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NAKNEK RIVER SOCKEYE SALMON SMOLT STUDIES, 1993-1994.

by

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[a] Crewleader

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ABSTRACT

In order to measure the freshwater production from the record 3.6 million sockeye salmon *Oncorhynchus nerka* escapement to the Naknek River drainage in 1991, numbers of sockeye salmon smolt emigrating to sea from the Naknek River, were estimated from sonar counts from mid-May to mid-June in 1993 and 1994. Hydroacoustic equipment was used to estimate total smolt biomass, and age-weight-length data from fyke net catch samples were used to convert biomass estimates into numbers of smolt by age group. The total production estimate of age-1. and -2. sockeye salmon smolt from the record 1991 escapement was 66.5 million smolt.; 24.2 million (36%) age-1. smolt emigrated in 1993 and 42.3 million (64%) age-2. smolt emigrated in 1994. The smolt-per-spawner value for the 1991 brood year was significantly less than those observed for prior brood years. Age-1. and -2. smolt produced by the 1991 escapement were slightly smaller than the average smolt size for previous brood years, however the mean lengths and weights were not significantly different than those observed historically. The percentage of age-2. smolt produced by the 1991 escapement was not significantly higher than previous years. Therefore, based on smolt data, it appears that the record escapement of sockeye salmon that entered the Naknek River drainage in 1991 did not produce a record number of smolt.

KEYWORDS: smolt, sockeye salmon, *Onchorhynchus nerka*, smolt emigration, sonar, Bristol Bay, Naknek River,

INTRODUCTION

The Bristol Bay Management Area includes all waters east of a line from Cape Newenham to Cape Menshikof (Figure 1) and supports the largest sockeye salmon *Oncorhynchus nerka* fishery in the world. From 1985 to 1994 the commercial catch in Bristol Bay averaged 26.6 million sockeye salmon.

Naknek River flows approximately 35 miles to Kvichak Bay and drains seven major lakes (Naknek, Brooks, Coville, Grosvenor, Hammersly, Murray, and Idavain) which are included in the Katmai National Park and Preserve (KATM; Figure 2). The Naknek River drainage is a major producer of sockeye salmon with total runs averaging 5.0 million from 1983-1992. These fish are harvested by a commercial gill net fishery in Kvichak Bay, by sport and subsistence fishers in Naknek River, and by sport fishers within Katmai National Park and Preserve. In addition to sustaining major fisheries, Naknek River sockeye salmon play a major role in the food web of the Katmai Park ecosystem. Sockeye salmon carcasses are an important source of marine derived nutrients upon which the ecosystem is dependent. They also provide a direct food source to feeding brown bears. Brown bears catching sockeye salmon at Brooks River falls attract many visitors to the Park.

Sockeye salmon escaping the commercial and downriver sport and subsistence fisheries are available within the Park as food for wildlife, for sport fishing, and/or for spawning. Consequently, good management of the commercial fishery by the Alaska Department of Fish and Game (ADF&G) greatly benefits the Park ecosystem.

To effectively manage this fishery, managers need accurate abundance forecasts of returning sockeye salmon. Estimates of the number, age, and size composition of outmigrating smolt from specific spawning populations are used as an index of production for adult salmon; this improves the accuracy of preseason forecasts and aids in setting goals for optimum numbers of spawners.

ADF&G manages the commercial fishery for an escapement of 1.0 million (range 0.8 to 1.4 million) sockeye salmon into the Naknek River. The escapement goal is based on historical spawner-recruit data and limited smolt data and represents a best estimate of the number of spawners required to produce maximum-sustained-yield. In 1991, approximately 3.6 million sockeye salmon escaped the fishery and entered the lake system to spawn. This was the largest escapement on record and was 40% greater than the previous high of 2.6 million. It was very important to measure the freshwater production from an escapement of this size. The numbers of smolt surviving freshwater residency and the size and age structure of these smolt are critical information. Because the 1991 escapement was the greatest observed escapement for the Naknek River it will be a very influential data point when fitting production curves to estimate optimum escapements. In addition, estimates of smolt production from the 1991 escapement would increase the accuracy and precision of Naknek River forecasts for returning runs in 1995 through 1997.

Fyke nets were used to estimate smolt numbers on Naknek River from 1956 to 1978; (Rietze and Spangler 1958; Robertson 1967; Van Valin 1969a, 1969b; McCurdy and Paulus 1972a; McCurdy

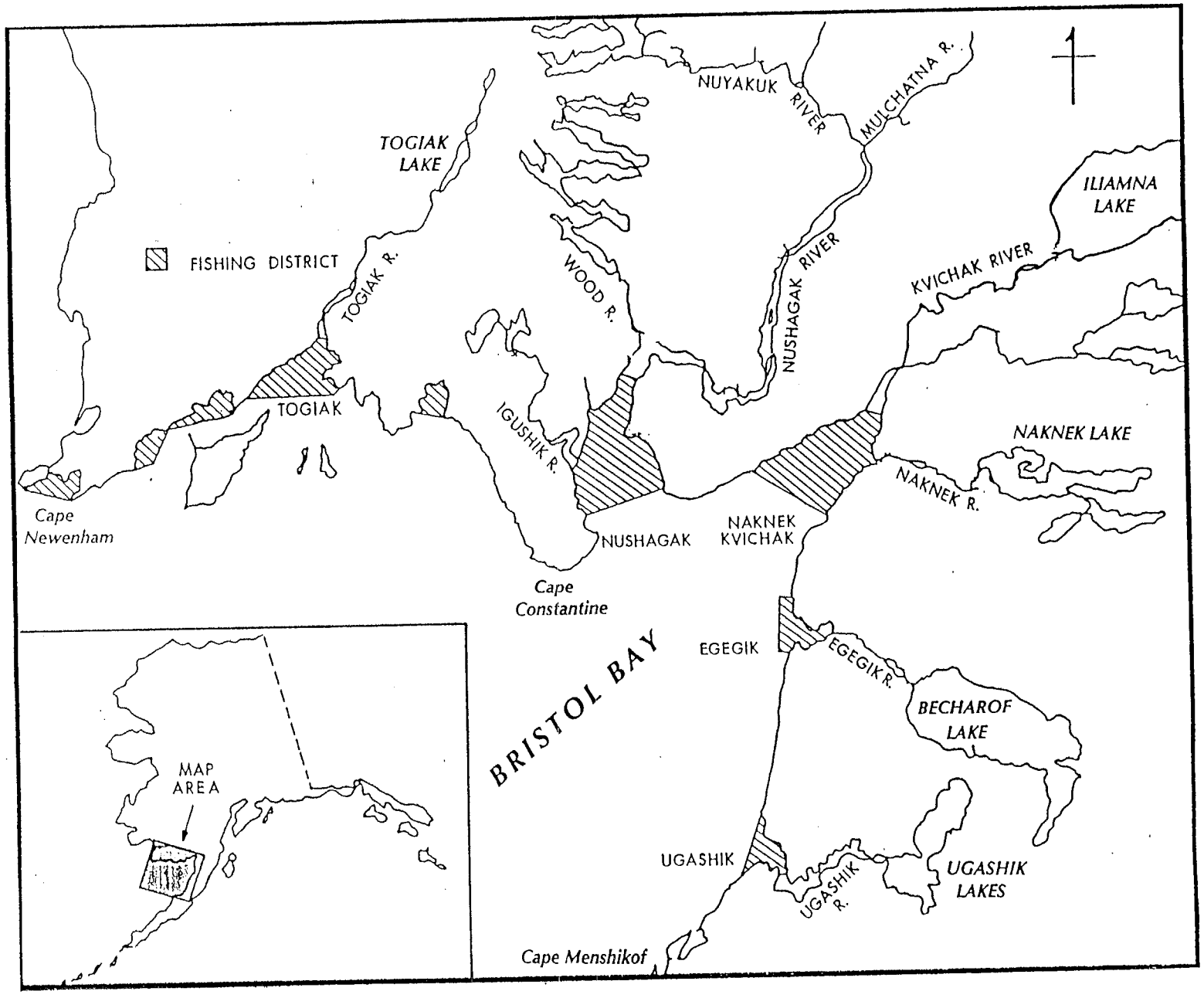

Figure 1. Bristol Bay Area commercial salmon fishing districts, major rivers, and lakes.

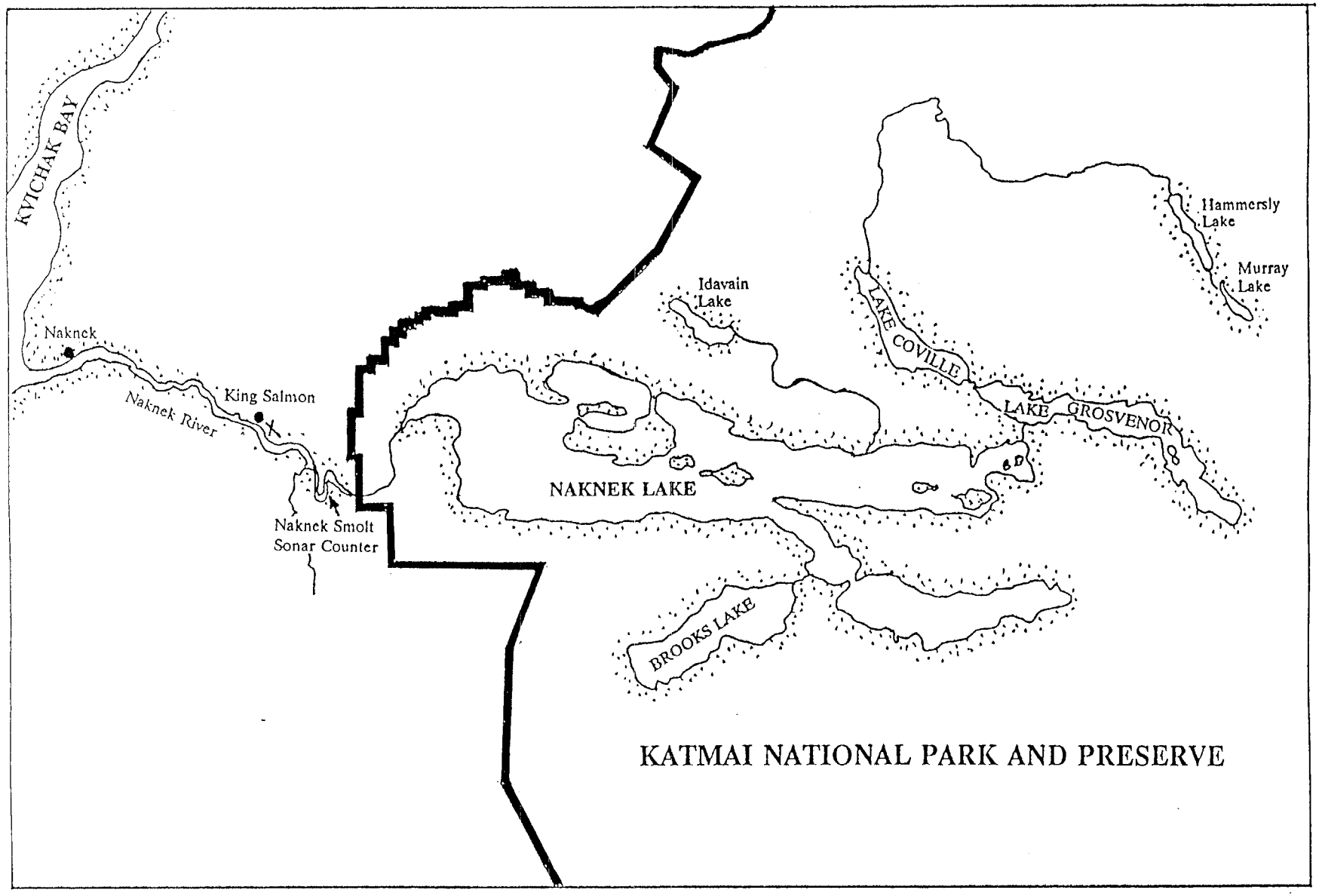

Figure 2. Map of the Naknek River drainage showing the location of the sockeye salmon smolt sonar counter.

1974a, 1974b; Bill 1975, 1976, 1977; Pella and Jaenicke 1978; Yuen 1978). Smolt studies on Naknek River were limited to occasional fyke net sampling to obtain age and size data from 1975 to 1982 (Huttunen 1980). Although fyke net sampling provided information on age, size, and relative abundance of smolt, it did not provide an accurate estimate of total smolt numbers. To improve estimates of smolt numbers, the department began experimenting with and using hydroacoustic equipment.

Smolt enumeration projects using modified hydroacoustic equipment developed by Bendix Corporation[2] began on Naknek River in 1982 (Huttunen 1984). ADF&G continued to use hydroacoustic equipment to estimate sockeye salmon smolt numbers on Naknek River from 1983 to 1986 (Eggers and Yuen 1984; Bue 1986a, 1986b; Bue and Fried 1987; Bue et al. 1988).

Side-scanning sonar was used in 1985 to determine the lateral distribution of smolt passing the sonar site. Bue (1986b) reported that most smolt pass the Naknek River sonar site within an 80-m corridor from the left bank[3].

Due to budget reductions, the monitoring of smolt migrations was discontinued on Naknek River in 1986 (Bue et al. 1988).

In 1993, approval of a cooperative agreement between the National Park Service and the Alaska Department of Fish and Game allowed for continued enumeration of sockeye salmon smolt with hydroacoustic equipment on Naknek River in 1993 and 1994. The primary impetus for resuming the Naknek River smolt study was to measure freshwater production from the record sockeye salmon escapement (3.6 million fish) that entered the Naknek River drainage to spawn during the 1991 commercial fishermen strike. Both agencies deemed it important to measure the number of smolt surviving freshwater residency and the size and age structure of smolt from an escapement of this size. Most sockeye salmon smolt from the 1991 brood year were expected to outmigrate from the Naknek River drainage as age-1. smolt in 1993 and as age-2. smolt in 1994.

Upward-looking sonar studies were conducted on Naknek River from May 19 through June 19 in 1993 and 1994. Specific objectives of these studies were:

(1) Estimate biomass of sockeye salmon smolt outmigrating with hydroacoustic equipment;

(2) Estimate age, weight, and length composition of outmigrating sockeye salmon smolt from samples collected with fyke nets;

(3) Convert smolt biomass into numbers of sockeye salmon smolt by age by combining estimates of biomass with age and size composition;

(4) Test the hypothesis that the average number of smolt-per-spawner is significantly less for the 1991 escapement compared to previously observed years;

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[2] Use of a company's name does not constitute endorsement.

[3] In this report the location of projects and the placement of equipment are referenced to the right and left bank of the respective river as determined by facing downstream at the study site.

(5) Test the hypothesis that the average size of sockeye salmon smolt produced by the 1991 escapement is smaller than previously recorded;

(6) Test the hypothesis that there is a significantly higher percentage of age 2. sockeye salmon smolt produced by the 1991 escapement compared to previous years; and

(7) Test the hypothesis that smolt from the 1993 and 1994 outmigrations had similar migration patterns throughout the day as those described in previous years.

METHODS

Hydroacoustic Equipment

Bendix Corporation constructed all hydroacoustic systems used to estimate smolt numbers at Naknek River; the 1982 to 1986 projects used a 1982 model smolt counter (Serial # 823001) and the 1993 to 1994 projects used a 1983 model smolt counter (Serial # 832003). Transducers used to transmit and receive sound pulses were housed in three 3.03-m long arrays set on the river bottom and connected by coaxial cable to a control unit located on shore. Each array had 10 upward-facing single-element International Transducer Corporation, Model 5095 transducers which were designed to operate at a frequency of 235 Khz and a half power beamwidth angle of 9°. Detected echoes from each transducer were accumulated in the smolt counter and a printer produced a hard copy of totaled counts by array at prescribed intervals which were summed and recorded on a field data collection form. Each smolt counting system was powered by a single 12-volt battery recharged by a pair of 43 watt, 2.9 amp solar panels.

The width of the river ensonified was approximately 10.97-m, which was the same amount ensonified at Naknek River during previous years. Consequently smolt biomass was only counted hydroacoustically for a portion of the river. Biomass between arrays was estimated by linear interpolation expansion of average counts over each array as describe in Crawford and Cross (1992).

Due to the large and complex nature of the Naknek Lake system, the peak smolt outmigration at Naknek River, is less pronounced and more prolonged then the Kvichak, Egegik, and Ugashik Rivers . Based on previous years counts, the hydroacoustic equipment was operated on Naknek River from May 19 through June 19 in 1993 and 1994 to monitor the peak period of outmigration. All arrays at the project site were removed from the water at the end of each field season.

