# POPULATION MONITORING OF LAKE CLARK AND TAZIMINA RIVER SOCKEYE SALMON, KVICHAK RIVER WATERSHED, BRISTOL BAY, ALASKA 2000-2003

## Final Report for Study 01-095

Julia Vinciguerra and Kristy Balluta sample otoliths collected from the Nondalton subsistence harvest.

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# EXECUTIVE SUMMARY

Sockeye salmon originating from the Kvichak River watershed historically dominated valuable subsistence, sport and commercial fisheries in Bristol Bay, Alaska. In 1996 salmon runs to western Alaska declined and the Kvichak River sockeye salmon escapement average dropped from 5.7 million fish during 1955–1995 (range = 0.2 to 24.3 million fish) to an average of 2.1 million fish during 1996−2003 (range = 0.7 to 6.2 million fish). This decline concerned fishers and resource managers and two new escapement monitoring programs were initiated within the Kvichak River watershed to examine status and trends of two important component stocks that spawn in Lake Clark and the Tazimina River. This final report describes findings from a 2000-2003 study with four primary objectives:

1. Estimate sockeye salmon escapement to Lake Clark and Iliamna Lake.
2. Determine age and size composition of the Lake Clark escapement.
3. Estimate sockeye salmon escapement to the Tazimina River.
4. Determine age and size composition of the Tazimina River escapement.

*Lake Clark and Iliamna Lake Sockeye Salmon Escapement*
Estimates of sockeye salmon escapement to Lake Clark were made during 2000−2003 at river kilometer 36 of the Newhalen River using the same tower site and protocols that were used during 1980−1984 escapement estimates. Escapement estimates and percent contribution to the total Kvichak River escapement were made annually, while 90% confidence intervals (90% CI) could only be calculated for three of the years. Data were compared with Kvichak River escapement data collected by the Alaska Department of Fish and Game. Iliamna Lake escapement was estimated by subtracting Lake Clark escapement from the total Kvichak escapement.

| Year | Lake Clark Escapement | 90% CI | % of Kvichak | Kvichak River Escapement | Iliamna Lake Escapement |
|---|---|---|---|---|---|
| 2000 | 172,902 | 165,500 to 180,300 | 10 | 1,827,780 | 1,654,878 |
| 2001 | 222,414 | * | 20 | 1,095,348 | 872,934 |
| 2002 | 203,682 | 193,800 to 213,600 | 29 | 703,884 | 500,214 |
| 2003 | 264,690 | 252,600 to 275,400 | 16 | 1,686,804 | 1,422,114 |

* CI not calculated as raw data unavailable

Average escapement to Lake Clark during 2000–2003 was 215,922 sockeye salmon, about 81% less than the average escapement during 1980–1984, which was 1,135,464 sockeye salmon. Lake Clark escapement during 2000–2003 comprised, on average, 19% of the total Kvichak escapement, about 3% more than observed during the 1980−1984 study. Inclusion of 2004 escapement data for Lake Clark will provide a more accurate comparison relative to the time frame (4 years) and potential influence of remnant Kvichak River salmon production cycles.

The relative variation of Lake Clark escapement was half that of the Kvichak River escapement (Lake Clark coefficient of variation CV=0.18; Kvichak CV=0.39) during 2000−2003. Because Iliamna Lake escapement is the difference between total Kvichak River escapement and Lake Clark escapement, results therefore imply greater relative variability of Iliamna Lake escapement. Lake Clark escapement showed a variable but increasing trend during this study compared to the overall Kvichak River escapement which was highly variable and showed no trend.

*Lake Clark Sockeye Salmon Age and Size Composition*
Sockeye salmon ages were determined from otoliths (ear bones) collected from Newhalen River subsistence gillnet harvests and from seine sampling. Annual sample sizes were 631 (2001), 682 (2002), and 482 (2003). Overall trends in age composition were generally similar between Lake Clark and Kvichak River sockeye salmon samples. Age-1.3 was the most abundant age class in both samples during 2001, while age-1.2 was the most abundant during 2002 and 2003. However, distribution of age classes in samples from these two locations differed significantly (all chi square tests; $p<0.05$) each year:

- Newhalen River samples did not have any age-0. or -.1 sockeye salmon (jacks), but Kvichak River samples had small percentages of both age-0. (1.7%) and age -.1 (0.6%) sockeye salmon in 2002 and age-2.1 in 2003 (4.1%).
- In 2001, Newhalen River samples had more age-1.2 (19% versus 9%) and fewer -1.3 (72% versus 83%) sockeye salmon than Kvichak River samples.
- In 2002, Newhalen River samples had more age-1.2 (56% vs. 49%) and -1.3 (30% versus 12%), and fewer -2.2 (13% versus 34%) sockeye salmon than Kvichak River samples.
- In 2003, Newhalen River samples had fewer age-1.2 (53% versus 61%) and -2.2 (9 versus 14%), and more-1.3 (38% versus 16%) sockeye salmon than Kvichak River samples.

Lake Clark sockeye salmon were generally larger at age when compared to Kvichak River sockeye salmon. In 2001, size at age was more similar but this may be due to a sampling bias toward smaller fish detected in the Lake Clark sampling method that year. The overall mean difference in size for all age categories across all years with sample sizes greater than 10 fish was about 13 mm (SD = 8.2).

*Tazimina River Sockeye Salmon Escapement*
Annual Tazimina River escapement estimates were made within the first kilometer of the river mouth during 2001−2003. Tower sites changed slightly from year to year to reduce problems due to flooding and fish movement patterns. Annual escapement estimates, including 90% confidence intervals (CIs) and percent contribution to the total Lake Clark escapement were obtained.

| Year | Tazimina River Escapement | 90% CI | % of Lake Clark Escapement |
|---|---|---|---|
| 2001 | 9,180 | 7,680-10,680 | 4 |
| 2002 | 13,187 | 10,837-15,537 | 7 |
| 2003 | 14,213 | 13,013-15,413 | 5 |

Tazimina River escapement estimates during 2001–2003 averaged 12,193 sockeye salmon, which was about 78% less than the average of 55,000 sockeye salmon for peak aerial escapement indices made during 1955–2000.

*Tazimina River Sockeye Salmon Age and Size Composition*

Otoliths were sampled annually from post-spawning sockeye salmon captured with seines. Annual sample sizes were 124 (2001), 99 (2002) and 100 (2003). Overall trends in age composition were generally similar between Tazimina River and Lake Clark sockeye salmon samples. Neither Tazimina nor Newhalen River samples had either age-0. or -.1 sockeye salmon in any year. Age-1.3 was the most abundant age class in both samples during 2001, while age-1.2 was the most abundant during 2002 and 2003. However, the distribution of annual age classes differed significantly (chi square, $p<0.05$ all tests) between sample locations:

- In 2001, Tazimina River samples had slightly more age-1.2 (23.4% versus 19.1%) and age-1.3 (75.0% versus 72.9%) sockeye salmon than Lake Clark samples, and fewer age-2.3 sockeye salmon (0.8% versus 6.5%).
- In 2002, Tazimina River samples had more age-1.2 (76% versus 56%) and fewer age-1.3 (14% versus 30%) than Lake Clark samples.
- In 2003, Tazimina River samples had more age-1.3 (45% versus 38%) and fewer age-1.2 (48% versus 53%) than Lake Clark samples.

Tazimina River fish were generally smaller at the same age compared to Lake Clark and Kvichak River samples. On average, Tazimina River fish were 25 mm (SD = 15.86) smaller than Lake Clark samples, and 16 mm (SD = 21.29) smaller than Kvichak samples of the same age category.

*Conclusions and Recommendations*

The 77% decline in total sockeye salmon escapement to the Kvichak River since 1996 is similar to that observed in monitoring Lake Clark and Tazimina River escapements during this study. The mean 2000–2003 escapement to Lake Clark of 215,924 sockeye salmon was 81% less than the mean 1980–1984 escapement of 1,135,264 sockeye salmon. The mean 2001–2003 escapement to the Tazimina River of 12,164 sockeye salmon was 78% less than the mean 1955–2000 peak aerial index of 55,000, although comparisons of tower to peak aerial data likely underestimate the decline. The relative variation of Lake Clark escapement was half that of the Kvichak River escapement, implying wider fluctuations in spawning escapements to Iliamna Lake. If escapement declines persist, they may have long term effects on salmon productivity as a result of: 1) reduced marine derived nutrients due to fewer salmon carcasses, 2) loss of genetic diversity due to low spawning populations size, and 3) degradation of spawning habitats due to reduced spawner densities.

Continued monitoring of Lake Clark sockeye salmon escapement, age, and size is recommended because the data can provide a broader understanding of population dynamics within the Kvichak River watershed. Such information is needed to assess the factors influencing variation in production from the system.

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KEY WORDS: age and size, Bristol Bay, escapement, Kvichak River, Lake Clark, Lake Clark National Park and Preserve, Newhalen River, *Oncorhynchus nerka*, sockeye salmon, subsistence, Tazimina River, Nondalton.

# POPULATION MONITORING OF LAKE CLARK AND TAZIMINA RIVER SOCKEYE SALMON, KVICHAK RIVER WATERSHED, BRISTOL BAY, ALASKA 2000-2003

# INTRODUCTION

The world's largest most valuable sockeye salmon fisheries occur in Bristol Bay, Alaska, and fish originating in the Kvichak River watershed historically dominated regional harvests (Figure 1) (Demory et al. 1964, Forrester 1987, Fall et al. 2001, ADF&G 2002, Dye and Schwanke In Press). The largest regional subsistence harvest for sockeye salmon took place in the Kvichak River drainage and fishers averaged about 75,000 fish during 1974–1995 (Fall et al. 2001). The sockeye salmon sport fish harvest averaged about 14,900 fish during 1988–1995, making it the largest recreational fishery in Bristol Bay (Dye and Schwanke In Press) while commercial harvest averaged 8.1 million sockeye salmon during 1980-1995, making it the dominant producer of sockeye salmon in the region (Forrester 1987, ADF&G 2002).

Since 1996, unpredicted declines in sockeye salmon runs to the Kvichak River (Figure 2) impacted all harvests and resulted in the Bristol Bay region being declared an economic disaster area five of the last eight years. Annual subsistence harvests declined from a mean of 75,000 salmon during 1974–1995, to a mean of 50,000 salmon during 1996–2000 and interviews with subsistence fishers indicated catch per unit effort also declined (ADF&G 2001, Fall et al. 2001). Mean sport fish harvest dropped 50% due to fishing closures and bag limit reductions (Dye and Schwanke In Press), and commercial catches fell from a 1980–1995 mean of 8.1 million to a 1996–2003 mean of 1.4 million (ADF&G 2004). The Kvichak District was closed to commercial fishing in 2002. Economic and ecologic impacts have not yet been quantified and both the Bristol Bay economy and sockeye salmon production from the Kvichak River watershed remain depressed.

Depressed runs to the Kvichak River resulted in decreased spawning escapements (Figure 3) and minimum escapement goals (2-6 million) were only met two of the last eight years (ADF&G 2002). Salmon production, measured as number of adults produced by each spawning sockeye salmon has also declined, implying a slow recovery rate. Over 150 sockeye salmon spawning populations have been identified within the Kvichak River watershed, but there is little consistent time-series information regarding the spawning abundance for many of these component populations (Demory et al. 1964, Anderson 1968, Regnart 1998).

Poor returns of salmon across much of western Alaska in 1996 and 1997 suggest marine factors played a role in Kvichak River salmon declines (see review by Kruse 1998). However, freshwater factors may also be involved since escapements to nearby Naknek and the Alagnak River, a tributary to the Kvichak River, are increasing while escapement to the Kvichak River is not. The Naknek River run has increased by about a million fish annually since 1997 (Fair 2000, ADF&G 2002) and the Alagnak River had an escapement of 3.8 million sockeye salmon in 2003 (ADF&G 2004), while the Kvichak River only had an escapement of 1.3 million in 2003. Improved information on important component populations will provide managers with a better understanding of population dynamics within the Kvichak system and enable them to make more informed decisions.

