Regional Information Report No. 4K14-01

Karluk Lake Sockeye Salmon Reduced Runs Memo Compilation

by

M. Birch Foster

January 2014

Alaska Department of Fish and Game **Divisions of Sport Fish and Commercial Fisheries**

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$\log_2$, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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KARLUK LAKE SOCKEYE SALMON REDUCED RUNS MEMO COMPILATION

by
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January 2014

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ABSTRACT

From 2009 to 2012 a series of memos were written by Alaska Department of Fish and Game staff in Kodiak discussing reasons for the low runs of sockeye salmon to Karluk Lake that began in 2008 and persisted through 2011. Historical trends in escapement, run size, limnology, climate, and trends in fish size, age, and growth for Karluk Lake sockeye salmon were investigated. The authors emphasized the role that the small body size and low condition of outmigrating smolt in 2005 and especially 2006 likely played in determining marine survival and subsequent run strength. Major factors thought to cause the small size at smolt outmigration were decline of zooplankton biomass, decline in body size of the preferred sockeye salmon food source (*Bosmina*), decrease in Karluk Lake seasonal water temperatures, and overescapement. The suggested mechanism was that large escapements and favorable spawning conditions produced large numbers of fry for numerous years, which eventually overgrazed and reduced the number of zooplankton available to fry. Sockeye salmon fry then experienced slow growth and increased mortality, which led to poor condition (and fewer) smolts. Furthermore, it was predicted that Karluk would likely be depressed for a period of 3–5 years beginning in 2008. Data thus far remain consistent with the original hypothesis; however, the outlook appears to be one in which runs improve in 2012.

Editors note: While this memorandum compilation was published in early 2014, all content, including the abstract, reflect only thoughts determined during authorship of the original memorandums dating between April 2009 and January 2012.

Key words: Karluk, sockeye salmon, escapement, zooplankton, smolt, reduced runs, memo, age, size

ALASKA DEPARTMENT OF FISH AND GAME

DIVISION OF COMMERCIAL FISHERIES

MEMORANDUM

TO: Jim McCullough
Regional Supervisor
Division of Commercial Fisheries
Region IV - Kodiak

DATE: April 6, 2009

PHONE: (907) 486-1855

FAX: (907) 486-1841

THRU: Steve Honnold
Regional Finfish Research Coordinator
Division of Commercial Fisheries
Region IV - Kodiak

SUBJECT: Reduced sockeye salmon runs at Karluk Lake

FROM: Mark Witteveen, Birch Foster, and Heather Finkle
Regional Finfish Research Biologists
Division of Commercial Fisheries
Region IV - Kodiak

The 2008 sockeye salmon run to Karluk Lake was markedly weak with the lowest escapement levels since the early 1980s. The purpose of this memorandum is to examine the recent reduced run magnitude of sockeye salmon returning to Karluk Lake and to attempt to determine the specifics of the low runs, the causality, and determine the likely future trends.

Karluk Lake is located on the west side of Kodiak Island and supports the largest sockeye salmon run in the Kodiak Management Area (KMA; Dinnocenzo et al. 2007; Wadle 2004). The early run returns from late May until mid July while the late run returns from mid July through September. Karluk Lake was fertilized from 1986 to 1990 and sockeye salmon eyed eggs from Upper and Lower Thumb rivers, Karluk Lake tributaries, were backstocked into the Upper Thumb River from 1978 to 1986.

The 2008 early sockeye salmon run was approximately 153,000 fish with an estimated escapement of 82,000, below the lower end of the escapement goal range of 110,000 fish (Figure 1.; Honnold et al. 2007) despite very limited fishing time. The early run was the lowest since at least 1985 (prior to 1985 run reconstruction methods were different and the runs are not directly comparable). The late run also failed to meet the lower end of the escapement goal range of 170,000 fish (Figure 2.; Honnold et al. 2007) with an escapement of 164,000 sockeye salmon.

With very little fishing pressure later in the season, the Karluk Lake late run was only 295,000 sockeye salmon.

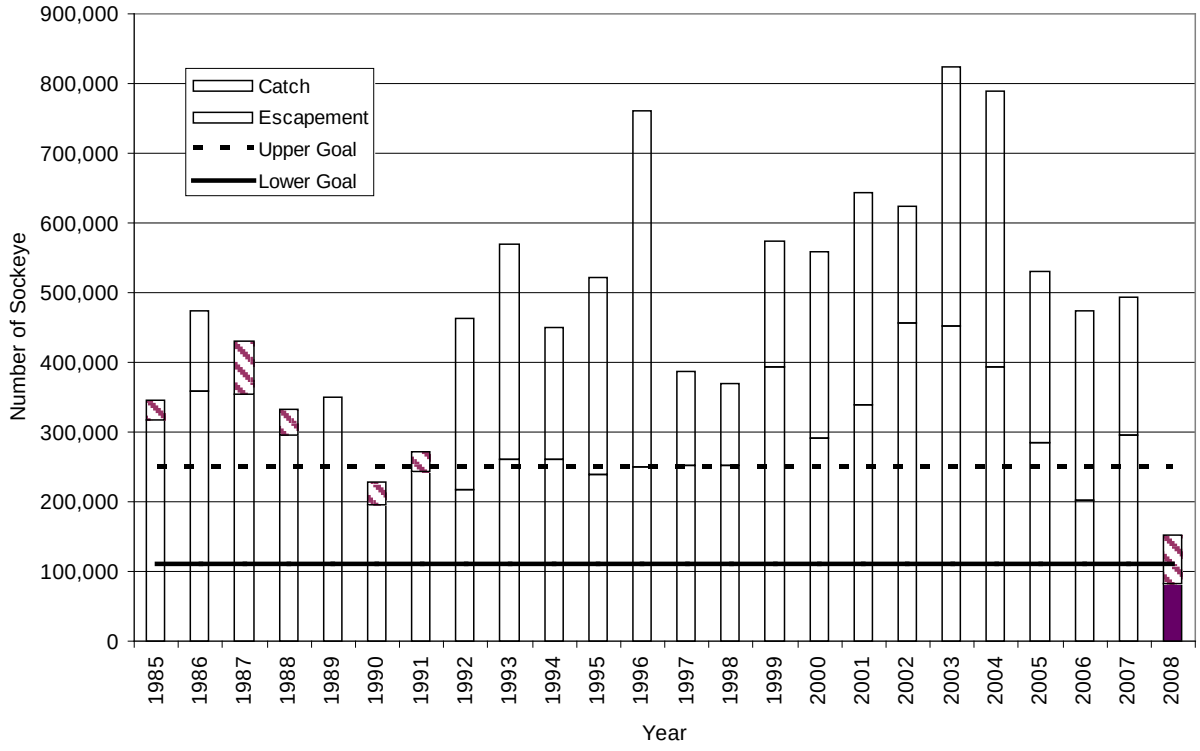

Figure 1. Karluk early-run sockeye salmon escapement, catch, and run estimates, 1985-2008 and the lower and upper goals.

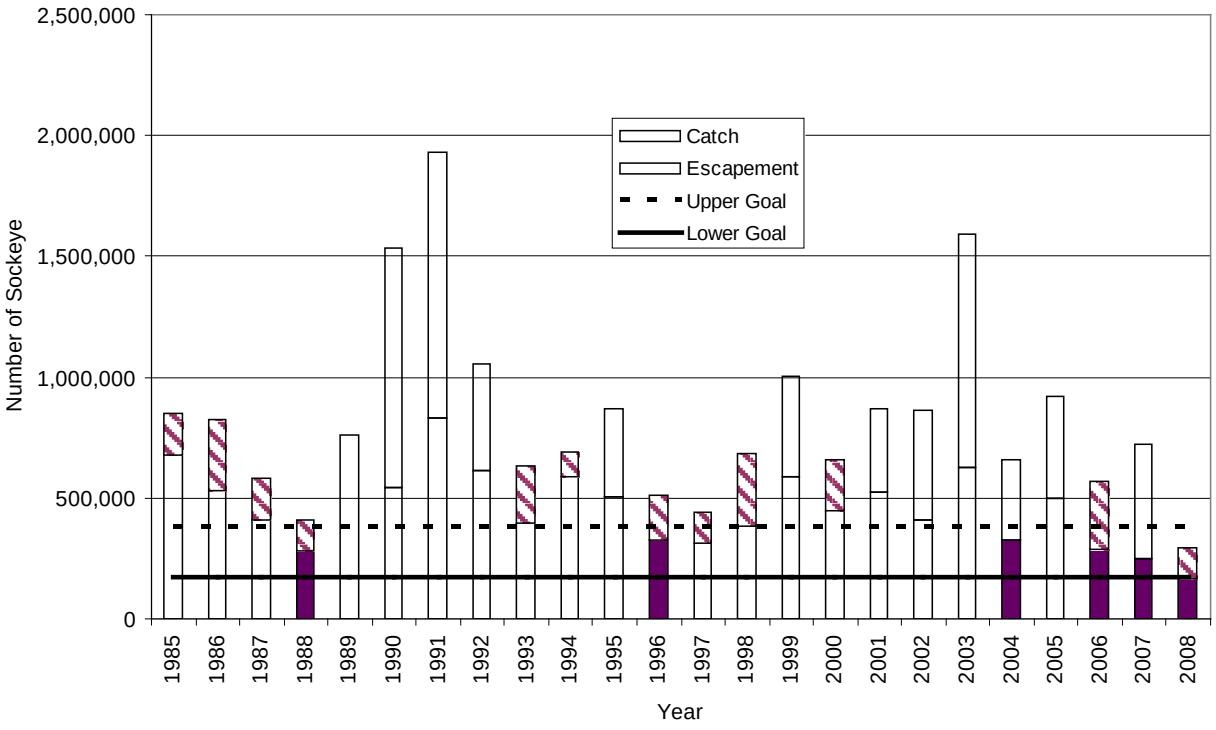

Figure 2. Karluk late-run sockeye salmon escapement, catch, and run estimates, 1985-2008 and the lower and upper escapement goals.

From 1985 to 2007 the Karluk early run has had the most consistent sockeye salmon production of any large sockeye salmon run in the Westward Region (Foster 2008). Karluk early-run sockeye salmon abundance is positively correlated to all early run systems (Nelson, Upper Station early, and Chignik early). The Karluk late run, while not as consistent as the early run, has been the most abundant Kodiak area sockeye salmon run since 1985. The Karluk late run is positively correlated to Ayakulik, Frazer, and Chignik late run. The 2008 season marked a drastic departure from that consistency and magnitude common since 1985. The Karluk total run (early- and late-runs combined) was roughly 1/3 of average and the escapement was the lowest since at least 1985 (Figures 1 and 2).

While the causes of these reduced runs are speculative, we explored factors affecting the productivity of Karluk Lake sockeye salmon. We also explored historical trends to determine if this sort of low productivity has happened before, how long it has remained reduced in the past, and what sort of recovery we may expect. We also investigated the freshwater conditions and abundance and size of smolt outmigrations from what limited data we still collect. Synthesis of these data allowed us to speculate what the future may hold for Karluk sockeye salmon runs.

2008 Forecast

The 2008 early Karluk Lake sockeye salmon run was expected to be well below average with a lower than average run of 2-ocean fish. The 2008 early run was approximately 240,000 fish below the forecast of 401,000. If we examine the run by forecasted age class however, it is clear

that the reduced run is largely due an apparent decrease in abundance of saltwater-age-2 fish (also referred to as 2-ocean). The other age classes came in generally as expected (Figure 3).

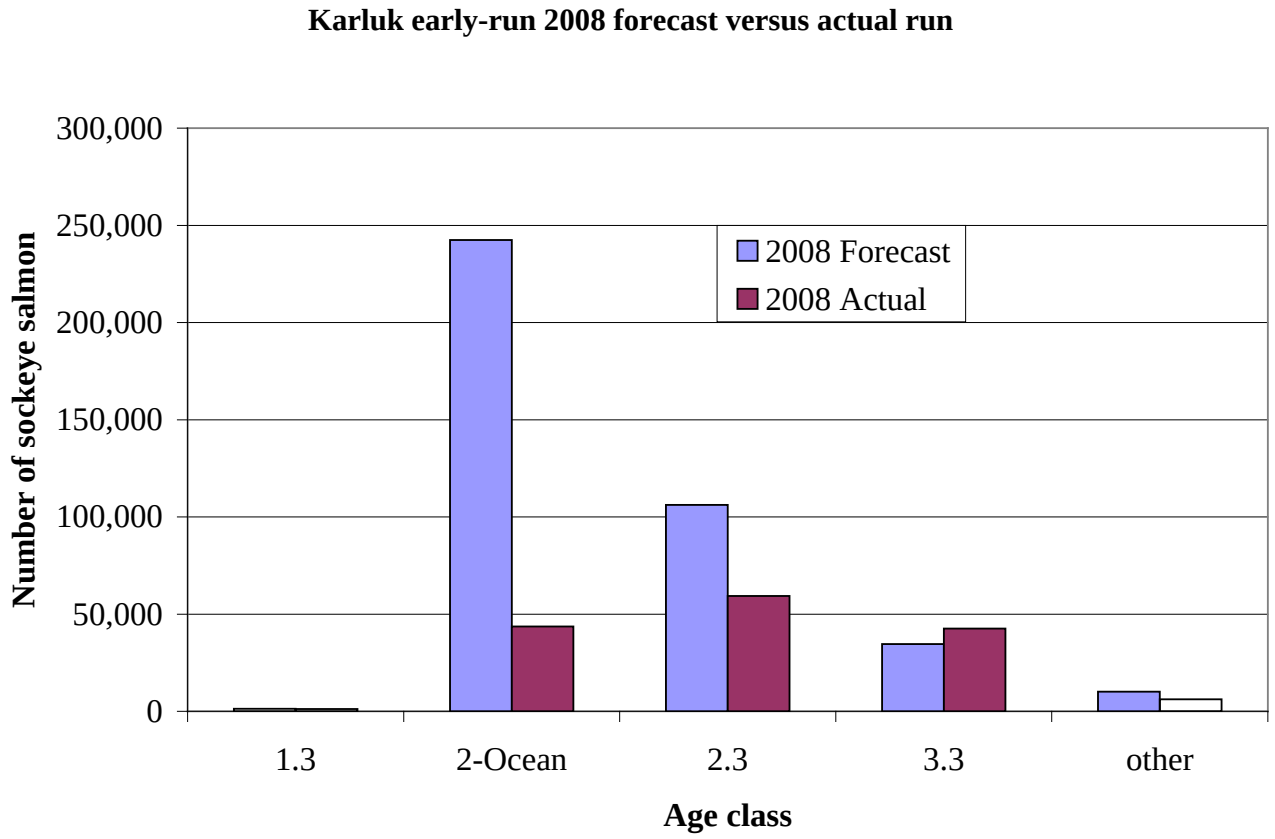

Figure 3. Karluk Lake early sockeye salmon forecast versus actual run.

The same situation is apparent when examining the late run. The 2008 late Karluk Lake sockeye salmon run was forecasted to be well below average and came in about 167,000 fish short of the 461,000 fish forecast. When we examine the run by age class, again, 2-ocean fish are the main source of the shortfall (Figure 4).