The hydroacoustic system was factory calibrated to record one count whenever 41.5 g of biomass passed through each transducer beam during a given period. Because most smolt migrate within the upper portion of the water column, individual arrays were calibrated independently, which allowed the operator to set the counting range as near the surface as possible. The equipment was set to record counts to within 1-2 cm of the water surface to avoid counting debris or entrapped air. The signal pulse rate of the smolt counter was set to correspond with the river velocity which was measured once every 15-30 min by Gurley flow meter depending on the tide stage.

Hydroacoustic equipment were monitored 24 h per day and sources of false counts, e.g., boats, wind, rain, debris, were noted and the hydroacoustic equipment was disabled whenever false-count conditions were detected. Known false counts were subtracted from hourly totals, and linear interpolations were used to estimate counts missed while equipment was disabled. The control unit automatically recorded and stored the length of time the system was disabled. Manual control was available for adjusting printing intervals for accumulated counts, transducer pulse rate, and the portion of the water column monitored. Transducer signal characteristics were visually monitored with an oscilloscope. The Naknek River smolt counter monitored three transducer arrays.

Project Locations

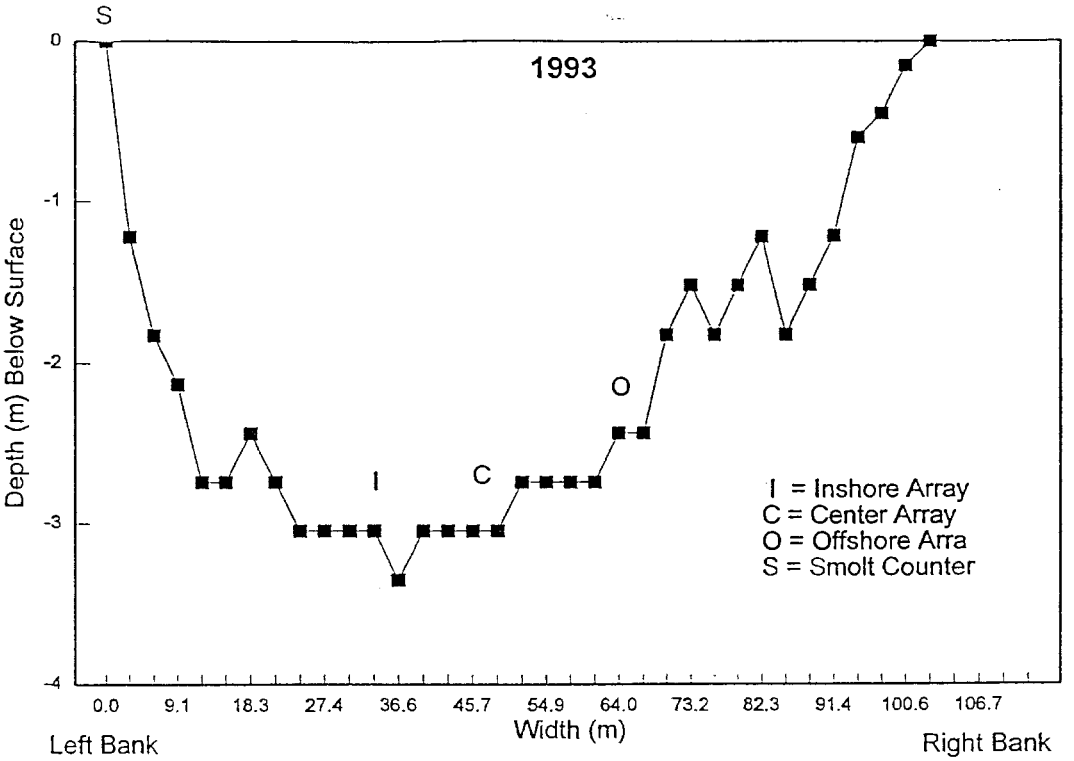
The 1993 and 1994 Naknek River smolt counting site was located 13 km below the outlet of Naknek Lake (Figure 2), this is the same location that it was operated during 1982 to 1986. The 1993 inshore, center, and offshore arrays were anchored 32 m, 47 m, and 64 m from the left bank (Figure 3). Naknek River was 102 m wide at this site in 1993. The 1994 inshore, center, and offshore arrays were anchored 31 m, 47 m, and 63 m from the left bank (Figure 3). Naknek River was 107 m wide at this site in 1994.

Impacts on Park Resources

There were minimal impacts on Park resources from the Naknek River smolt studies. Sonar operations had no affect on smolt outmigration. Some smolt captured with fyke nets were affected. Smolt sampled for age, weight, and length were anesthetized and revived before they were returned to the river. Smolt sampled for length only were not anesthetized, but were taken out of the water for as short of a time as possible and then released in the river. Some small number of smolt were killed during the sampling process, but the numbers were insignificant in terms of the numbers of smolt in the total outmigration. The smolt counting had no impact on sport or visiting activities within the Park.

Estimation of Smolt Numbers

The process of estimating smolt numbers was divided into three steps: (1) determining total fish biomass emigrating past the study site; (2) sampling the emigrating fish population to estimate species, age, weight, and length composition; and (3) converting fish biomass into numbers of smolt by age and species.



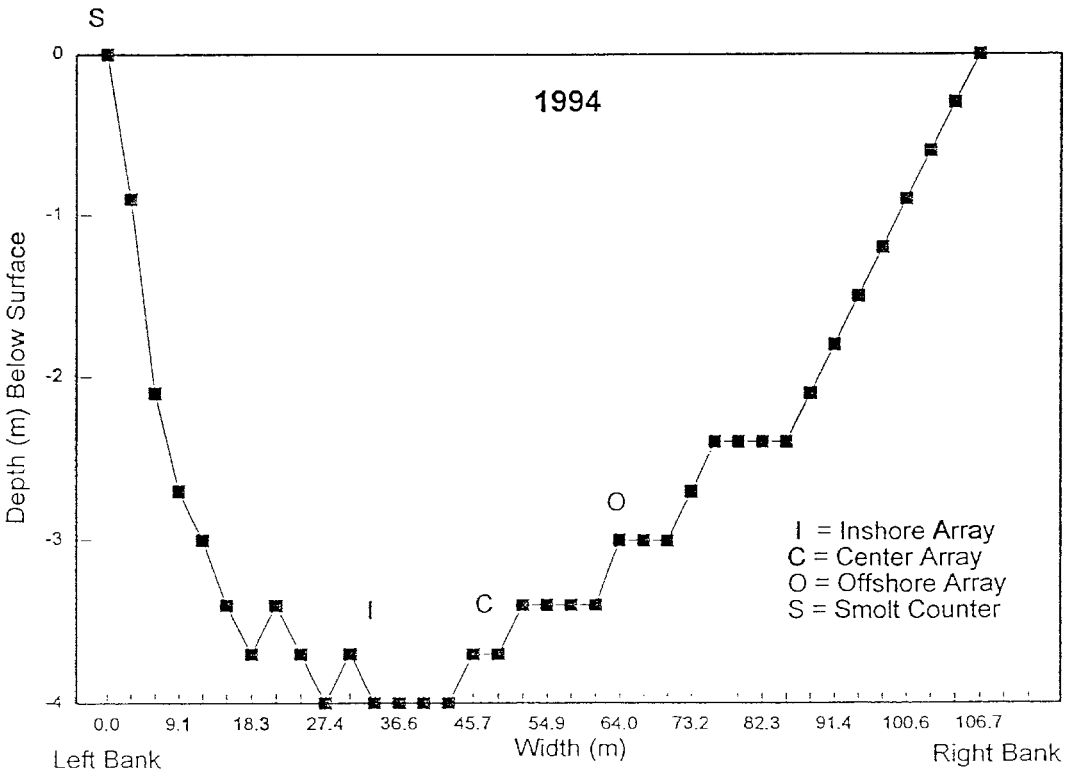


Figure 3. River bottom profile and array placement at Naknek River smolt sonar site, 1993 and 1994.

Biomass Estimation

Fish biomass was estimated using continually monitored hydroacoustic equipment. The signal pulse rate of the smolt counter was set to correspond with the river velocity measured at a location referred to as the *velocity index*. At Naknek River, a buoyed flow meter anchored downriver of the inshore array was used as the velocity index.

Estimation of River Velocities and Adjustments to Sonar Counts. River velocities at the Naknek River sonar site were influenced by tides, therefore river velocities were measured continuously by a Gurley, Model 622 or Model 625 flow meter[4], anchored directly behind the velocity index array, and transducer pulse rates were adjusted every 15-30 min to account for changes in river velocity. To account for differences in river velocities between the velocity index and the arrays (i), readings over each array were taken at specified intervals and velocity correction factors (vcf_i)were then calculated:

$$vcf_i = \frac{v_i}{v_{index}} , \qquad 1$$

where

v_i = velocity over array i, and
v_{index} = velocity over the velocity index array.

Using these correction factors, adjustments to daily counts ($ac_{i,z}$) were made for differences in river velocity:

$$ac_{i,z} = c_{i,z}\ (vcf_i) , \qquad 2$$

where $c_{i,z}$ = counts for array i on day z.

Ideally, all sonar arrays monitored fish biomass 24 h/d, so daily counts for each array represented actual sonar counts. If an array was not monitored during an hour, counts were linearly interpolated using estimated counts from the previous and following hours.

Expansion of Biomass Estimates. The width of the section of river ($l_{i,z}$) monitored by array i on day z depended on array length (3.03 m), water depth over the array, and transducer signal beam width:

[4] During mid-to-late May, the Pygmy Gurley, Model 625 current meter was used whenever the river velocities were less than or equal to 3 ft/sec. As the sampling season progressed the river velocity generally increased and when the water velocities exceeded 3 ft/sec the Gurley, Model 622 was used for measurements.

$$l_{i,z} = 3.03 + 2\left(d_{i,z} \tan\frac{bw}{2}\right) , \qquad 3$$

where

$d_{i,z}$ = water depth over array i on day z, and

bw = transducer beam width in degrees (9° for all transducers).

Arrays were placed perpendicular to the river current; distances from each array to a reference point on one river bank were measured to the nearest foot. Estimates of the inshore and offshore limits of smolt passage were made based on past studies with side-scanning hydroacoustic equipment (Bue 1986b). Distances were calculated between inshore limit of smolt passage to first array (D_1); first to second array (D_2); second to third array (D_3); and offshore array to offshore limit of smolt passage (D_4).

The biomass of fish ($\hat{B}_z$) passing the counting site on day z was estimated as follows:

$$\hat{B}_z = \frac{1}{2}D_1\left(\frac{ac_{1,z}}{l_{1,z}}\right) + \sum_{i=2}^{na}\left[\frac{1}{2}D_i\left(\frac{ac_{i-1,z}}{l_{i-1,z}} + \frac{ac_{i,z}}{l_{i,z}}\right) + \frac{1}{2}D_{na+1}\left(\frac{ac_{na,z}}{l_{na,z}}\right)\right] , \qquad 4$$

where

D_i = the distance for interval i, and

na = number of transducer arrays used.

Age, Weight, and Length Estimation

Data on age, weight, and length of sockeye smolt were obtained from samples captured in a fyke net. Smolt weight in grams and length, from tip-of-snout to fork-of-tail, in millimeters were measured; age was determined from visual observations of scales mounted on glass slides. European ages -- 1., 2., or 3. depending on the number of freshwater annuli -- were used. Parent year escapements that produced 1993 smolt occurred in 1991 for age-1. smolt, 1990 for age-2. smolt, and 1989 for age-3. smolt. Parent year escapements that produced 1994 smolt occurred in 1992 for age-1. smolt, 1991 for age-2. smolt, and 1990 for age-3. smolt.

Sample size goals for Naknek River were 400 smolt/d. Based on binomial proportions for the two major age groups, a sample size of 400 smolt would simultaneously estimate the percentage of each age class within 5% of the true percentage 95% of the time (Goodman 1965; Cochran 1977). When the daily goal of 400 smolt was not obtained, samples from subsequent days were combined until a total of at least 400 was reached.

Mean length of smolt differs among fyke net samples from a single day (Minard and Brandt 1986). Thus, to ensure that daily age composition estimates were representative of the population, attempts were made daily to obtain 100 smolt from each of six different fyke net catches. Because weight and age of smolt are strongly correlated to length, the time and cost of data collection was reduced

by measuring all smolt collected each day: up to a maximum of 600 for length and weighing and sampling up to 100 of those smolt for age (Bue and Eggers 1989).

Weight was estimated for smolt measured only for length using a least squares linear regression. Based on paired weight-length data obtained from smolt sampled for age, weight, and length, we estimated weights (W_j) of age j smolt measured only for length as explained by (Ricker 1975):

$$W_j = \alpha L_j^{\beta} \quad , \qquad 5$$

where

L_j = fork length of an age j smolt, and

α and β = parameters which determine the y-axis intercept and the slope of the line.

Age was estimated for smolt measured only for length using an age-length key (Bue and Eggers 1989). The key used length to categorize age-1. or -2. sockeye salmon smolt by determining a discriminant length that minimized classification error. This discriminant length was chosen such that the number of age-1. smolt classified as age-2. smolt was equal to the number of age-2. smolt classified as age-1. smolt. Age-3 smolt were not included in this analysis because no samples were collected.

Due to the variability of age and size composition estimates among subsamples (e.g., fyke net catches) taken the same day, daily mean weight ($\hat{W}$) and age proportions ($\hat{P}_j$) were estimated as the mean of subsampled values:

$$\hat{W} = \frac{\sum_{k=1}^{m}\left(\frac{\sum w_k}{n_k}\right)}{m} \quad , \qquad 6$$

where

m = number of subsamples collected during a sampling period,

w_k = observed weights from subsample k, and

n_k = number of observations in subsample k; and

$$\hat{P}_j = \frac{\sum_{k=1}^{m}\left(\frac{n_{j,k}}{n_k}\right)}{m} \quad , \qquad 7$$

where $n_{j,k}$ = number of observations of age j in subsample k.

Estimation of Smolt Numbers

Numbers of smolt by age $(S\hat{P}C)$ were estimated by combining biomass estimates with estimates of age and weight composition. Mean weight of smolt was used to convert estimates of biomass per count into estimates of smolt per count:

$$S\hat{P}C = \frac{BPC}{\hat{W}} \quad , \qquad 8$$

where BPC = biomass (g) per count.

The estimated number of smolt passing the counting site $(\hat{N}_z)$ each day (z) was computed:

$$\hat{N}_z = \hat{B}_z \ (S\hat{P}C) \quad . \qquad 9$$

The estimated number $(\hat{N}_{j,z})$ of age j smolt on day z were then apportioned:

$$\hat{N}_{j,z} = \hat{N}_z(\hat{P}_j) \quad . \qquad 10$$

Finally, daily estimates of smolt numbers were summed: the seasonal total of all smolt passing the sonar site $(\hat{N}_{tot})$ was

$$\hat{N}_{tot} = \sum \hat{N}_z \qquad 11$$

and the estimated number of age j smolt that passed the site during the season $(\hat{N}_{jtot})$ was

$$\hat{N}_{jtot} = \sum \hat{N}_{j,z} \quad . \qquad 12$$

Changes in Survival, Size, and Age Composition

Freshwater survival rates, size, and age compositions of smolt from the 1991 escapement were compared to those from earlier years. Size and age composition data from Naknek River smolt were available for approximately 26 years. A one-sided t-test was used to determine if the mean lengths and weights of smolt produced by the 1991 escapement were less than those historically observed.

Freshwater survival rates for Naknek River smolt were only available for brood years 1980-1983 and 1991. A one-sided t-test was used to determine whether the 1991 smolt-per-spawner value was less than the historically observed.

Climatological Data Collection

Climatological data were recorded at each counting site. Observations of sky conditions and measurements of wind direction, wind velocity (kilometers/hour), daily precipitation (millimeters), air and water temperatures (^{o} Centigrade) were recorded at 0800 and 2000 hours daily.