The Kvichak River watershed contains two large lake systems, Lake Clark and Iliamna Lake, in which sockeye salmon spawn and rear (Figure 1). Lake Clark is a smaller watershed (9,583 $km^2$) than Iliamna Lake (11,137 $km^2$; Demory et al. 1964) and is also less productive due to the influence of active glaciers that make it colder and more turbid (Mathisen and Poe 1969). Despite these characteristics, salmon originating from the Lake Clark drainage have comprised a substantial proportion of the total Kvichak River run (Poe and Rogers 1984). For example, escapement monitoring on the upper Newhalen River from 1980−1984 indicated that Lake Clark contributed 7–30% (0.2 – 3.1 million) to the total Kvichak River escapement (Poe and Rogers 1984), while escapement indexing on the lower Newhalen River from 1979-2001 indicated a 2-80% (0.04–9.00 million) contribution of sockeye salmon to the total Kvichak River escapement (Rogers et al.2002). The ability to track proportional contribution made by the two largest spawning and rearing lakes within the Kvichak River watershed would allow managers to consider component population dynamics in decisions and planning, and may help investigators focus attention on factors contributing to these dynamics.

The Tazimina River is an important sockeye salmon producing tributary of the upper Newhalen River (Figure 1). Sockeye salmon originating from this system are of high cultural, economic, and recreational importance to local users (Crutchfield et al. 1982). The system has been annually surveyed, primarily by air, for peak escapement since 1939, with indices ranging from a low of 12 (1973) to a high of 504,000 sockeye salmon (1979) with an average of about 55,000 fish (Demory et al. 1964; Poe and Mathisen 1982, Regnart 1998, ADF&G unpublished data). Both subsistence and sport fishers are concerned about sockeye salmon escapements to the Tazimina River, which they indicate are now very low compared to the past. Besides peak escapement estimates, no other escapement data were available for this system, making trend evaluation difficult. A series of total escapement estimates for the Tazimina River would provide information on the current status of this sockeye salmon population and, through comparisons with peak aerial survey counts, a better understanding of the utility of aerial surveys.

# OBJECTIVES

Managers and subsistence fishers have both expressed concern regarding the status and trends of sockeye salmon originating from Lake Clark and the Tazimina River. The objectives of this study were to:

1. Estimate sockeye salmon escapement to Lake Clark and Iliamna Lake.
2. Determine age and size structure of the Lake Clark escapement.
3. Estimate sockeye salmon escapement to the Tazimina River.
4. Determine age and size structure of the Tazimina River escapement.

# STUDY AREA

This study focused on sockeye salmon populations that spawn in Lake Clark and the Tazimina River, Kvichak River watershed, Bristol Bay, Alaska (Figure 1). Lake Clark is the largest lake within Lake Clark National Park and Preserve measuring about 74 km long, 5 km wide, with a surface area of about 267 $km^2$, a mean depth of 103 m and a maximum depth greater than 300 m (Anderson 1969, Wilkins 2002). The rearing area for juvenile sockeye salmon in Lake Clark (267 $km^2$) is approximately one-tenth the size of Iliamna Lake (2,622 $km^2$). Six major rivers and over 23 lesser tributaries drain a watershed of 7,620 $km^2$ into Lake Clark (Anderson 1969). The most influential tributary is the Tlikakila River, which drains a large glacial valley and annually contributes a mean of 0.4 to 1.0 million tons of suspended glacial sediments to the lake and accounts for about 45% of the annual lake water budget (Brabets 2002).

Past sockeye salmon escapement data for Lake Clark consist of aerial escapement indices collected since 1955, an escapement index conducted on the lower Newhalen River, and total escapement estimates conducted on the upper Newhalen River. Aerial estimates provide some indication of relative peak spawner abundance in select clear water tributaries, but typically underestimate actual escapement (Jones et al. 1998). For example, aerial indices of the Lake Clark watershed (see summary by Regnart 1998) indicate that most sockeye salmon spawn in two clear water tributaries to Lake Clark, in contrast, a radio-telemetry study by Young (2004) indicated most sockeye salmon spawn in turbid waters where they cannot be detected from the air. Past escapement indices conducted on the lower Newhalen River (river kilometer 1.2) from 1979-1999 and from 2001-2002 provide an indicator of run timing and strength into the Newhalen River relative to Kvichak River escapement, but data are less reliable in years of high water and high salmon escapement as both affect count accuracy (Poe and Mathisen 1981; Rogers and Poe 1984, Poe and Rogers 1984; Rogers 1999, USGS unpublished data). Total escapement estimates derived from the index count range from 0.2–8.4 million sockeye salmon. To obtain a more accurate escapement estimate for Lake Clark, another counting tower site was established at river kilometer 36 during 1980–1984 (Figure 1). Escapement estimates from that study ranged from 0.15 to 3.10 million sockeye salmon and averaged 1.14 million.

The Tazimina River is a major clear water tributary to the upper Newhalen River with a length of about 87 km long and a drainage area of approximately 829 $km^2$ (Figure 1). Water from the upper portion of the watershed drains through two lakes; pours over a 30 m waterfall (river kilometer 15), flows through a canyon (~ 1.6 km) and finally winds 13.7 km through a low gradient (~3%) braided floodplain to its outlet in the upper Newhalen River (Figure 1). Spawning sockeye salmon have been observed throughout the Tazimina River below the falls, although the most important spawning sites are the 3.0 km section from the outlet to the end of the first braided reach; the 1.5 km braided section between river km 4.5 and 6, and the 2.0 km section between river km 6.5−8.5 (Dames & Moore 1982). Annual aerial estimates as well as some ground based estimates of peak escapement have been made since 1955, and peak indices have ranged from 12 (1973) to 504,000 (1979) fish, and averaged about 55,000 fish (Demory et al. 1964; Regnart 1998; ADF&G, Anchorage, AK, unpublished data).

# METHODS

### Lake Clark and Iliamna Lake Sockeye Salmon Escapement Estimates

Lake Clark sockeye salmon escapement estimates were made at river kilometer 36 (Figure 1) of the Newhalen River, using standard protocols outlined in Anderson (2000) and the same site and specific procedures outlined in Poe and Rogers (1984). Systematic, hourly, 10 minute counts were made from 5 m towers on both banks during the 2001-2003 sockeye salmon runs. Night counts (00:00 – 04:00 hours) were made using rheostat controlled 12 volt auto lights powered by solar charged car batteries. If counting crews were short-handed, the night shift (00:00 to 04:00 hours) was skipped and a regression estimate, based on previous night passage data, was used to expand the 20 h to a 24 h estimate (Poe and Rogers 1984).

An estimate of Iliamna Lake escapement was made for comparative purposes, by subtracting the total annual Lake Clark escapement estimate from the total annual Kvichak River escapement estimate. This estimate did not include fish spawning in the lower Newhalen River, Alexi Creek and Alexi lakes component, Lover's Creek Little Bear Creek and pond, and Steambath Creek. Contribution by these populations is negligible as peak index counts made since 1996 indicate peak escapement to all these areas is less than 6,000 sockeye salmon (Regnart 1998; ADF&G, Anchorage, Alaska, unpublished aerial escapement data).

### Lake Clark Sockeye Salmon Age and Size Composition

Age and size composition of the 2000−2003 Lake Clark escapement were determined by sampling pre-spawning sockeye salmon from subsistence gillnets in the communities of Nondalton and Newhalen (Figure 1) and by seine hauls. Samples were obtained from 1−24 July in all years. Otoliths were extracted and ages later determined by contracted professional readers; either the ADF&G Age and Tag Laboratory in Juneau, Alaska, or Brenda Rogers of the Fisheries Research Institute, University of Washington, Seattle, Washington.

Lengths were measured as mid-eye to hypural plate (MEH) in millimeters. To make these data comparable with to mid-eye to fork lengths (MEF) collected by ADF&G for the Kvichak River escapement project conducted at the outlet of Iliamna Lake, MEH measures were converted to MEF estimates using regression equations derived from 1005 paired measures of MEH and MEF collected in 2000 and 2001. The conversion equation for females ($r^2 = 0.96$; SE = 8.32) was:

$$MEF = 25.95 + 1.07 * MEH.$$

The conversion equation used for males ($r^2 = 0.96$; SE = 8.1) was:

$$MEF = 27.8 + 1.06 * MEH;.$$

All data were entered, checked for errors 4 times and saved as an ACCESS database.

## Tazimina River Sockeye Salmon Escapement Estimates

Annual escapement estimates during 2001–2003 for the Tazimina River were made within the first kilometer of the river mouth. Standard counting tower protocols were modified from those described by Anderson (2000) in three ways: 1) tower location was moved about 500 m from year to year to reduce problems due to flooding and milling fish, 2) counts were made from a single tower in 2002 and 2003 because one provided a clear view of the entire river, and 3) hourly 10 minute counts were increased to hourly 20 minute counts in 2003 in an effort to increase estimate accuracy (Reitze 1957). If tower counting crews were shorthanded, the shift from 00:00–04:00 hours was skipped and the daily total escapement was increased by 5% which is the estimated mean proportion of daily fish passage for that shift based on 24 hr count data. Because the Tazimina River is a terminal tributary, sockeye salmon often moved up- and downstream seeking mates and establishing territories. Therefore, upstream counts were recorded as positive numbers and downstream counts were recorded as negative numbers so that net upstream passage could be estimated.

## Tazimina River Sockeye Salmon Age and Size Composition

Tazimina River sockeye salmon were sampled annually using seines, between July and August during 2001–2003. Methods used for age determinations and MEH to MEF conversions were the same as those previously described for Lake Clark samples to ensure data were comparable.

## Data Analysis

### *Escapement Estimates*

Actual fish counts obtained over a 10 or 20 minute observation period each hour, were expanded by the appropriate factor (6 for 10 minute counts; 3 for 20 minute counts made during 2003 at Tazimina River site) to obtain a total hourly estimate; total hourly estimates for each 24 period were summed to obtain daily estimates. Variance was estimated by considering tower counts as a systematic sample and then applying one of the methods developed for such sampling designs (Wolter 1984). To estimate variance, the seasonal mean count needed be calculated. To do this, the mean count per observation period was calculated, expanded to a mean hourly count based on observation period length and number of hours observed per day, and then multiplied by the number of days in the observation season. “Variance estimator 5” in Wolter (1984) was chosen for its robustness against underlying autocorrelation, stratification, or nonlinear trends in the population sequence due to its construction from higher order differences between sequential observations.

Standard tower count protocols provide an unreplicated systematic sample of fish passage in time. This sampling design does not allow for unbiased variance estimation (Yates 1948, Cochran 1977, Wolter 1985). The variance of the estimated total escapement is often estimated by treating the systematic observations as if from a simple random sample. This commingles process variation with sampling variation and can badly overestimate the true sampling variance. Simulation investigations by Wolter (1985, Table 7.3.5) and (Skalski et al. 1993) both found this approach to overestimate the true variance by as much as 300% when the underlying process exhibited non-random variation.

