denton KP, Rich HB, Jr, Quinn TP. 2009. Diet, movement, and growth of non-anadromous Dolly Varden *Salvelinus malma* in response to sockeye salmon *Oncorhynchus nerka* subsidies. *Transactions of the American Fisheries Society* 138:1207–1219. DOI: 10.1577/T09-006.1

Doctor KK, Quinn TP. 2009. The potential for adaptation-by-time in sockeye salmon (*Oncorhynchus nerka*): The interactions of body size and in-stream reproductive lifespan with date of arrival and breeding location. *Canadian J of Zoology* 87:708-717. DOI: 10.1577/T09-006.1

Hilborn R. 2009. Life History Models for Salmon Management: The Challenges. *In* Pacific salmon environmental and life history models: advancing science for sustainable salmon in the future. Edited by E. E. Knudsen and J. H. J. Michael. American Fisheries Society, Bethesda, Maryland. 71. pp. 23–32. (pdf only)

Holtgrieve GW, Schindler DE, Jewett PK. 2009. Large predators and biogeochemical hotspots: brown bear (*Ursus arctos*) predation on salmon alters nitrogen cycling in riparian soils. *Ecol. Res.* 24:1125–1135. DOI 10.1007/s11284-009-0591-8.

Honea JM, Jorgensen JC, McClure MM, Cooney TD, Engie, K, Holzer D, Hilborn R. 2009. Evaluating habitat effects on population status: influence of habitat restoration on spring-run Chinook salmon. *Freshwater Biology*, 54:576–1592. DOI: 10.1111/j.1365-2427.2009.02208.x

Johnson SP, Schindler DE. 2009. Trophic ecology of Pacific salmon (*Oncorhynchus* spp.) in the ocean: a synthesis of stable isotope research. *Ecological Research* 24:855–863. DOI 10.1007/s11284-008-0559-0

Kendall NW, Quinn TP. 2009. Effects of population-specific variation in age and length on fishery selection and exploitation rates of sockeye salmon (*Oncorhynchus nerka*). *Canadian J of Fisheries and Aquatic Sciences* 66:896–908. DOI:10.1139/F09-047

Kendall NW, Hard JJ, Quinn TP. 2009. Quantifying six decades of fishery selection for size and age at maturity in sockeye salmon. E*volutionary Applications* (2) 523–536. DOI:10.1111/j.1752-4571.2009.00086.x

McPhee MV, Zimmerman MS, Beacham TD, Beckman BR, Olsen JB, Seeb LW, Templin WD. 2009. A hierarchical framework to identify influences on Pacific salmon population abundance and structure in the Arctic-Yukon-Kuskokwim Region. Pages 1177-1197 in C. C. Krueger, and C. E. Zimmerman, editors. Pacific salmon:ecology and management of western Alaska's populations. American Fisheries Society, Symposium 70, Bethesda, Maryland.

Post E, Forchhammer MC, Bret-Harte MS, Callaghan TV, Christensen TR, Elberling B, Fox AD, Gilg O, Hik DS, Hoye TT, Ims RA, Jeppesen E, Klein DR, Madsen J, McGuire AD, Rysgaard S, Schindler, DE, Stirling I, Tamstorf MP, Tyler NJC, van der Wal R, Welker J, Wookey PA, Schmidt NM, Aastrup P. 2009. Ecological dynamics across the Arctic associated with recent climate change. *Science* 325:1355–1358. DOI: 10.1126/science.1173113

Quinn TP. 2009. Changing themes in the study of diadromous fishes. Pages 823–828 in A Haro, KL Smith, RA Rulifson, CM Moffitt, RJ Klauda, MJ Dadswell, RA Cunjak, JE Cooper, KL Beal, TS Avery (eds), Challenges for Diadromous Fishes in a Dynamic Global Environment. *American Fisheries Society Symposium* 69:23–42. (pdf only)

Quinn TP. 2009. Pacific salmon population structure and dynamics: A perspective from Bristol Bay on life history variation across spatial and temporal scales. *American Fisheries Society Symposium* 70:857–871 (pdf only)

Quinn TP, Carlson SM, Gende SM, Rich HB, Jr. 2009. Transportation of Pacific salmon carcasses to riparian forests by bears. *Canadian Journal of Zoology* 87:195–203. DOI: 10.1126/science.1173113

Quinn TP, Doctor Kendall KN, Rich HB, Jr. 2009. Diadromy and the life history of sockeye salmon: nature, nurture, and the hand of man. Pages 23–42 in A Haro, KL Smith, RA Rulifson, CM Moffitt, RJ Klauda, MJ Dadswell, RA Cunjak, JE Cooper, KL Beal, TS Avery (eds), Challenges for Diadromous Fishes in a Dynamic Global Environment. *American Fisheries Society Symposium* 69:23–42. (pdf only)

Rich HB, Jr, Quinn TP, Scheuerell MD, Schindler DE. 2009. Climate and intra-specific competition control the growth and life history of juvenile sockeye salmon (*Oncorhynchus* *nerka*) in Iliamna Lake, Alaska. *Canadian Journal of Fisheries and Aquatic Sciences* 66:238–246. DOI:10.1139/F08-210

Scheuerell M, Hilborn R. 2009. Estimating the freshwater component of essential fish habitat for Pacific salmon (*Oncorhynchus* spp.) with the Shiraz model. In Pacific salmon environmental and life history models: advancing science for sustainable salmon in the future. Edited by E. E. Knudsen and J. H. J. Michael. American Fisheries Society, Bethesda, Maryland. 71. pp. 187–202. (pdf only)

Schindler DE, Rogers LA. 2009. Responses of Pacific salmon populations to climate variation in freshwater ecosystems. Sustainability of the Arctic-Yukon-Kuskokwim Salmon Fisheries. C.E. Zimmerman and C.C. Krueger, Editors. American Fisheries Society. Pages 1127–1142. (pdf only)

Seeb JE, Pascal CE, Ramakrishnan R, Seeb LW. 2009. SNP genotyping by the 5’-nuclease reaction: advances in high throughput genotyping with non-model organisms. Pages 277–292 in A. Komar, editor. Methods in Molecular Biology, Single Nucleotide Polymorphisms, 2d Edition. Humana Press.