RESULTS

1993

A total of 3,104,378 sonar counts were recorded at the Naknek River counting site from May 19 to June 19, 1993 (Table 1). More counts were recorded over the center array (54.9%) than over the offshore (23.5%) or inshore (21.6%) arrays (Figure 4). Daily sonar counts were highest from May 22-30 and June 2-9 when 49.4% and 37.9% of the total counts were recorded (Figures 5, 6). The peak daily sonar count of 329,509 occurred on June 7. Similar high counts also occurred on May 26 (324,901) and May 29 (314,288). The increase in daily sonar counts from June 15-19 indicate that some unknown number smolt continued to emigrate from the Naknek River after June 19. Over the course of the sampling season, over half of the total sonar counts were recorded from 2200 hours to 0600 hours (Figure 7); while the remainder of the counts were spread fairly evenly over the remaining hours.

Locals residents reported that Naknek Lake was 70% ice free by April 7 and completely ice free by April 27 (R. Russell, ADF&G, King Salmon, personal communication). No sockeye salmon smolt or signs of birds successfully feeding on smolt were reported prior to the startup of this project. The Naknek River smolt sonar began counting at 1200 hours on May 19 and the first reported smolt counts occurred at 2320 hours that evening. Smolt counts obtained during the first three days of operation indicated low smolt abundance. A fyke net was first fished from 2320 hours to 2400 hours on May 20 and caught only 30 sockeye salmon smolt. Smolt passages began to build on May 22.

All center and offshore array sonar counts from May 19 to May 24 were multiplied by 1.11 to account for bad transducers (center #7, offshore #3). All weak transducers (inshore #7 and #9) and bad transducers (center #7, offshore #3) were replaced on May 25. Transducer tests following the repairs revealed inshore replacement transducer #9 was bad and offshore replacement #6 was weak. Therefore all inshore array counts from May 25 to June 19 were multiplied by 1.11 to account for the bad transducer.

Table 1. Sonar counts recorded from three arrays at the sockeye salmon smolt counting site on Naknek River, 1993.

Smolt Day [a]	Sonar Count by Transducer Array			
	Inshore	Center	Offshore	Total
5/19 [b]	1,134	5,516	3,435	10,085
5/20	1,665	7,809	13,558	23,032
5/21	2,165	10,059	16,426	28,650
5/22	2,012	43,035	45,729	90,776
5/23 [c]	8,917	73,421	44,860	127,198
5/24 [c]	30,064	122,038	33,422	185,524
5/25 [c d]	57,881	110,851	26,969	195,701
5/26	132,886	170,287	21,728	324,901
5/27	28,527	74,506	13,293	116,326
5/28	20,719	52,714	8,503	81,936
5/29 [c]	96,476	157,934	59,878	314,288
5/30	10,915	38,809	48,486	98,210
5/31 [c]	2,307	6,683	6,573	15,563
6/01	13,616	6,924	2,193	22,733
6/02	22,958	48,834	20,580	92,372
6/03	6,361	26,033	8,848	41,242
6/04	31,077	97,557	33,775	162,409
6/05	13,514	83,631	10,830	107,975
6/06	30,291	137,447	77,595	245,333
6/07	27,078	188,092	114,339	329,509
6/08	11,795	46,295	19,346	77,436
6/09	45,558	48,066	26,260	119,884
6/10	7,304	9,461	3,674	20,439
6/11	6,052	10,978	5,207	22,237
6/12	12,923	5,950	4,515	23,388
6/13	2,765	2,808	2,254	7,827
6/14	4,083	6,296	2,581	12,960
6/15	6,018	6,671	3,376	16,065
6/16	6,613	12,048	17,565	36,226
6/17	2,490	5,266	2,290	10,046
6/18	13,771	33,185	14,167	61,123
6/19	9,818	54,515	18,651	82,984
Total	669,753	1,703,719	730,906	3,104,378
Percent	21.6	54.9	23.5	

[a] Sample day began at 1200 hours and ended at 1159 hours the next calendar day.

[b] All center array and offshore array counts from May 19-24 were multiplied by 1.11 to account for bad transducers (e.g., center #7, offshore #3).

[c] Interpolated data for all arrays:
1500-1800 hours on May 23 due to high winds
1200-1500 hours on May 24 due to printer repairs
1200-1100 hours on May 25-26 to replace transducers
1700-1800 hours on May 29 to repair flow meter
1600-1800 hours on May 31 to reinstall flow meter

[d] All weak transducers (inshore #7 and #9, offshore #6) and bad transducers (center #7, offshore #3) were replaced on May 25. Transducer tests following the repairs revealed inshore replacement transducers #9 was bad and offshore replacement transducer #6 was weak. Therefore all inshore array counts from May 25 to June 19 were multiplied by 1.11 to account for the bad transducer.

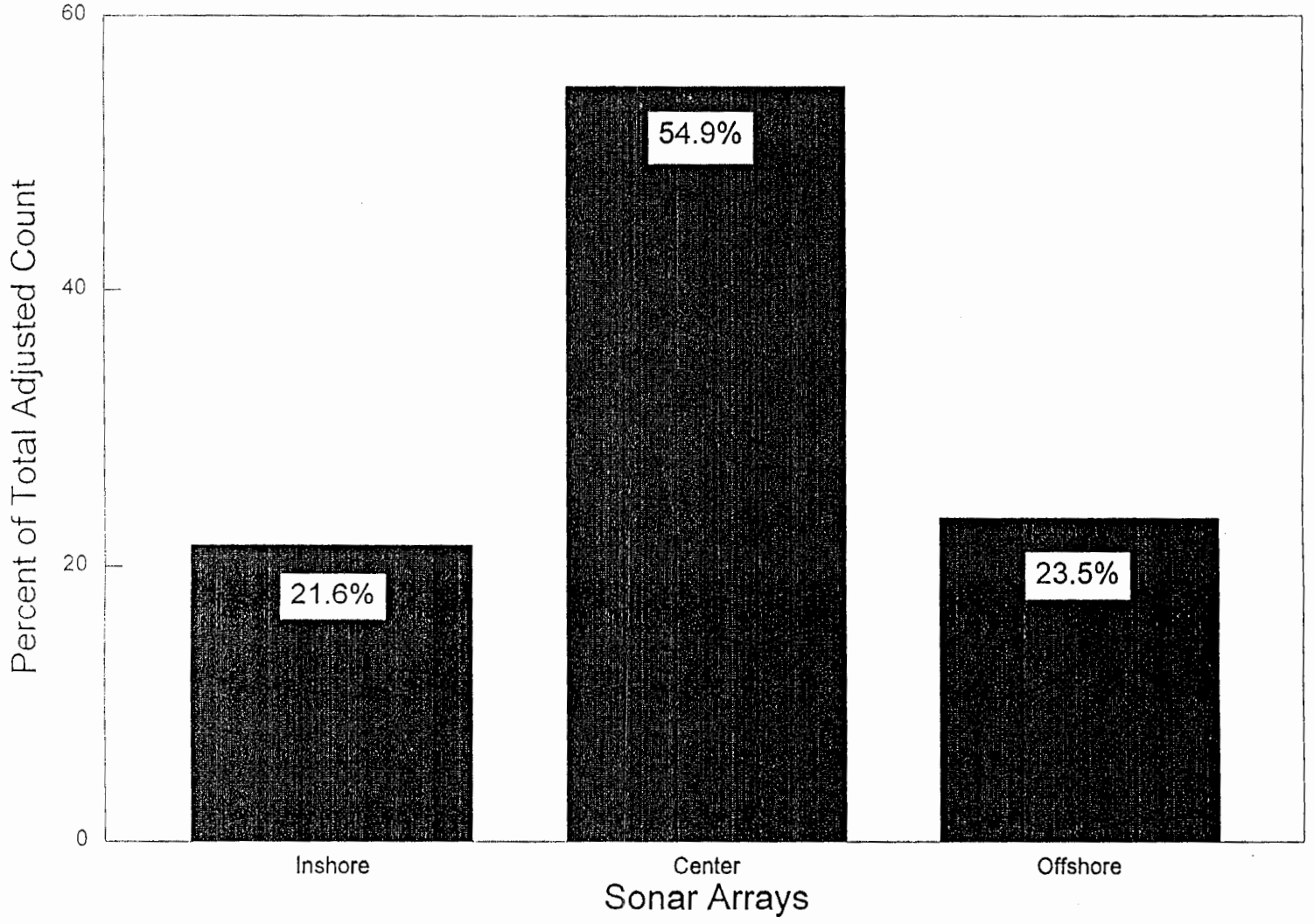


Figure 4. Lateral distribution of Naknek River smolt sonar counts, 1993.

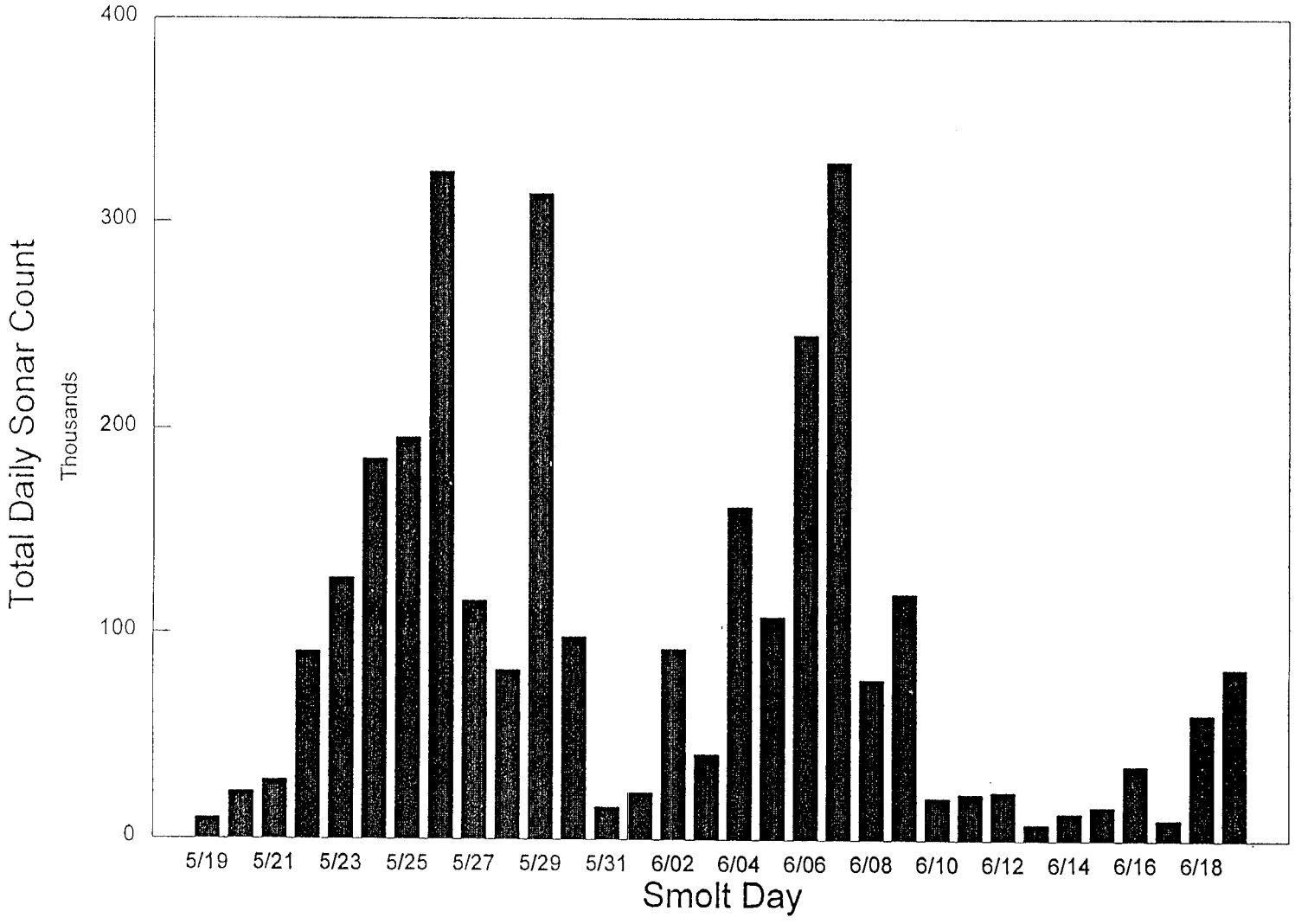


Figure 5. Total daily sonar counts at Naknek River smolt project, May 19 to June 19, 1993.

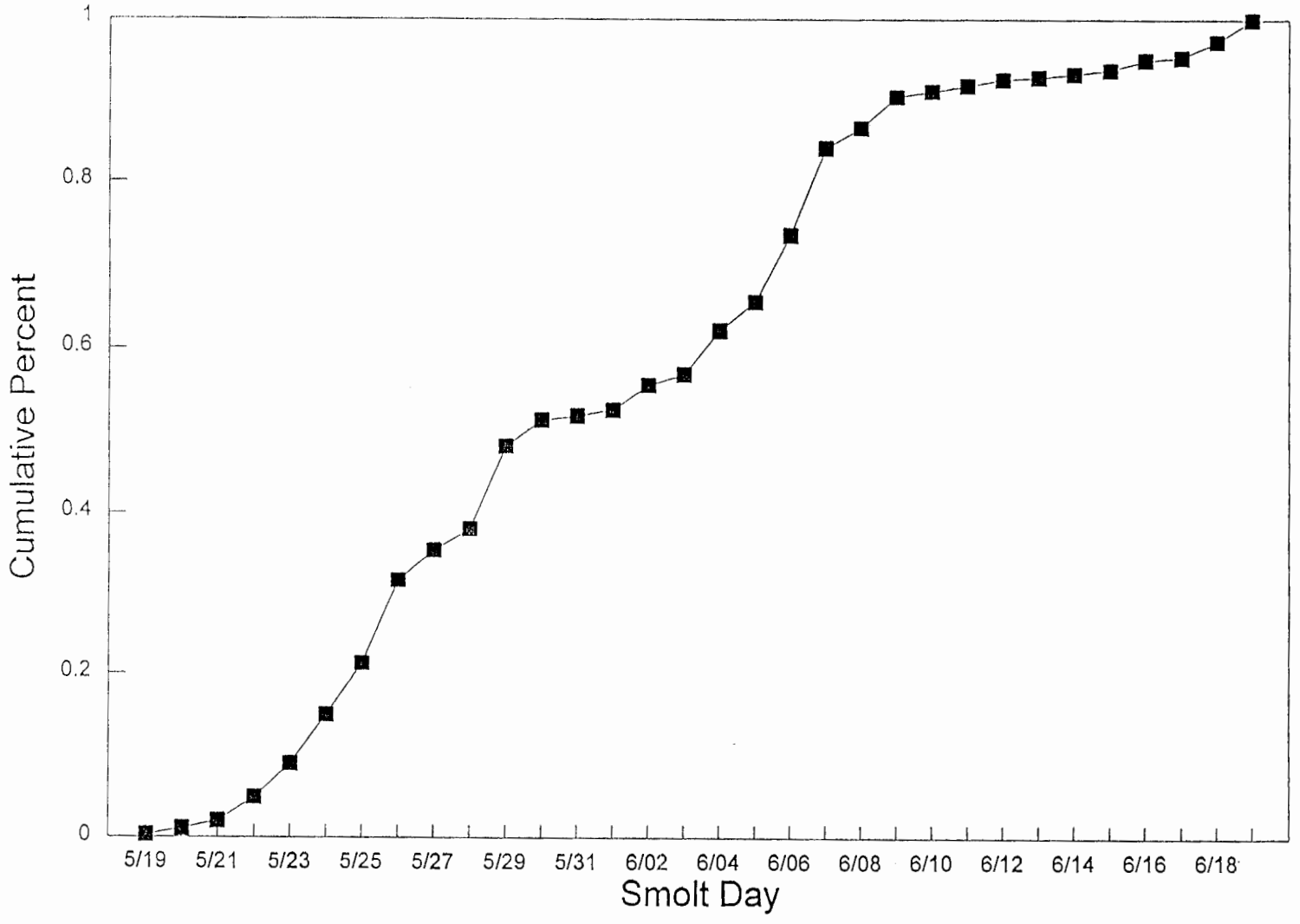


Figure 6. Naknek River smolt sonar count, cumulative percent by date, May 19 to June 19, 1993.