Other variance estimators have been developed for systematic samples (Cochran 1977; Wolter 1985), each specifically designed to account for a particular type of underlying process variation with respect to the sample ordering (in time or space): e.g., random process, linear trend, nonlinear, stratified, autocorrelated, etc.. A general review of variance estimators for systematic samples broadly recommended two estimators for process variation exhibiting autocorrelation, nonlinear trends, or complex stratification in the sampling sequence (Wolter 1984, 1985). One estimator, denoted 'v4', was recommended for smaller samples, the other, 'v5', for larger samples. This study used v5 to estimate variance of the mean 10 minute escapement count:

$$V_5 = (1-f)(1/n)\sum_{j=5}^{n} c_j^2 / 3.5(n-4)$$

where $c_j = y_j/2 - y_{j-1} + y_{j-2} - y_{j-3} + y_{j-4}/2$ and $y_j$ is the total count of the j[th] observation period (Wolter 1984, 1985). This variance for the mean escapement count was then expanded to estimate the variance for the total escapement count:

Var(Total Escapement) = Var(Mean 10 min. count)*(6*24*number of days in the observation period)$^2$.

In the case of simultaneous counts from both banks, the bank observations were summed for each observation period.

Total escapement 95% confidence intervals were calculated as

total escapement estimate +/-1.96 * $\sqrt{Est.Var(Total\ Escapement\ Est.)}$ .

### *Age at Maturity Comparisons*

Chi square tests (α = 0.05) were used to test for differences in age composition among sockeye samples from the Kvichak, Newhalen, and Tazimina Rivers sockeye salmon escapement. When sample sizes were below 10 in the chi square comparison, that category was dropped from the age analysis.

### *Size at Maturity Comparisons*

Intra-annual size within each age group was compared for Kvichak, Newhalen and Tazimina River samples using one-way ANOVA (α = 0.05); Tukey multiple comparisons were applied when tests were significant (Zar 1984). Because two gear types were used to sample fish, e.g. subsistence gill nets and seines, potential bias of the gill net catch was assessed by comparing mean lengths (mm) of fish captured by each gear type. A 95% confidence interval was calculated for the difference in mean lengths; seine – gill net (from two-sample t-test with unequal variances). Human measurement error was considered to be ± 5 mm, when determining if confidence intervals actually indicated a bias.

# RESULTS

## Lake Clark Sockeye Salmon Escapement Estimates

Sockeye salmon escapement into Lake Clark began the first week of July, ended by the second week of August, and lagged behind Kvichak River escapement by 10 to 14 days (Figures 4 and 5, Appendix I). Lake Clark escapement during 2000–2003 averaged 215,922 fish, ranged from 172,902 to 264,690 fish and contributed, on average, 19% to the total Kvichak River escapement (Table 1). The relative variation of Lake Clark escapement was half that of Kvichak River escapement (Lake Clark coefficient of variation CV=0.18; Kvichak CV=0.39) during 2000−2003. Because Iliamna Lake escapement is the difference between the total Kvichak River escapement and Lake Clark escapement, results therefore imply greater relative variability of Iliamna Lake escapement. Lake Clark escapement showed a variable but increasing trend during this study compared to the overall Kvichak River escapement which was highly variable and showed no trend (Table 1).

## Lake Clark Sockeye Salmon Age and Size Composition

Overall trends in age composition were generally similar between Lake Clark and Kvichak River sockeye salmon samples. Age-1.3 was the most abundant age class in both samples during 2001, while age-1.2 was the most abundant during 2002 and 2003. However, the distribution of age classes in samples from these two locations differed significantly (chi square tests, $p<0.05$) each year (Table 2, Figure 6):

- In 2001, Newhalen River samples had more age-1.2 (19% versus 9%) and fewer -1.3 (72% versus 83%) sockeye salmon than Kvichak River samples.
- In 2002, Newhalen River samples had more age-1.2 (56% vs. 49%) and -1.3 (30% versus 12%), and fewer -2.2 (13% versus 34%) sockeye salmon than Kvichak River samples.
- In 2003, Newhalen River samples had fewer age-1.2 (53% versus 61%) and -2.2 (9 versus 14%), and more -1.3 (38% versus 16%) sockeye salmon than Kvichak River samples.
- Newhalen River samples did not have any age-0. or -.1 sockeye salmon, but Kvichak River samples had small percentages of age-0.2 (1.0%) and -1.1 (0.3%) sockeye salmon in 2002.

Within each age class, sockeye salmon returning to spawn in the Lake Clark drainage were similar in size to those sampled at the Kvichak River site in 2001, but were significantly (ANOVA, $p<0.05$) larger than those sampled at the Kvichak River site in 2002 and 2003 (Table

3, Figures 7 and 8). The mean size difference for all age categories with sample sizes greater than 10 sockeye salmon was about 13 mm (SD = 8.2).

Sockeye salmon sampled from subsistence gill nets were significantly (ANOVA, $p<0.05$) smaller than those we captured with a seine in 2001 (Figure 9). Therefore, the 2001 age composition estimate of the Lake Clark escapement may be biased toward younger fish since size and marine age are correlated.

## Tazimina River Sockeye Salmon Escapement Estimates

Sockeye salmon escapement into Tazimina River began the last week of July or first week of August, ended by the third or fourth week of August, and lagged behind Lake Clark escapement by 10 to 14 days (Figure 5). Tazimina River escapement during 2001–2003 averaged 12,193 fish, ranged from 9,180 (2001) to 14,213 (2003) and contributed, on average, 5% to the total Lake Clark escapement (Table 4). Tazimina River escapement estimates during 2001-2003 fell within the range for past peak aerial escapement indices (12 to 504,000 sockeye salmon), but were about 78% less than mean peak escapement indices (55,000 sockeye salmon).

## Tazimina River Sockeye Salmon Age and Size Composition

Otoliths were sampled from post-spawning sockeye salmon captured with seines and annual sample sizes were 124 (2001), 99 (2002) and 100 (2003). Overall trends in age composition were generally similar between Tazimina River and Lake Clark sockeye salmon samples (Table 3, Figure 6). Neither sample group contained age-0. or -.1 sockeye salmon in any year. Age-1.3 was the most abundant age class in both samples during 2001, while age-1.2 was the most abundant during 2002 and 2003. However, the distribution of annual age classes differed significantly (chi square, $P<0.05$ all tests) between sample locations:

- In 2001, Tazimina River samples had slightly more age-1.2 (23.4% versus 19.1%) and age-1.3 (75.0% versus 72.9%) sockeye salmon than Lake Clark samples, and fewer age-2.3 sockeye salmon (0.8% versus 6.5%).
- In 2002, Tazimina River samples had more age-1.2 (76% versus 56%) and fewer age-1.3 (14% versus 30%) than Lake Clark samples.
- In 2003, Tazimina River samples had more age 1.3 (45% versus 38%) and fewer age-1.2 (48% versus 53%) Lake Clark samples.

Within each age class, sockeye salmon returning to spawn in Tazimina River were generally significantly (ANOVA, $p<0,05$) smaller than those sampled at the Newhalen River site (Table 3, Figures 7 and 8). The mean size difference for all age categories with sample sizes greater than 10 sockeye salmon was about 25 mm (SD = 15.9).

# DISCUSSION

Compared to a past mean escapement to Lake Clark of 1,135,464 sockeye salmon (1980–1984; Poe and Rogers 1984) current escapement declined about 81% to a mean of 215,922 sockeye salmon (2000-2003). Our data are comparable to that collected by Poe and Rogers (1984) because the same tower sites, protocols, and even some of the same personnel, including Poe, were used. The accuracy of the comparison would be improved by inclusion of 2004 escapement data which would equalize the study time frames to five field seasons. Comparison of mean Tazimina escapement during this study with earlier estimates are less clear since only peak aerial estimates were made prior to our tower work (Demory et al. 1964, Regnart 1998, ADF&G unpublished data). Aerial surveys tend to underestimate the actual number of salmon present by 32% to 75% (Jones et al. 1998) and cannot be used to estimate total escapement unless area-under-the-curve calculations can be made, which require frequent surveys over the duration of the run as well as estimates of stream life and observer efficiency (Bue et al. 1998). In contrast, escapement estimates made from tower counts can provide total escapement estimates within 7% to 13% of actual total escapement (Reitz 1957, Spangler and Reitz 1958). These data imply that the 78% decline calculated for the Tazimina River escapement is an underestimate. In general, declines in escapement abundance to both Lake Clark and the Tazimina River were similar to the 77% decline in overall mean escapement to the Kvichak River watershed since 1996 (Rogers et al. 1999, ADF&G 2002). If these escapement declines persist, they may have long term effects on salmon productivity as a result of 1) reduced marine derived nutrients due to fewer salmon carcasses, 2) loss of genetic diversity due to low spawning populations size, and 3) degradation of spawning habitats due to reduced spawner densities.

Reduced amounts of marine derived nutrient (MDN) inputs from salmon to Lake Clark and the greater Kvichak River watershed may affect freshwater productivity of sockeye salmon (Koenings and Burkett 1987, Kline et al. 1993, Finney et al. 2000). Sockeye salmon gain about 99% of their body weight in the ocean (Burgner 1991), and the nutrients in their bodies enter both freshwater and terrestrial food webs when they return to spawn in freshwater then die (Cederholm et al. 2000, Burgner 1991, Koenings and Burkett 1987, Willson and Halupka 1995, Finney 2000). Both Lake Clark and Iliamna Lake are oligotrophic, or “nutrient poor” so MDN inputs can be important to freshwater sockeye salmon productivity. Kline et al. (1993) found Lake Iliamna sockeye salmon fry MDN levels to be dependent on adult escapement abundance and suggested that escapements greater than 10 million spawners to the Kvichak River watershed were important for maintaining sockeye salmon production through MDN remineralization into limnetic food webs. Edmundson and Mazumder (2001) found that zooplankton biomass was the strongest single predictor of sockeye salmon smolt size, which is positively related to marine survival (Koenings et al. 1987). Based on Kvichak River sockeye salmon escapement and adult return data, Rogers and Poe (1984) found that escapements of 6 to 10 million spawners generally produced large returns of adults. These results all imply that recent annual escapements of less than 2 million spawners to the Kvichak River watershed may be reducing freshwater productivity and may make it more difficult to rebuild sockeye salmon runs to former abundance levels.

The Kvichak River watershed, excluding the Alagnak drainage, supports about 150 sockeye salmon spawning populations (Demory et al. 1964, Anderson 1969, Woody et al. 2003, Young 2004). Lake Clark and the upper Newhalen River provide habitat for about 38 known sockeye salmon spawning populations (Demory et al. 1964, Young 2004) which exhibit some of the highest levels of genetic population structuring observed within a lake (Ramstad et al. 2004). Genetic bottlenecks, which indicate a loss of genetic diversity due to reduced spawning population numbers (Futuyma 1986), have been observed within both Lake Clark (Ramstad et al. 2004) and Lake Iliamna (Habicht et al. 2004). Continued low escapement to the greater Kvichak watershed could contribute to further reductions in genetic diversity if component spawning populations are reduced to very low levels. This could decrease sockeye salmon population productivity through 1) inbreeding, whereby deleterious recessive genes may be expressed, 2) increased rates of genetic drift, which results in gene loss, and 3) increased population variability, all of which reduce the ability of populations to adapt to change and increase the probability of extinction (Futuyma 1986, Luikart et al. 1998, Soule and Mills 1998). Recovery of lost genetic diversity is a slow process that is accomplished through mutation (Futuyma 1986) and straying of sockeye salmon from one natal habitat to another, which naturally occurs at very low rates (< 3%; Foerster 1936, Quinn et al. 1987).

Mass spawning events by salmon remove fine sediments from spawning areas, which increase gravel permeability (Kondolf et al. 1993), and improve stream bed resistance to scour by coarsening gravel (Montgomery et al. 1996). This improves salmon embryo survival, which is typically less than 10% in Pacific salmon (Hartman et al. 1962, Foerster 1968, Woody 1998), and is caused, in part, by reduced permeability of gravels from sedimentation (Tapple and Bjornn 1983, Chapman 1988) and mechanical disturbance due to scour by floods (McNeil 1964, Lisle 1989). Continued low salmon escapements may contribute to a decline in spawning habitat quality and reduced embryo survival through increased gravel sedimentation, compaction, and susceptibility to scour (Montgomery et al. 1996).