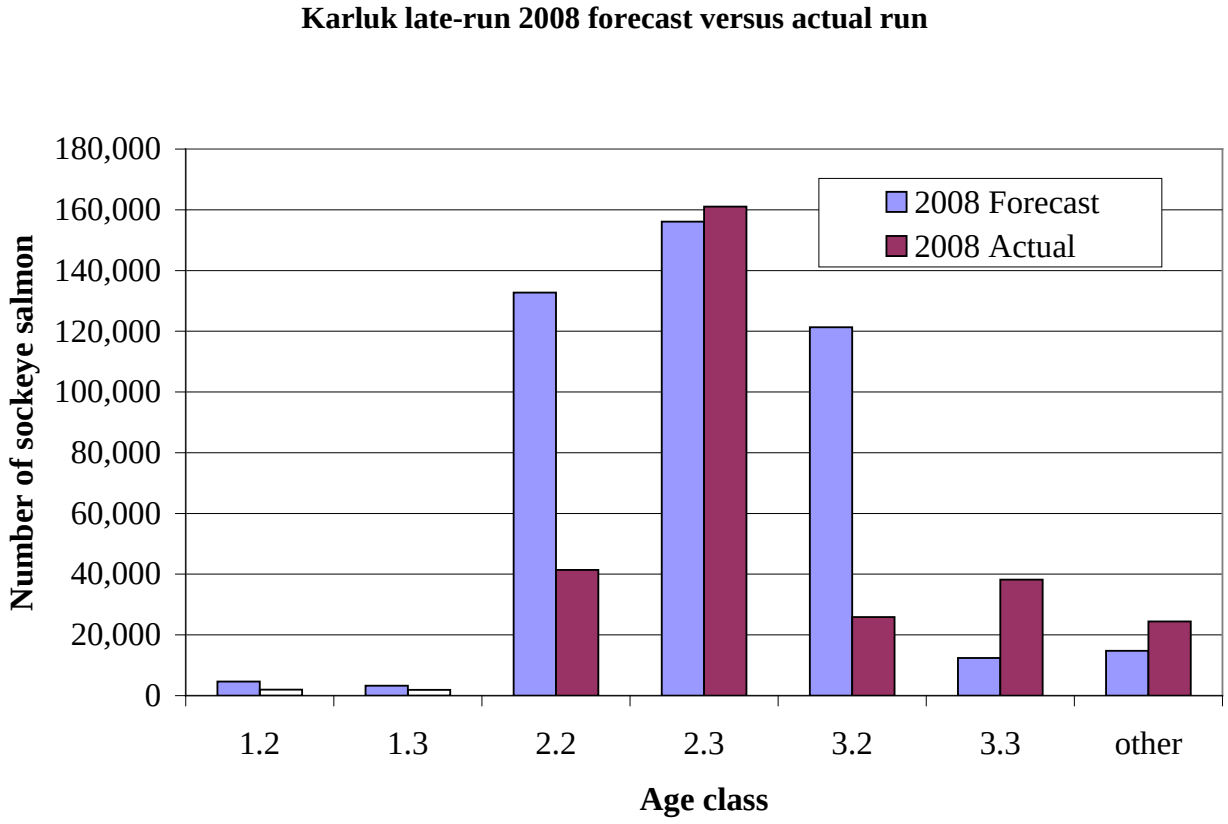

Figure 4. Karluk Lake late sockeye salmon forecast versus actual run.

Historically, 2-ocean fish, especially age 2.2s have been the dominant age class to return to Karluk Lake. In 2007 and 2008, the age 2.2 fish returned in lower proportions.

Age and Growth Trends

Sockeye salmon freshwater residence time in Karluk Lake is typically 2 years but often will extend to 3 years (Kyle et al. 1988; Rounsefell 1958). Since 1985, freshwater-age-2 sockeye salmon have dominated the annual runs (Figures 5a and 5b) with the exception of the early 1990s when freshwater-age-3 fish spiked in abundance. While contrary to the theorized impact that fertilization would have (Schrof and Honnold 2003), this peak in fresh-water-age-3 adult returns, coincidentally or not, resulted from juveniles produced or rearing during the onset or in the midst of nutrient fertilization in the lake.

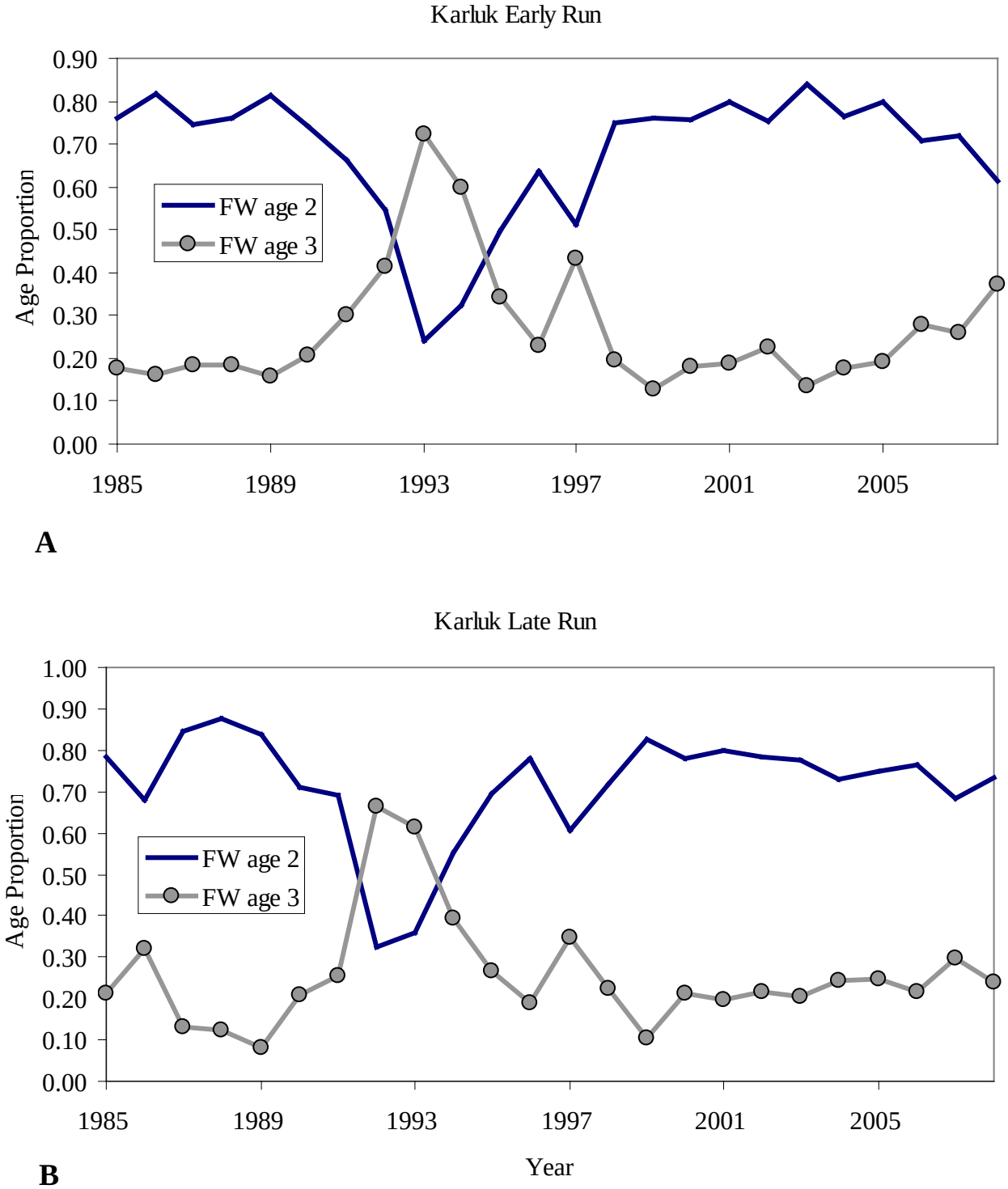

Figure 5. Karluk early- (A) and late-run (B) historical freshwater age composition comprising the annual run, 1985-2008.

Freshwater-age-3 fish, while not normally dominant, since the inception of sampling for salmon age (1920s) consistently have been an important part of the Karluk Lake early and late runs. Over

the last 10 years freshwater-age-3 fish have composed over 20% of the annual run and have been remarkably consistent. Since 1999, the Karluk early-run has shown a slightly increasing proportion of freshwater-age-3 fish, with about 37% in 2008. The late run has remained stable in the same time frame averaging 22% freshwater-age-3 fish.

Both early- and late- run Karluk Lake sockeye salmon typically spend two years in the ocean, making age-2.2 the dominant historical age class since the 1920s. Since 1985, 2-ocean sockeye salmon have dominated both runs but are a greater percentage of the late run (Figures 6a and 6b). There appears to be a 5 or 6 year cycle of 3-ocean sockeye salmon dominating during the early run. The most significant change in age components recently for both the early and late components is the atypically high proportions of 3-ocean fish from 2007 and 2008.

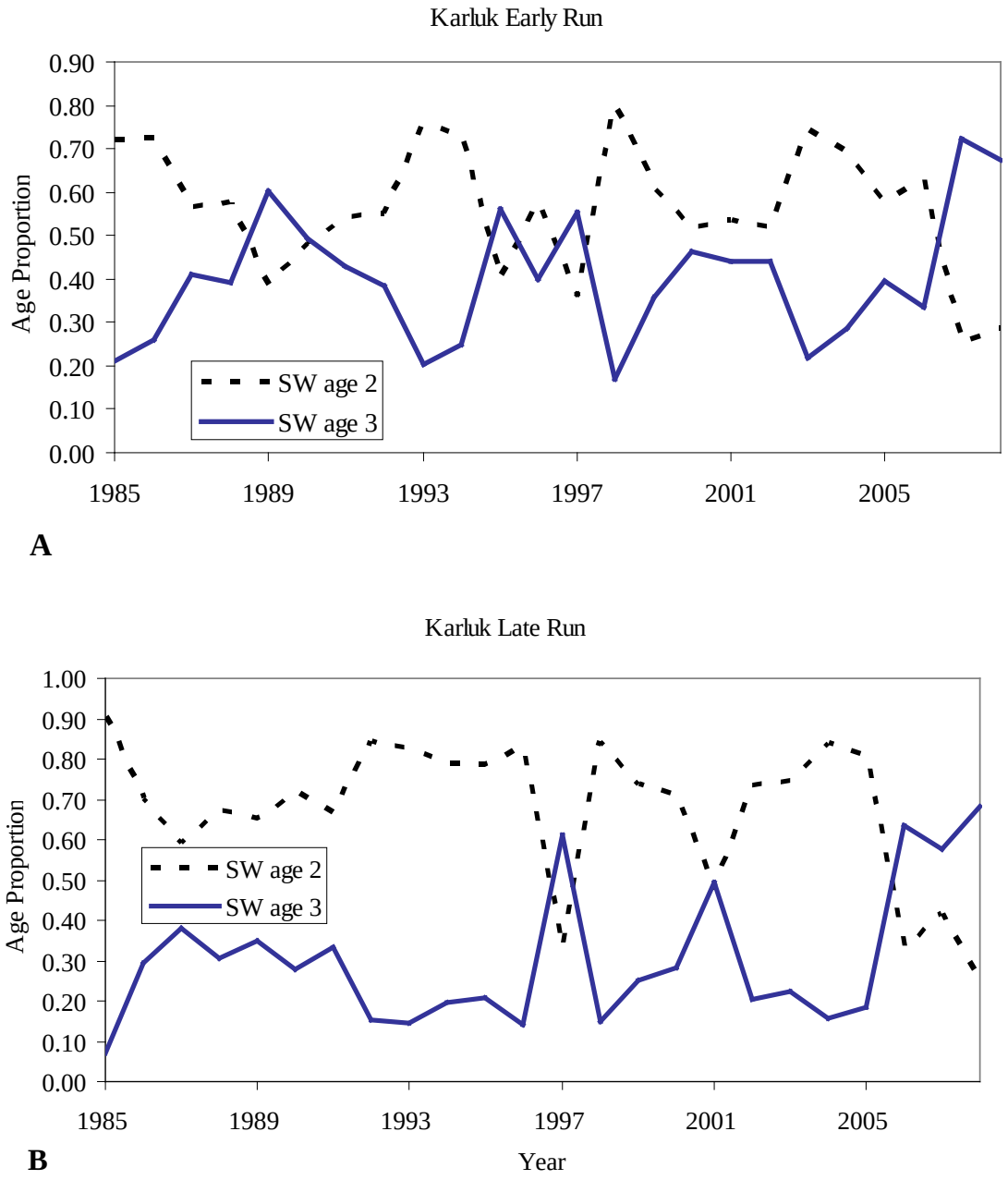

Figure 6. Karluk early- (A) and late-run (B) historical saltwater age composition comprising the annual run, 1985-2008.

Average size of saltwater-age-2 sockeye salmon at Karluk have followed the general trends as other Kodiak area sockeye salmon stocks. However, Karluk and Ayakulik saltwater-age-2 sockeye salmon have tended to get smaller since 1985, while Upper Station and Litnik fish have tended to increase in size (Figure 7). Frazer Lake saltwater-age-2 fish have remained stabile in size.

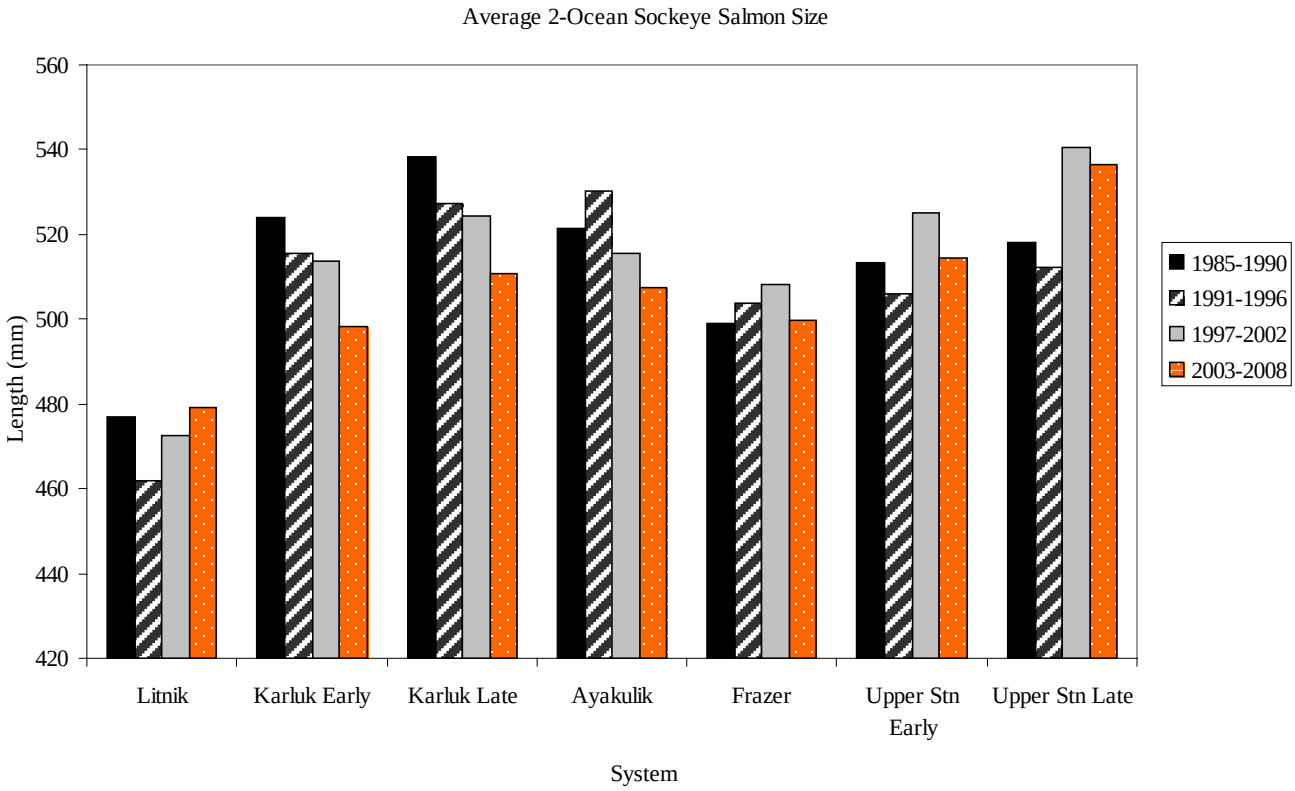

Figure 7. Kodiak area average saltwater-age-2 sockeye salmon size (mm), by system 1985-2008.