Selbie DT, Finney BP, Barto D, Bunting L, Chen G, Leavitt PR, MacIsaac EA, Schindler DE, Shapley MD, Gregory-Eaves J. 2009. Ecological, landscape and climatic controls on sediment geochemistry in North American sockeye salmon nursery lakes: Insights for paleoecological salmon investigations. *Limnology & Oceanography* 54:1733–1745 (pdf only)

Photo: J Ching

10. References

Allen CS, Rich HB, Jr, Quinn TP. 2007. Condition-dependent reproductive tactics by large and small anadromous male sockeye salmon *O. nerka*. *J Fish Biol* 70:1302–1307.

Beacham TD, McIntosh B, MacConnachie C, Miller KM, Withler RE, Varnavskaya N. 2006. Pacific rim population structure of sockeye salmon as determined from microsatellite analysis. *Trans Am Fish Soc* 135:174–187.

Blair GR, Rogers DE, Quinn TP. 1993. Variation in life history characteristics and morphology of sockeye salmon in the Kvichak River system, Bristol Bay, Alaska. *Trans Am Fish Soc* 122:550–559.

Burgner RL. 1962. Studies of red salmon smolts from the Wood River lakes, Alaska. Pages 247–314 in TSY Koo ed, Studies of Alaska red salmon, Univ of Washington Press, Seattle.

Carlson SM, Quinn TP. 2007. Ten years of varying lake level and selection on size-at-maturity in sockeye salmon. *Ecology* 88:2620–2629.

Carlson SM, Hilborn R, Hendry AP, and Quinn TP. 2007. Predation by bears drives senescence in natural populations of salmon. *PLoSOne* 2(12): e1286.

Carlson SM, Rich HB, Jr, Quinn TP. 2004. Reproductive lifespan and sources of mortality for alternative male life-history strategies in sockeye salmon, *Oncorhynchus nerka*. *Can J Zool* 82:1878–1885.

Carlson SM, Rich HB, Jr, Quinn TP. 2009. Does variation in selection imposed by bears drive divergence among populations in the size and shape of sockeye salmon? *Evolution* 63:1244–1261.

Carter JL. 2010. Responses of zooplankton populations to four decades of climate warming in lakes of southwestern Alaska. MS Thesis. University of Washington. 89 p.

Doctor KK, Quinn TP. 2009. The potential for adaptation-by-time in sockeye salmon (*O. nerka*): The interactions of body size and in-stream reproductive lifespan with date of arrival and breeding location. *Can J Zool* 87:708–717.

Doctor KK, Hilborn R, Rowse M, and Quinn TP. 2010. Spatial and temporal patterns of upriver migration by sockeye salmon, *Oncorhynchus nerka*, populations in the Wood River system, Bristol Bay, Alaska. *Trans Am Fish Soc*.

Habicht C, Olsen JB, Fair L, Seeb JE. 2004. Alleles in tributary spawning populations of sockeye salmon from the Kvichak River, Alaska drainage. *Environ Bio Fish* 69:51–62

Hamon TR, Foote CJ, Hilborn R, Rogers DE. 2000. Selection on morphology of spawning wild sockeye salmon by a gill-net fishery. *Trans Am Fish Soc* 129:1300–1315.

Hendry AP, Day T. 2005. Population structure attributable to reproductive time: isolation by time and adaptation by time. *Mol Ecol* 14:901–916.

Hodgson S, Quinn TP, Hilborn R, Francis RC, Rogers DE. 2006. Marine and freshwater climatic factors affecting interannual variation in the timing of return migration to fresh water of sockeye salmon (*O. nerka*). *Fish Oceanogr* 14:1–24.

Lin J, Quinn TP, Hilborn R, Hauser L. 2008a. Fine-scale differentiation between sockeye salmon ecotypes and the effect of phenotype on straying. *Heredity* 101:341–350.

Lin J, Ziegler E, Quinn TP, Hauser L. 2008b. Contrasting patterns of morphological and neutral genetic divergence among geographically proximate populations of sockeye salmon *O. nerka* in Lake Aleknagik, *Alaska J Fish Bio*l 73:1993–2004.

McGlauflin MT, Schindler D, Habicht C, Seeb LW, Seeb JE. Influences of spawning habitat and geography: population structure and juvenile migration timing of sockeye salmon in the Wood River lakes, Alaska. *Trans Am Fish Soc*.

Moore JW, Schindler DE. 2010. Convergent phenologies of spawning salmon and emerging aquatic insects. *Proc Roy Soc London B*

Quinn TP, Buck GB. 2001. Size and sex selective mortality on adult Pacific salmon: bears, gulls and fish out of water. *Trans Am Fish Soc* 130:995–1005

Quinn TP, Hendry AP, Buck GB. 2001a. Balancing natural and sexual selection in sockeye salmon: interactions between body size, reproductive opportunity and vulnerability to predation by bears. *Evol Ecol Res* 3:917–937.