Age at maturity is an environmentally affected, heritable trait in salmonids (Healey 1986, Burgner 1991, Gall et al. 1988, Hankin et al. 1993) and is a pivotal life history trait because it is the most important determinant of size at maturity (Healy 1987) which in turn, is positively correlated with fecundity and egg size (Beacham 1982, Healy and Heard 1984, Woody 1998) both of which affect fitness (Stearns 1997). Escapement samples obtained at Kvichak, Newhalen, and Tazimina sampling sites were dominated by age-1.3 sockeye salmon in 2001, but by age-1.2 sockeye salmon in 2002 and 2003 (Figure 6, Table 2). This could have resulted from similar parent age dominance patterns and/or a recent change in oceanic conditions that favored spending two years in the ocean rather than three. In 2001, subsistence fishers consistently commented on the large body size and apparent good health of returning sockeye salmon.

Variation in size at age was relatively consistent across years with Tazimina River fish being smallest, Lake Clark bound fish largest, and Kvichak River samples intermediate in size (Table 3; Figures 7 and 8). Our results support those from an earlier tagging study by Mathisen and Poe (1969) which found that Newhalen River fish sampled both with seines and gillnets were generally 2 cm longer than Kvichak River seine samples. This trend is not obvious in the 2001 data because our gillnet samples were biased toward smaller fish in 2001, probably because subsistence gillnets retained the smaller 1.2 fish more easily than the very large age 1.3 fish that dominated that year (Figures 6 and 9). Lake Clark samples collected from the Nondalton subsistence fishery represent about 35 spawning populations, including the smaller Tazimina River stock, while the Kvichak River samples represent about 150 populations including Lake Clark. If Lake Clark bound fish are generally larger that the overall Kvichak River samples then this implies Iliamna Lake bound fish are even smaller at age than the mean sizes presented here (Table 3).

Tazimina River sockeye salmon samples had the smallest mean size at age and represent the only group sampled on their spawning grounds. Researchers have previously observed patterns of smaller, younger salmon dominating phenotypes in relatively small tributaries, such as the Tazimina River and larger older salmon in larger tributaries (Blair et al. 1993, Rogers 1987, Beacham and Murray 1987, Woody 1998). Consistent correlations between age and size variation by habitat type suggest adaptive differences (Endler 1986), although such patterns should be considered in conjunction with genetic data. Local adaptations among populations are important and increase genetic variation within a species (Altukhov 1981) which is important in maintaining healthy, viable populations. Research on phenotypic and genotypic diversity of Lake Clark sockeye salmon populations is ongoing and, when complete, will provide further insight on patterns of phenotypic and genotypic variation within the Kvichak River watershed.

Maintaining long-term productivity of sockeye salmon production in Lake Clark and the Tazimina River for all user groups will depend on ensuring sufficient escapement to component populations of the entire Kvichak River escapement. Because Bristol Bay sockeye salmon populations are currently managed at the watershed level, individual biological escapement goals for component populations, such as Lake Clark, are nonexistent. Therefore, increasing spawning escapements into the Kvichak River at the earliest available opportunity to at least 4 million, and up to 10 million sockeye salmon as recommended by Rogers and Poe (1984), Kline et al. (1993), and Cross (1994) will help to: maintain population genetic diversity and therefore overall population health; increase available MDN, and aid in maintenance of spawning habitats.

# CONCLUSIONS

1. Sockeye salmon escapements into Lake Clark declined 81% compared to a 1980s study.
2. Tazimina River escapements declined about 78% since 1996 compared to past peak aerial estimates made during 1955–2000.
3. The relative variation of Lake Clark escapement was half that of the Kvichak River escapement, implying wider fluctuations in spawning escapements to Iliamna Lake.
4. Tower estimates of sockeye salmon escapement into Lake Clark are relatively accurate and feasible; however, tower estimates of escapement into the Tazimina River are probably less accurate due to frequent flooding events and sockeye salmon milling behavior in a terminal spawning stream.
5. Sockeye salmon escapements at the Newhalen River counting site comprised 10% to 29% and averaged 19% of total Kvichak River watershed escapement estimates, while Tazimina River escapements comprised 4% to 6% and averaged 5% of Newhalen River estimates.

6. Overall trends in age composition were similar among Lake Clark, Tazimina River, and Kvichak River sockeye salmon samples, with age-1.3 sockeye salmon the most abundant age class in 2001 and age-1.2 the most abundant class in both 2002 and 2003. A significant difference was observed in age composition among sample sites.
7. Lake Clark sockeye salmon were generally larger at age when compared to Kvichak River sockeye salmon and Tazimina River fish were generally smaller at the same age compared to Lake Clark and Kvichak River samples.
8. Continued low sockeye salmon escapements to the Kvichak River watershed may hinder recovery of former run abundance due to reduced availability of marine derived nutrients, increased risk of genetic diversity losses, and decreased spawning habitat quality (siltation and compaction of gravels).

# RECOMMENDATIONS

1. Continue monitoring Lake Clark sockeye salmon escapement to:
    - Provide the basis for Lake Clark abundance, size, and age trend analyses;
    - Allow an estimate of Iliamna Lake escapement; e.g. Kvichak escapement – Newhalen escapement = Iliamna Lake escapement.
    - Supply data for construction of Lake Clark sockeye salmon brood year tables;
    - Provide state and federal managers more complete and accurate data with which to analyze management options for sockeye salmon commercial, subsistence and sport fisheries.

2. Improve sockeye salmon production from Lake Clark and the overall Kvichak River watershed by increasing spawning escapements into the Kvichak River at the earliest available opportunity to at least 4 million, and up to 10 million sockeye salmon (also recommended by: Rogers and Poe 1984, Kline et al. 1993, and Cross 1994).

3. Continue to improve comparability of Lake Clark escapement and samples with samples obtained at the Kvichak River tower site.

4. Continue to monitor age and size of sockeye salmon harvested in the upper Newhalen River subsistence fishery to provide data for brood table construction.

5. Determine resulting production from adult escapement through implementation of a Lake Clark smolt estimation program.

6. Conduct a comparative study of fresh water sockeye salmon production from major lakes within the Kvichak River watershed. Implement a monthly lake monitoring program during the ice free period to obtain information on thermal conditions (stored heat), zooplankton biomass, and fry and yearling density and size, which, combined with estimates of smolt abundance, size and age, would allow examination of factors potentially affecting fresh water production (see: Edmundson and Mazumder 2001).

7. Compile and standardize historic and contemporary age and size data for the Kvichak, Newhalen, and Tazimina Rivers and examine these data for trends and patterns relative to climate change, fishing, and escapements.

8. Discontinue tower monitoring of the Tazimina River sockeye salmon escapement. If continued escapement monitoring is needed for this river system, then other abundance estimation methods such as mark-recapture should be explored.

9. Compare Lake Clark escapement estimates to ADF&G peak aerial escapement estimates for this watershed to determine whether aerial estimates provide a relatively consistent and representative index of total Lake Clark escapement.

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# FIGURES

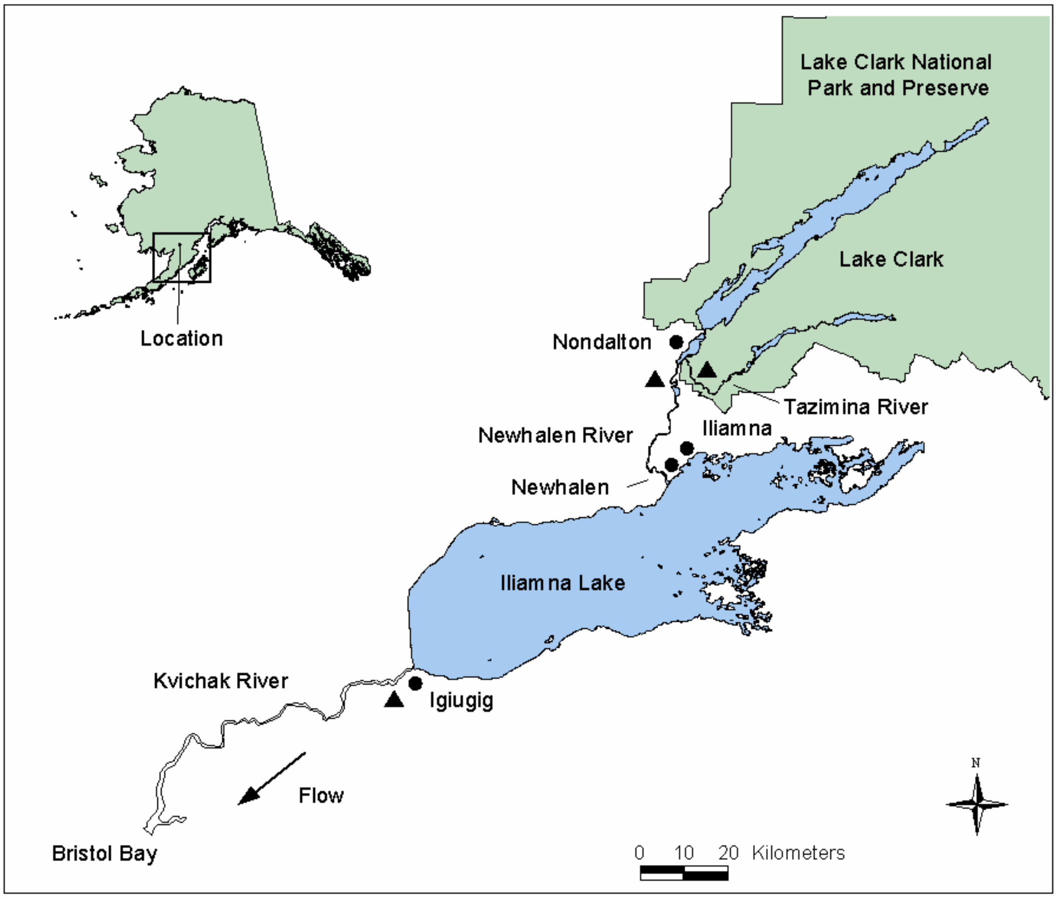



Figure 1. Map of the Kvichak River watershed including escapement monitoring sites (triangles) and select local communities (dots). The monitoring site located by the community of Igiugig is operated by the Alaska Department of Fish and Game.