Average Karluk Lake smolt size has been variable but are consistently large compared to outmigrating sockeye salmon from other regional systems. The Karluk sockeye smolt project and sampling ended in 2006. The average size of smolt outmigrating in 2005 and 2006 was abnormally small (Figures 8 and 9). Outmigrating fish from the 2005 and 2006 season made up the vast majority of fish in the weak 2008 return. While smolt size data at Karluk have been infrequently collected since the 1920s, the unusually small size recorded in 2006 was unprecedented (Figure 9). Furthermore, it is important to point out that the returning 2-ocean fish in 2008 (or lack there of) outmigrated in 2006 at that small size (Figures 3, 4, and 9).

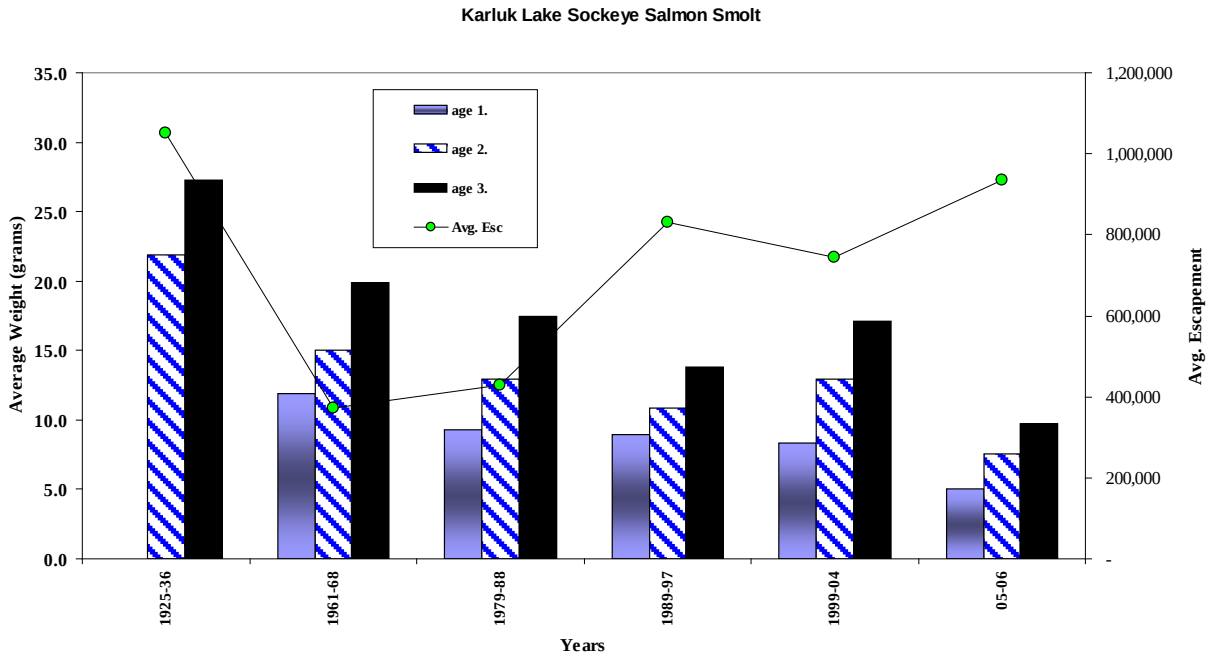

Figure 8. Karluk Lake average sockeye salmon smolt size (weight in grams) using all available data and associated average brood escapements during the timeframe.

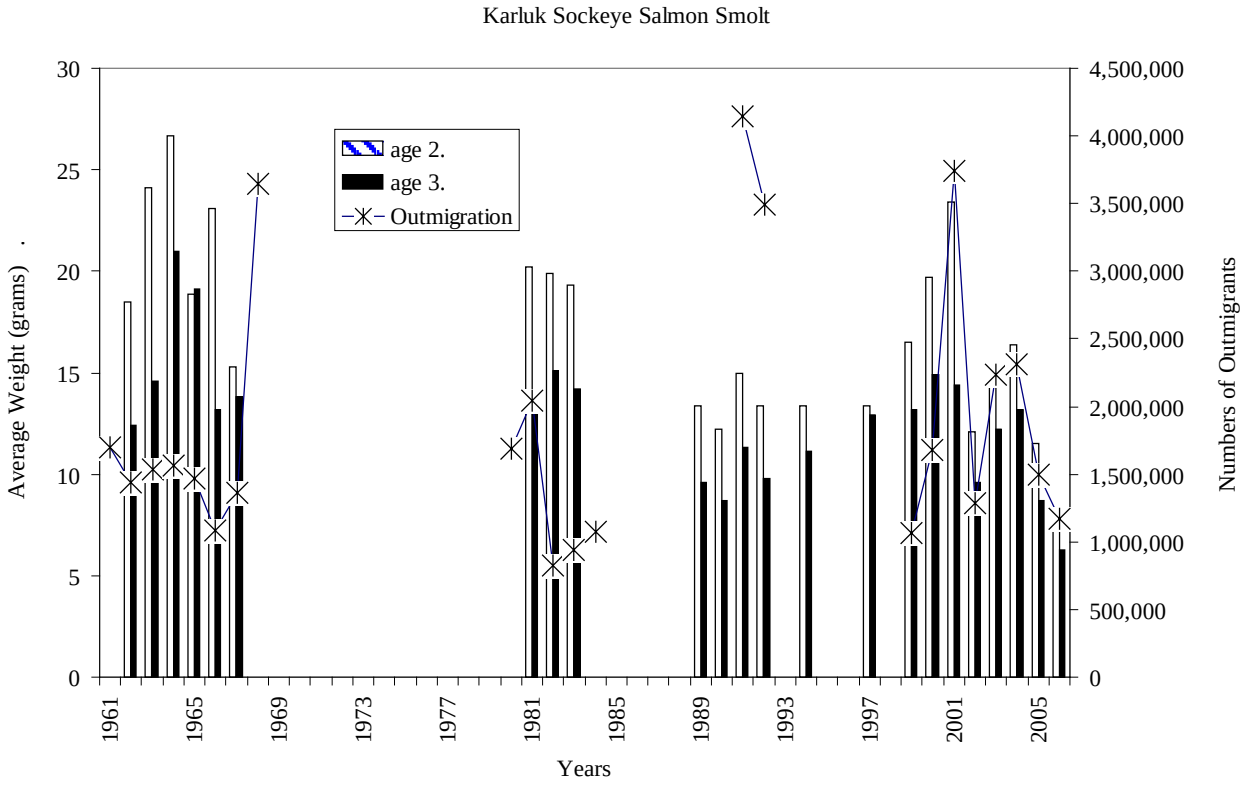

Figure 9. Karluk Lake average sockeye salmon smolt size (weight in grams) by age and associated outmigration estimate, 1962-2006.

While Karluk Lake sockeye salmon smolt data are limited, an extensive time series of scale growth measurements exist for Karluk Lake sockeye salmon. Fukawaka (1998) found a positive relationship between fork length and scale radius at check formation in juvenile sockeye salmon. He also found that circuli spacing was positively correlated with somatic growth. From 1924 to 2008 (excluding only 6 years), the first year of freshwater growth in age-2.2 sockeye was measured using the Biosonics optical pattern recognition system (OPRS), which integrates a compound microscope, ocular lens, frame grabber, digitizing tablet, and microcomputer.

It is noteworthy that when examining scale measurements the growth measured actually occurred 4 years prior to the sample year (Figure 10). The general trend in the data is a common theme in Alaska salmon productivity and similar to any number of indices such as the Pacific Decadal Oscillation, air temperature, and sea surface temperatures of the North Pacific. In addition, it corresponds well to Karluk Lake sockeye salmon escapement. Compared to average size of outmigrating smolt (age-2 and age-3) data (Figure 9), the trend in scale growth measurements roughly correspond, but deviate with the 1960s data. Obviously, a rigorous analysis of this data is outside the scope of this memorandum and hence explains the brief treatment. Of greater importance currently is the relationship between the scale measurements and total return of sockeye salmon to Karluk Lake.

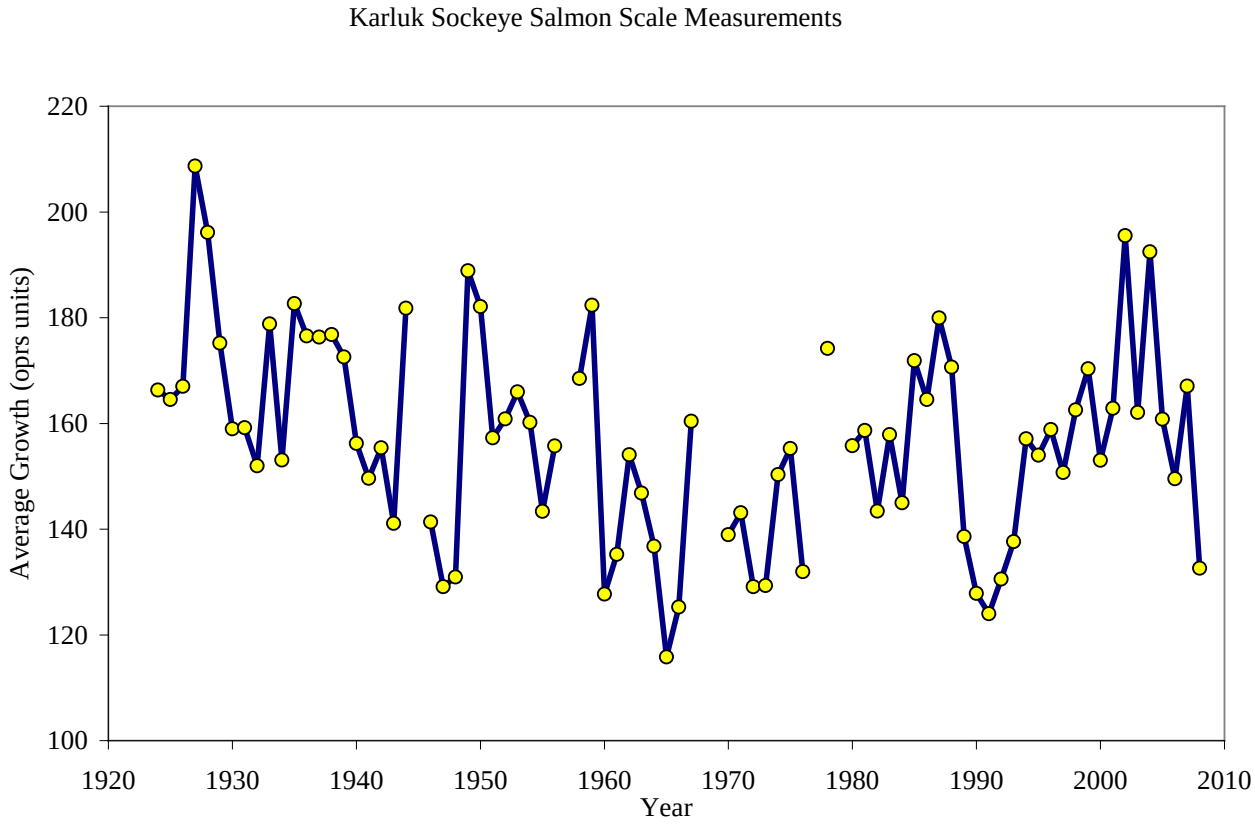

Figure 10. Karluk Lake sockeye salmon age-2.2 first year of freshwater scale growth, 1924-2008.

With the extended freshwater residency and intraspecific brood year competition of Karluk Lake sockeye salmon, relating the scale growth data to actual returns can be difficult. There is however correlation between the 3-year average first year scale growth and 3-year average total return (Figure 11). A cursory look at age-2.1 fish from the 2008 escapement (indicating 2009 age-2.2s) suggest first year scale growth for 2009 will be at or below the 2008 level of age-2.2 fish in the escapement. Incorporating this information with the data on Figure 11 indicates 2009 and 2010 will most likely be at or below the 2008 total run magnitude and depressed.

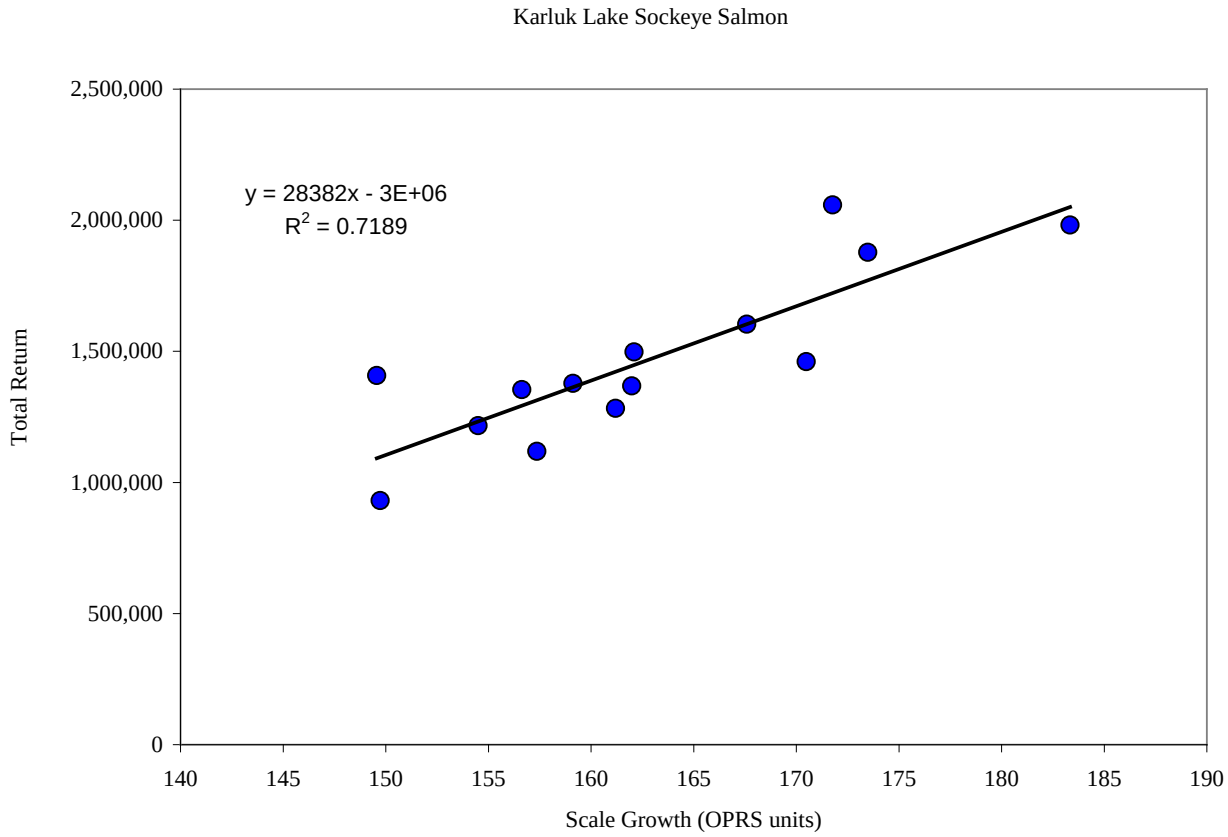

Figure 11. Three year-average total Karluk Lake sockeye salmon return vs average (3-yr) first year scale growth of age-2.2 fish 1995-2008.

Karluk Limnology

Karluk Lake is the largest lake in the Kodiak Management Area and drains in a northeasterly direction via the 35 km Karluk River, emptying into the Shelikof Strait. The lake has a mean depth of 48.6 m, and a maximum depth of 126 m (Schrof and Honnold 2003). The lake is considered oligotrophic, having low nutrient concentrations, and dimictic, turning over in the spring and fall.

Karluk Lake was fertilized from 1986 to 1990 in an effort to address sockeye salmon production declines in the 1970s and 1980s. Limnology data, including temperature, solar illuminance, pH, alkalinity, nutrient concentration, and zooplankton biomass and species composition, have been

collected seasonally with varying effort from Karluk Lake from 1985 to the present to evaluate and monitor the effects of the rehabilitation efforts and assess rearing habitat quality.