Quinn TP, Wetzel L, Bishop S, Overberg K, Rogers DE. 2001b. Influence of breeding habitat on bear predation an age at maturity and sexual dimorphism of sockeye salmon populations. *Can J Zoolog* 79(10):1782–1793.

Quinn TP, Stewart IJ, Boatright CP. 2006. Experimental evidence of homing to site of incubation by mature sockeye salmon, *O. nerka. Anim Behav* 72:941–949.

Quinn TP, Hodgson S, Flynn L, Hilborn R, and Rogers DE. 2007a. Directional selection by commercial fisheries and the timing of sockeye salmon (*O. nerka*) migrations. *Ecol Appl* 17:731–739.

Quinn TP, Eggers DM, Clark JH, Rich Jr, HB. 2007b. Density, climate, and the processes of prespawning mortality and egg retention in Pacific salmon (*Oncorhynchus* spp.). *Can J Fish Aquat Sci* 64:574–582.

Quinn TP, Rich HB Jr, Gosse D, Schtickzelle N. In review.

Population dynamics and asynchrony at fine spatial scales: A case history of sockeye salmon population structure in Alaska. *Can J Fish Aquat Sci*.
Rich HB, Jr, Carlson SM, Chasco BE, Briggs KC, Quinn TP. 2006. Movements of male sockeye salmon, *O. nerka*, on spawning grounds: the effects of instream residency, density, and body size. *Anim Behav* 71:971–981.
Rich HB, Jr, Quinn TP, Scheuerell MD, Schindler DE. 2009. Climate and intra-specific competition control the growth and life history of juvenile sockeye salmon (*O. nerka*) in Iliamna Lake, Alaska. *Can J Fish Aquat Sci 66*:238–246.
Schindler DE, Rogers DE, Scheuerell MD, Abrey CA. 2005. Effects of changing climate on zooplankton and juvenile sockeye salmon growth in southwestern Alaska. *Ecology* 86(1):198–209.
Stewart IJ, Carlson SM, Boatright CP, Buck GB, and Quinn TP. 2004. Site fidelity of spawning sockeye salmon (*O. nerka* W.) in the presence and absence of olfactory cues. *Ecol Freshw Fish* 13:104–110.

Photo: H Rich

11. Glossary

Acronyms

ADFG	Alaska Department of Fish & Game
ASP	Alaska Salmon Program
BBSRI	Bristol Bay Science and Research Institute
FRI	Fisheries Research Institute, the former University of Washington department through which Alaska salmon research was conducted; also still used to refer to the Alaska Salmon Program at the UW School of Aquatic & Fishery Sciences
NSF	National Science Foundation
UW	University of Washington

Common Names, Genus and Species

Arctic char	*Salvelinus alpinus*
Arctic grayling	*Thymallus arcticus*
Brown bear	*Ursus arctos*
Dolly Varden	*Salvelinus malma*
Ninespine stickleback	*Pungitius pungitius*
Pacific halibut	*Hippoglossus stenolepis*
Pacific salmon	*Oncorhynchus* spp.
Sockeye	*O. nerka*
Chinook	*O. tshawytscha*
Chum	*O. keta*
Pink	*O. gorbuscha*
Silver	*O. kisutch*
Steelhead/rainbow trout	*O. mykiss*
Pond smelt	*Hypomesus olidus*
Threespine stickleback	*Gasterosteus aculeatus*

12. Appendices

Appendix A. Summary of ground-based spawning ground surveys of adult sockeye salmon in Wood River streams, 2010. *Jacks are included in the live and dead counts. Average jack counts are from 2003–20010. Counts prior to these years are sporadic and unreliable. ** Total does not include the estimate off the mouth.

Site	Date		Live		Dead		Jacks*		Total**		Est. off mouth	
	2010	Avg.	2010	Avg.	2010	Avg.	2010	Avg.	2010	Avg.	2010	Avg.
LAKE ALEKNAGIK												
Big Whitefish	8/23/10	1950–2009	1488	673	451	135	1	78	1940	1087	75	172
Yako	8/5/10	1946–2009	1037	1756	30	615	2	23	1069	2369	400	633
Bear	8/4/10	1946–2009	1383	2579	107	937	1	11	1491	3455	200	442
Ice	8/8/10	1946–2009	597	4708	119	2950	0	4	2385	7469		191
Sunshine		1982–2009		1075		550		0		1305		1260
Happy	8/7/10	1946–2009	1828	3350	1823	3039	19	6	3670	6066		503
Hansen	8/7/10	1947–2009	10096	2420	723	1731	9	70	10828	4070		475
Eagle	8/11/10	1970–2009	881	859	295	169	5	11	1181	1107	100	269
Mission	8/13/10	1954–2009	725	877	239	334	1	9	965	945	100	87
LAKE NERKA												
Allah	8/12/10	2005–2009	753		1078		4		1835			
Berm	8/4/10		390		211		0	12	601		100	
Fenno	8/12/10	1946–2009	1960	1923	508	2390	8	20	2466	4266	150	30
Pick	8/19/10	1946–2009	3605	6734	318	2541	1	7	3924	10190	50	258
Lynx	8/23/10	1946–2009	430	2294	45	885	0	25	475	3012	0	377
N–4				11		12				23		
Hidden Lake Cr	8/17/10	1946–2009	517	1559	125	1134	1	9	643	2647		105
Hidden Lake	8/17/10	2000–2009	1049		0		1		1059		0	
Elva	8/28/10	1946–2009	22	135	12	51	0	1	34	186	300	207
Sam	8/9/10	1946–2009	701	1455	276	1143	1	6	978	2170		690
Joe	8/6/10	1983–2009	2101	1836	90	1076	1	7	301	2915		201
Stovall	8/25/10	1954–2009	5538	1057	1781	699	0	10	7319	1811	0	3
Pike	8/18/10	1970–2009	730	1149	176	748	0	21	906	1897	0	0
Teal	8/18/10	1970–2009	394	556	159	1030	24	23	577	1059	0	8
Kema	8/26/10	1955–2009	244	1022	1027	1135	1	4	1281	2472	30	0
Little Togiak R.	8/30/10	1947–2009	3434	7648	56	291			3490	5560	150	1670
LITTLE TOGIAK LAKE												
A Creek	8/25/10	1947–2009	0	43	370	94		0	370	139		94
C Creek	8/30/10	1947–2009	0	158	210	174		0	210	264		226
BEVERLEY												
Moose	8/20/10	1955–2009	536	1507	777	968	0	8	1313	2521	500	33
KULIK												
Grant River	8/21/10	1946–2009	8808	5182	246	1625	0	2	9054	6885	500	78