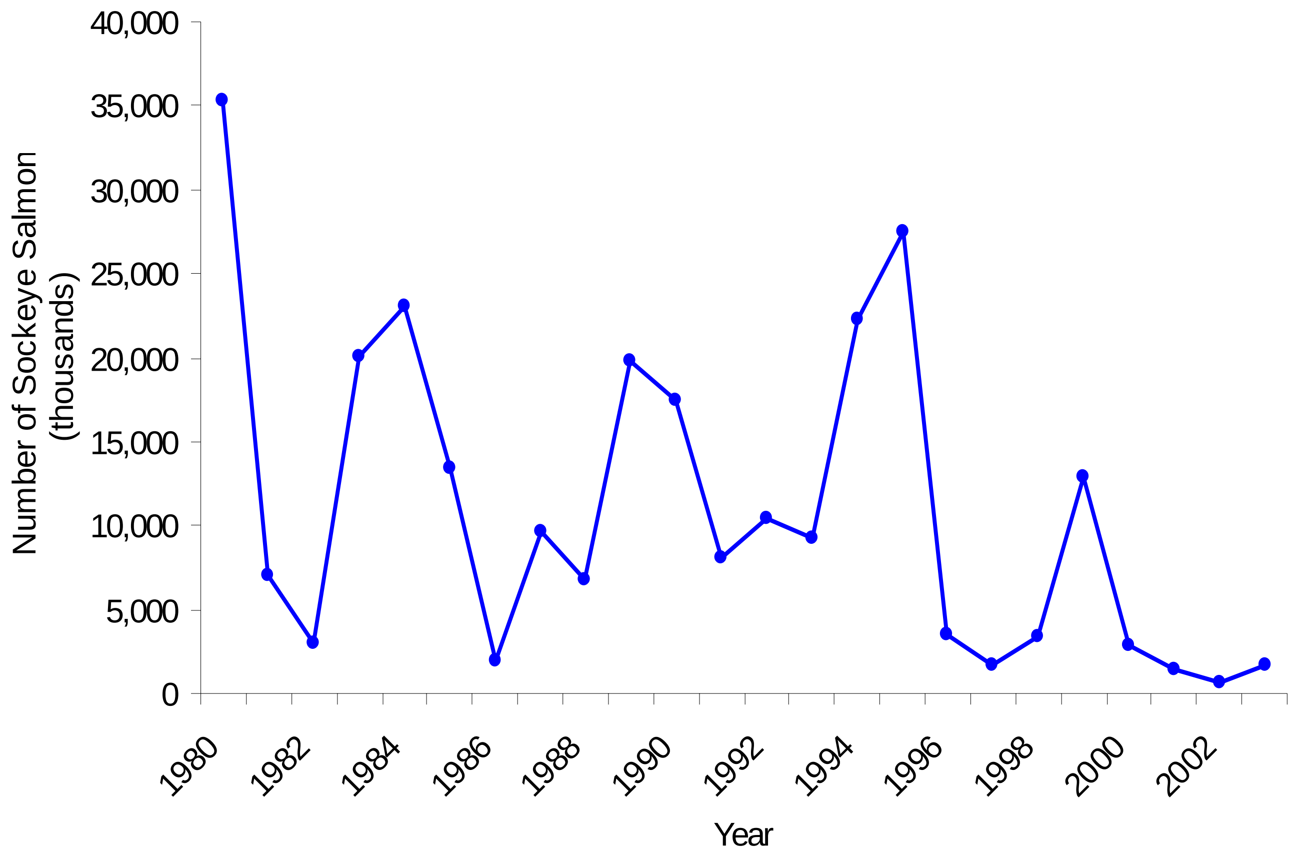



Figure 2. Kvichak River sockeye salmon runs (escapement + harvest) 1980 to 2003. Data provided by the Alaska Department of Fish and Game, Anchorage, Alaska.

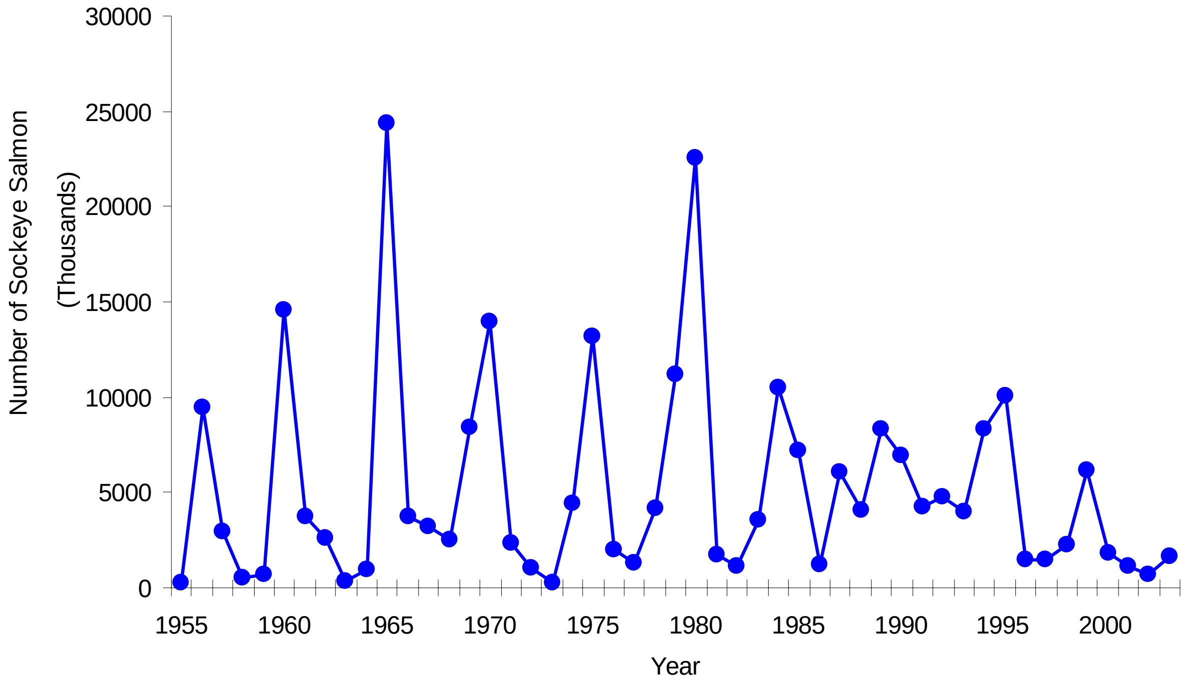



Figure 3. Annual sockeye salmon escapements to the Kvichak River, 1955 to 2003. Data provided by the Alaska Department of Fish and Game, Anchorage, Alaska.

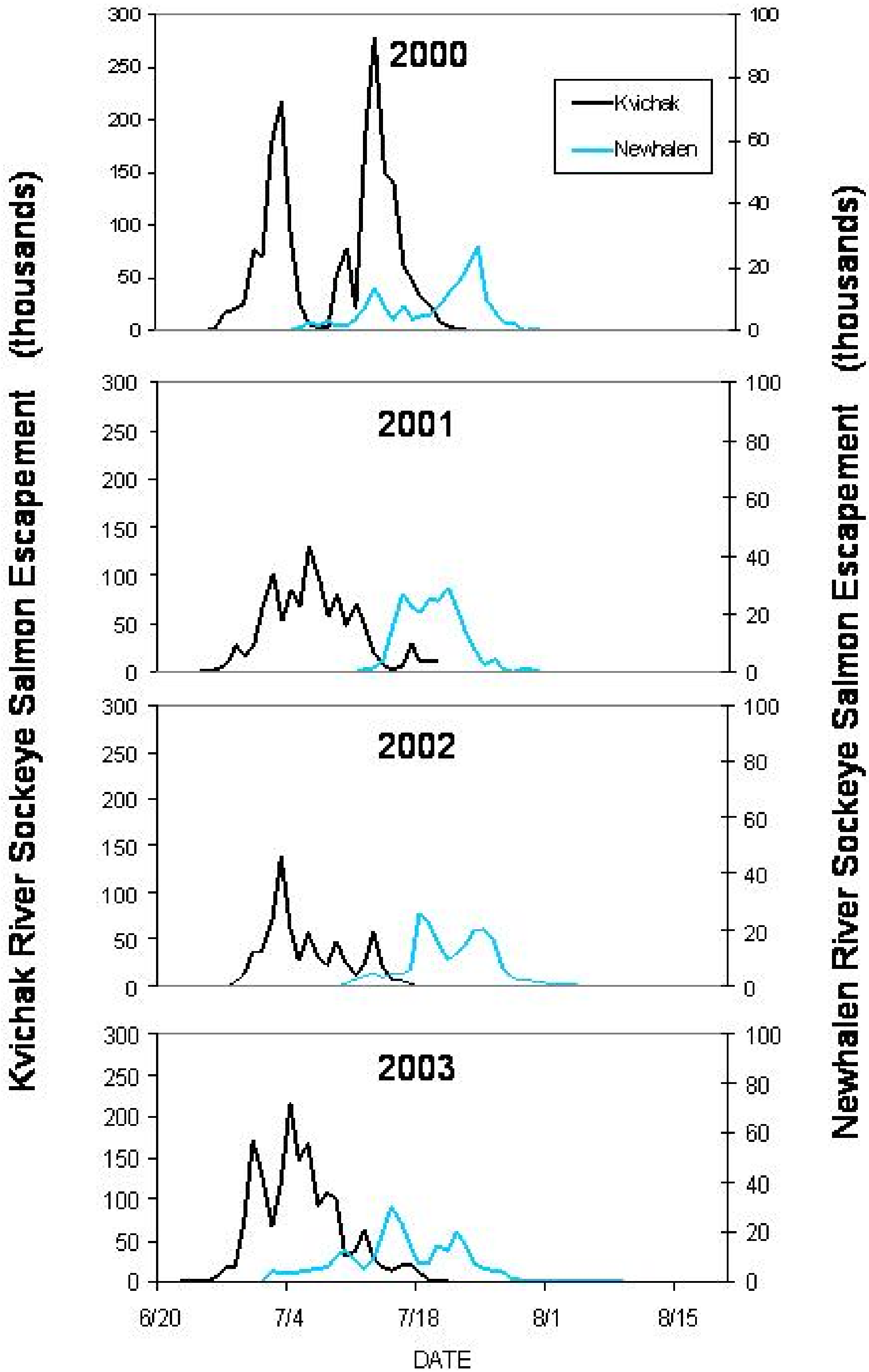



Figure 4. Sockeye salmon daily escapement to the Kvichak and Newhalen Rivers, 2000-2003. Kvichak River data provided by the Alaska Department of Fish and Game, Anchorage, Alaska.

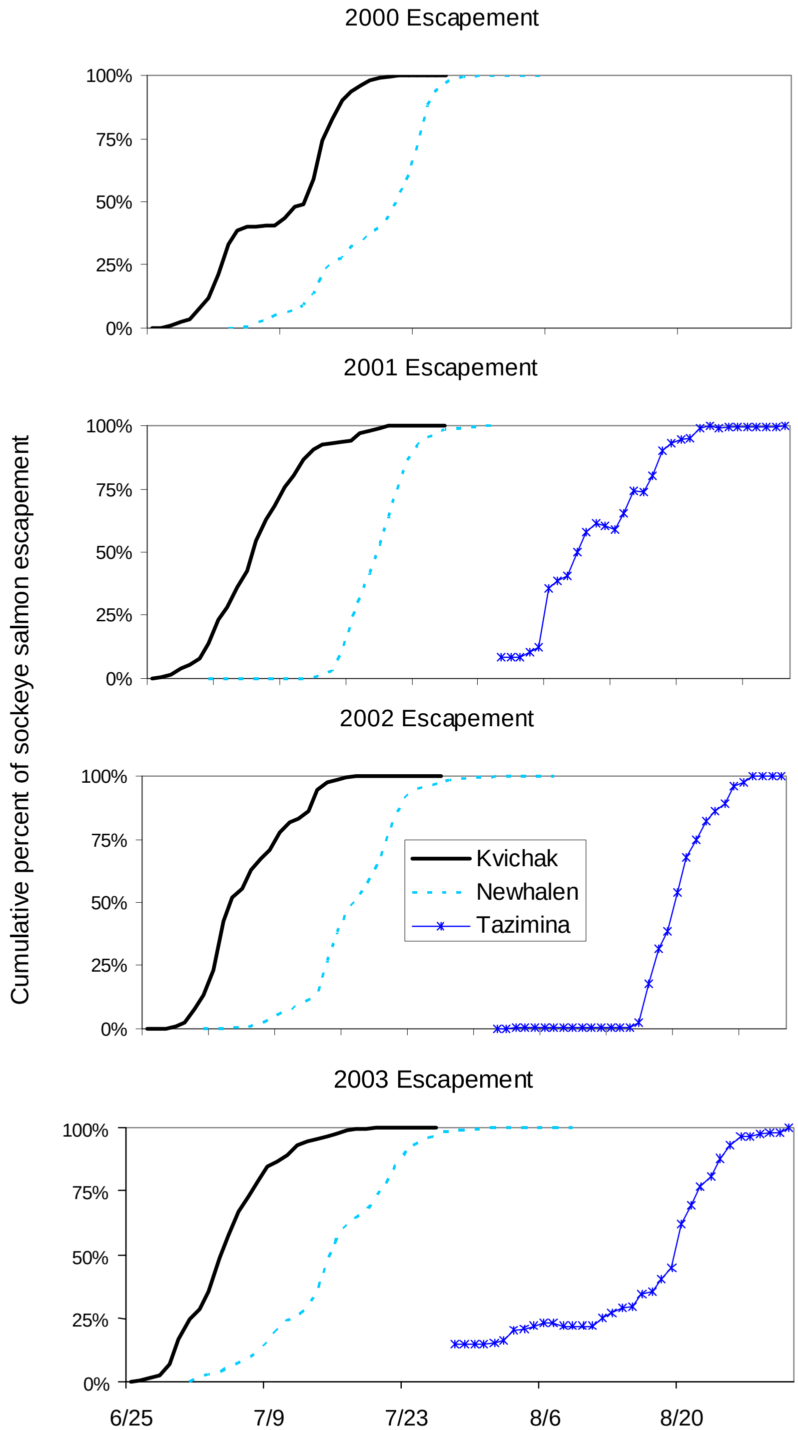



Figure 5. Cumulative percentiles by date of sockeye salmon total escapement to the Kvichak, Newhalen and Tazimina Rivers, 2000–2003. Kvichak River escapement data provided by the Alaska Department of Fish and Game.