Temperature and Solar Illuminance

Monthly temperature profiles of Karluk Lake (Figure 12) indicated that the lake mixes in the spring and the fall. The epilimnion has stratified within approximately 10 to 15 m of the lake's surface from July through September. The average 1-m temperature from 1993 to 2008 was 10.3 °C, with the coldest 1-m temperature occurring in 2008 (8.0 °C) and the warmest 1-m temperature occurring in 2004 (12.9 °C; Figure 13).

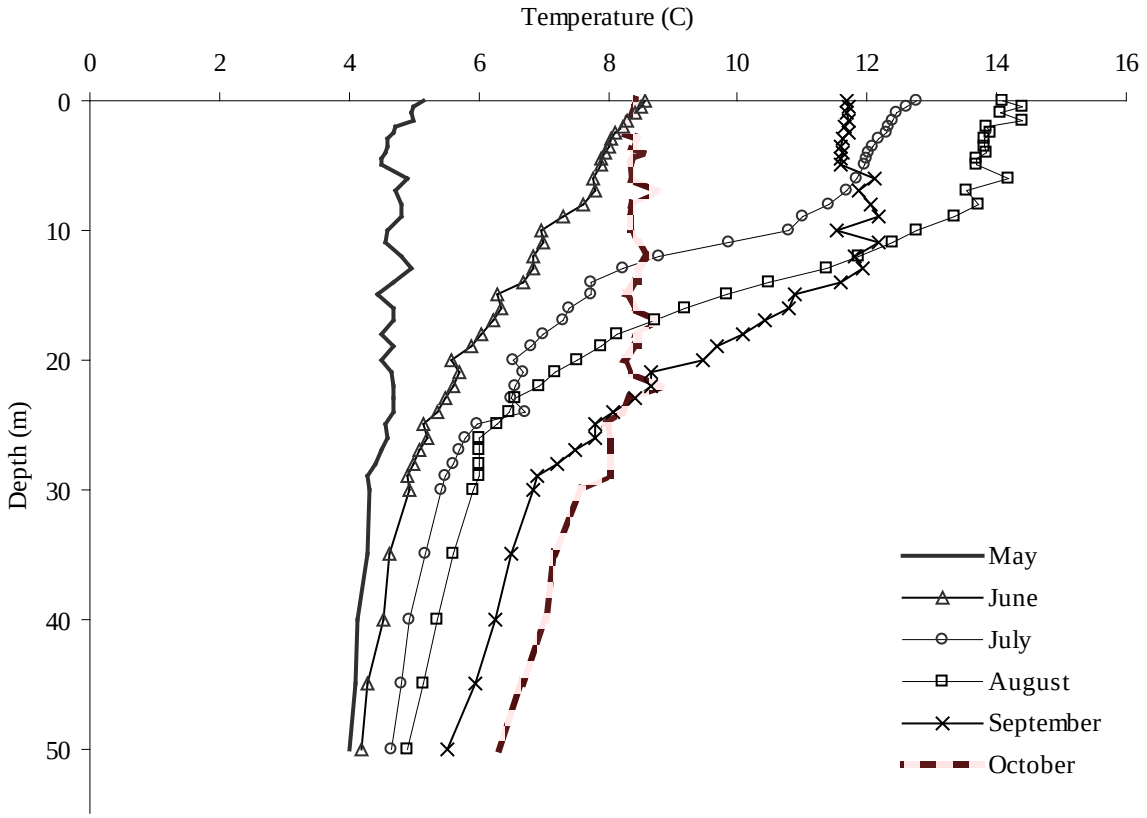

Figure 12. Average (1993 to 2008) seasonal temperature-depth profiles by month for Karluk Lake.

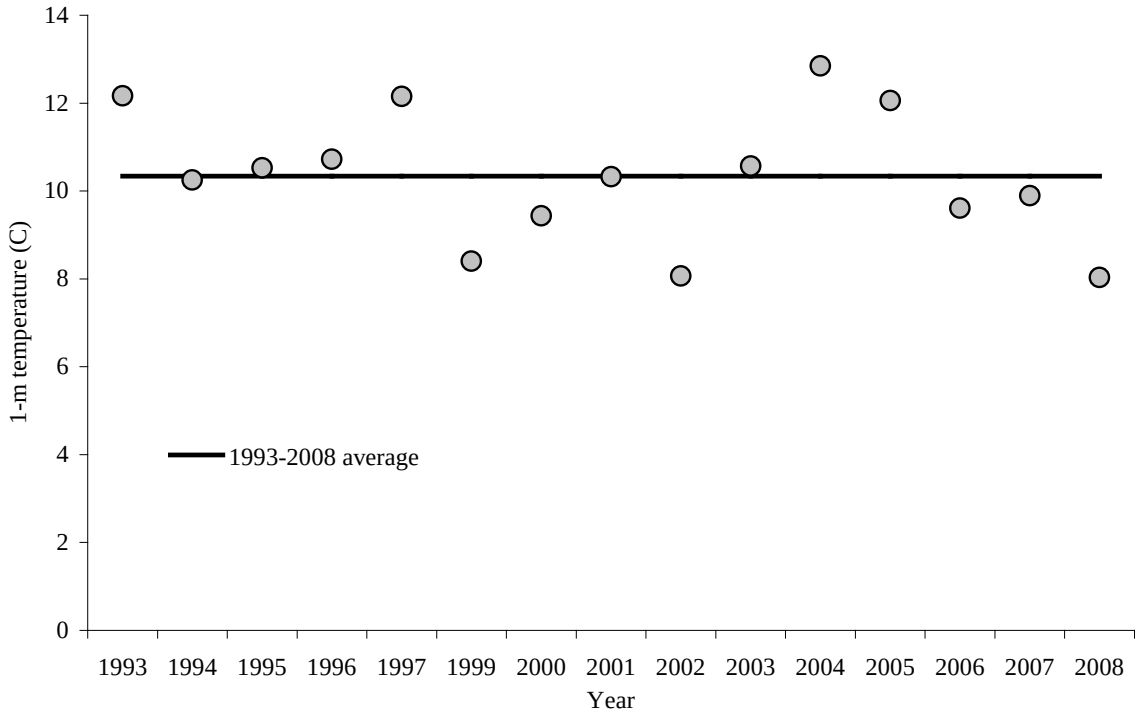

Figure 13. Seasonal average 1-m temperatures by year for Karluk Lake.

Solar illuminance data collected between 1989 and 2008 indicated that the depth to which photosynthetic activity would occur (euphotic zone depth; EZD) was the greatest in April (24.5 m) and October (23.3 m) and the least in June (19.8 m) and July (19.9 m). The lowest average seasonal EZD occurred in 1995 (17.8 m) and the greatest average seasonal EZD occurred in 2002 (24.7 m). The average seasonal EZD was 21.3 m from 1989 to 2008. Data from the last two years of fertilization showed that the EZD was lower (<20.5 m) than the annual average seasonal EZD (Figure 14).

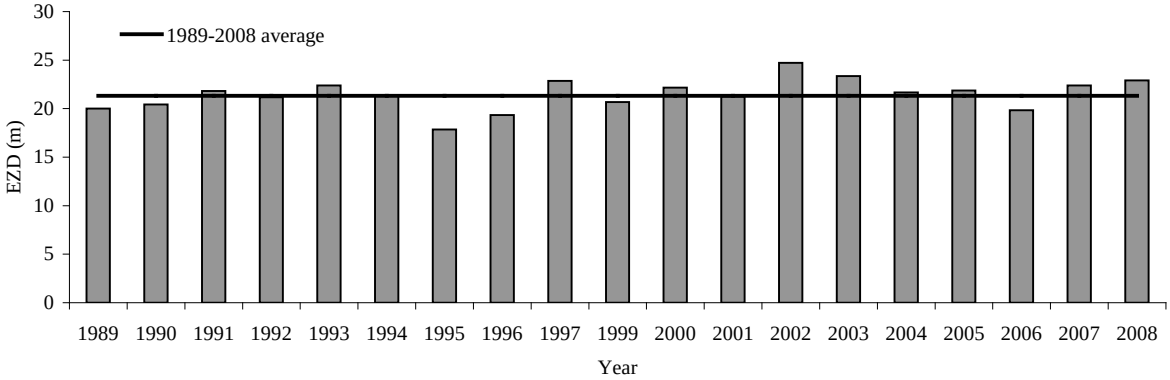

Figure 14. Seasonal average EZD by year for Karluk Lake.

Nutrient, pH, and Alkalinity Data

Nutrient, pH, and alkalinity data were collected from Karluk Lake from 1985 to 1994 and from 2004 to 2006 to help gauge levels of primary production (Table 1). This sampling time frame encompasses the year prior to fertilization, the fertilization period, and years directly following and somewhat after lake fertilization. Of the nutrients sampled, included were total phosphorous (TP), total Kjeldahl nitrogen (TKN), chlorophyll *a*, phaeophytin *a*, and silicon. Karluk Lake pH was generally neutral from year to year with a minimum pH of 6.94 in 1993 and 1994 and a maximum pH of 7.36 in 1991. Karluk Lake was also resistant to changes in pH as evidenced by an annual seasonal average alkalinity of 22.04 mg/L. Ratios of TKN to TP indicated that phosphorous was a limiting nutrient (TKN:TP >10:1) in all years except 1994, which had a TKN:TP ratio of 8.4:1.0. Comparisons of chlorophyll-*a* and phaeophytin-*a* (the by-product of photosynthesis) concentrations suggested that chlorophyll *a* was adequate for supporting primary production as phaeophytin-*a* concentrations did not exceed chlorophyll-*a* concentrations. Similarly, silicon concentrations where not affected by changes in chlorophyll-*a* concentrations, which suggested that silicon was not limiting to primary production.

Table 1. Average seasonal nutrient, pH, and alkalinity data by year for Karluk Lake.

	Year													
Data	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	2004	2005	2006	Mean
pH	7.17	7.15	7.00	7.17	7.14	7.35	7.36	7.01	6.94	6.94	7.18	7.07	7.29	7.18
Alkalinity (mg L^{-1})	21.83	23.67	21.83	20.17	21.15	22.32	23.07	20.68	21.82	21.13	22.38	21.98	22.62	22.04
TP (ug L^{-1})	6.60	8.17	8.48	8.60	8.00	8.01	7.47	7.21	7.32	13.78	9.47	9.31	6.16	8.39
TKN (ug L^{-1})	107.67	93.50	113.33	90.08	110.55	97.60	117.42	127.77	108.54	115.75	151.83	204.75	229.44	121.28
Chlorophyll *a* (ug L^{-1})	1.72	1.61	2.31	2.44	1.27	1.06	1.44	1.58	2.73	0.94	2.23	1.85	2.20	1.92
Phaeophytin *a* (ug L^{-1})	0.99	0.59	0.56	0.72	0.55	0.50	0.69	0.68	1.02	0.23	0.36	NA	0.47	0.58
Silicon (ug L^{-1})	72.67	88.83	100.67	83.94	94.15	168.56	107.07	186.20	136.10	178.88	417.47	352.05	615.91	343.00

Zooplankton Data

Zooplankton data were collected from Karluk Lake from 1980 to 1997 and from 1999 to the present. The most prevalent zooplankton in Karluk Lake were the copepods *Cyclops* and *Diaptomus* and the cladocerans *Bosmina* and *Daphnia*. Zooplankton biomass levels in Karluk Lake have varied considerably over time (Figure 15). Prior to the first year of fertilization (1986), zooplankton biomasses were generally above satiation levels (1,000 mg/m^2; Mazumder and Edmundson 2002). During the fertilization period (1986 to 1990), the zooplankton biomass ranged from 540.2 mg/m^2 in 1987 to 1,253.8 mg/m^2 in 1989. Following the fertilization period, the zooplankton biomass reached its highest levels in 1992 (1,780.3 mg/m^2), 1995 (2,045.5 mg/m^2), and 2000 (2,333.3 mg/m^2). However, of the 17 years following the last year of fertilization, 10 years have been below the satiation level, and from 2005 to 2008, the zooplankton biomass has been at some of its lowest historical levels (365.0 mg/m^2 in 2008).

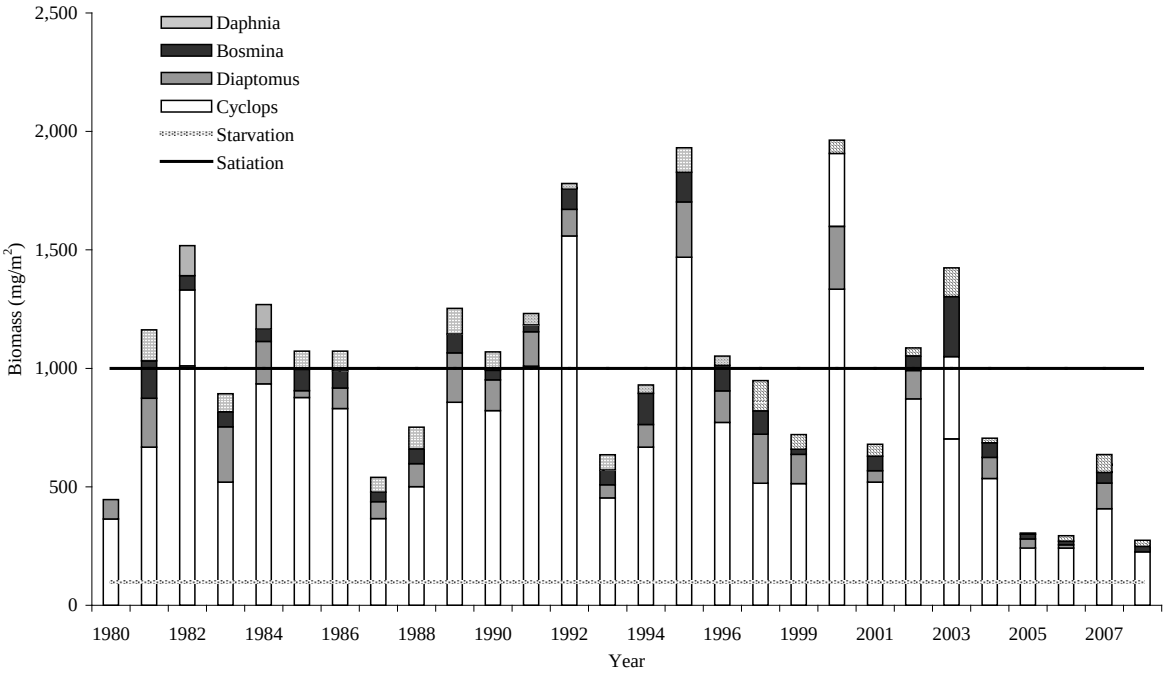

Figure 15. Seasonal average weighted zooplankton biomass by year for Karluk Lake.

Of the prevalent taxa of zooplankton, the average lengths of *Cyclops*, *Bosmina,* and *Daphnia* have declined through the pre-fertilization, fertilization and post-fertilization periods (Table 2). The average seasonal length of *Diaptomus* declined from the pre-fertilization to fertilization period and increased on average during the post-fertilization period; however, the average length was smaller during the post-fertilization period than in the pre-fertilization period. *Bosmina*, which are considered the preferred food of rearing juvenile sockeye salmon, generally were longer than the minimum elective feeding threshold of 0.40 mm (Kyle 1992) prior to and during the fertilization period. However, the average length of *Bosmina* dropped below 0.40 mm for 12 of the 17 years following fertilization (Figure 16), which suggests that the zooplankton population experienced grazing pressure or was subject to other unfavorable conditions such as cooler temperatures or increased turbidity.

Table 2. Average seasonal weighted lengths of the major zooplankton taxa of Karluk Lake.