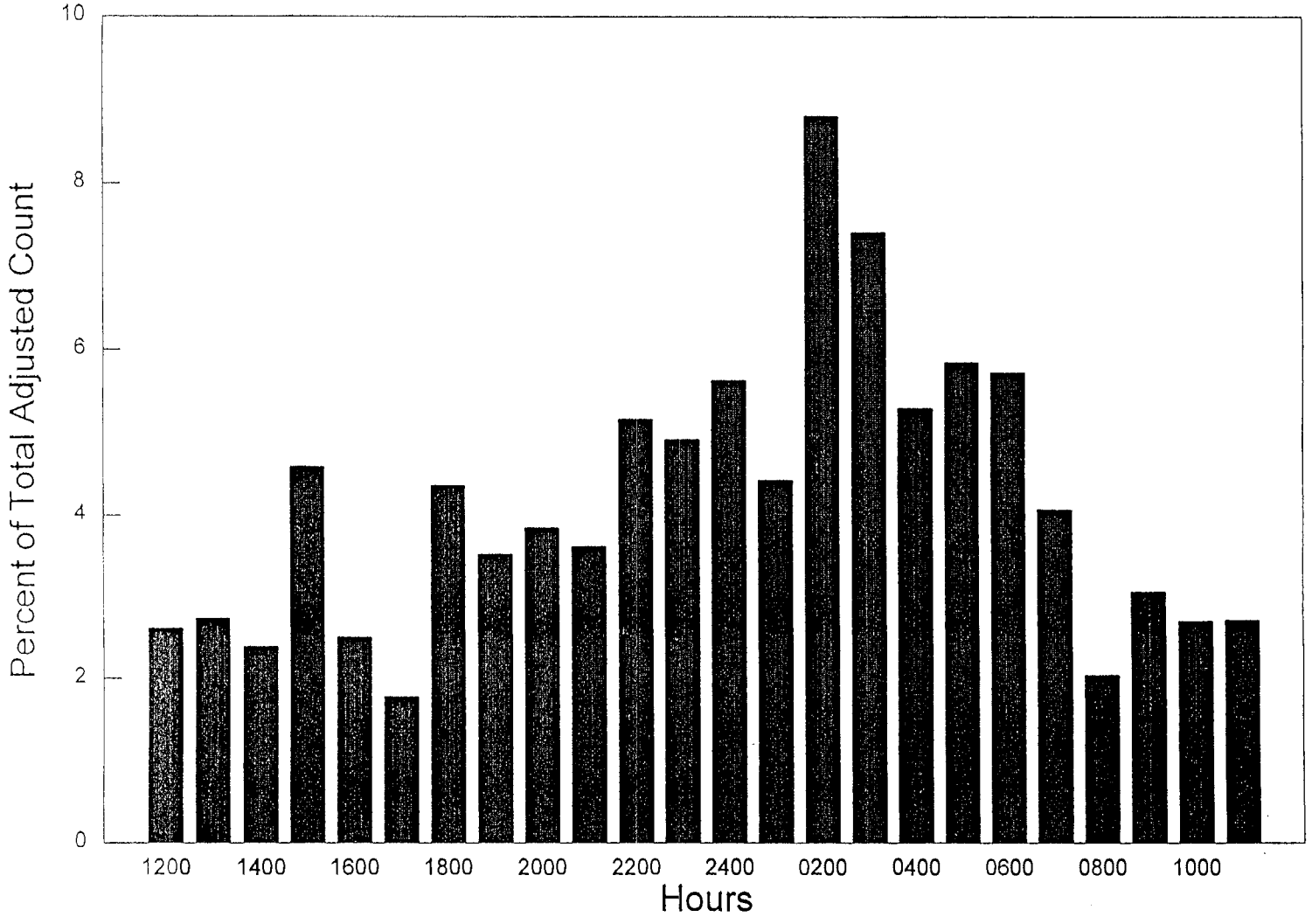


Figure 7. Percent of the total adjusted sonar count summarized by hour, Naknek River smolt project, May 19 to June 19, 1993.

All arrays were interpolated for the following periods: 1500 hours to 1800 hours on May 23 due to high winds, 1200 hours to 1500 hours on May 24 to repair printer, 1200 hours to 1100 hours on May 25-26 to replace transducers, 1700 hours to 1800 hours on May 29 to repair flow meter, and 1600-1800 hours on May 31 to reinstall flow meter displaced by floating debris.

River velocity at the counting site ranged from 0.5 m/s to 1.1 m/s over the sonar arrays. From 1982 to 1986, the inshore array was used as the index array at this site. In 1993, continuous velocity measurements were taken from a flow meter that was attached to a buoy anchored 7 m to 9 m downriver of the inshore array. Because of increased boat and aircraft traffic from a popular rainbow trout sport fishery that has developed in this reach of Naknek River it was necessary to position the continuous velocity meter out of the main flow of traffic. On May 29 we discovered that the velocity at the flow meter buoy was slower than the velocity at the inshore array and therefore the flow meter buoy was adopted as the index and the smolt counter was calibrated according to the water velocity at the index buoy for the remainder of the 1993 field season. Velocity correction factors used for the three arrays were as follows:

Smolt Days	Index Buoy	Inshore	Center	Offshore
May 19 -May 28	-	1.00	1.05	0.61
May 29 - Jun 07	1.00	1.06	1.09	0.75
Jun 08 - Jun 16	1.00	1.12	1.15	0.79
Jun 17 - Jun 19	1.00	0.99	1.05	0.64

An estimated 53,021,762 sockeye salmon smolt migrated from the Naknek River in 1993 (Table 2). Because the velocity correction factor that was used to calibrate the smolt counter from May 19 to May 28 was low by 6%, this smolt estimate may be low by as much as 2% (1 million smolt). We believe that this smolt estimate constitutes the bulk of the 1993 Naknek River smolt outmigration, however the increasing daily sonar counts from June 15-19 (Figures 5, 6) indicate that some unknown portion of the tail end of this outmigration was not counted. Age-2. smolt (1990 brood year) composed 54.4% of the total migration. Although the daily percentage of age-1. and -2. smolt fluctuated during the 1993 migration, the percentage of age-1. smolt increased and the percentage of age-2. smolt decreased over time (NSC = nonstatistical comparison). Mean weight of smolt generally decreased during the season (NSC), which resulted in an increase in the estimated number of smolt per count (Table 3).

Age, weight, and length data were collected from 2,247 sockeye salmon smolt in 1993 (Table 4). All smolt sampled were age 1. or 2. Mean weights by age were 8.8 g for age-1. and 12.4 g for age-2. smolt. Mean lengths by age were 95 mm for age-1. and 109 mm for age-2. smolt. An additional 11, 892 smolt were measured for length only (Table 5).

River and weather conditions were recorded at the counting site from May 17 to June 20 (Table 6). There were no ice problems during the 1993 sampling season and the weather was generally good for smolt counting. The smolt counter was disabled for 4 h on May 23 because of northeast winds gusting in excess of 56 km/h. Mean water temperature during the project was 12.1° C (range 9.0° C to 16.0° C). Mean daily water temperature during the peak of the smolt migration was 12.0° C on June 7.

Table 2. Daily number of sockeye salmon smolt emigrating seaward estimated with hydroacoustic equipment, Naknek River, 1993.

Smolt Day [a]	Age 1. Number	Age 1. Percent	Age 1. Cumulative Total	Age 2. Number	Age 2. Percent	Age 2. Cumulative Total	All Ages Daily Total	All Ages Cumulative Total
5/19	4,816	3.9	4,816	117,420	96.1	117,420	122,236	122,236
5/20	10,500	3.9	15,316	255,999	96.1	373,419	266,499	388,735
5/21	13,081	3.9	28,397	318,941	96.1	692,360	332,022	720,757
5/22	40,667	3.9	69,064	991,511	96.1	1,683,871	1,032,178	1,752,935
5/23	58,794	3.9	127,858	1,433,457	96.1	3,117,328	1,492,251	3,245,186
5/24	112,854	4.8	240,712	2,248,126	95.2	5,365,454	2,360,980	5,606,166
5/25	305,376	10.5	546,088	2,602,972	89.5	7,968,426	2,908,348	8,514,514
5/26	525,746	10.5	1,071,834	4,481,367	89.5	12,449,793	5,007,113	13,521,627
5/27	99,730	6.0	1,171,564	1,562,449	94.0	14,012,242	1,662,179	15,183,806
5/28	198,302	16.0	1,369,866	1,038,769	84.0	15,051,011	1,237,071	16,420,877
5/29	1,140,066	21.4	2,509,932	4,182,371	78.6	19,233,382	5,322,437	21,743,314
5/30	1,342,282	70.7	3,852,214	556,278	29.3	19,789,660	1,898,560	23,641,874
5/31	115,855	44.0	3,968,069	147,333	56.0	19,936,993	263,188	23,905,062
6/01	193,714	44.0	4,161,783	246,346	56.0	20,183,339	440,060	24,345,122
6/02	968,380	56.8	5,130,163	737,716	43.2	20,921,055	1,706,096	26,051,218
6/03	417,501	56.8	5,547,664	318,054	43.2	21,239,109	735,555	26,786,773
6/04	1,082,596	40.2	6,630,260	1,611,098	59.8	22,850,207	2,693,694	29,480,467
6/05	1,432,659	70.4	8,062,919	602,657	29.6	23,452,864	2,035,316	31,515,783
6/06	3,239,351	69.6	11,302,270	1,414,220	30.4	24,867,084	4,653,571	36,169,354
6/07	4,821,583	75.7	16,123,853	1,546,906	24.3	26,413,990	6,368,489	42,537,843
6/08	1,436,632	82.5	17,560,485	304,529	17.5	26,718,519	1,741,161	44,279,004
6/09	2,133,019	77.6	19,693,504	614,654	22.4	27,333,173	2,747,673	47,026,677
6/10	318,223	71.2	20,011,727	128,657	28.8	27,461,830	446,880	47,473,557
6/11	337,837	71.2	20,349,564	136,586	28.8	27,598,416	474,423	47,947,980
6/12	407,989	73.5	20,757,553	147,400	26.5	27,745,816	555,389	48,503,369
6/13	152,595	82.0	20,910,148	33,587	18.0	27,779,403	186,182	48,689,551
6/14	249,668	82.0	21,159,816	54,953	18.0	27,834,356	304,621	48,994,172
6/15	316,379	81.8	21,476,195	70,297	18.2	27,904,653	386,676	49,380,848
6/16	671,939	81.8	22,148,134	149,301	18.2	28,053,954	821,240	50,202,088
6/17	135,439	72.2	22,283,573	52,227	27.8	28,106,181	187,666	50,389,754
6/18	820,193	72.2	23,103,766	316,280	27.8	28,422,461	1,136,473	51,526,227
6/19	1,079,328	72.2	24,183,094	416,207	27.8	28,838,668	1,495,535	53,021,762
	24,183,094	45.6		28 ,838, 668	54.4		53,021,762	

[a] Sample day began at 1200 hours and ended at 1159 hours the next calendar day.

Table 3. Adjustment factors used to expand sonar counts into estimated numbers of sockeye salmon smolt, Naknek River, 1993.

Smolt Day [a]	Mean Weight of Smolt (g)	Smolt per Count
5/19	15.2	2.7
5/20	15.2	2.7
5/21	15.2	2.7
5/22	15.2	2.7
5/23	15.2	2.7
5/24	14.9	2.8
5/25	13.3	3.1
5/26	13.3	3.1
5/27	13.5	3.1
5/28	12.8	3.2
5/29	12.3	3.4
5/30	10.1	4.1
5/31	11.6	3.6
6/01	11.6	3.6
6/02	10.9	3.8
6/03	10.9	3.8
6/04	11.8	3.5
6/05	10.1	4.1
6/06	10.1	4.1
6/07	9.7	4.3
6/08	9.0	4.6
6/09	9.5	4.4
6/10	9.9	4.2
6/11	9.9	4.2
6/12	9.7	4.3
6/13	9.1	4.5
6/14	9.1	4.5
6/15	9.1	4.6
6/16	9.1	4.6
6/17	10.0	4.2
6/18	10.0	4.2
6/19	10.0	4.2

[a] Sample day began at 1200 hours and ended at 1159 hours the next calendar day.

Table 4. Mean fork length and weight of sockeye salmon smolt captured in fyke nets, Naknek River, 1993.

	Age 1.					Age 2.				
Smolt Day [a]	Mean Length (mm)	Std. Error	Mean Weight (g)	Std. Error	Sample Size	Mean Length (mm)	Std. Error	Mean Weight (g)	Std. Error	Sample Size
5/20	109		15.9		1	117	16.5	16.1	5.77	28
5/22	102	10.7	8.7	1.01	2	117	15.9	15.4	6.44	25
5/23	104	5.6	11.5	1.92	5	117	26.2	15.9	10.59	145
5/24	103	15.4	11.0	4.15	15	115	18.7	15.0	7.30	85
5/26	99	15.1	9.0	3.40	17	109	23.5	12.2	7.53	122
5/27	105	13.5	11.2	3.12	10	108	18.8	12.4	6.54	89
5/28	97	9.5	9.8	2.66	17	107	17.7	12.2	5.93	82
5/29	100	12.5	10.3	4.37	21	106	18.1	11.3	5.19	77
5/30	95	11.3	8.2	3.57	86	104	14.5	10.2	4.59	14
5/31	93	12.6	8.1	3.32	48	103	1.8	10.6	.06	2
6/01	100	14.5	10.0	4.41	31	107	10.9	12.2	4.71	19
6/02					0					0
6/03	95	16.4	8.9	4.55	62	105	18.4	11.6	5.82	35
6/04	98	17.1	9.9	4.33	58	105	18.3	12.0	5.78	42
6/05	92	14.0	8.0	3.37	86	107	17.7	12.2	6.75	13
6/06	92	11.0	7.6	3.05	84	104	13.9	10.2	3.45	16
6/07	91	11.6	8.0	3.16	94	104	8.9	11.5	2.53	6
6/08	90	16.3	8.0	5.16	98	100	5.4	10.4	1.37	2
6/09	91	15.6	8.0	3.92	93	108	10.7	13.3	2.08	6
6/10	91	15.5	6.6	3.27	23	114	9.7	12.3	3.46	7
6/11	93	16.0	7.3	3.90	59	114	9.6	13.3	3.76	11
6/12	86	18.4	6.7	3.67	72	108	10.0	11.0	2.81	8
6/13	89	17.2	7.2	4.47	73	112	11.1	12.8	2.86	7
6/14	91	21.9	7.2	5.21	99	111	3.0	11.6	1.78	2
6/15	87	15.1	7.4	4.10	49	108		12.4		1
6/16	92	19.6	8.2	4.49	97	112	8.1	13.1	1.95	3
6/17	89	23.3	7.6	5.28	46	112	3.3	12.6	2.30	4
6/18	94	18.6	8.7	4.22	50					0
Total					1,396					851
Mean	95		8.8			109		12.4		

[a] Sample day began at 1200 hours and ended at 1159 hours the next calendar day.

Table 5. Mean fork length and estimated mean weight for age-1. and -2. sockeye salmon smolt, Naknek River, 1993.

	Estimated Age 1. [a]				Estimated Age 2. [a]			
Smolt Day [b]	Mean Length (mm)	Std. Error	Estimated Weight (g)	Sample Size	Mean Length (mm)	Std. Error	Estimated Weight (g)	Sample Size
5/21	94	7.5	8.3	3	115	16.8	14.4	64
5/23	97	6.8	8.9	20	117	31.9	15.2	614
5/24	97	8.4	8.9	18	116	28.2	14.9	544
5/26	97	10.4	8.9	66	112	26.2	13.5	515
5/27	98	7.5	9.2	29	112	25.3	13.4	483
5/28	98	10.7	9.1	102	110	24.5	13.0	454
5/29	98	11.2	9.1	149	109	21.1	12.5	450
5/30	95	16.1	8.5	433	107	12.0	11.9	103
5/31	94	13.5	8.4	193	109	16.2	12.7	51
6/01	97	11.6	8.9	46	112	21.4	13.5	172
6/03	95	16.6	8.6	400	110	22.4	12.9	203
6/04	97	13.0	9.1	257	110	22.9	12.8	327
6/05	95	16.9	8.5	482	109	21.8	12.6	115
6/06	94	16.2	8.4	467	110	18.4	12.8	117
6/07	93	17.7	8.2	488	108	12.2	12.1	75
6/08	90	20.4	7.6	564	109	11.9	12.4	28
6/09	92	20.0	8.0	527	108	14.4	12.3	63
6/10	92	15.7	7.9	125	114	18.3	14.3	43
6/11	93	18.9	8.1	412	111	19.8	13.2	66
6/12	92	20.0	7.9	340	110	10.4	12.7	34
6/13	92	19.8	7.9	232	112	20.5	13.4	39
6/14	94	21.4	8.3	603	107	13.7	12.1	61
6/15	90	21.6	7.6	228	111	22.4	13.3	58
6/16	92	23.8	7.9	506	109	13.0	12.7	32
6/17	92	21.4	7.9	195	113	22.7	14.0	58
6/18	94	18.9	8.3	203	108	10.2	12.2	35
Total				7,088				4,804
Mean	94		8.4		111		13.1	

[a] Length-weight parameters by age group and discriminating length used to seperate ages from May 21 to June 18 were:

Age 1. a= -9.2014 b= 2.4884 r^2= 0.72 n= 1,396
Age 2. b= -10.0614 b= 2.6803 r^2= 0.82 n= 851

Discriminating Length = 102.04 mm

[b] Sample day began at 1200 hours and ended at 1159 hours the next calendar day.