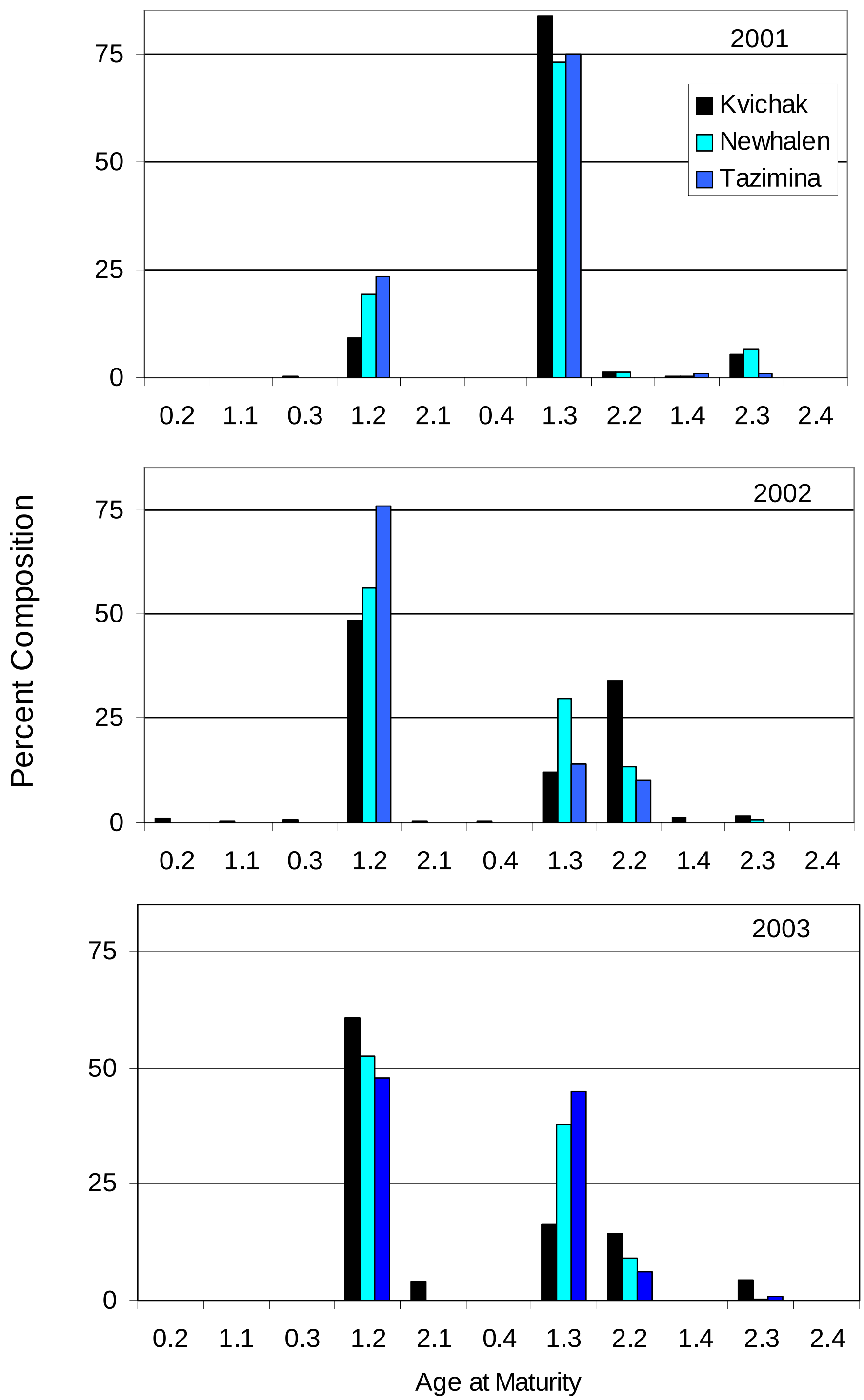



Figure 6. Age composition (%) of sockeye salmon escapements to the Kvichak, Newhalen and Tazimina Rivers, 2000-2003. Data for Kvichak River sockeye salmon provided by the Alaska Department of Fish and Game, Anchorage, Alaska.

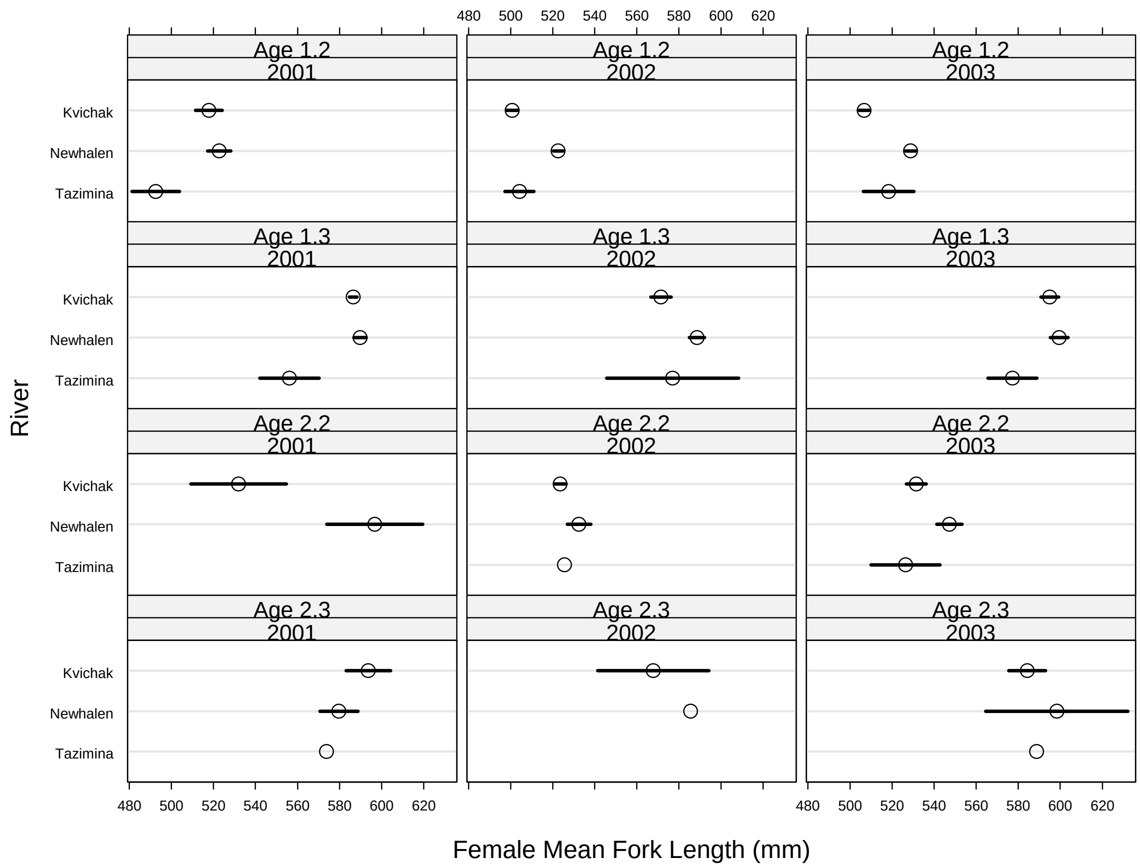



Figure 7. Mean mid eye to fork length (circles) and 90% confidence intervals (bars) for adult female sockeye salmon returning to the Kvichak, Newhalen, and Tazimina Rivers, 2001–2003. Age-1.3 predominated in all rivers in 2001 and age-1.2 predominated in 2002 and 2003. Kvichak River data provided by the Alaska Department of Fish and Game, Anchorage, Alaska.

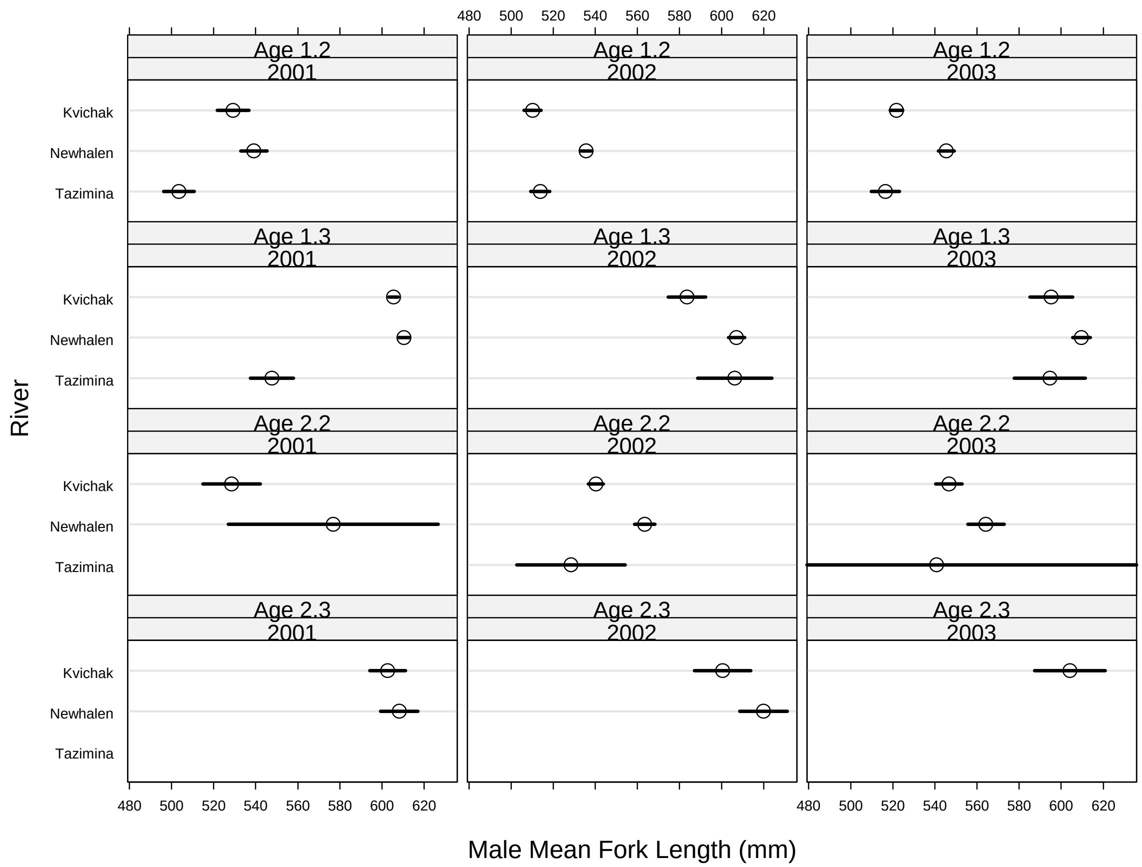
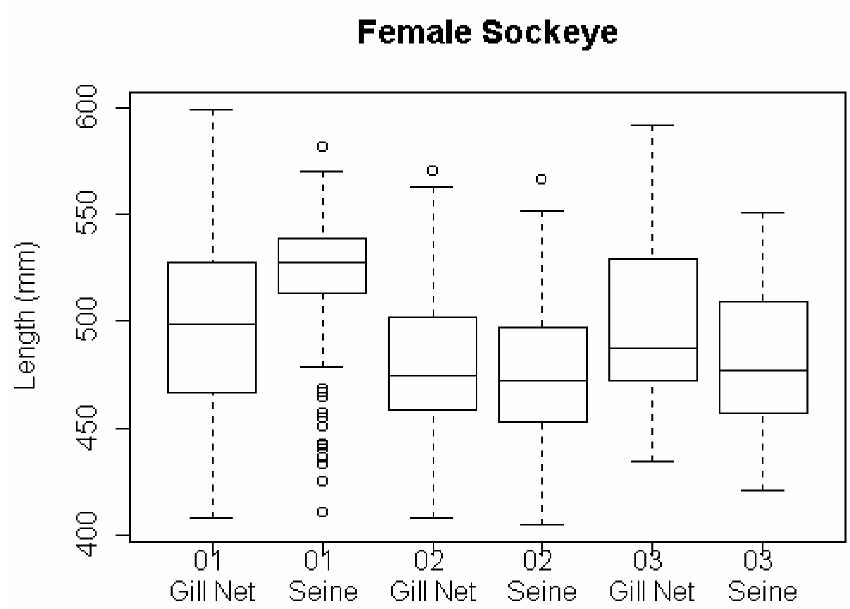