	Genera length (mm)			
Period	Diaptomus	Cyclops	Bosmina	Daphnia
Pre fertilzation (1980-1985)	0.95	0.76	0.44	0.71
Fertilization (1986-1990)	0.88	0.70	0.42	0.70
Post fertilization (1991-1997, 1999-2008)	0.92	0.68	0.38	0.59
0verall average (1980-1997, 1999-2008)	0.92	0.70	0.40	0.63

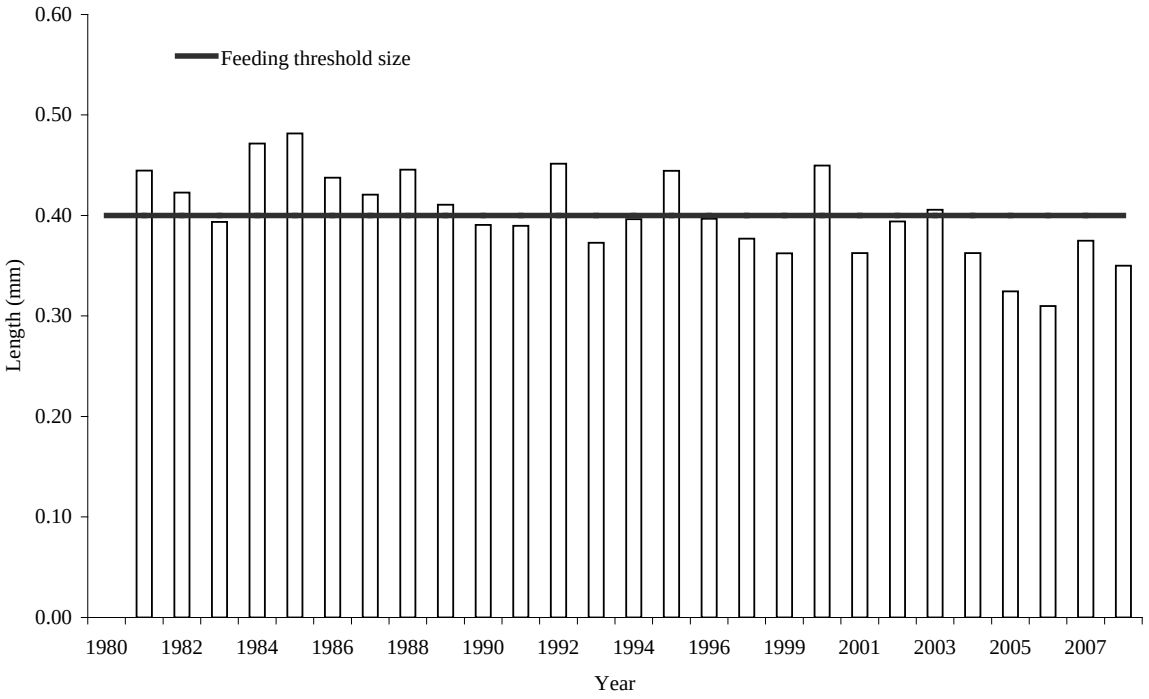

Figure 16. Seasonal average weighted length of *Bosmina* by year for Karluk Lake.

Summary of Karluk Lake Limnology Data

Limnology data are a useful tool for describing changes in sockeye salmon populations. Coupled with juvenile sockeye salmon data, factors that affect life history strategies or survival such as bottom-up (nutrient or physical conditions) or top-down (competition) pressures can be identified.

From a bottom-up perspective, Karluk Lake possesses a substantial pelagic rearing area for its juvenile fishes as evidenced by its deep EZD. In light of available nutrient levels, a sizable volume of water exists in which photosynthesis can occur, thus providing adequate food for zooplankton in the form of phytoplankton. The availability of phytoplankton does not appear to be limited as evidenced by the relatively low concentrations of phaeophytin *a*, the by-product of photosynthesis. That is to say, because phaeophytin-*a* concentrations are low relative to chlorophyll-*a* concentrations, the algal population has adequate light and nutrients available for photosynthesis.

Because bottom-up limitations do not appear likely, this suggests that top-down grazing pressures may be affecting Karluk Lake sockeye salmon. The analysis of available zooplankton data suggests that *Bosmina* have been over grazed as evidenced by their reduction in size. Karluk sockeye salmon smolt data may also support evidence of top-down grazing pressures. Karluk sockeye salmon smolt data are available from 1961 to 1968, 1980 to 1984, 1991 to 1992, and from 1999 to 2006. During these years, the size of the outmigrating smolt run had ranged from 821 thousand in 1982 to 4.14 million in 1991 (Schrof and Honnold 2003). Since 1999, the average outmigration has been 1.97 million fish. Since 1980, the majority of outmigrating

sockeye salmon smolt have been freshwater-age-2 fish, with the exception of 2006, which was composed of 66% freshwater-age-3 fish. Relative to freshwater age, the recent decline in zooplankton biomass is positively correlated to the abundance of rearing freshwater-age-1 and freshwater-age-2 sockeye salmon ($P = 0.002$, $R^2 = 0.82$; Figure 17). Thus, large abundances of rearing age-1 and freshwater-age-2 sockeye salmon in Karluk Lake (possibly the product of sockeye salmon overescapements into the system) may be taxing the available forage base and increasing competition for food. Further inspection of smolt data also revealed that the condition of outmigrant Karluk sockeye salmon smolt was generally good (>0.80; Schrof and Honnold 2003) until 2005 when condition declined below 0.80. This decline in condition also accompanies declines in zooplankton biomass and *Bosmina* size.

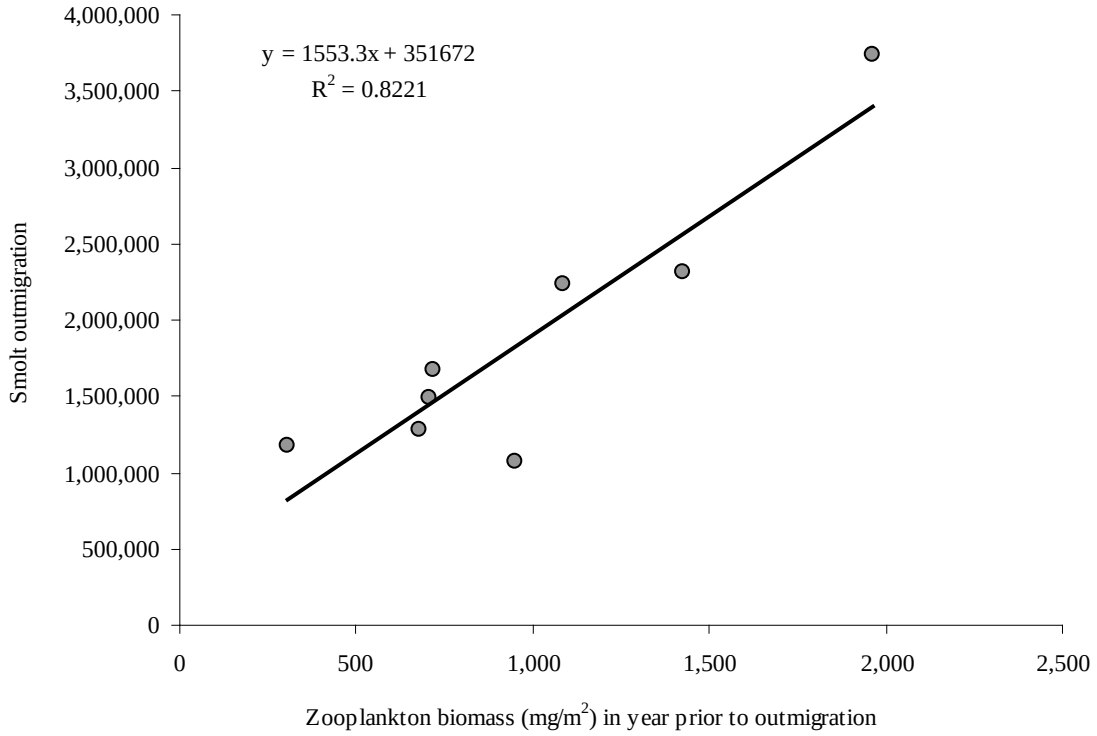

Figure 17. Karluk Lake sockeye salmon smolt outmigration size relative to the zooplankton biomass in the year prior to the outmigration.

The extent to which top-down pressures affect Karluk Lake sockeye salmon smolt, however, is still difficult to quantify. Climate change and random events, such as turbidity events, or changes in physical conditions can also greatly affect sockeye salmon populations. Cold temperatures like those observed in 1997, 2002, and 2008 can reduce photosynthetic activity and therefore primary productivity. Similarly, copepods can enter a state of diapause, or dormancy, as eggs or copepodids (juveniles) in response to overcrowding, photoperiod, or predation pressure, effectively removing themselves from the zooplankton population and predators.

Climate

Many factors effect the productivity of the sockeye salmon runs at Karluk Lake. While there are a

large amount of data on the Karluk Lake sockeye salmon stocks, our understanding of what drives the productivity of this system is still very limited. Climate change may also play a significant roll in productivity of Karluk Lake sockeye salmon; however, it is difficult to accurately measure. Natural climate fluctuations as indexed by the Pacific Decadal Oscillation (PDO; Mantua et al. 1997) certainly have an influence on productivity, but many other factors such as freshwater competition and food availability may effect productivity differently at the same time thereby confounding our predictive powers. Climate variability shown in the PDO appear to have an influence on Karluk Lake escapement over the longer term (Figure 18); however, lack of direct correlation suggest latent or cumulative effects on productivity.

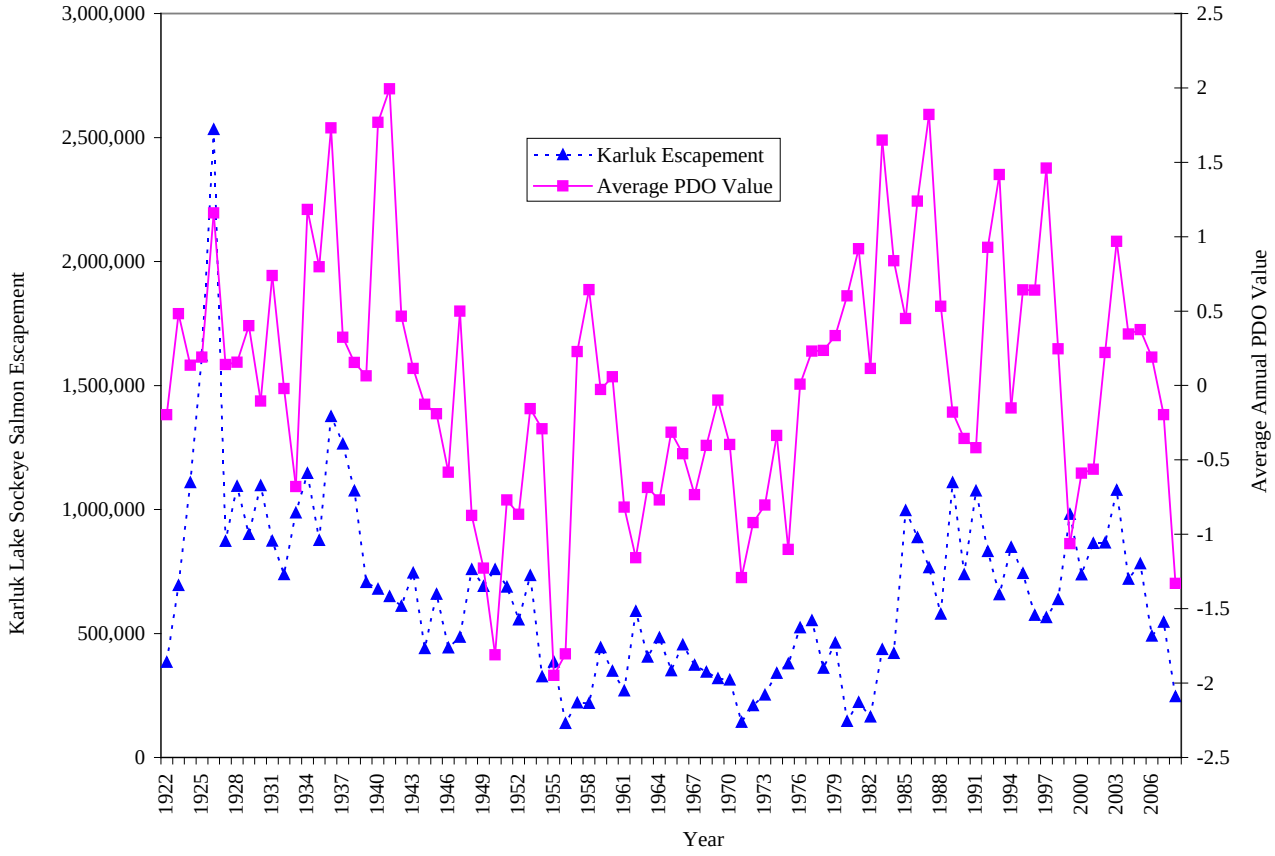

Figure 18. Karluk Lake sockeye salmon escapement versus Pacific Decadal Oscillation average annual values, 1922-2008.

It is notable however, that the past few years have exhibited significantly decreasing PDO values as well as decreasing escapement levels. The PDO trend coupled with (or the cause of) recent unfavorable freshwater conditions may be significant components influencing Karluk Lake sockeye salmon productivity. It is important to point out though, with differing physical parameters and productivity, sockeye salmon systems respond differently to variability in the environment (Peterman et al. 2003).

It is possible that the myriad of different environmental and man-made factors (such as fishing) effect the Karluk Lake sockeye salmon runs differently, but do not often have a negative effect at

the same time. In years such as 2008, several of these factors may simply have been negative at the same time, thereby reducing the masking effect and resulting in a large effect on the runs. Unfortunately, many of the influences that we are aware of such as freshwater rearing conditions, PDO, and trends in age compositions, tend to be slow to change and exhibit a particular tendency for several years.

2009 Forecast

The Karluk Lake sockeye salmon forecasts predict a low run for 2009 with a continued low proportion of age 2.2 fish. While Karluk Lake runs continue to be difficult to predict, several indicators point to low runs. The 2-ocean component of the early run is predicted from the previous years' run of 1-ocean fish. The 2008 1-ocean run is the lowest on record within the current run reconstruction methodology (1985-2008) indicating a low level of 2-ocean returns in 2009. The regression relationship for this prediction is fair with a R^2 of 0.39 and a *P*-value of .001 for the slope of the regression. Despite the relative predictive power of this forecast, the 2008 age 2.2 run was well below the regression line and well under what was predicted.

The 2-ocean component of the late Karluk Lake sockeye salmon run is predicted using the previous years' return of age 2.2 fish (a non-typical relationship) to predict the return of age 3.2 fish. A very low run of age 2.2 fish in 2008 provides a very low predictor value of the age 3.2 fish in 2009. A temperature index is used to predict the age 2.2 component of the late run. The temperature index is a May through September average (measured at the Kodiak airport) during the first summer of lake residence and is negatively correlated with the return of age 2.2 fish. The predictor for the 2009 run is also very low, but provides a slightly better prediction than for the 2008 run; however, this relationship was not used to predict the 2008 run and therefore its predictive powers are untested.

Conclusion and Long Term Assessment

There is not a single factor to explain the weak Karluk Lake sockeye salmon run in 2008. Examining the list of factors seemingly detrimental to production and backtracking from the most recent indicators should however, shed light on the multitude of impacts to Karluk Lake sockeye salmon. Most indicative is the relative small size and condition of outmigrating smolt in 2005 and especially 2006. The small size (Figures 8 and 9) suggest that marine survival in those outmigrants would be much lower than normal and would help explain the poor 2008 Karluk Lake run. The natural question would then be what caused the small size at outmigration in those years. Far more speculation comes into play with this question, but the most likely scenario would employ a number of factors including but not absolutely limited to;

1) Declining zooplankton biomass in Karluk Lake since 2004 (Figure 15) and available food for the rearing sockeye salmon suggest poor feeding conditions,
2) Since 2004, the size of the preferred food source, *Bosmina*, has been below the optimal feeding threshold size (Figure 16),
3) Decreases in Karluk Lake seasonal water temperatures (Figure 13),
4) Decreases in the average PDO (Figure 18), and

5) Continued overescapement during the return years of 1985 to 2005 (Figure 18) likely producing a highly competitive rearing environment, taxing the forage base and affecting growth (Burgner et al. 1969).