Table 6. Climatological and hydrological observations made at sockeye salmon smolt counting site at 0800 and 2000 hours, Naknek River, 1993.

Date	Cloud Cover[a]		Wind Velocity (km/h)		Air Temp. (°C)		Water Temp. (°C)		Precipitation (mm)	Water Clarity[b]
	0800	2000	0800	2000	0800	2000	0800	2000		
5/17	4	3	0	0	8.0	13.0	9.0	11.0	0.0	clear
5/18	5	1	0	32 SW	4.0	11.0	9.0	11.5	0.0	clear
5/19	1	2	0	0	7.0	-	10.0	-	0.0	clear
5/20	1	2	11 N	5 NE	7.2	17.2	10.5	13.0	0.0	clear
5/21	4	3	8 NE	8-16 N	6.0	14.4	11.0	12.0	0.0	clear
5/22	3	3	19 S	16-24 N	8.0	10.0	11.0	11.0	0.2	clear
5/23	4	3	16 NW	24-32 E	8.0	15.0	11.0	11.0	0.0	clear
5/24	2	4	16 S	24-32 SW	7.0	7.8	10.0	11.0	trace	clear
5/25	4	-	16-24 S	-	9.0	-	10.0	-	-	clear
5/26	-	2	-	16-24 N	-	11.0	-	10.5	0.0	-
5/27	1	1	0	0-08 N	7.0	16.0	10.0	12.0	0.0	clear
5/28	3	1	0	8-16 N	7.0	15.0	10.0	13.0	-	clear
5/29	1	1	0	0-08 N	7.0	16.0	11.0	13.0	-	clear
5/30	1	1	0	0-08 N	7.0	17.0	12.0	14.0	-	clear
5/31	1	1	0	8-16 SE	10.0	17.0	14.0	15.0	-	clear
6/01	1	1	0	16-24 S	7.0	16.0	14.0	15.0	-	clear
6/02	3	4	0	32-48 NE	9.5	11.0	14.0	12.0	0.0	clear
6/03	3	3	16-24 ENE	16-24 ENE	11.0	13.0	11.0	12.5	0.0	clear
6/04	4	3	0	0	12.0	15.0	12.0	13.0	0.0	glacial
6/05	4	3	13 NE	8-16 NE	11.0	11.5	12.0	11.0	0.0	clear
6/06	4	3	11 NE	0	11.0	11.5	12.0	12.0	0.0	clear
6/07	2	3	0	16-24 NE	10.0	12.5	11.5	12.5	0.0	glacial
6/08	2	3	11 NE	0-08 SW	9.0	13.0	11.5	13.0	trace	clear
6/09	4	1	0	8-24 SW	10.0	16.0	12.0	13.0	trace	clear
6/10	4	4	11 S	0-08 S	7.0	9.0	11.5	11.0	-	clear
6/11	2	1	6 S	0-08 S	9.0	9.0	12.0	12.0	-	clear
6/12	3	3	0	8-16 SW	11.0	11.0	12.0	13.0	-	clear
6/13	4	3	8 SW	0-08 S	10.0	16.0	12.0	13.0	0.2	clear
6/14	3	4	0	0-08 SE	9.0	10.0	12.5	13.0	0.2	clear
6/15	1	3	0	0	9.0	14.0	12.0	13.5	0.1	clear
6/16	1	3	0	8 SW	10.0	15.0	12.0	13.5	0.0	clear
6/17	3	3	0	0-08 NE	11.0	16.0	12.0	14.0	0.0	clear
6/18	4	3	8 NE	24 SW	13.0	17.5	12.5	15.5	trace	clear
6/19	5	2	8-11 NE	24-32 SW	11.0	18.0	13.0	16.0	0.0	glacial
6/20	5	-	08 NE	-	9.0	-	13.5	-	0.0	clear

[a] 1 = Cloud cover not more than 1/10
2 = Cloud cover not more than 1/2
3 = Cloud cover more than 1/2
4 = Completely overcast
5 = Fog

[b] Water clarity at 0800 hours

1994

A total of 2,955,649 sonar counts were recorded at the Naknek River counting site from May 19 to June 19, 1994 (Table 7). More counts were recorded over the center array (42.3%) than over the offshore (37.2%) or inshore (20.5%) arrays (Figure 8). Daily sonar counts were highest from June 6-12 when 62.0% of the total counts were recorded (Figures 9, 10). The peak daily sonar count of 383,243 occurred on June 7. Similar high counts also occurred on June 8 (379,673) and June 9 (352,968). The fluctuation in daily sonar counts from June 15-19 indicate that some unknown number of smolt continued to emigrate from the Naknek River after June 19. Over the course of the sampling season, half of the total sonar counts were recorded from 2200 hours to 0600 hours (Figure 11); while the remainder of the counts were spread fairly evenly over the remaining hours.

Locals residents reported that Naknek Lake was 50% ice free by April 21 and completely ice free by May 4 (R. Russell, ADF&G, King Salmon, personal communication). No sockeye salmon smolt or signs of birds successfully feeding on smolt were reported prior to the start up of this project. The Naknek River smolt sonar began counting at 1200 hours on May 19 and the first reported smolt counts occurred at 1100 hours on May 20. Smolt counts obtained during the first three days of operation indicated low smolt abundance. The first fyke net fished from 2000 hours to 2015 hours on May 20 and caught only 1 sockeye salmon smolt. Smolt passages fluctuated up and down between May 22 and June 4. On June 2, from 0850 hours to 1130 hour, a continuous band of smolt were observed passing the smolt site with the current just beneath the surface of the water approximately 12 m from the right bank (F. Tilly, ADF&G, King Salmon, personal communication). Some of these smolt passed over the offshore array, however according to our crew members visual sighting of this event, it appeared that the majority passed beyond the offshore array. The winds were calm at the time and this was the only instance we observed a sizable number of smolt passing the sonar site beyond the range of our sonar. After June 4, the smolt outmigration began to build to a peak on June 7-9 and decreased steadily thereafter.

All offshore array sonar counts from 1700 hours May 22 to June 19 were multiplied by 1.11 to account for a bad transducer (#6). All center array sonar counts from 1200 hours May 31 to June 19 were multiplied by 1.11 to account for a bad transducer (#2). All inshore array sonar counts from 1200 hours June 6 to June 19 were multiplied by 1.11 to account for a bad transducer (#7).

All arrays were interpolated for the following time and date: 2100 hours on May 29 due to high winds.

River velocity at the counting site ranged from 0.6 m/s to 1.1 m/s over the sonar arrays. As in 1993, a flow meter attached to an anchored buoy was used as a velocity index. Velocity correction factors (m/s) used for the three arrays were as follows:

Smolt Days	Index Buoy	Inshore	Center	Offshore
May 19-May 29	1.00	1.00	1.10	0.76
May 30-June 08	1.00	1.17	1.25	0.89
June 09-June 19	1.00	1.16	1.29	1.01

Table 7. Sonar counts recorded from three arrays at the sockeye salmon smolt counting site on Naknek River, 1994.

Smolt Day [a]	Sonar Count by Transducer Array			
	Inshore	Center	Offshore	Total
5/19 [b]	572	1,714	1,256	3,542
5/20	3,865	21,070	3,352	28,287
5/21	3,289	13,804	6,693	23,786
5/22 [c]	11,463	21,385	32,414	65,262
5/23	5,904	23,269	6,945	36,118
5/24	7,738	12,880	3,216	23,834
5/25	1,299	1,937	3,872	7,108
5/26	3,262	4,690	5,904	13,856
5/27	4,001	3,648	6,422	14,071
5/28	53,998	42,701	34,927	131,626
5/29 [d]	19,025	5,893	16,227	41,145
5/30	8,562	14,868	24,975	48,405
5/31 [e,f]	12,161	25,583	15,936	53,680
6/01 [e]	23,266	23,491	33,372	80,129
6/02	5,827	16,203	23,020	45,050
6/03 [g]	13,459	31,642	47,224	92,325
6/04	6,300	3,878	3,409	13,587
6/05	15,233	30,850	40,456	86,539
6/06	17,582	95,192	113,540	226,314
6/07	61,117	171,220	150,906	383,243
6/08	49,186	161,589	168,898	379,673
6/09 [e]	52,663	184,407	115,898	352,968
6/10	46,188	92,234	91,726	230,148
6/11	29,051	35,701	14,833	79,585
6/12	49,451	67,148	53,377	169,976
6/13	24,174	16,406	8,484	49,064
6/14	29,261	61,179	23,538	113,978
6/15	18,594	21,423	9,983	50,000
6/16	5,301	9,930	7,256	22,487
6/17	8,361	18,515	7,478	34,354
6/18	4,365	3,271	5,208	12,844
6/19	10,940	12,718	19,007	42,665
Total	605,458	1,250,439	1,099,752	2,955,649
Percent	20.5	42.3	37.2	

[a] Sample day began at 1200 hours and ended at 1159 hrs the next calendar day.

[b] The first smolt counts on the smolt counter were reported at 1100 hours on smolt day May 19.

[c] All offshore array counts from 1700 hours May 22 till the end of the project were multiplied by 1.11 to account for a bad transducer # 6.

[d] Interpolated data for all array: 2100 hours on May 29 due to high wind

[e] Peak fyke net catch per unit effort (CPUE) dates and times:
0147-0149 hours on May 31, CPUE = 250
0149-0152 hours on June 1, CPUE = 233
0132-0135 hours on June 9, CPUE = 333 (1994 peak)

[f] All center array counts from 1200 hours May 31 till the end of the project were multiplied by 1.11 to account for a bad transducer #2.

[g] All inshore array counts from 1200 hours June 3 till the end of the project were multiplied by 1.11 to account for a bad transducer #7.

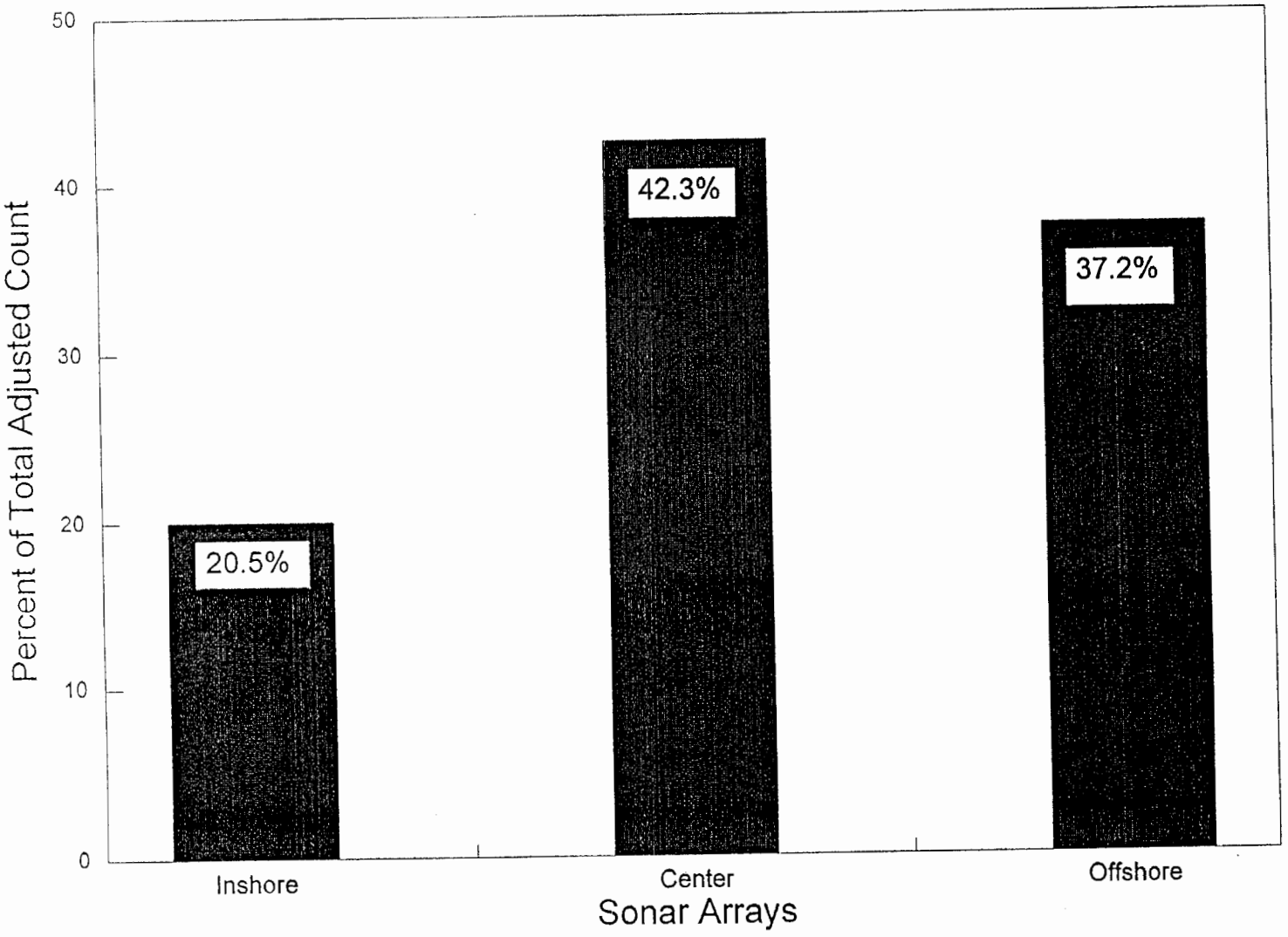


Figure 8. Lateral distribution of Naknek River smolt sonar counts, 1994.

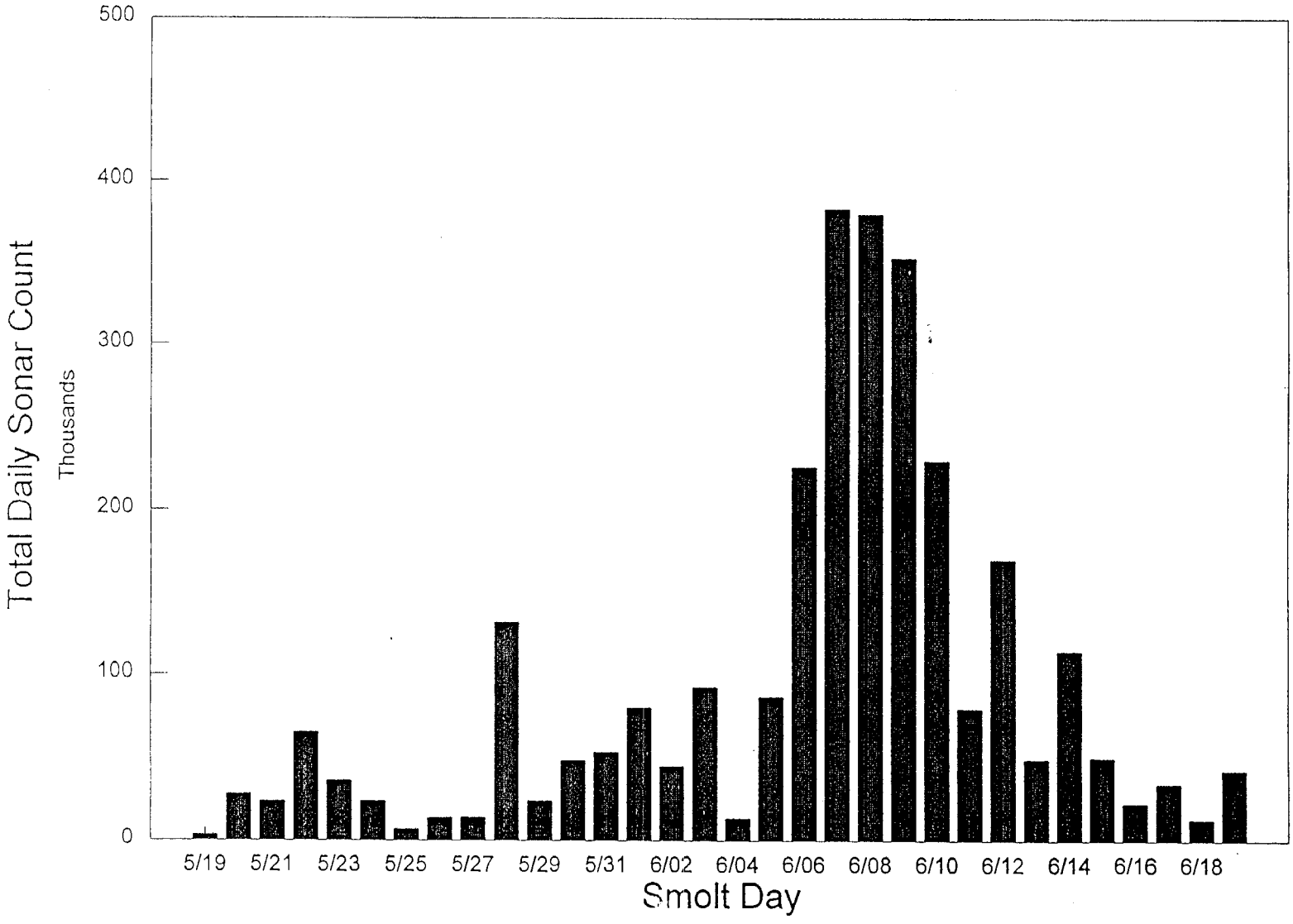


Figure 9. Total daily sonar counts at Naknek River smolt project, May 19 to June 19, 1994.