* Average counts for jacks are from 2003–2008. Counts prior to these years are sporadic and unreliable.
** Totals do not include the estimate of fish off the mouth.
Blanks indicate no data taken.

Appendix B1. Age composition of adult sockeye salmon determined by otolith sampling in Wood River spawning sites, 2010.

	Males						No. of	Females						No. of	Combined						No. of
Location	1.1	2.1	1.2	2.2	1.3	2.3	fish	1.1	2.1	1.2	2.2	1.3	2.3	fish	1.1	2.1	1.2	2.2	1.3	2.3	fish
ALEKNAGIK																					
Agulowak River	0.00	0.00	0.11	0.00	0.88	0.01	102	0.00	0.00	0.08	0.00	0.91	0.01	108	0.00	0.00	0.10	0.00	0.90	0.01	210
Bear Creek	0.03	0.00	0.47	0.00	0.50	0.00	70	0.00	0.00	0.68	0.00	0.32	0.00	110	0.01	0.00	0.60	0.00	0.39	0.00	180
Eagle Creek	0.07	0.00	0.80	0.00	0.13	0.00	45	0.00	0.00	0.93	0.00	0.07	0.00	109	0.02	0.00	0.89	0.00	0.09	0.00	154
Hansen Creek	0.05	0.00	0.89	0.00	0.06	0.00	109	0.00	0.00	0.99	0.00	0.01	0.00	123	0.02	0.00	0.94	0.00	0.03	0.00	232
Happy Creek	0.05	0.00	0.40	0.00	0.55	0.00	100	0.00	0.00	0.45	0.01	0.54	0.00	106	0.02	0.00	0.43	0.00	0.54	0.00	206
Ice Creek	0.00	0.00	0.48	0.00	0.53	0.00	40	0.00	0.00	0.21	0.00	0.76	0.03	38	0.00	0.00	0.35	0.00	0.64	0.01	78
Midnight Creek	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0
Mission Creek	0.01	0.00	0.99	0.00	0.00	0.00	115	0.00	0.00	.99	0.00	0.01	0.00	116	0.00	0.00	.99	0.00	0.00	0.00	231
Sunshine Creek	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0
Whitefish Creek (Big)	0.04	0.00	0.86	0.00	0.11	0.00	57	0.00	0.00	0.96	0.01	0.02	0.00	84	0.01	0.00	0.92	0.01	0.06	0.00	141
Whitefish Creek (Little)	0.00	0.00	1.00	0.00	0.00	0.00	5	0.00	0.00	1.00	0.00	0.00	0.00	22	0.00	0.00	1.00	0.00	0.00	0.00	27
Wood River	0.00	0.00	1.00	0.00	0.00	0.00	43	0.00	0.00	0.96	0.00	0.04	0.00	81	0.00	0.00	0.98	0.00	0.02	0.00	124
Yako Creek	0.11	0.00	0.53	0.00	0.37	0.00	19	0.00	0.00	0.83	0.00	0.17	0.00	136	0.01	0.00	0.79	0.00	0.19	0.00	155
NERKA																					
Agulukpak River	0.00	0.00	0.10	0.00	0.86	0.04	105	0.00	0.00	0.08	0.01	0.85	0.07	106	0.00	0.00	0.09	0.00	0.85	0.05	211
Allah Creek	0.02	0.00	0.37	0.00	0.61	0.00	95	0.00	0.00	0.48	0.00	0.52	0.00	111	0.01	0.00	0.43	0.00	0.56	0.00	206
Anvil Bay Beaches	0.00	0.00	0.29	0.01	0.68	0.03	108	0.00	0.00	0.47	0.03	0.49	0.01	122	0.00	0.00	0.38	0.02	0.58	0.02	230
Berm Creek	0.00	0.00	0.88	0.00	0.13	0.00	48	0.00	0.00	0.95	0.00	0.05	0.00	56	0.00	0.00	0.91	0.00	0.09	0.00	104
Elva Creek	0.00	0.00	1.00	0.00	0.00	0.00	1	0.00	0.00	0.22	0.00	0.78	0.00	9	0.00	0.00	0.30	0.00	0.70	0.00	10
Fenno Creek	0.01	0.00	0.75	0.00	0.24	0.00	101	0.00	0.00	0.88	0.00	0.13	0.00	112	0.00	0.00	0.82	0.00	0.18	0.00	213
Hidden Lake Creek	0.03	0.00	0.56	0.03	0.34	0.03	32	0.00	0.00	0.90	0.00	0.10	0.00	106	0.01	0.00	0.82	0.01	0.16	0.01	138
Joe Creek	0.00	0.00	0.65	0.00	0.35	0.00	20	0.00	0.00	0.47	0.00	0.53	0.00	32	0.00	0.00	0.54	0.00	0.46	0.00	52
Kema Creek	0.00	0.00	0.74	0.00	0.26	0.00	47	0.00	0.00	0.67	0.00	0.33	0.00	106	0.00	0.00	0.69	0.00	0.31	0.00	153
Lynx Creek	0.00	0.00	0.11	0.00	0.89	0.00	9	0.00	0.00	0.37	0.00	0.63	0.00	46	0.00	0.00	0.33	0.00	0.67	0.00	55
N4-N6 Beach	0.00	0.00	0.32	0.05	0.59	0.05	22	0.00	0.00	0.54	0.01	0.45	0.00	85	0.00	0.00	0.50	0.02	0.48	0.01	107
Pick Creek	0.00	0.00	0.45	0.00	0.55	0.00	22	0.00	0.00	0.55	0.00	0.45	0.00	141	0.00	0.00	0.53	0.00	0.37	0.00	163
Pike Creek	0.00	0.00	0.75	0.00	0.25	0.00	32	0.00	0.00	0.88	0.00	0.12	0.00	112	0.00	0.00	0.85	0.00	0.15	0.00	144
Sam Creek	0.00	0.00	0.57	0.00	0.43	0.00	35	0.00	0.00	0.59	0.00	0.41	0.00	87	0.00	0.00	0.58	0.00	0.42	0.00	122
Stovall Creek	0.00	0.00	0.94	0.00	0.06	0.00	111	0.00	0.00	1.00	0.00	0.00	0.00	111	0.00	0.00	0.97	0.00	0.03	0.00	222
Teal Creek	0.38	0.00	0.63	0.00	0.00	0.00	8	0.00	0.00	1.00	0.00	0.00	0.00	44	0.06	0.00	0.94	0.00	0.00	0.00	52
LITTLE TOGIAK																					
A Beach	0.00	0.00	0.62	0.04	0.35	0.00	26	0.00	0.00	0.71	0.03	0.26	0.00	66	0.00	0.00	0.68	0.03	0.28	0.00	92
A Creek	0.00	0.00	0.72	0.01	0.27	0.00	79	0.00	0.00	0.81	0.00	0.19	0.00	118	0.00	0.00	0.78	0.01	0.22	0.00	197
C Beach	0.00	0.00	0.46	0.08	0.31	0.15	13	0.00	0.00	0.83	0.00	0.17	0.00	29	0.00	0.00	0.71	0.02	0.21	0.00	42
C Creek	0.00	0.00	0.43	0.00	0.57	0.00	21	0.00	0.00	0.66	0.00	0.34	0.00	29	0.00	0.00	0.56	0.00	0.44	0.00	50
Little Togiak River	0.00	0.00	0.43	0.03	0.70	0.04	103	0.00	0.00	0.12	0.01	0.86	0.02	111	0.00	0.00	0.17	0.02	0.78	0.03	214
Little Togiak Lake	0.02	0.00	0.86	0.00	0.12	0.00	65	0.00	0.00	1.00	0.00	0.00	0.00	15	0.01	0.00	0.89	0.00	0.10	0.00	80