We have not collected samples of outmigrating sockeye salmon smolt at Karluk Lake since 2006. However, other factors such as those listed above have been continually collected and thus serve as indicators for the next 3-5 years. Zooplankton biomass in 2005, 2006, and 2008 has been extremely low. In addition, *Bosmina* size data does not look favorable for feeding sockeye salmon. Climate data, as represented by average lake temperatures and the PDO all suggest unfavorable conditions. In conclusion, qualitatitive assessment of the data in the memo in combination with the historical escapement trends indicate that the Karluk Lake sockeye salmon run will most likely be depressed for a period of at least 3 to 5 years, including 2008.

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cc: Sterritt, Wadle, Baer, Schrof, Thomsen, Jackson, Loewen, Volk, Dinnocenzo, Spalinger, Barnard

ALASKA DEPARTMENT OF FISH AND GAME

DIVISION OF COMMERCIAL FISHERIES

MEMORANDUM

TO: Steve Honnold
Regional Supervisor
Division of Commercial Fisheries
Region IV - Kodiak

DATE: July 23, 2010

PHONE: (907) 486-1857
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THRU: Matt Nemeth
Regional Finfish Research Biologist
Division of Commercial Fisheries
Region IV – Kodiak

SUBJECT: Reduced sockeye salmon runs at Karluk Lake (II)

FROM: Birch Foster, Mark Witteveen, and Heather Finkle
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Region IV - Kodiak

Background

In 2008 and 2009, sockeye salmon escapements to Karluk Lake were unusually low; in particular, the early run was the lowest since the 1980's, despite minimal commercial fishing time. In April of 2009, research biologists with Alaska Department of Fish and Game (ADF&G) examined the evidence for low returns, discussed potential causes, and predicted future trends. This memo will summarize those findings and update them based on subsequent data collected in 2009. Additional information collected in 2009 was consistent with the theorized causes of declines. The 2009 return of sockeye salmon was extremely low and the outlook for 2010 through 2012 remains one in which salmon runs will likely be below average.

April 2009 Memo

The April 2009 memo reviewed several factors that could affect sockeye salmon production in Karluk Lake: historical escapement, limnology, climate, and trends in fish size, age, and growth. The authors emphasized the importance that the exceedingly small size and condition of outmigrating smolt in 2005 and especially 2006 plays in determining marine survival and thus influencing run strength. The authors listed five major factors thought to cause the small size at smolt outmigration:

1) Declining zooplankton biomass in Karluk Lake since 2004 and available food for the rearing sockeye salmon suggested poor feeding conditions,

2) Since 2004, the size of the preferred food source, *Bosmina*, was below the optimal feeding threshold size,
3) Decreases in Karluk Lake seasonal water temperatures,
4) Decreases in the average PDO (Pacific Decadal Oscillation; climatological indicator), and
5) Continued overescapement during the return years of 1985 to 2005 likely producing a highly competitive rearing environment, taxing the forage base and affecting growth.

Based on this evidence, the April 2009 memo stated that adult returns would again be low in 2009, recommended additional information to collect to better understand the situation, and suggested indicators that would signal improved conditions for sockeye salmon returns. Overall, the authors concluded Karluk Lake sockeye salmon runs would most likely be depressed until zooplankton biomass and body size increased, likely a period of 3 to 5 years (i.e., possibly through the 2012 run).

New data collected in 2009

Sockeye Salmon Returns

As predicted, the 2009 Karluk sockeye salmon runs were low relative to historic levels. The total return of the early run was estimated at 69,000 fish, the lowest in recent history. The estimated escapement was 53,000 fish, which was the lowest since 1971 and well below the lower end of the escapement goal range of 110,000 fish (Figure 1). The total return of the late run was estimated at 330,000 fish, which was a slight increase from 2008, but otherwise the lowest in recent history as well. The 2009 late-run escapement was estimated at 277,000 fish, which was within the escapement goal range of 170,000 to 380,000 fish (Figure 2) and the lowest since 1984.

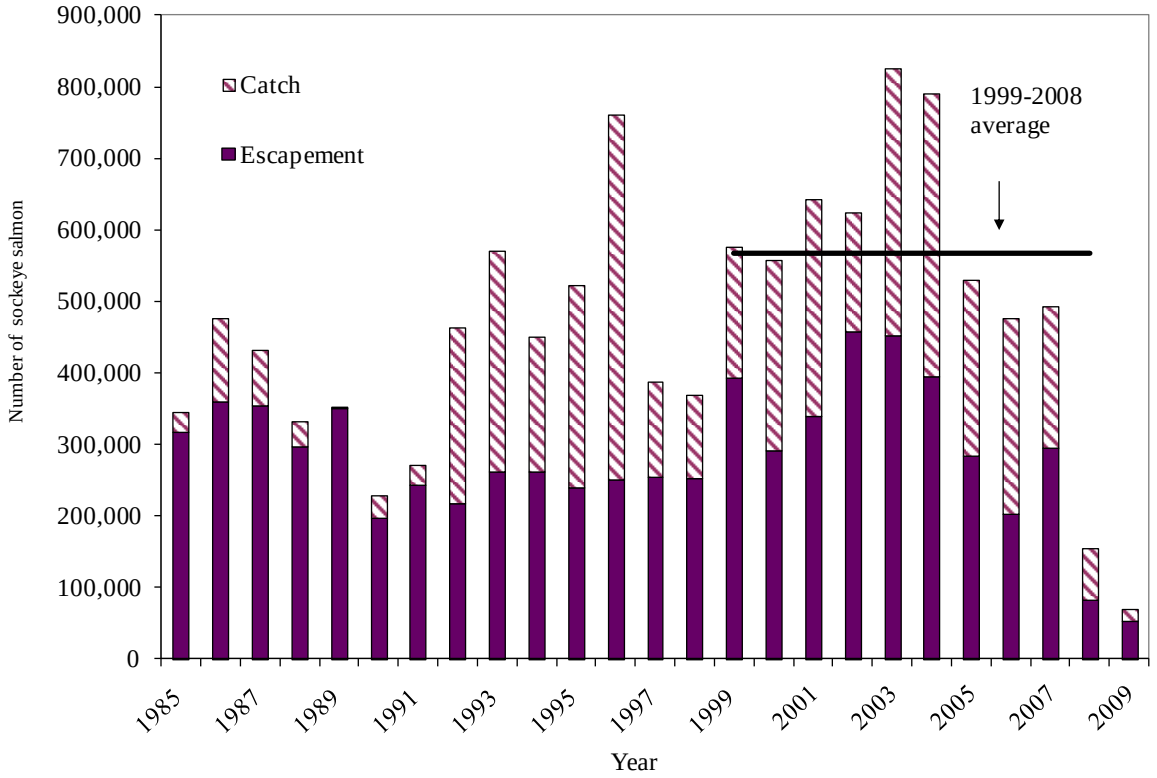

Figure 1. Karluk early-run sockeye salmon escapement, catch, and run estimates, 1985-2009.

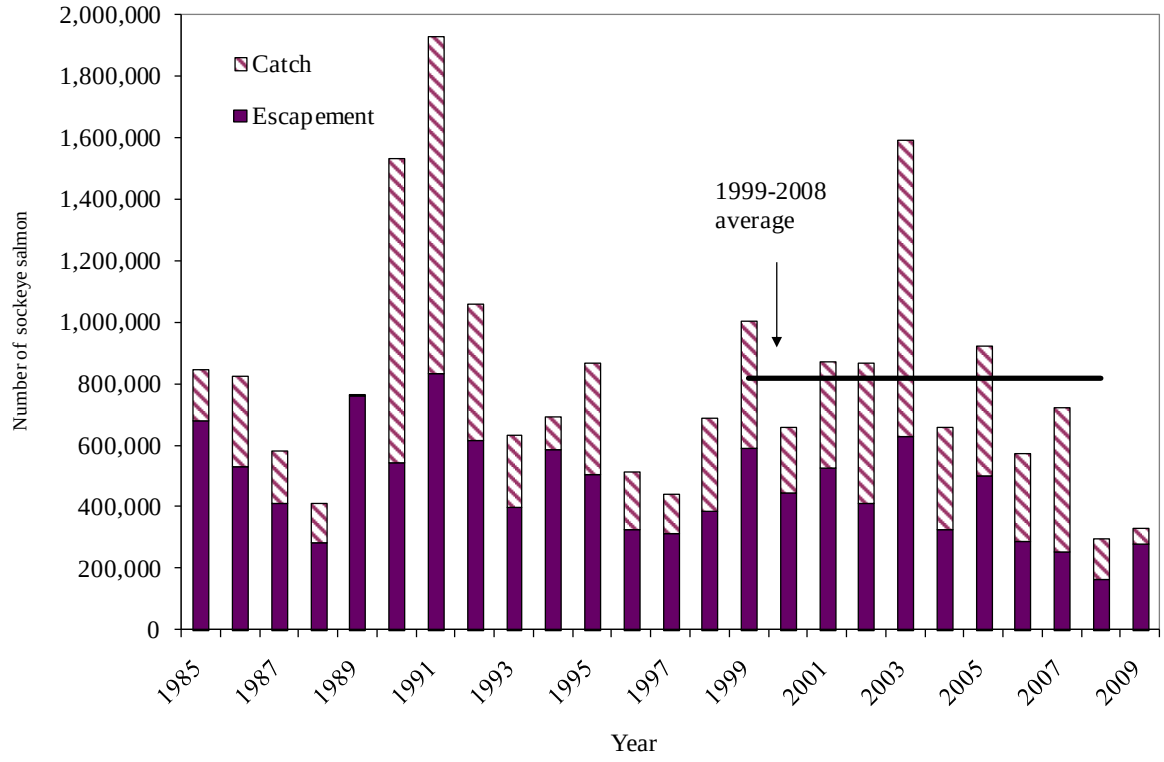

Figure 2. Karluk late-run sockeye salmon escapement, catch, and run estimates, 1985-2009.

Additional data collected in 2009 from the Karluk sockeye salmon escapement supported the preliminary conclusions of the April 2009 memo that rearing conditions were poor in 2005 through 2008 and likely caused the small smolt size that contributed to the low adult returns. A large percentage of sockeye salmon returning in 2009 were freshwater-age-3 in 2009. Increased freshwater age is often associated with poorer rearing conditions that cause juvenile salmon to take longer to reach a minimum size needed for onset of smolting and migration to sea. In the early-run escapement in 2009, 41% of the saltwater-age-2 fish and 70% of the saltwater-age-1 were freshwater-age-3. In the late-run escapement in 2009, 90% of the run was freshwater-age-3. By comparison, freshwater-age-3 fish typically compose between 10% and 25% of the run.

Freshwater rearing conditions

There were several indications in 2009 that suggested rearing conditions had improved in the lake, and that such improvement was already reflected in salmon growth. Of the salmon returning in 2009, freshwater growth appeared to have been higher in 2007 (based on scale patterns from saltwater age-1-salmon) than in 2006 (from saltwater-2-salmon) or 2005 (from saltwater-age-3 salmon). The age-2.2 fish returning in 2010 (the age class that typically dominates the returns) will have experienced the improved freshwater growth conditions in 2007, and may thus have fared better and be more abundant than the 2.2 class that returned in 2009 (which reared in the lake in 2005 and 2006).

The zooplankton biomass estimated in Karluk Lake in 2009 increased substantially from recent low numbers (Figure 3), increasing from near-starvation to satiation levels for rearing salmon. Similarly, the average length of *Bosmina* surpassed juvenile sockeye salmon feeding threshold size (Figure 4). Both of these indicators were the highest seen since 2003. Zooplankton biomass and average length of *Bosmina* were relatively high during the period from 1995 to 2003, resulting in smolts that were highly abundant, had large body size, and contributed to the strong adult returns from 1999 to 2007.

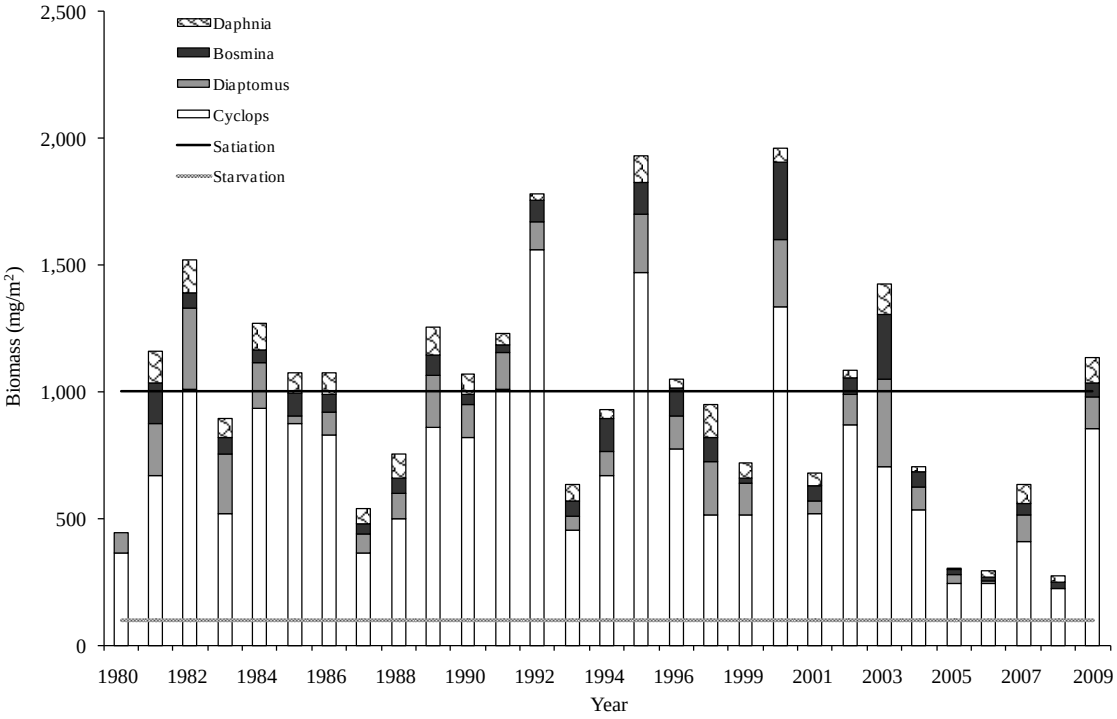

Figure 3. Karluk Lake zooplankton biomass (mg/m^2) from 1980 to 2009.

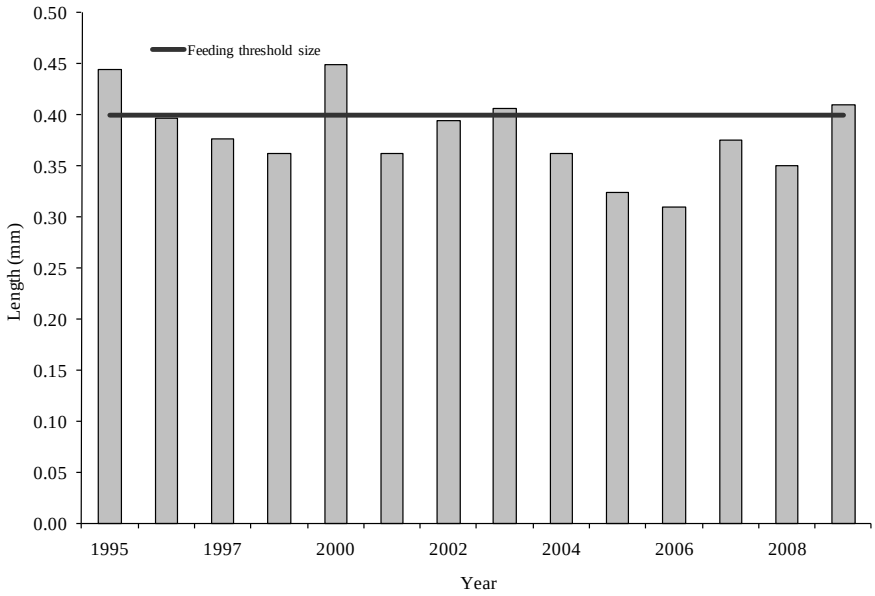

Figure 4. Length of Karluk Lake *Bosmina* relative to the juvenile sockeye salmon feeding threshold size of 0.400mm from 1995 to 2009.