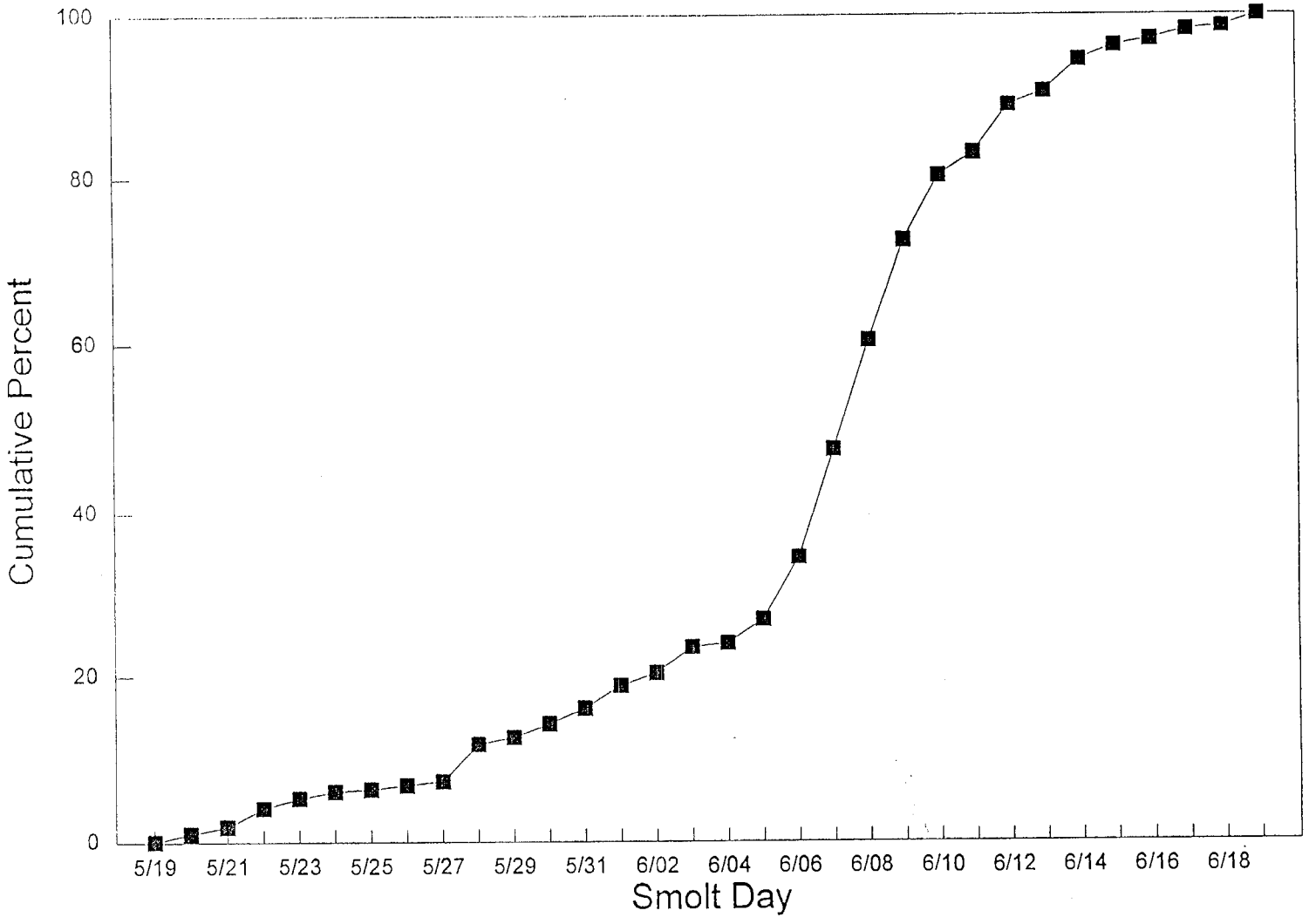


Figure 10. Naknek River smolt sonar count, cumulative percent by date, May 19 to June 19, 1994.

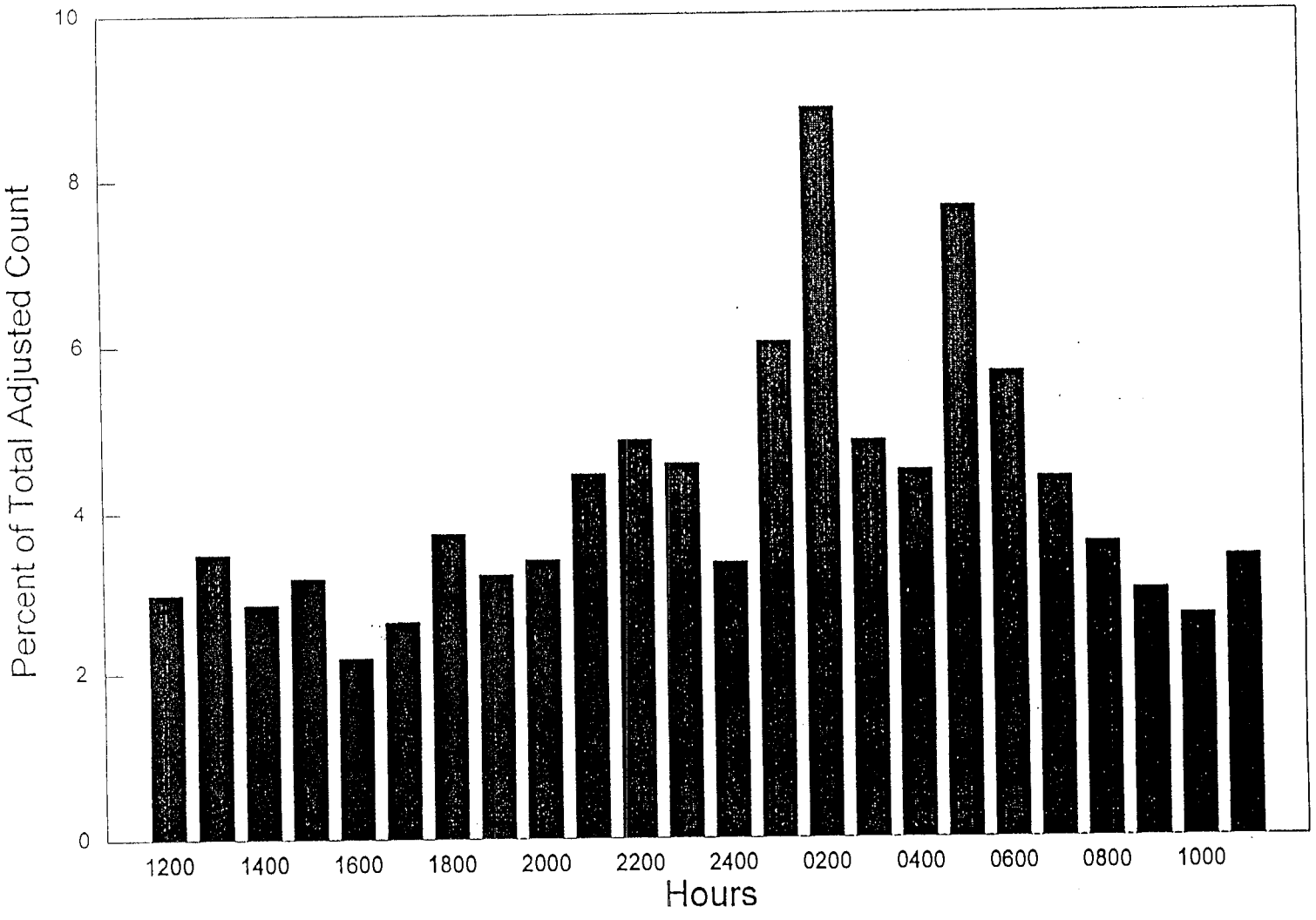


Figure 11. Percent of the total adjusted sonar count summarized by hour, Naknek River smolt project, May 19 to June 19, 1994.

An estimated 74,937,354 sockeye salmon smolt migrated from the Naknek River in 1994 (Table 8). We believe that this smolt estimate constitutes the bulk of the 1994 Naknek River smolt outmigration, however the fluctuating daily sonar counts from June 15-19 (Figures 9, 10) indicate that some unknown portion of the tail end of this outmigration was not counted. Age-2. smolt (1991 brood year) composed 56.5% of the total migration. Although the daily percentage of age-1. and -2. smolt fluctuated during the 1994 migration, the percentage of age-2. smolt predominated on 21 out of 31 days that this project was operated and the percentage of age-2. smolt decreased over time (NSC = nonstatistical comparison). Mean weight of smolt remained high for much of the season (Table 9).

Age, weight, and length data were collected from 2,305 sockeye salmon smolt in 1994 (Table 10). All smolt sampled were age 1. or 2. Mean weights by age were 7.4 g for age-1. and 10.9 g for age-2. smolt. Mean lengths by age were 93 mm for age-1. and 107 mm for age-2. smolt. An additional 12,494 smolt were measured for length only (Table 11).

River and weather conditions were recorded at the counting site from May 19 to June 20 (Table 12). There were no ice problems during the 1994 sampling season and the weather was generally good for smolt counting. The smolt counter was disabled for 1 h on May 29 because of waves produced by strong southerly winds. Mean water temperature during the project was 10.0° C (range 7.7° C to 15.0° C). Mean daily water temperature during the peak of the smolt migration was 10.2° C on June 9.

DISCUSSION

Summary of Smolt Production from 1991 Escapement

The total production estimate of age-1. and -2. sockeye salmon smolts from the record 1991 Naknek River spawning escapement of 3,578,508 sockeye salmon was 66,505,945 smolt (Table 13). Comparing spawning escapements, smolt production, and smolt-per-spawner values for brood years 1980-1983 and 1991, we see that the high spawning escapement in 1991 produced the third highest smolt outmigration, but the lowest smolt-per-spawner value (e.g., 18.58) (Figure 12). The smolt-per-spawner value for the 1991 brood year of 18.64 was significantly less ($p=0.0497$) than those observed for brood years 1980-1983.

Marine survival, adult returns per smolt, has averaged 6% for age-1. smolt for the 1980-1984 brood years and 7% for age-2. smolt for the 1979-1983 brood years (Table 14). We cannot calculate the marine survival for age-1. and age-2. smolt from the 1991 brood year until the 1996-1997 adult returns have been estimated. In 1994, an estimated 12,538 age-1.1 (jacks) sockeye salmon adults returned from the 1991 brood year. Although this age group is a minor contributor to the overall adult salmon returns to the Naknek River, it is the largest return of age-1.1 sockeye salmon on record. In 1995, an estimated 547,993 age-1.2 and 774 age-2.1 sockeye salmon adults returned from the 1991 brood year. The age 1.2 estimate is comparable to the 1981-1990 average of 549,000 fish, however the age 2.1 estimate is well below the recent ten-year average of 13,000 fish.

Table 8. Daily number of sockeye salmon smolt migrating seaward estimated with hydroacoustic equipment Naknek River, 1994.

Smolt Day [a]	Age 1. Number	Age 1. Percent	Age 1. Cumulative Total	Age 2. Number	Age 2. Percent	Age 2. Cumulative Total	All Ages Daily Total	All Ages Cumulative Total
5/19	804	1.3	804	61,564	98.7	61,564	62,368	62,368
5/20	6,204	1.3	7,008	474,793	98.7	536,357	480,997	543,365
5/21	5,277	1.3	12,285	403,809	98.7	940,166	409,086	952,451
5/22	215,625	16.0	227,910	1,132,035	84.0	2,072,201	1,347,660	2,300,111
5/23	115,795	16.0	343,705	607,927	84.0	2,680,128	723,722	3,023,833
5/24	50,519	10.9	394,224	414,669	89.1	3,094,797	465,188	3,489,021
5/25	46,500	29.8	440,724	109,489	70.2	3,204,286	155,989	3,645,010
5/26	90,680	29.8	531,404	213,515	70.2	3,417,801	304,195	3,949,205
5/27	92,690	29.8	624,094	218,247	70.2	3,636,048	310,937	4,260,142
5/28	717,915	24.8	1,342,009	2,181,582	75.2	5,817,630	2,899,497	7,159,639
5/29	218,518	24.1	1,560,527	689,705	75.9	6,507,335	908,223	8,067,862
5/30	270,803	24.1	1,831,330	854,731	75.9	7,362,066	1,125,534	9,193,396
5/31	563,057	41.5	2,394,387	792,401	58.5	8,154,467	1,355,458	10,548,854
6/01	1,339,949	57.7	3,734,336	981,515	42.3	9,135,982	2,321,464	12,870,318
6/02	388,673	35.4	4,123,009	710,826	64.6	9,846,808	1,099,499	13,969,817
6/03	1,415,192	55.2	5,538,201	1,149,026	44.8	10,995,834	2,564,218	16,534,035
6/04	110,217	32.7	5,648,418	226,839	67.3	11,222,673	337,056	16,871,091
6/05	893,980	41.3	6,542,398	1,270,097	58.7	12,492,770	2,164,077	19,035,168
6/06	2,212,375	40.5	8,754,773	3,248,932	59.5	15,741,702	5,461,307	24,496,475
6/07	3,477,210	38.0	12,231,983	5,675,752	62.0	21,417,454	9,152,962	33,649,437
6/08	1,436,743	17.8	13,668,726	6,634,850	82.2	28,052,304	8,071,593	41,721,030
6/09	4,176,835	44.3	17,845,561	5,255,945	55.7	33,308,249	9,432,780	51,153,810
6/10	2,630,399	42.8	20,475,960	3,521,143	57.2	36,829,392	6,151,542	57,305,352
6/11	1,933,149	75.1	22,409,109	641,636	24.9	37,471,028	2,574,785	59,880,137
6/12	3,667,778	70.2	26,076,887	1,554,745	29.8	39,025,773	5,222,523	65,102,660
6/13	1,110,037	71.1	27,186,924	452,295	29.0	39,478,068	1,562,332	66,664,992
6/14	2,581,671	72.8	29,768,595	963,606	27.2	40,441,674	3,545,277	70,210,269
6/15	876,332	60.2	30,644,927	578,885	39.8	41,020,559	1,455,217	71,665,486
6/16	393,241	60.2	31,038,168	259,766	39.8	41,280,325	653,007	72,318,493
6/17	587,535	60.2	31,625,703	388,112	39.8	41,668,437	975,647	73,294,140
6/18	231,229	60.2	31,856,932	152,744	39.8	41,821,181	383,973	73,678,113
6/19	758,315	60.2	32,615,247	500,926	39.8	42,322,107	1,259,241	74,937,354
	32,615,247	43.5		42,322,107	56.5		74,937,354	

[a] Sample day began at 1200 hours and ended at 1159 hours the next calendar day.