Figure 8. Mean mid eye to fork length (circles) and 90% confidence intervals (bars) for adult male sockeye salmon returning to the Kvichak, Newhalen, and Tazimina Rivers, 2001–2003. Age-1.3 predominated in all rivers in 2001 and age-1.2 predominated in 2002 and 2003. Kvichak River data provided by the Alaska Department of Fish and Game, Anchorage, Alaska.



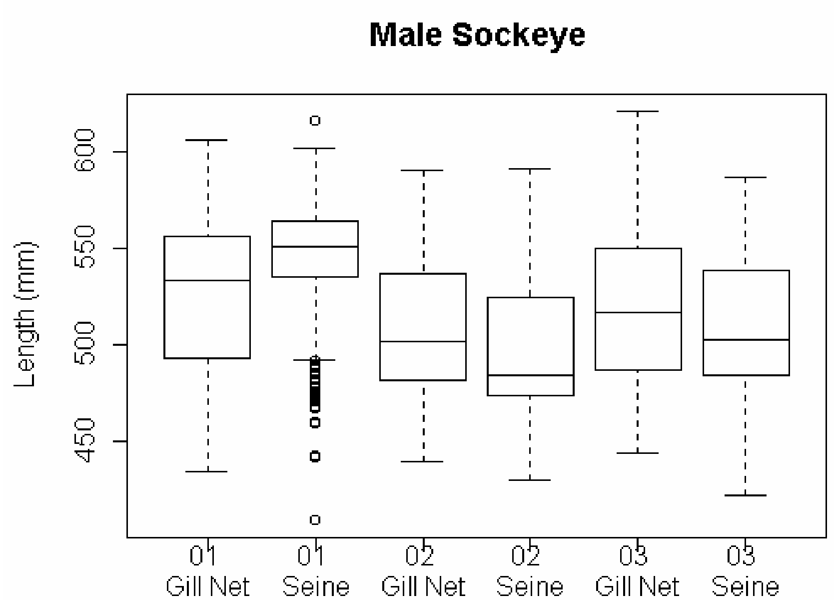




Figure 9. Box plots illustrating differences in mid eye to fork lengths of sockeye salmon sampled with gill nets and seines, Newhalen River, Alaska. Significant differences (ANOVA; $P<0.05$ all tests) were observed in 2001, with gill net sampled fish being smaller on average than seine sampled fish. No difference in average size of fish captured by these two methods was observed in 2002 or 2003.

# TABLES

Table 1. Summary of sockeye salmon escapement data for Lake Clark, the Kvichak River, and Iliamna Lake, Alaska during 2000–2003. Iliamna Lake escapement was estimated by subtracting Lake Clark escapement from the Kvichak River escapement. Kvichak River data provided by the Alaska Department of Fish and Game, Anchorage, Alaska.

| Year | Lake Clark Escapement | 90% CI | % of Kvichak | Kvichak River Escapement | Iliamna Lake Escapement |
|---|---|---|---|---|---|
| 2000 | 172,902 | 165,500 to 180,300 | 10 | 1,827,780 | 1,654,878 |
| 2001 | 222,414 | * | 20 | 1,095,348 | 872,934 |
| 2002 | 203,682 | 193,800 to 213,600 | 29 | 703,884 | 500,214 |
| 2003 | 264,690 | 252,600 to 275,400 | 16 | 1,686,804 | 1,422,114 |

* CI not calculated as raw data unavailable

Table 2. Age composition of sockeye salmon escapements sampled annually from the Kvichak, Newhalen, and Tazimina Rivers during 2001–2003. Sample sizes (n) and percentage composition (%) are shown. Kvichak River data provided by the Alaska Department of Fish and Game, Anchorage, Alaska.

| | | Age Composition | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| River | | 0.2 | 1.1 | 0.3 | 1.2 | 2.1 | 0.4 | 1.3 | 2.2 | 1.4 | 2.3 | 2.4 | Total |
| | | | | | | *2001* | | | | | | | |
| Kvichak | n | 0 | 0 | 3 | 119 | 0 | 0 | 1094 | 17 | 5 | 70 | 0 | 1308 |
| | % | 0 | 0 | 0.2 | 9.1 | 0 | 0 | 83.6 | 1.3 | 0.4 | 5.4 | 0 | 100 |
| Newhalen | n | 0 | 0 | 0 | 147 | 0 | 0 | 561 | 10 | 2 | 50 | 0 | 770 |
| | % | 0 | 0 | 0 | 19.1 | 0 | 0 | 72.9 | 1.3 | 0.2 | 6.5 | 0 | 100 |
| Tazimina | n | 0 | 0 | 0 | 29 | 0 | 0 | 93 | 0 | 1 | 1 | 0 | 124 |
| | % | 0 | 0 | 0 | 23.4 | 0 | 0 | 75 | 0 | 0.8 | 0.8 | 0 | 100 |
| | | | | | | *2002* | | | | | | | |
| Kvichak | n | 14 | 4 | 6 | 654 | 4 | 3 | 162 | 458 | 17 | 23 | 1 | 1346 |
| | % | 1.0 | 0.3 | 0.5 | 48.6 | 0.3 | 0.2 | 12.0 | 34.0 | 1.3 | 1.7 | 0.1 | 100 |
| Newhalen | n | 0 | 0 | 0 | 425 | 0 | 0 | 225 | 101 | 0 | 6 | 0 | 757 |
| | % | 0 | 0 | 0 | 56.2 | 0 | 0 | 29.7 | 13.3 | 0 | 0.8 | 0 | 100 |
| Tazimina | n | 0 | 0 | 0 | 75 | 0 | 0 | 14 | 10 | 0 | 0 | 0 | 99 |
| | % | 0 | 0 | 0 | 75.8 | 0 | 0 | 14.1 | 10.1 | 0 | 0 | 0 | 100 |

-continued-

Table 2. Continued.

| River | | Age Composition 0.2 | 1.1 | 0.3 | 1.2 | 2.1 | 0.4 | 1.3 | 2.2 | 1.4 | 2.3 | 2.4 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | *2003* | | | | | | | |
| Kvichak | n | 0 | 0 | 0 | 857 | 58 | 2 | 233 | 202 | 0 | 62 | 0 | 1413 |
| | % | 0 | 0 | 0 | 60.7 | 4.1 | 0.1 | 16.4 | 14.3 | 0 | 4.4 | 0 | 100 |
| Newhalen | n | 0 | 0 | 0 | 260 | 0 | 0 | 187 | 45 | 0 | 2 | 0 | 494 |
| | % | 0 | 0 | 0 | 52.6 | 0 | 0 | 37.9 | 9.1 | 0 | 0.4 | 0 | 100 |
| Tazimina | n | 0 | 0 | 0 | 48 | 0 | 0 | 45 | 6 | 0 | 1 | 0 | 100 |
| | % | 0 | 0 | 0 | 48 | 0 | 0 | 45 | 6 | 0 | 1 | 0 | 100 |

Table 3. Mean size at age of sockeye salmon sampled annually from the Kvichak, Newhalen, and Tazimina Rivers, Bristol Bay, Alaska, 2001-2003. Mean lengths (ML) are mid-eye to fork of tail (mm), with standard deviations (SD), and sample sizes (n) shown. Kvichak River sockeye salmon data provided by the Alaska Department of Fish and Game, Anchorage, Alaska.

| River | Sex | | 0.2 | 1.1 | 0.3 | 1.2 | 2.1 | 0.4 | 1.3 | 2.2 | 1.4 | 2.3 | 2.4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | <u>*2001*</u> | | | | | | | |
| Kvichak | Male | ML | | | 618 | 530 | | | 606 | 530 | 612 | 603 | |
| | | SD | | | | 33.9 | | | 20.5 | 19.6 | 6.0 | 32.4 | |
| | | n | | | 1 | 47 | | | 419 | 7 | 2 | 43 | |
| Newhalen | | ML | | | | 539 | | | 609 | 577 | 644 | 608 | |
| | | SD | | | | 28.4 | | | 23.9 | 29.6 | | 26.6 | |
| | | n | | | | 62 | | | 265 | 3 | 1 | 29 | |
| Tazimina | | ML | | | | 504 | | | 548 | | | | |
| | | SD | | | | 18.3 | | | 46.9 | | | | |
| | | n | | | | 19 | | | 59 | | | | |
| Kvichak | Female | ML | | | 584 | 518 | | | 586 | 534 | 608 | 594 | |
| | | SD | | | | 33.2 | | | 26.0 | 36 | 31.1 | 30.6 | |
| | | n | | | 2 | 70 | | | 675 | 10 | 3 | 27 | |
| Newhalen | | ML | | | | 523 | | | 590 | 597 | | 582 | |
| | | SD | | | | 25.8 | | | 23.7 | 31.0 | | 17.0 | |
| | | n | | | | 63 | | | 188 | 7 | | 13 | |
| Tazimina | | ML | | | | 493 | | | 556 | | 564 | 574 | |
| | | SD | | | | 19.5 | | | 48.6 | | | | |
| | | n | | | | 10 | | | 34 | | 1 | 1 | |
| | | | | | | <u>*2002*</u> | | | | | | | |
| Kvichak | Male | ML | 377 | 346 | 612 | 511 | 386 | 610 | 584 | 538 | 624 | 592 | |
| | | SD | 138 | | 55.4 | 51.4 | | | 59.3 | 41.8 | 17.9 | 20.8 | |
| | | n | 10 | 2 | 4 | 294 | 2 | 2 | 56 | 195 | 6 | 13 | |
| Newhalen | | ML | | | | 536 | | | 607 | 563 | | 620 | |
| | | SD | | | | 19.7 | | | 22.2 | 18.6 | | 11.8 | |
| | | n | | | | 169 | | | 95 | 42 | | 5 | |
| Tazimina | | ML | | | | 514 | | | 606 | 529 | | | |
| | | SD | | | | 19.5 | | | 24.0 | 41.6 | | | |
| | | n | | | | 53 | | | 7 | 9 | | | |
| Kvichak | Female | ML | 426 | 372 | 556 | 502 | 340 | 621 | 565 | 523 | 561 | 555 | 531 |
| | | SD | 8.5 | | | 36.2 | | | 40.8 | 48.5 | 69.0 | 72.0 | |
| | | n | 3 | 2 | 2 | 328 | 2 | 1 | 105 | 262 | 10 | 10 | 1 |