Lake temperatures were also warmer in 2009 (Figure 5), suggesting improved opportunities for growth for rearing sockeye salmon, which may improve overall condition and therefore, survival.

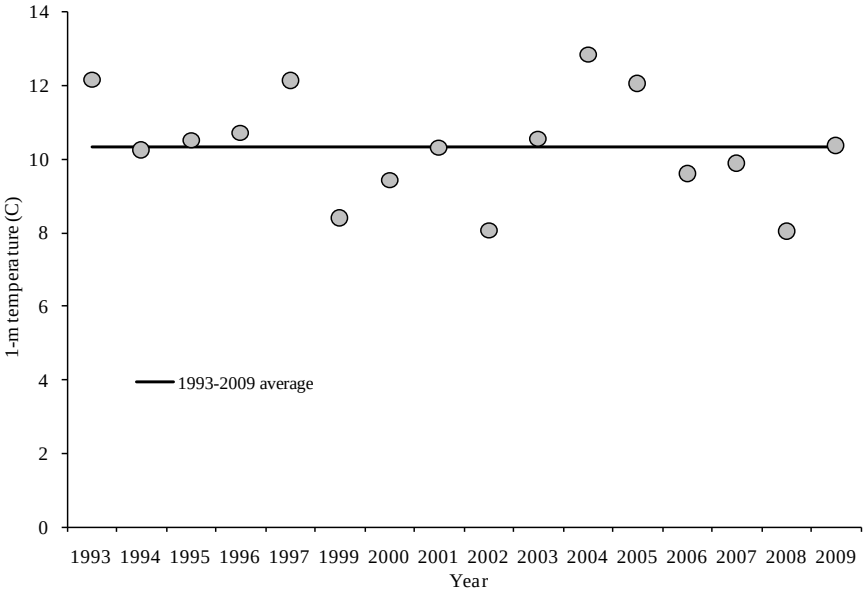

Figure 5. Karluk Lake 1- meter temperature (°C) from 1993 to 2009.

2010 Prediction and Indications

The 2010 forecast for Karluk Lake sockeye salmon is indicating an increase from 2009 returns. The 2010 Karluk early run prediction is 205,000 fish (reversing a 5-year declining trend) and the late run prediction is for 710,000 fish (stronger than three of the past five year late runs). These increases are mainly due to age 2.2 fish, which contribute the bulk of the run in most years and which will have had one year of good freshwater rearing conditions (in 2007) for the first time since the adults that returned in 2007. While the early run should still be well below average, an increase from 2009 will be viewed as a positive sign and remain consistent with the overall theories of decline. Overall, our current assessment of Karluk Lake sockeye salmon is similar to that outlined in the 2009 memo; there are strong signals that low adult returns were caused by depleted forage for juveniles associated with prior high escapements and a highly competitive rearing environment. There are a number of indicators that forage in Karluk Lake began to improve in 2007, but adult returns will be depressed for another 1 to 3 years until the improved lake rearing conditions translate into adult returns.

Although there is not enough data to definitively prove the causes of the declines or measure the relative contribution of each factor, what data we do have is consistent with the idea that large escapements from 1985 to 2005, coupled with poor environmental conditions, likely taxed the forage base, provided poor rearing conditions for juvenile sockeye salmon from 2005 onwards, and led to the low adult salmon returns observed starting in 2008. The mechanism for this would be that large escapements produced large numbers of fry for many years, which eventually reduced the number of zooplankton available to fry. Sockeye salmon fry then had reduced growth and abundance, which led to smaller (and fewer) smolts, which, in turn, translated into the reduced adult returns seen in 2008 and 2009. Seasonal water temperatures were also unfavorable during this time, possibly having a cumulative effect on rearing fry. Evidence that supports this is:

1) Zooplankton biomass began to decline in Karluk Lake in 2004 and remained at or near long-term lows until 2009;
2) Similarly, the size of the preferred food source, *Bosmina*, dropped below the feeding threshold size in 2004, and remained below it until 2009;
3) The average body size of smolts in the 2006 outmigration was the smallest recorded in the available time series of data spanning back to the 1920s;
4) The first year of adult declines (2008) was primarily caused by scarcity in the run component that had smolted in 2006 (and thus had reared in the lakes during the first two years of low food availability in 2004 and 2005).
5) Seasonal water temperature declined in Karluk Lake from 2004 to 2008;

2010 Season Data Collection

During the 2010 salmon season the department will continue to monitor sockeye salmon escapement at the Karluk weir, collect scale samples from the escapement and harvest, and collect seasonal limnology and lake habitat information in Karluk Lake. For the first time since 2006, the department will collect age and size information from smolts at the outlet of Karluk Lake; smolts will be sampled during three sampling strata in May and June 2010, in collaboration with KRAA and Koniag Inc. These data will yield important information on the size and condition of Karluk sockeye salmon outmigrants. Data collected in 2010 will be crucial in monitoring this important system and should shed new light on the current and expected status of the freshwater environment.

cc: Wadle, Baer, Schrof, Thomsen, Jackson, Loewen, Volk, Dinnocenzo, Spalinger, Barnard, Tracy

ALASKA DEPARTMENT OF FISH AND GAME

DIVISION OF COMMERCIAL FISHERIES

MEMORANDUM

TO: Steve Honnold
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DATE: January 4, 2012

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SUBJECT: Reduced sockeye salmon runs at Karluk Lake (III)

FROM: M. Birch Foster and Heather Finkle
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Region IV - Kodiak

Introduction

This memo is the third in a series investigating the reasons for the low runs of sockeye salmon to Karluk Lake that began in 2008 and have persisted through 2011. Alaska Department of Fish and Game (ADF&G) memos released in 2009 and 2010 explained that available data were consistent with the hypothesis that low runs were caused primarily by overescapement and secondarily by unfavorable climatic conditions that led to small smolt body size and low ocean survival. Furthermore, the memos predicted that Karluk would likely be depressed for a period of 3-5 years. This memo updates prior investigations using data through the 2011 season. Data thus far remain consistent with the original hypothesis, however the outlook appears to be one in which runs will continue to improve in 2012.

Previous memos

The April 2009 memo reviewed historical escapement, run size, limnology, climate, and trends in fish size, age, and growth for Karluk Lake sockeye salmon. The authors emphasized the role that the small size and low body condition of outmigrating smolt in 2005 and especially 2006 likely played in determining marine survival and subsequent run strength. The authors listed major factors thought to cause the small size at smolt outmigration: decline of zooplankton biomass, decline in body size of the preferred sockeye salmon food source (*Bosmina*), decrease in Karluk Lake seasonal water temperatures, and persistent overescapement from 1985 to 2005. Based on this evidence, the authors predicted that the adult run would again be low in 2009 and most likely be below average until zooplankton biomass and body size increased, likely a period

of 3 to 5 years (i.e., possibly through the 2012 run).

The July 2010 memo updated the April 2009 memo and expounded on the current theory to explain the depressed run state. The 2010 assessment of Karluk Lake sockeye salmon was similar to that outlined in the 2009 memo. While definitive proof of the causes of the declines or an estimated contribution of each factor was not established, all of the data were consistent with the 2009 hypothesis. The mechanism for this would be that large escapements and favorable spawning conditions produced large numbers of fry for numerous years, which eventually overgrazed and reduced the number of zooplankton available to fry. Sockeye salmon fry then experienced slow growth and increased mortality, which led to poor condition (and fewer) smolts. The culmination of this was reduced adult runs seen in 2008 and 2009. Compounding factors may have been cold water temperatures, which may also have had a negative effect on rearing sockeye salmon. Evidence that supports this was

1) Increased freshwater residence time (to freshwater-age-3) for both early and late runs.
2) Zooplankton biomass began to decline in Karluk Lake in 2004 and remained at or near long-term lows until 2009.
3) Similarly, the size of the preferred food source, *Bosmina*, dropped below the feeding threshold size in 2004, and remained below it until 2009.
4) The average body size of smolts in the 2006 outmigration was the smallest recorded in the available time series of data spanning back to the 1920s.
5) The first year of adult declines (2008) was primarily caused by scarcity in the run component that had reared in the lakes during the first two years of low food availability in 2004 and 2005.
6) Seasonal water temperatures in Karluk Lake were colder than normal in 2006 and 2008.

New data collected in 2010 and 2011

Sockeye Salmon Returns

As predicted in earlier memos, the 2010 and 2011 Karluk sockeye salmon runs were low relative to historical levels. The 2011 early run failed to meet its lower escapement goal for the fourth year in a row despite showing progressive increases in run size over the last 3 years (Figure 1). The 2011 late-run sockeye salmon escapement was above the lower goal for the 3rd straight year despite the weak returns (Figure 2).

The 2010 and 2011 run numbers finalize the total returns from brood years (returns from a singular spawning year) 2003 and 2004 (the first brood years to be greatly affected by the decreases in zooplankton biomass) and demonstrate unusually low return-per-spawner estimates of less than 0.2 for the early run and less than 0.8 for the late run. That magnitude of production is simply not sustainable for any stock because a salmon is not replacing itself in the population. By comparison, the average long-term return-per-spawner estimate for Karluk early run is 1.8 and 2.1 for the late run.

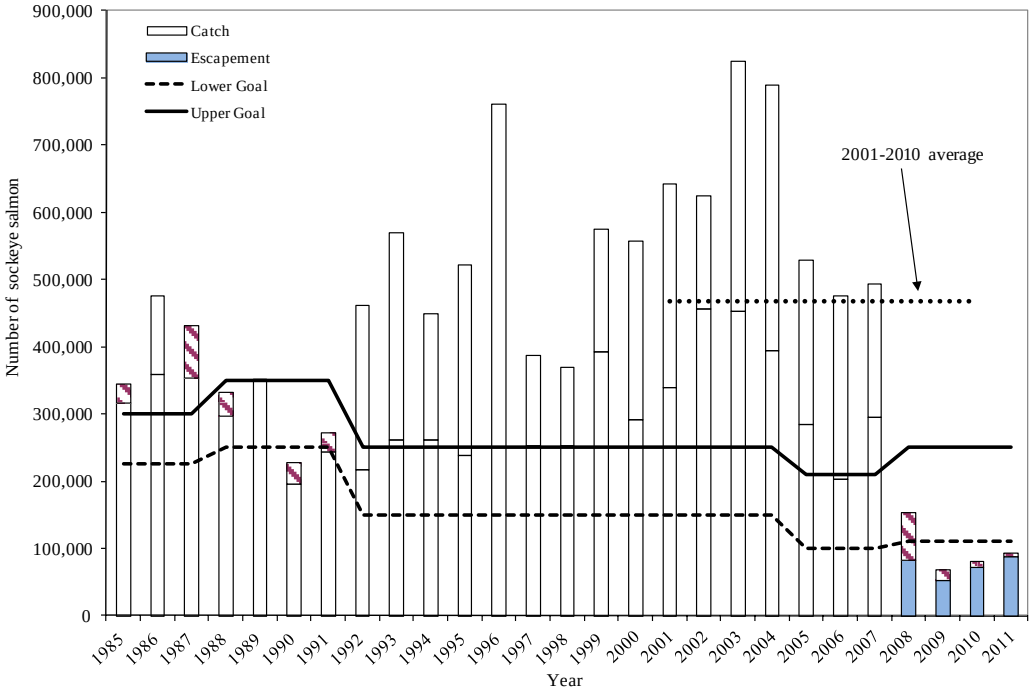

Figure 1. Karluk early-run sockeye salmon escapement and catch estimates relative to the historical lower and upper escapement goals 1985 to 2011, and the 2001 to 2010 average run size.

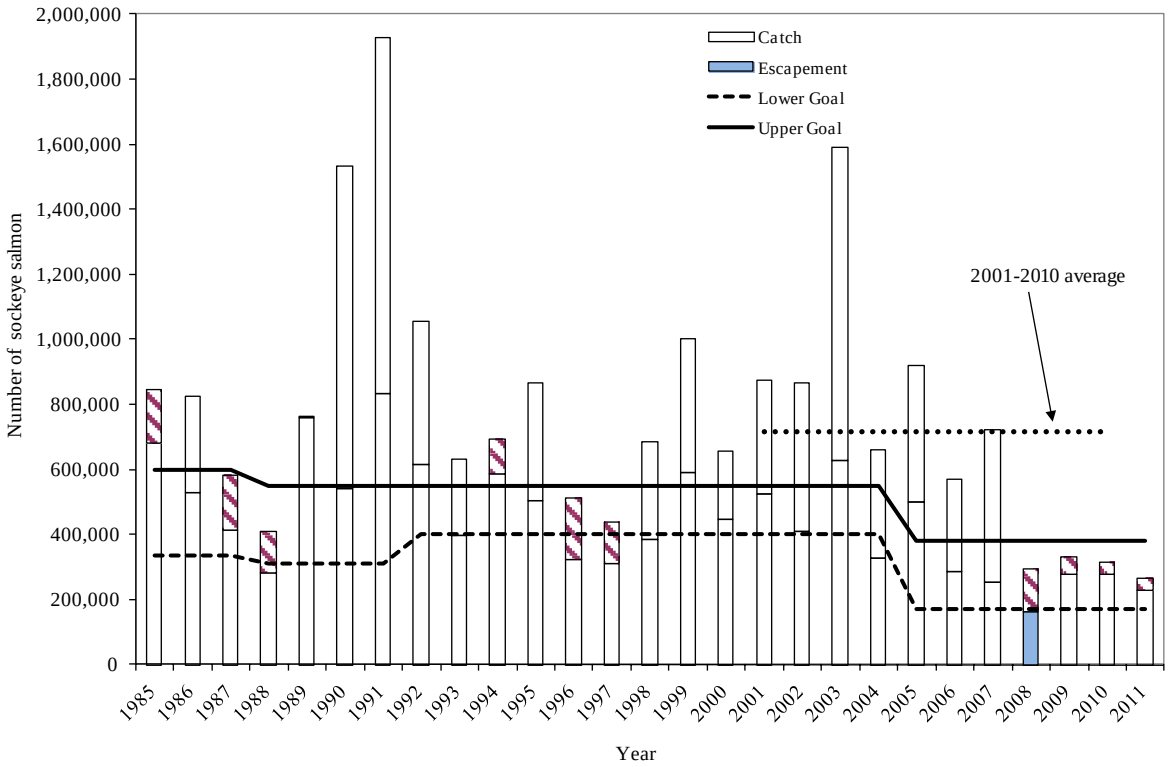

Figure 2. Karluk late-run sockeye salmon escapement and catch estimates relative to the historical lower and upper escapement goals 1985 to 2011, and the 2001 to 2010 average run size.

Freshwater rearing conditions

Additional data collected in 2010 and 2011 supported the existing hypotheses that poor rearing conditions from 2004 through 2008 likely caused the small smolt body size that contributed to the low adult returns. A large percentage of sockeye salmon returning in 2008 through 2010 were freshwater-age-3 (Figures 3-4). Increased freshwater age is often associated with poorer rearing conditions that cause juvenile salmon to take longer to reach a minimum size needed for onset of smolting and migration to sea. Freshwater-age-3 fish averaged 47% of the early run in 2009 and 2010. More dramatically, freshwater-age-3 fish averaged 81% of the late run in 2009 and 2010. Both the early and late runs returned toward more typical proportions in 2011 (Figures 3-4).