Table 9. Adjustment factors used to expand sonar counts into estimated numbers of sockeye salmon smolts, Naknek River, 1994.

Smolt Day [a]	Mean Weight of Smolt (g)	Smolt per Count
5/19	12.6	3.3
5/20	12.6	3.3
5/21	12.6	3.3
5/22	10.7	3.9
5/23	10.7	3.9
5/24	11.3	3.7
5/25	10.1	4.1
5/26	10.1	4.1
5/27	10.1	4.1
5/28	10.3	4.0
5/29	10.5	4.0
5/30	10.5	4.0
5/31	9.6	4.3
6/01	8.6	4.8
6/02	9.9	4.2
6/03	8.8	4.7
6/04	10.3	4.0
6/05	9.8	4.2
6/06	9.9	4.2
6/07	10.1	4.1
6/08	11.3	3.7
6/09	9.4	4.4
6/10	9.7	4.3
6/11	7.8	5.3
6/12	8.4	5.0
6/13	8.1	5.1
6/14	8.0	5.2
6/15	8.7	4.8
6/16	8.7	4.8
6/17	8.7	4.8
6/18	8.7	4.8
6/19	8.7	4.8

[a] Sample day began at 1200 hours and ended at 1159 hours the next calendar day.

Table 10. Mean fork length and weight of sockeye salmon smolt captured in fyke nets, Naknek River, 1994.

	Age 1.					Age 2.				
Smolt Day [a]	Mean Length (mm)	Std. Error	Mean Weight (g)	Std. Error	Sample Size	Mean Length (mm)	Std. Error	Mean Weight (g)	Std. Error	Sample Size
5/20	90		5.4		1	115	15.4	12.5	4.83	49
5/21	92	13.5	6.9	2.71	3	114	20.9	12.3	6.38	97
5/22	100	23.8	8.3	5.05	21	108	21.3	10.4	5.87	79
5/23	99	28.2	8.8	6.00	36	109	19.7	10.9	5.69	63
5/24	95	19.0	8.1	3.68	20	108	18.8	11.4	4.78	80
5/25					0					0
5/26	97	18.0	8.4	3.98	23	108	12.3	10.4	3.29	19
5/27	98	15.1	9.5	4.35	62	103	15.9	10.8	3.80	37
5/28	96	20.9	8.2	6.17	46	104	12.7	10.0	5.15	51
5/29	94	20.5	7.5	4.65	31	106	11.4	10.0	3.20	19
5/30	97	17.1	8.8	4.04	27	108	20.4	11.1	5.83	72
5/31	96	15.4	8.0	3.64	41	107	22.2	10.2	5.52	59
6/01	90	14.1	6.3	3.97	54	103	15.9	8.8	4.15	44
6/02	95	21.6	7.4	4.99	43	113	17.7	11.8	5.14	56
6/03	92	19.0	6.8	4.78	43	108	19.1	10.9	5.93	57
6/04	94	18.8	7.8	4.70	25	110	25.7	11.7	7.45	73
6/05	89	19.3	6.7	4.18	60	102	18.3	9.7	5.04	36
6/06	91	17.3	7.4	4.62	34	111	22.4	12.7	7.64	65
6/07	88	21.3	6.3	4.93	57	111	19.0	12.2	5.80	42
6/08	97	16.6	8.1	4.27	29	112	18.9	12.4	6.46	71
6/09	93	23.5	6.9	6.05	42	111	22.7	11.6	7.42	58
6/10	91	17.4	7.2	4.17	29	108	17.0	11.2	5.37	21
6/11	86	18.4	6.1	3.91	95	101	9.7	9.3	2.96	5
6/12	90	20.3	7.1	4.76	74	107	11.2	10.9	2.76	6
6/13	91	22.8	7.1	5.38	78	101	18.7	9.2	4.51	22
6/14	90	10.6	7.0	2.52	41	97	9.8	8.7	2.34	9
6/15 [b]										
6/16	90	16.9	6.9	3.90	41	110	17.5	12.3	4.93	9
6/17 [b]										
6/18	87	13.6	6.4	2.78	46	108	4.4	10.9	1.33	4
Total					1,102					1,203
Mean	93		7.4			107		10.9		

[a] Sample day began at 1200 hours and ended at 1159 hours the next calendar day.

[b] Fyke net not fished.

Table 11. Mean fork length and estimated weight for age-1. and -2. sockeye salmon smolt, Naknek River, 1994.

Smolt Day [b]	Estimated Age 1.[a] Mean Length (mm)	Std. Error	Estimated Weight (g)	Sample Size	Estimated Age 2.[a] Mean Length (mm)	Std. Error	Estimated Weight (g)	Sample Size
5/20				0	118	7.0	13.5	17
5/21	99	1.1	8.6	3	115	23.1	12.7	244
5/22	95	15.3	7.9	40	111	19.7	11.5	209
5/23	94	17.2	7.5	81	109	21.4	11.0	470
5/24	94	15.7	7.7	59	111	26.3	11.6	477
5/25				0				0
5/26	95	11.3	7.8	36	106	15.2	10.3	132
5/27	95	17.0	7.7	189	107	24.5	10.7	437
5/28	94	19.0	7.5	158	108	23.2	10.8	455
5/29	92	16.6	7.1	78	109	24.4	11.1	156
5/30	95	14.4	7.8	110	109	24.8	11.3	460
5/31	93	18.7	7.4	287	107	23.1	10.5	299
6/01	90	24.2	6.7	427	108	23.2	10.8	186
6/02	90	22.5	6.8	241	109	27.2	11.2	353
6/03	89	27.1	6.6	402	108	22.9	10.9	186
6/04	90	21.1	6.8	235	111	28.5	11.6	350
6/05	90	23.0	6.7	259	112	31.8	12.0	316
6/06	90	24.4	6.7	293	111	25.6	11.6	288
6/07	90	24.1	6.7	269	112	30.0	12.1	379
6/08	93	17.9	7.5	116	112	28.7	11.9	489
6/09	88	23.7	6.4	301	110	23.6	11.4	262
6/10	91	21.9	6.9	211	109	21.0	11.0	191
6/11	89	22.8	6.6	515	107	17.6	10.7	84
6/12	91	24.2	7.0	487	106	17.2	10.5	118
6/13	89	24.5	6.5	509	109	18.4	11.1	103
6/14	88	20.3	6.4	348	107	11.1	10.7	31
6/15 [c]								
6/16	86	13.4	6.0	57	108	9.7	10.8	10
6/17 [c]								
6/18	85	17.6	5.8	79	108		10.7	2
Total				5,790				6,704
Mean	91		7.0		109		11.3	

[a] Length-weight parameters by age group and discriminating length used to seperate ages from May 20 to June 18 were:

Age 1. a = - 10.5662 b = 2.7675 r2 = 0.85 n = 1,102
Age 2. a = - 9.9442 b = 2.6297 r2 = 0.81 n = 1,203

Discriminating Length = 100.86 mm

[b] Sample day began at 1200 hours and ended at 1159 hours the next calendar day.

[c] Fyke net not set.

Table 12. Climatological and hydrological observations made at sockeye salmon smolt counting site at 0800 and 2000 hours, Naknek River, 1994.

Date	Cloud Cover[a]		Wind Velocity (km/h)		Air Temp. (°C)		Water Temp. (°C)		Precipitation (mm)	Water Clarity[b]
	0800	2000	0800	2000	0800	2000	0800	2000		
5/19	3	1	-	24 S	-	10.0	8.5	8.8	trace	glacial
5/20	4	3	13 NE	24-32 NE	6.0	10.0	9.0	8.8	trace	clear
5/21	4	3	16 NE	16 NE	7.5	8.0	9.0	8.8	0.0	clear
5/22	4	-	16-24 NE	-	9.0	-	9.0	-	-	clear
5/23	3	-	8-16 NE	-	6.0	-	8.0	-	-	glacial
5/24	2	4	0-08 NE	0-08 NE	6.0	6.5	9.0	8.5	11.4	clear
5/25	4	3	0	08 NW	6.0	8.5	9.0	8.5	14.2	clear
5/26	3	3	08 S	16-24 SE	5.0	12.0	8.0	8.3	-	clear
5/27	2	2	0	08 NW	4.0	18.0	7.5	-	0.0	clear
5/28	4	4	13 S	08 S	8.0	9.0	9.0	9.0	5.1	clear
5/29	1	4	0	40 S	6.5	7.0	9.0	9.0	0.5	clear
5/30	4	3	08 S	0-08 var	4.0	10.0	9.0	9.5	0.8	clear
5/31	1	2	05 NW	8-13 NE	8.0	13.0	9.0	10.0	-	clear
6/01	5	1	11 SE	16 SE	5.0	12.0	9.5	10.0	-	clear
6/02	4	3	0	0	5.0	11.0	9.5	10.0	0.8	clear
6/03	5	2	11 S	08 S	6.0	10.0	9.5	10.0	0.8	clear
6/04	5	3	05 S	08-16 S	5.0	11.0	9.5	11.0	-	clear
6/05	4	2	0	16-24 SE	10.0	17.0	11.0	12.0	-	clear
6/06	2	2	0	5-11 SE	10.0	12.0	11.0	13.0	-	clear
6/07	3	4	0	19 E	6.6	10.0	8.3	11.5	-	clear
6/08	4	4	3-13 E	0	10.0	14.0	8.3	12.0	trace	lt brown
6/09	2	3	0	0	11.0	16.0	8.3	12.0	-	clear
6/10	3	2	0	08 S	10.0	-	7.7	13.0	-	clear
6/11	2	3	08 E	0	8.0	15.0	10.0	12.0	trace	clear
6/12	3	4	0	8-16 S	10.0	13.0	11.0	12.5	-	clear
6/13	4	1	08 SE	5-13 SE	7.5	18.0	11.0	13.5	-	clear
6/14	4	4	10-13 E	19 S	9.0	10.0	8.3	12.0	-	clear
6/15	4	4	8-11 SE	8-16 S	5.0	7.0	7.7	7.0	-	clear
6/16	4	2	16-24 SE	-	5.0	21.0	7.7	13.0	-	clear
6/17	5	1	8-16 SE	16-32 S	8.5	17.0	10.0	15.0	-	clear
6/18	4	1	8-16 E	5-10 SW	6.0	16.0	11.0	14.0	-	clear
6/19	4	4	0	0-03 S	12.0	12.0	11.5	13.0	2.5	clear
6/20	4	-	0	-	10.0	-	12.0	-	2.5	clear

[a] 1 = Cloud cover not more than 1/10
2 = Cloud cover not more than 1/2
3 = Cloud cover more than 1/2
4 = Completely overcast
5 = Fog

[b] Water clarity at 0800 hours

Table 13. Sockeye salmon spawning escapement, total number of smolt produced by age class, percent of total smolt production composed by each age class, and number of smolt produced per spawner for 1978-1992 brood years, Naknek River.

Brood Year	Total Spawning Escapement	Number of Smolt Produced								Total	Per Spawner
		Age 1.	(%)[a]	Age 2.	(%)[a]	Age 3.					
1978	813,378	-		-		-				-	-
1979	925,362	-		12,898,936		23,256				-	-
1980	2,644,698	115,624,396	(88)	16,497,326	(12)	594,898				132,716,620	50.18
1981	1,796,220	36,798,239	(43)	48,825,473	(57)	20,579				85,644,291	47.68
1982	1,155,552	32,139,569	(71)	13,370,305	(29)	37,647				45,547,521	39.42
1983	888,294	6,306,803	(25)	19,147,877	(75)	-				25,454,680[b]	28.66[b]
1984	1,242,474	22,143,831		-		-				[b]	-
1985	1,849,938	-		-		-				[b]	-
1986	1,977,645	-		-		-				[b]	-
1987	1,061,806	-		-		-				[b]	-
1988	1,037,862	-		-		-				[b]	-
1989	1,161,984	-		-		0				[b]	-
1990	2,092,578	-		28,838,668		0				[b]	-
1991	3,578,508	24,183,838	(36)	42,322,107	(64)					66,505,945[c]	18.58[c]
1992	1,606,650	32,615,247									

[a] Percent of total smolt production

[b] No Naknek River smolt enumeration project conducted from 1987 to 1992. Therefore smolt production data for brood years 1983, 1984, 1989, and 1990 are incomplete, and no smolt data exists for brood years 1985 to 1988.

[c] Outmigrations of Age 3. smolt in 1995 could increase these values.

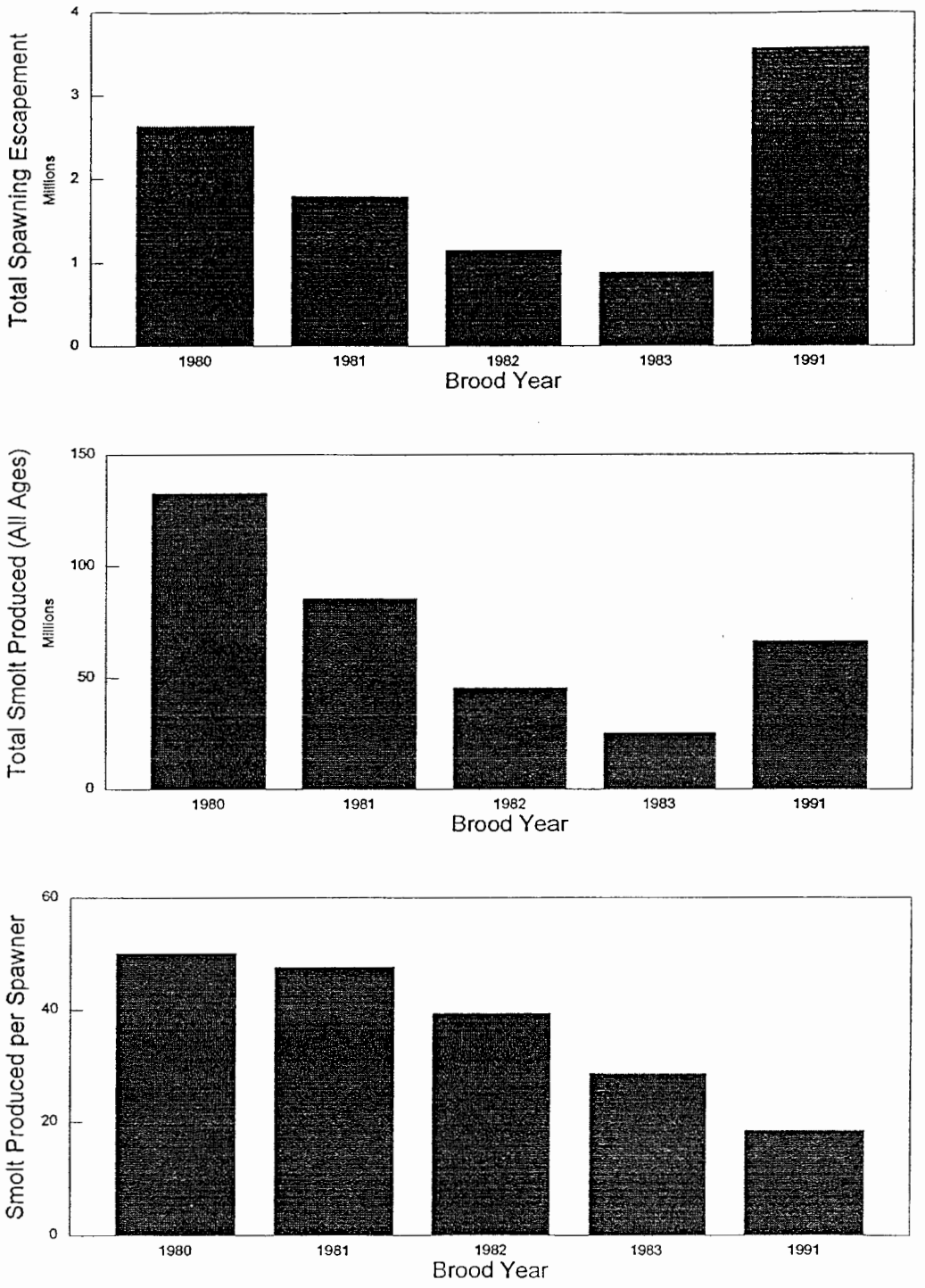


Figure 12. Comparison of spawning escapements, smolt production, and smolt-per-spawner values for Naknek River brood years 1980-1983 and 1991.