Appendix B1 - continued on next page

Appendix B1. Age composition of adult sockeye salmon determined by otolith sampling in Wood River spawning sites, 2010 CONTINUED.

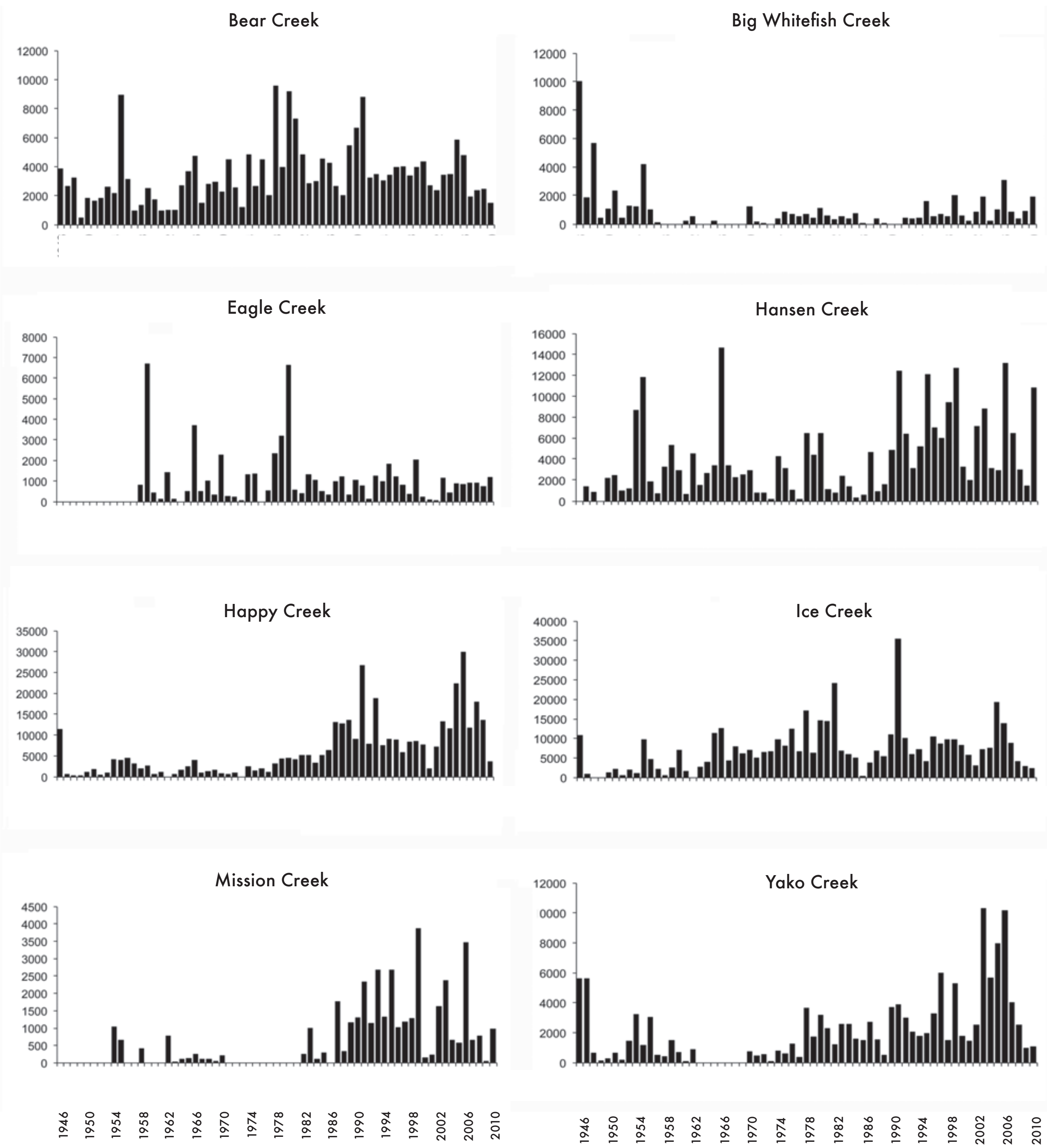
	Males						No. of	Females						No. of	Combined						No. of
Location	1.1	2.1	1.2	2.2	1.3	2.3	fish	1.1	2.1	1.2	2.2	1.3	2.3	fish	1.1	2.1	1.2	2.2	1.3	2.3	fish
BEVERLEY																					
B-12 Beaches	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0
Hardluck Bay Beach	0.00	0.04	0.88	0.04	0.04	0.00	26	0.00	0.00	0.98	0.00	0.02	0.00	105	0.00	0.01	0.96	0.01	0.02	0.00	131
Moose Creek	0.00	0.00	0.76	0.02	0.17	0.05	106	0.00	0.00	0.93	0.00	0.03	0.04	115	0.00	0.00	0.85	0.01	0.10	0.05	221
Silver Horn Beaches	0.00	0.00	0.95	0.02	0.03	0.00	106	0.00	0.00	0.95	0.02	0.03	0.00	99	0.00	0.00	0.95	0.02	0.03	0.00	205
Uno Creek	0.00	0.00	0.80	0.02	0.19	0.00	122	0.00	0.00	0.84	0.01	0.15	0.00	99	0.00	0.00	0.81	0.01	0.17	0.00	221
KULIK																					
Grant River	0.02	0.00	0.75	0.00	0.24	0.00	59	0.00	0.00	0.72	0.09	0.18	0.01	105	0.01	0.00	0.73	0.05	0.20	0.01	164
Kulik Lake Beaches	0.00	0.00	0.82	0.03	0.09	0.06	107	0.00	0.00	0.95	0.05	0.00	0.00	111	0.00	0.00	0.89	0.04	0.05	0.03	218
Unweighted mean	0.02	0.00	0.63	0.01	0.33	0.01		0.00	0.00	0.70	0.01	0.29	0.00		0.01	0.00	0.68	0.01	0.30	0.01	

Appendix B2. Age composition of adult sockeye salmon determined by otolith sampling, Iliamna Lake spawning sites, 2010.