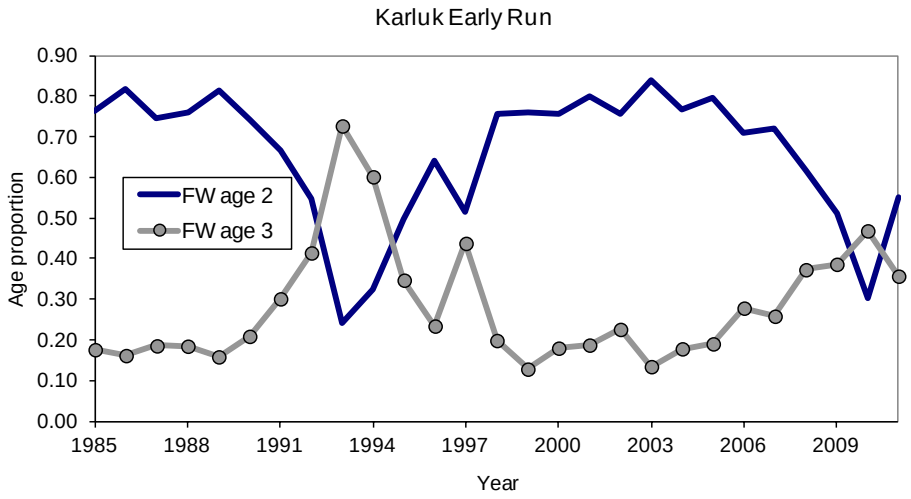

Figure 3. Proportion of freshwater-age-2 and -3 sockeye salmon composing annual Karluk early run.

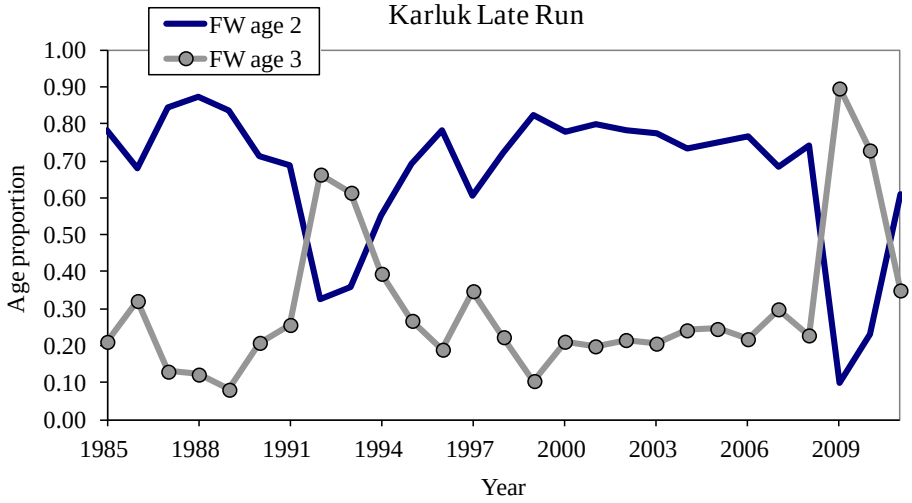

Figure 4. Proportion of freshwater-age-2 and -3 sockeye salmon composing annual Karluk late run.

The zooplankton biomass estimated in Karluk Lake in 2009 through 2011 increased substantially from 2004-2008 recent low numbers (Figure 5), increasing from near-starvation to above satiation levels for rearing salmon. In 2011, both *Diaptomus* and *Daphnia* were the highest in the time series. The average length of *Bosmina* surpassed juvenile sockeye salmon feeding threshold size the last 3 years (Figure 6). Zooplankton biomass and the average length of *Bosmina* were relatively greater during the period from 1995 to 2003, and corresponded with strong adult returns from 1999 to 2007.

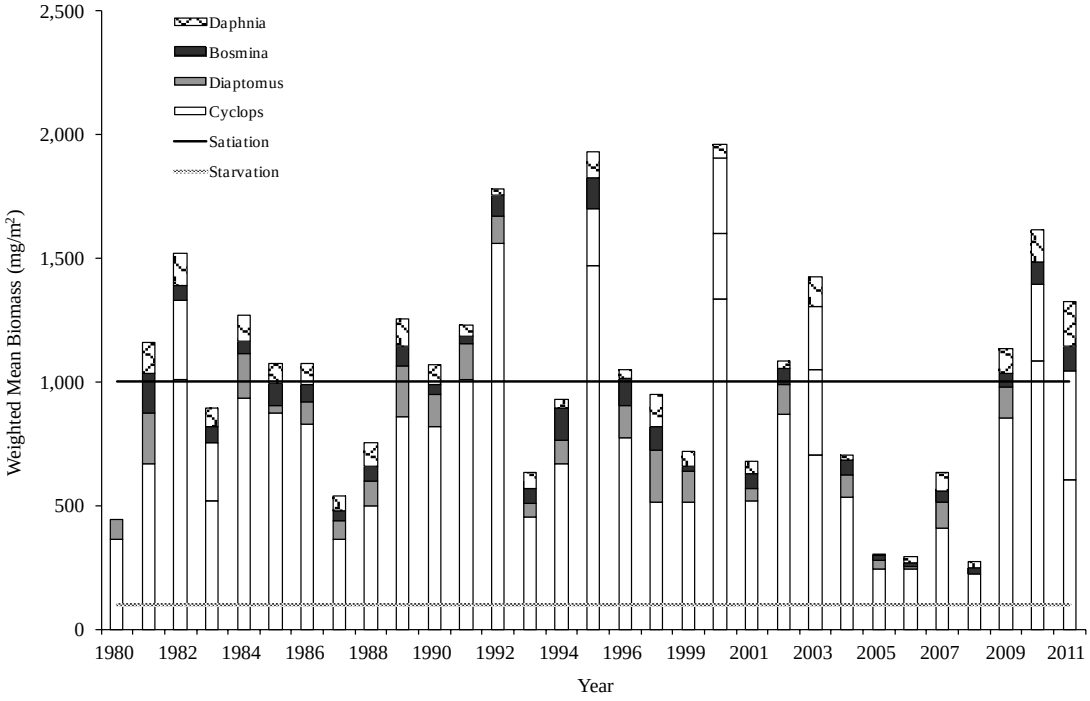

Figure 5. Karluk Lake weighted mean zooplankton biomass (mg/m^2) from 1980 to 2011.

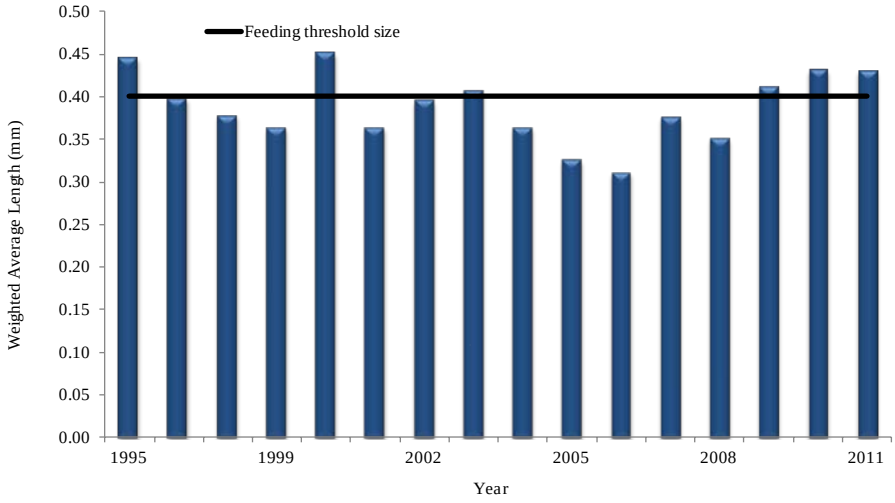

Figure 6. Length of Karluk Lake *Bosmina* relative to the juvenile sockeye salmon feeding threshold size of 0.40 mm from 1995 to 2011.

Smolt

During 2010 and 2011 sockeye salmon smolt outmigrants at Karluk Lake were sampled to estimate size and condition. The average size of age-2 sockeye salmon outmigating smolt during 2010 and 2011 was the largest recorded in the variably collected time series since the mid 1960s (Figure 7). This increase represents a nearly 4 fold increase in size compared to those fish outmigrating in 2006. Age of outmigrating smolt has also trended back to the typical freshwater age-2 life history. Smolt samples from 2010 and 2011 averaged 75% age-2, 12% age-3, 11% age-1, more historically typical for Karluk sockeye smolt outmigrants.

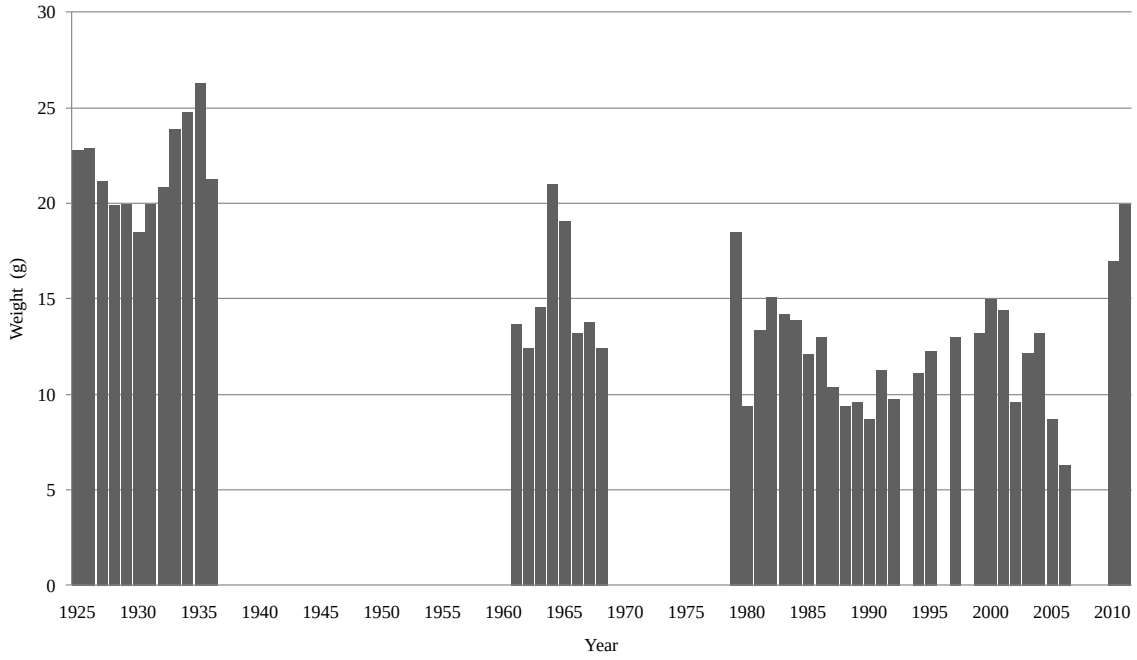

Figure 7. Karluk Lake age-2 sockeye salmon smolt average weight (g) 1925 to 2011.

Positive Indications

Overall, there are a number of positive indications that Karluk Lake is recovering in the absence of overescapement and an overcrowded rearing habitat:

1) Decreased freshwater residence time (from freshwater-age-3 to freshwater-age-2) for both early- and late-run sockeye salmon escapement.
2) Decreased freshwater residence time (from freshwater-age-3 to freshwater-age-2) in the sockeye salmon smolt outmigrants.
3) Increased body size of the sockeye salmon smolt outmigrants.
4) Increased zooplankton biomass from 2009 to 2011 compared with 2004 through 2008 levels.
5) Increased *Bosmina* size from 2009 to 2011 compared with that measured from 2004 to 2008.

While these indicators suggest future increases in sockeye salmon returns, the ultimate confirmation lies in the successful return of a healthy population in the form of escapement and

sustainable harvest. One of the finest short-term early predictors of the magnitude of Karluk sockeye salmon runs is the return of early maturing male "jacks". For the first time since 2003, a large number of jacks were estimated in the escapement from age samples collected from Karluk River weir in 2011. Historically, strong returns of jacks have resulted in strong returns of 2-ocean fish in the next season, thus the outlook for 2012 is one where a significant rebound is expected.

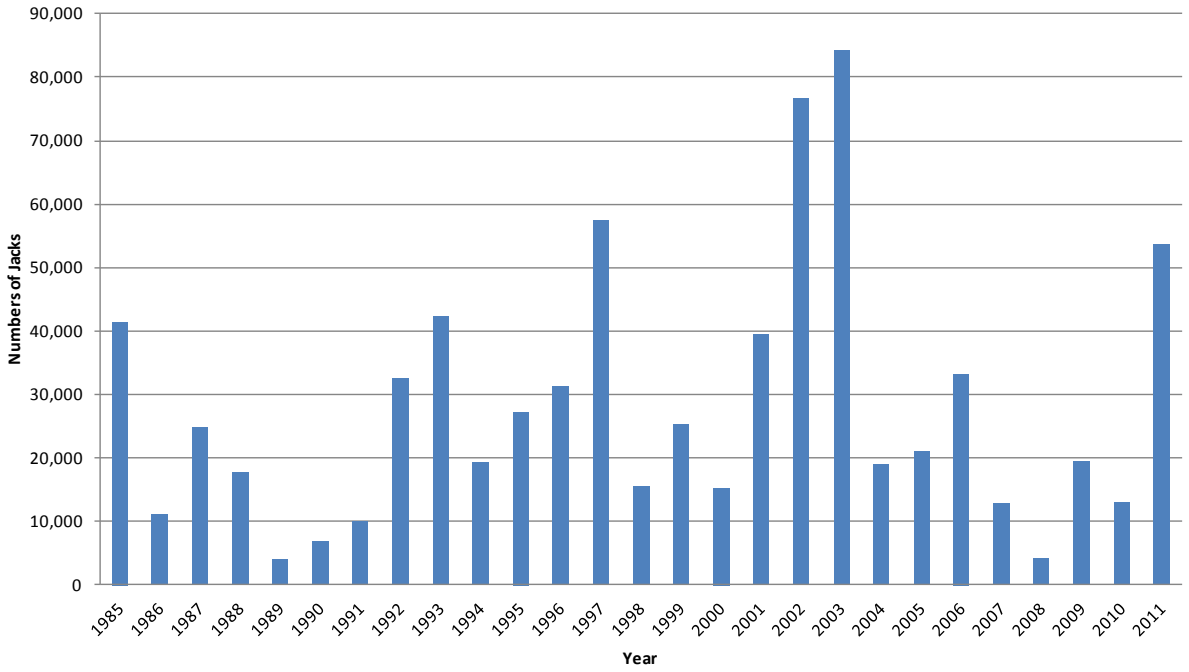

Figure 8. Karluk Lake sockeye salmon run jack (1-ocean) abundance, 1985 to 2011.

Summary and 2012 Forecast

The preliminary 2012 forecast for Karluk Lake sockeye salmon indicates an increase from 2011 returns. The 2012 Karluk early-run prediction is 261,000 fish and the late-run prediction is for 637,000 fish. These predictions are less than the recent 10-year average but significant increases from 2011 and should allow for achievement of the escapement goals in addition to subsistence, recreational and commercial fishing opportunities.

The department's current assessment of Karluk Lake sockeye salmon mirrors that outlined in the previous memos. That is, all available data support the theory that reduced sockeye salmon returns to Karluk Lake were caused by greatly decreased zooplankton forage base for juveniles associated with prior high escapements and a highly competitive feeding environment. Overall, the authors maintain the Karluk sockeye salmon runs will most likely increase in 2012. For the long-term outlook, all data in combination suggest high probabilities that typical Karluk sockeye salmon production could be expected depending on environmental stochasticity and the effect of the less than optimal early-run escapements observed in from 2008 to 2011.

cc: Wadle, Schrof, Thomsen, Jackson, Witteveen, Volk, Dinnocenzo, Spalinger, Barnard, Tracy, Moore