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Table 3. Continued.

| River | Sex | | Age at Maturity | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0.2 | 1.1 | 0.3 | 1.2 | 2.1 | 0.4 | 1.3 | 2.2 | 1.4 | 2.3 | 2.4 |
| | | | | | | *2002* | | | | | | | |
| Newhalen | Female | ML | | | | 522 | | | 589 | 533 | | 586 | |
| | | SD | | | | 20.7 | | | 20.2 | 24.2 | | | |
| | | n | | | | 227 | | | 90 | 53 | | 1 | |
| Tazimina | | ML | | | | 504 | | | 577 | 526 | | | |
| | | SD | | | | 18.7 | | | 42.8 | | | | |
| | | n | | | | 22 | | | 7 | 1 | | | |
| | | | | | | *2003* | | | | | | | |
| Kvichak | Male | ML | | | | 522 | 398 | | 597 | 547 | | 606 | |
| | | SD | | | | 20.1 | 27.7 | | 47.2 | 32.7 | | 34.9 | |
| | | n | | | | 403 | 49 | | 63 | 68 | | 16 | |
| Newhalen | | ML | | | | 545 | | | 610 | 564 | | | |
| | | SD | | | | 24.8 | | | 25.4 | 21.8 | | | |
| | | n | | | | 119 | | | 101 | 19 | | | |
| Tazimina | | ML | | | | 517 | | | 595 | 541 | | | |
| | | SD | | | | 22.0 | | | 39.9 | | | | |
| | | n | | | | 31 | | | 17 | 2 | | | |
| Kvichak | Female | ML | | | | 508 | 399 | 581 | 595 | 533 | | 586 | |
| | | SD | | | | 21.3 | 17.0 | | 38.9 | 34.6 | | 40.2 | |
| | | n | | | | 454 | 9 | 2 | 169 | 134 | | 46 | |
| Newhalen | | ML | | | | 529 | | | 600 | 547 | | 598 | |
| | | SD | | | | 17.3 | | | 23.2 | 17.2 | | | |
| | | n | | | | 135 | | | 82 | 24 | | 2 | |
| Tazimina | | ML | | | | 518 | | | 577 | 526 | | 589 | |
| | | SD | | | | 28.3 | | | 36.1 | 13.9 | | | |
| | | n | | | | 17 | | | 28 | 4 | | 1 | |

Table 4. Tazimina River sockeye salmon escapement estimates, 90% confidence intervals (90% CI) and proportional contribution to estimated Lake Clark escapement, Kvichak River watershed, Bristol Bay, Alaska, 2001–2003.

| Year | Tazimina River Escapement | 90% CI | % of Lake Clark Escapement |
|---|---|---|---|
| 2001 | 9,180 | 7,680-10,680 | 4 |
| 2002 | 13,187 | 10,837-15,537 | 6 |
| 2003 | 14,213 | 13,013-15,413 | 5 |

# APPENDIX

Appendix 1. Daily sockeye salmon escapement for the Kvichak and Newhalen Rivers, 2000–2003, Kvichak River watershed, Alaska. Kvichak River escapement data courtesy of Alaska Department of Fish and Game, Anchorage, Alaska.

| | Kvichak River | | | | Newhalen River | | | |
|---|---|---|---|---|---|---|---|---|
| Date | 2000 | 2001 | 2002 | 2003 | 2000 | 2001 | 2002 | 2003 |
| 20 June | | 30 | | | | | | |
| 21 June | | 12 | 162 | | | | | |
| 22 June | | 258 | 348 | 18 | | | | |
| 23 June | 108 | 282 | 570 | 0 | | | | |
| 24 June | 72 | 156 | 270 | 888 | | | | |
| 25 June | 30 | 1,380 | 54 | 414 | | | | |
| 26 June | 3,360 | 2,868 | 210 | 4,926 | | | | |
| 27 June | 17,904 | 9,300 | 162 | 18,462 | | | | |
| 28 June | 20,412 | 28,194 | 3,978 | 18,102 | | | 0 | |
| 29 June | 24,600 | 15,708 | 11,796 | 69,972 | | | 0 | |
| 30 June | 77,280 | 27,528 | 37,830 | 171,006 | | 0 | 0 | |
| 1 July | 70,440 | 67,926 | 37,494 | 130,044 | | 6 | 0 | 198 |
| 2 July | 175,920 | 102,282 | 69,504 | 66,798 | 0 | 162 | 0 | 4,380 |
| 3 July | 216,582 | 53,562 | 137,400 | 121,938 | 114 | 0 | 0 | 3,138 |
| 4 July | 94,992 | 86,358 | 63,054 | 216,594 | 246 | 0 | 0 | 3,324 |
| 5 July | 23,508 | 68,628 | 26,184 | 146,808 | 858 | 0 | 78 | 4,020 |
| 6 July | 6,582 | 130,092 | 55,704 | 167,394 | 2,586 | 0 | 18 | 4,392 |
| 7 July | 2,436 | 95,646 | 31,824 | 92,070 | 1,608 | 0 | 0 | 5,256 |
| 8 July | 3,408 | 57,180 | 22,872 | 107,466 | 3,144 | 0 | 474 | 5,886 |
| 9 July | 52,848 | 81,852 | 47,868 | 100,086 | 1,746 | 108 | 42 | 10,020 |
| 10 July | 78,900 | 48,690 | 27,036 | 30,498 | 1,392 | 120 | 906 | 13,290 |
| 11 July | 22,188 | 71,598 | 11,394 | 37,158 | 3,720 | 114 | 2,418 | 8,682 |
| 12 July | 189,360 | 45,270 | 22,290 | 62,940 | 7,680 | 1,086 | 3,234 | 5,220 |
| 13 July | 277,434 | 18,564 | 58,614 | 30,378 | 13,530 | 1,482 | 4,392 | 8,940 |
| 14 July | 150,540 | 7,992 | 20,736 | 18,600 | 7,308 | 3,948 | 2,832 | 18,642 |

-continued-

Appendix 1. Continued.

| Date | Kvichak River 2000 | 2001 | 2002 | 2003 | Newhalen River 2000 | 2001 | 2002 | 2003 |
|---|---|---|---|---|---|---|---|---|
| 15 July | | | | | 3822 | 14,994 | 4,380 | 29,766 |
| 16 July | 62,418 | 6,168 | 5,616 | 20,202 | 7,722 | 26,910 | 3,846 | 23,346 |
| 17 July | 46,374 | 30,258 | 2,940 | 21,588 | 3,678 | 22,818 | 5,904 | 14,454 |
| 18 July | 31,824 | 10,842 | 348 | 12,576 | 4,428 | 20,514 | 25,854 | 7,452 |
| 19 July | 22,770 | 11,088 | | 1,416 | 5,226 | 25,188 | 22,824 | 7,128 |
| 20 July | 8,532 | 12,528 | | 2,118 | 8,028 | 24,474 | 15,810 | 14,226 |
| 21 July | 2,616 | | | 2,214 | 12,504 | 28,956 | 9,252 | 12,456 |
| 22 July | 1,854 | | | | 15,300 | 21,234 | 11,448 | 20,544 |
| 23 July | 726 | | | | 21,084 | 13,158 | 14,964 | 14,730 |
| 24 July | | | | | 26,748 | 7,236 | 19,944 | 7,344 |
| 25 July | | | | | 10,032 | 2,466 | 20,184 | 5,328 |
| 26 July | | | | | 5,376 | 4,452 | 16,308 | 4,422 |
| 27 July | | | | | 2,136 | 1,080 | 6,528 | 3,930 |
| 28 July | | | | | 2,202 | 78 | 3,306 | 1,152 |
| 29 July | | | | | 246 | 834 | 2,196 | 708 |
| 30 July | | | | | 318 | 798 | 1,878 | 648 |
| 31 July | | | | | 96 | 198 | 1,374 | 234 |
| 1 August | | | | | 24 | 0 | 1,140 | 864 |
| 2 August | | | | | | 0 | 336 | 96 |
| 3 August | | | | | | | 504 | 210 |
| 4 August | | | | | | | 690 | 78 |
| 5 August | | | | | | | 180 | 36 |
| 6 August | | | | | | | 84 | 120 |
| 7 August | | | | | | | 96 | 30 |
| 8 August | | | | | | | 42 | 0 |
| 9 August | | | | | | | 30 | 0 |
| 10 August | | | | | | | 90 | |
| 11 August | | | | | | | 84 | |
| 12 August | | | | | | | 12 | |
| Total | 1,827,780 | 1,095,348 | 703,884 | 1,686,804 | 172,902 | 222,414 | 203,682 | 264,690 |

Appendix 2. Sockeye salmon escapement estimates during 2001–2003, Tazimina River, Alaska. Above Tower Counts (ATC) are aerial estimates of in river fish abundance prior to tower installation; Below Tower Counts (BTC) are estimates of spawning sockeye salmon abundance below the tower at project end. Negative numbers indicate net downstream fish movement. CI = confidence interval around the total estimate.

| Date | 2001 | 2002 | 2003 |
|---|---|---|---|
| ATC | 760 | 20 | 2000 |
| 24-July | - | - | 0 |
| 25-July | - | - | 0 |
| 26-July | - | - | 96 |
| 27-July | - | - | 0 |
| 28-July | - | - | 0 |
| 29-July | - | - | -18 |
| 30-July | 0 | - | 0 |
| 31-July | 0 | - | 42 |
| 1-August | 0 | - | 24 |
| 2-August | 198 | - | 162 |
| 3-August | 174 | 12 | 552 |
| 4-August | 2,100 | 0 | 129 |
| 5-August | 240 | 0 | 93 |
| 6-August | 198 | 0 | 144 |
| 7-August | 852 | 0 | 51 |
| 8-August | 768 | 0 | -141 |
| 9-August | 282 | 0 | -12 |
| 10-August | -96 | 0 | 15 |
| 11-August | -102 | 3 | 0 |
| 12-August | 594 | 3 | 423 |
| 13-August | 810 | 0 | 258 |
| 14-August | -24 | 0 | 300 |
| 15-August | 558 | 0 | 78 |
| 16-August | 894 | 276 | 684 |
| 17-August | 300 | 2,028 | 168 |
| 18-August | 138 | 1,824 | 630 |
| 19-August | 18 | 909 | 699 |
| 20-August | 348 | 2,031 | 2,415 |
| 21-August | 108 | 1,881 | 1,110 |
| 22-August | -78 | 882 | 984 |
| 23-August | 24 | 948 | 582 |
| 24-August | 66 | 558 | 984 |
| 25-August | | 396 | 747 |
| 26-August | | 879 | 492 |
| 27-August | | 228 | 6 |
| 28-August | | 309 | 144 |
| 29-August | | | 63 |
| 30-August | | | 9 |
| BTC | 50 | | 300 |
| Total | 9,180 | 13,187 | 14,213 |
| Lower 90% CI | 7,680 | 10,837 | 13,013 |
| Upper 90% CI | 10,680 | 15,537 | 15,413 |