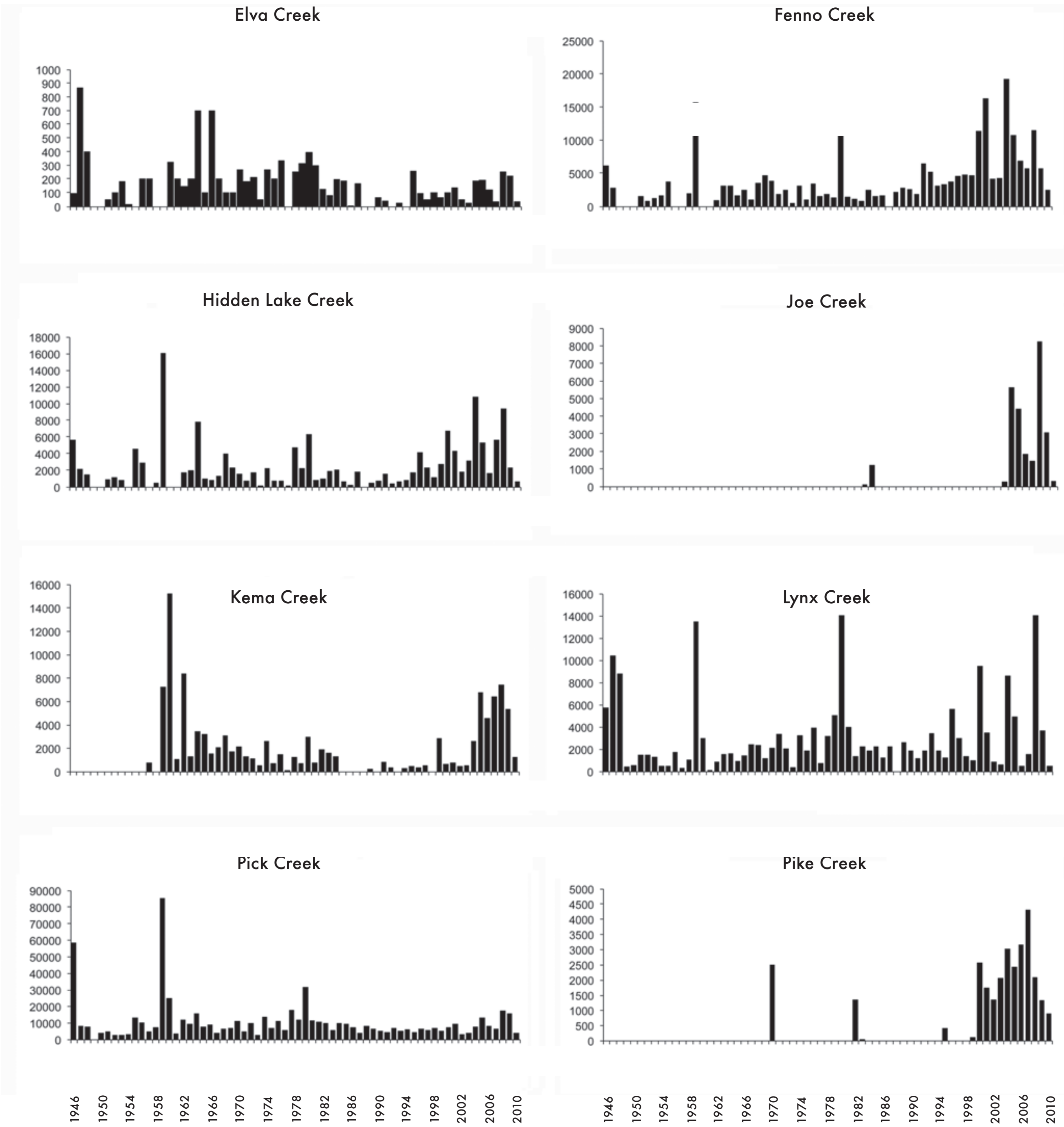
LAKE ILIAMNA

	Males						No. of	Females						No. of	Combined						No. of
Location	1.1	2.1	1.2	2.2	1.3	2.3	fish	1.1	2.1	1.2	2.2	1.3	2.3	fish	1.1	2.1	1.2	2.2	1.3	2.3	fish
COUNTS																					
Chinkelyes Creek	0	0	38	49	8	2	97	0	0	33	46	18	2	99	0	0	71	95	26	4	196
Copper River	0	0	10	59	12	19	100	0	0	5	74	6	13	98	0	0	15	133	18	32	198
Finger Bay Beach	0	0	28	11	11	0	50	0	0	30	10	8	1	49	0	0	58	21	19	1	99
Fuel Dump Island	0	0	48	1	2	0	51	0	0	49	1	0	0	50	0	0	97	2	2	0	101
Gibraltar Creek	0	2	6	40	2	0	50	0	0	4	17	2	2	25	0	2	10	57	4	2	75
Knutson Bay Beach	0	0	53	3	1	0	56	0	0	46	0	1	0	47	0	0	99	2	2	0	103
Pedro Ponds (total)	0	0	190	1	2	1	194	0	0	189	2	3	0	194	0	0	379	3	5	1	388
Trail Pond	0	0	48	1	0	0	49	0	0	48	0	1	0	49	0	0	96	1	1	0	98
Pond 1	0	0	46	0	2	0	48	0	0	47	0	0	0	47	0	0	93	0	2	0	95
Grass Pond	0	0	46	0	0	1	47	0	0	49	0	1	0	50	0	0	95	0	1	1	97
Bear Pond	0	0	50	0	0	0	50	0	0	45	2	1	0	48	0	0	95	2	1	0	98
Woody Island	0	0	44	3	2	0	49	0	0	49	0	1	0	50	0	0	93	3	3	0	99
PROPORTIONS																					
Chinkelyes Creek	0.00	0.00	0.39	0.51	0.08	0.02	97	0.00	0.00	0.33	0.46	0.18	0.02	99	0.00	0.00	0.36	0.48	0.13	0.02	196
Copper River	0.00	0.00	0.10	0.59	0.12	0.19	100	0.00	0.00	0.05	0.76	0.06	0.13	98	0.00	0.00	0.08	0.67	0.09	0.16	198
Finger Bay Beach	0.00	0.00	0.56	0.22	0.22	0.00	50	0.00	0.00	0.61	0.20	0.16	0.02	49	0.00	0.00	0.59	0.21	0.19	0.01	99
Fuel Dump Island	0.00	0.00	0.94	0.02	0.04	0.00	51	0.00	0.00	0.98	0.02	0.00	0.00	50	0.00	0.00	0.96	0.02	0.02	0.00	101
Gibraltar Creek	0.00	0.04	0.12	0.80	0.04	0.00	50	0.00	0.00	0.16	0.68	0.08	0.08	25	0.00	0.03	0.13	0.76	0.05	0.03	75
Knutson Bay Beach	0.00	0.00	0.95	0.04	0.02	0.00	56	0.00	0.00	0.98	0.00	0.02	0.00	47	0.00	0.00	0.96	0.02	0.02	0.00	103
Pedro Ponds (total)	0.00	0.00	0.98	0.01	0.01	0.01	194	0.00	0.00	0.97	0.01	0.02	0.00	194	0.04	0.00	0.98	0.01	0.01	0.00	388
Trail Pond	0.00	0.00	0.98	0.02	0.00	0.00	49	0.00	0.00	0.98	0.00	0.02	0.00	49	0.00	0.00	0.98	0.01	0.01	0.00	98
Pond 1	0.00	0.00	0.96	0.00	0.04	0.00	48	0.00	0.00	1.00	0.00	0.00	0.00	47	0.00	0.00	0.98	0.00	0.02	0.00	95
Grass Pond	0.00	0.00	0.98	0.00	0.00	0.02	47	0.00	0.00	0.98	0.00	0.02	0.00	50	0.00	0.00	0.98	0.00	0.01	0.01	97
Bear Pond	0.00	0.00	1.00	0.00	0.00	0.00	50	0.00	0.00	0.94	0.04	0.02	0.00	48	0.00	0.00	0.97	0.02	0.01	0.00	98
Woody Island	0.00	0.00	0.90	0.06	0.04	0.00	49	0.00	0.00	0.98	0.00	0.02	0.00	50	0.00	0.00	0.94	0.03	0.03	0.03	99
Unweighted mean	0.00	0.01	0.62	0.28	0.07	0.03		0.00	0.00	0.63	0.27	0.07	0.03		0.00	0.00	0.62	0.28	0.07	0.03	

Appendix C. Historical total peak sockeye counts for streams of lakes Aleknagik, Nerka, Little Togiak, Beverley, and Kulik, 1946–2010.

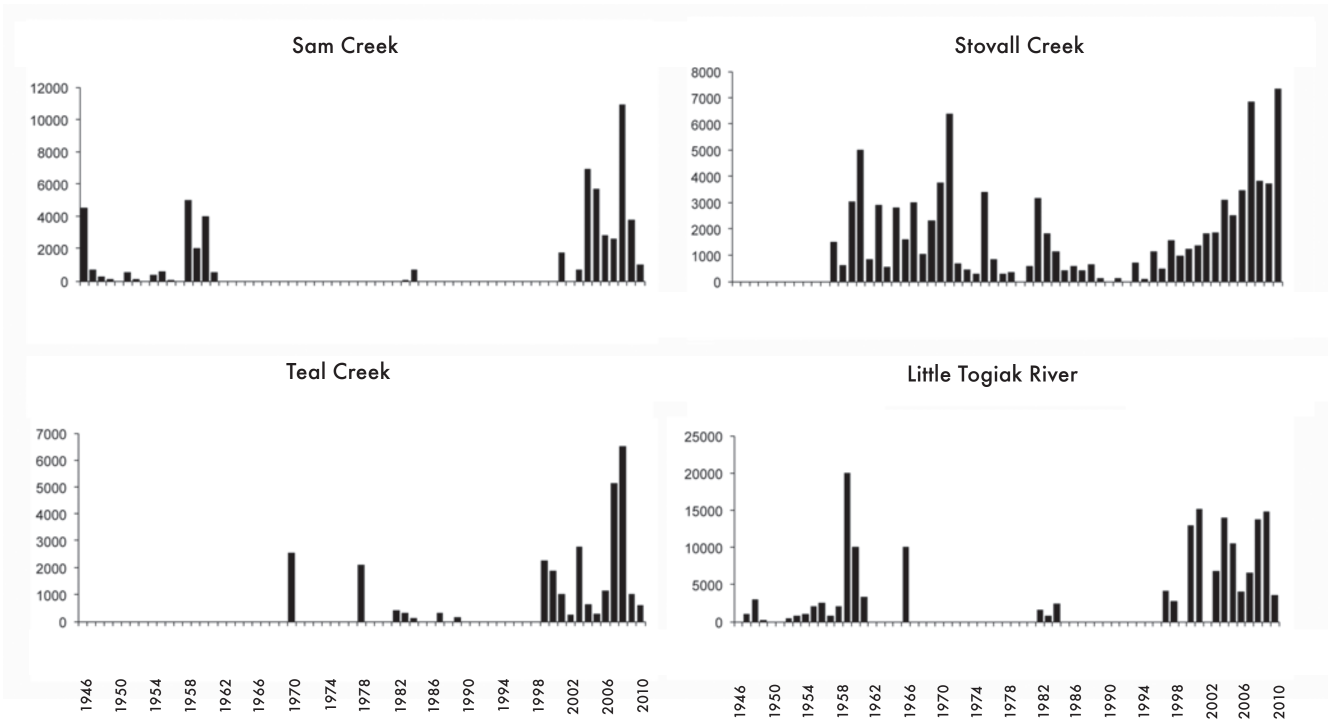


Appendix C



continued on next page

Appendix C


Sam Creek
0
2000
4000
6000
8000
10000
12000
Stovall Creek
0
1000
2000
3000
4000
5000
6000
7000
8000
Teal Creek
0
1000
2000
3000
4000
5000
6000
7000
Little Togiak River
0
5000
10000
15000
20000
25000
1946
1950
1954
1958
1962
1966
1970
1974
1978
1982
1986
1990
1994
1998
2002
2006
2010

SAFS-UW-1101
June 2011



2010 Annual Report

Alaska Salmon Program
University of Washington
School of Aquatic & Fishery Sciences

http://fish.washington.edu/research/alaska