Table 14. Sockeye salmon spawning escapements, smolt production, adult returns, and smolt survival (number of adults produced per smolt) for 1978-1992 brood years, Naknek River.

Brood Year	Total Spawning Escapement	Age 1. Number of Smolt	Age 1. Adult[a] Returns	Age 1. Adult Returns per Smolt	Age 2. Number of Smolt	Age 2. Adult[a] Returns	Age 2. Adult Returns per Smolt	Age 3. Number of Smolt	Age 3. Adult[a] Returns	Age 3. Adult Returns per Smolt
1978	813,378	-	2,037,650	[b]	-	1,654,963	[b]	-	1,514	[b]
1979	925,362	-	3,424,915	[b]	12,898,936	1,204,976	0.09	23,256	6,523	0.27
1980	2,644,698	115,624,396	2,238,099	0.02	16,497,326	2,034,978	0.12	594,898	0	0.00
1981	1,796,220	36,798,239	3,366,909	0.09	48,825,473	1,421,583	0.03	20,579	0	0.00
1982	1,155,552	32,139,569	1,383,640	0.04	13,370,305	656,761	0.05	37,647	0	0.00
1983	888,294	6,306,803	651,964	0.10	19,147,877	822,912	0.04	-	739	[b]
1984	1,242,474	22,143,831	1,402,754	0.06	-	3,036,120	[b]	-	8,721	[b]
1985	1,849,938	-	4,226,241	[b]	-	2,783,537	[b]	-	10,187	[b]
1986	1,977,645	-	9,579,674	[b]	-	4,129,493	[b]	-	4,531	[b]
1987	1,061,806	-	1,676,821	[b]	-	3,815,958	[b]	-	2,639	[b]
1988	1,037,862	-	1,105,675	[b]	-	1,064,783	[b]	-	2,461 [c]	[b]
1989	1,161,984	-	1,149,923	[b]	-	1,724,261 [c]	[b]	0	4,032 [c]	[b]
1990	2,092,578	-	1,628,978 [c]	[b]	28,838,668	1,401,515 [c]	0.05[b]	0	0 [c]	
1991	3,578,508	24,183,838	560,531 [c]	[b]	42,322,107	774 [c]				
1992	1,606,650	32,615,247	[c]							
Max	3,578,508	115,624,396	9,579,674	0.10	48,825,473	4,129,493	0.12	594,898	10,187	0.28
Avg	1,644,255	38,544,560	2,746,056	0.06	25,985,813	2,097,110	0.07	112,730	3,704	0.07
Min	888,294	6,306,803	651,964	0.02	12,898,936	656,761	0.03	0	0	0.00

[a] Includes estimates of returns through 1995.

[b] Insufficient smolt data to perform this calculation.

[c] Future adult returns will increase these values.

Age-1. and age-2. smolt produced by the 1991 escapement were slightly smaller than the average smolt size for previous brood years (Table 15). However, mean length and weight of age-1. smolt from the 1991 escapement were not significantly different ($p=0.24$ and $p=0.45$, respectively) than those observed historically. Similarly, the mean length and weight of age-2. smolt from the 1991 escapement were not significantly different ($p=0.14$ and $p=0.06$, respectively) than previously observed.

A graphical comparison of total Naknek River sockeye salmon smolt production by age class for brood years 1980-1983 and 1991 does not support the hypothesis that there is a significantly higher percentage of age-2. sockeye salmon smolt produced by the 1991 escapement compared to previous years (Figure 13).

Looking at the smolt outmigration from the Naknek River by age class over time for brood years 1980-1983 and 1991 indicates that there are no clear trends through time (Figure 14). In 1982, age-1. smolt predominated throughout the smolt outmigration. In 1983-1985 and 1993, age-2. smolt predominated in the beginning of the run and age-1. smolt were greater than or equal to number of age-2. smolt toward the end of the run. In other years, such as 1986 and 1994, age-1. and -2. smolt appeared to outmigrate together and there was no clear distinction between the timing of their outmigration by age class.

Figure 15 compares the timing of the 1993 and 1994 smolt outmigrations from the Naknek River with the average timing of previously observed years. The 1993 smolt outmigration was earlier than the 1982-1986 average timing of migration. In 1994, the timing of the smolt outmigration lagged behind the 1982-1993 average timing until June 5, however the overall timing in 1994 was similar to that observed in the past.

There have been no clear trends in the migration patterns of smolt at Naknek River throughout the day (Figure 16). Smolt at Naknek River outmigrated throughout all hours of the day and they showed no distinct preference for hours with or without daylight.

Therefore, based on smolt data, it appears that the record escapement of sockeye salmon that entered the Naknek River drainage in 1991 did not produce a record number of smolt. The next logical question would be what factors in the freshwater environment might have affected the survival of eggs, fry, and smolt from the 1991 brood year?

Factors Affecting Freshwater Survival

Climatological

The freshwater survival of salmon eggs, fry, and smolt from the 1991 brood year was probably affected by several climatic factors outlined below; however, we have no direct information indicating the magnitude or direction of the effects.

Table 15. Age composition of total migration and mean fork length and weight by age class for sockeye salmon smolt, Naknek River, 1957-1994.

	Age 1.				Age 2.				Age 3.				
Year of Migration	Brood Year	Percent of Total Estimate	Mean Length (mm)	Mean Weight (g)	Brood Year	Percent of Total Estimate	Mean Length (mm)	Mean Weight (g)	Brood Year	Percent of Total Estimate	Mean Length (mm)	Mean Weight (g)	Total Estimate [a]
1957	1955	58	111	13.1	1954	42	112	13.1	1953	-	-	-	3,040,416
1958	1956	96	91	6.9	1955	4	114	11.3	1954	-	-	-	10,060,200
1959	1957	81	97	8.2	1956	19	106	10.1	1955	0	-	-	12,465,487
1960	1958	53	99	8.8	1957	47	109	11.9	1956	0	-	-	6,691,377
1961	1959	78	103	10.8	1958	22	113	13.8	1957	0	-	-	5,612,647
1962	1960	49	105	10.4	1959	51	112	12.5	1958	-	-	-	16,462,216
1963	1961	41	98	8.1	1960	59	114	12.8	1959	0	-	-	14,900,855
1964	1962	31	97	7.7	1961	69	110	11.0	1960	0	-	-	7,228,339
1965	1963	60	99	8.4	1962	40	114	13.0	1961	0	-	-	24,708,672
1966	1964	34	106	10.6	1963	66	118	14.2	1962	-	-	-	9,212,910
1967	1965	44	113	13.1	1964	56	119	14.7	1963	0	-	-	9,407,200
1968	1966	41	99	8.4	1965	57	108	11.1	1964	0	-	-	18,596,039
1969	1967	60	100	7.5	1966	40	112	12.1	1965	-	-	-	11,546,017
1970	1968	55	100	9.0	1967	45	114	12.1	1966	-	-	-	3,652,864
1971	1969	74	102	8.8	1968	26	120	13.5	1967	-	-	-	10,864,064
1972	1970	7	98	9.1	1969	93	110	11.9	1968	-	-	-	10,990,739
1973	1971	27	106	10.7	1970	72	114	12.9	1969	1	122	15.2	2,712,150
1974	1972	19	104	10.3	1971	81	118	14.5	1970	0	109	11.3	819,369
1975	1973	48	98	8.3	1972	52	111	12.1	1971	0	109	11.5	9,188,154
1976	1974	39	91	7.2	1973	60	107	13.4	1972	1	131	22.2	2,139,980
1977	1975	11	92	7.2	1974	89	113	11.9	1973	-	-	-	3,223,885
1978	1976	-	96	8.3	1975	-	105	11.0	1974	-	-	-	-
1982	1980	96	94	8.0	1979	4	100	14.7	1978	-	-	-	128,523,332
1983	1981	69	94	8.0	1980	31	110	12.2	1979	0	133	19.1	53,318,822
1984	1982	39	97	8.8	1981	60	108	11.4	1980	1	124	16.7	81,559,941
1985	1983	32	96	8.7	1982	68	109	11.7	1981	0	119	15.6	19,697,687
1986	1984	54	99	9.9	1983	46	116	14.9	1982	0	134	21.8	41,329,355
1993	1991	46	95	8.8	1990	54	109	12.4	1989	0			53,021,762
1994	1992	43	93	7.4	1991	57	107	10.9	1990	0			74,937,354
Max			113	13.1			120	14.9			134	22.2	
Avg			99	9.0			111	12.5			123	16.7	
Min			91	6.9			100	10.1			109	11.3	

[a] Estimates of smolt numbers from 1957-1977 based on fyke net catches; no estimate of smolt numbers for 1978 or 1987-1992; estimates of smolt numbers for 1982-1986 and 1993-1994 based on hydroacoustic techniques.

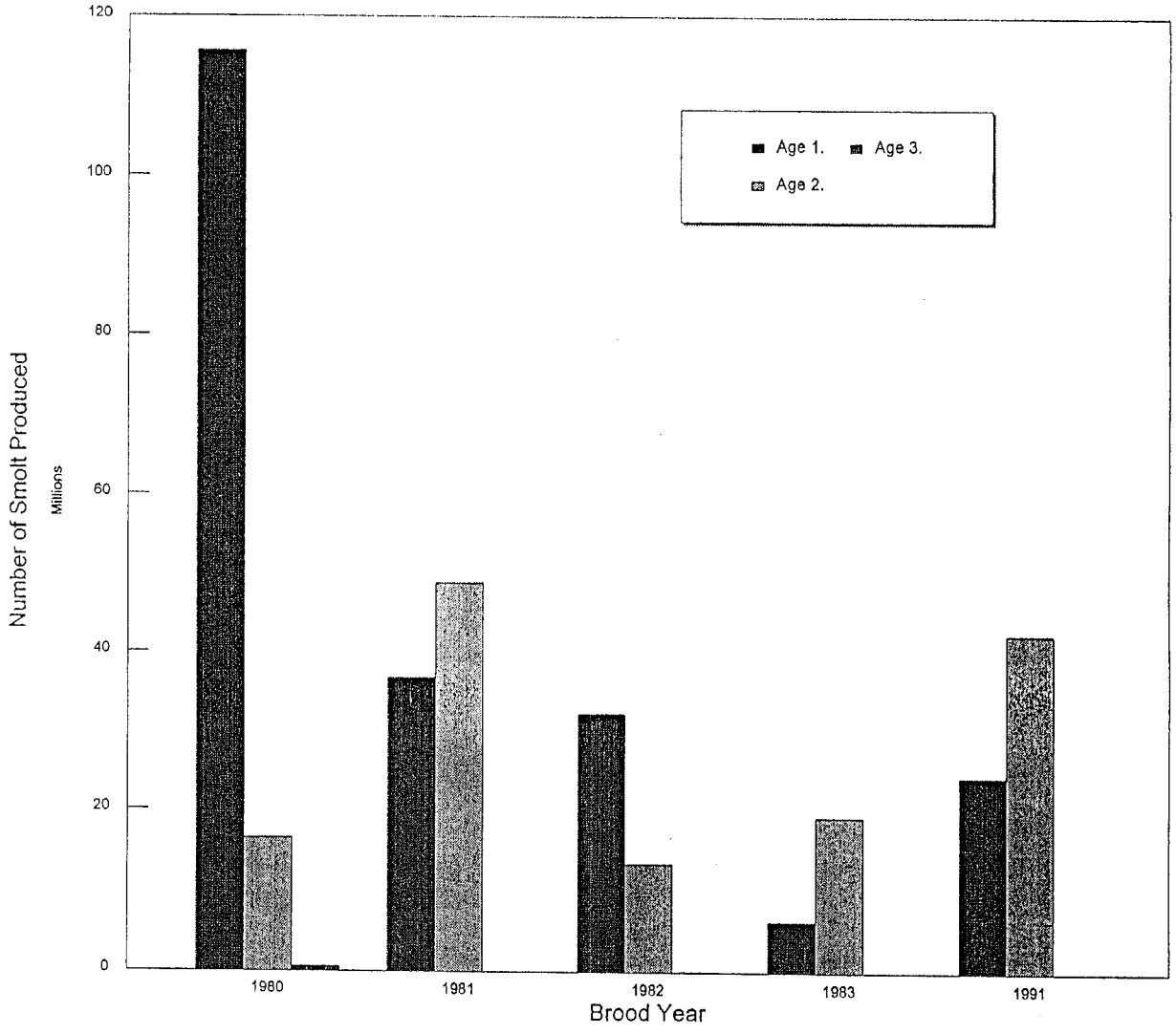


Figure 13. Total Naknek River sockeye salmon smolt production by age class for brood years 1980-1983 and 1991.

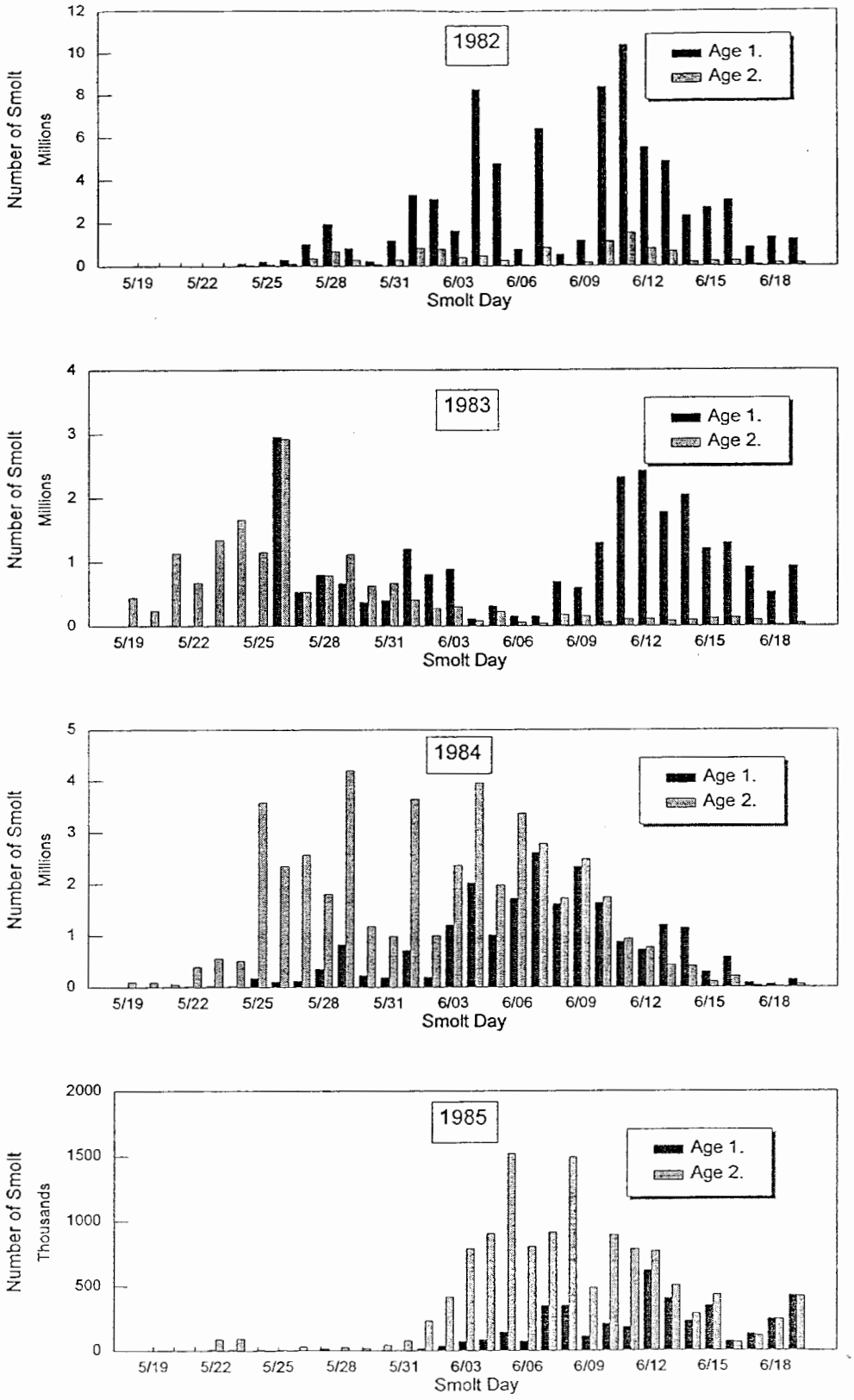


Figure 14. Age and number of sockeye salmon smolt outmigrants at Naknek River by smolt day, 1982-1986 and 1993-1994.

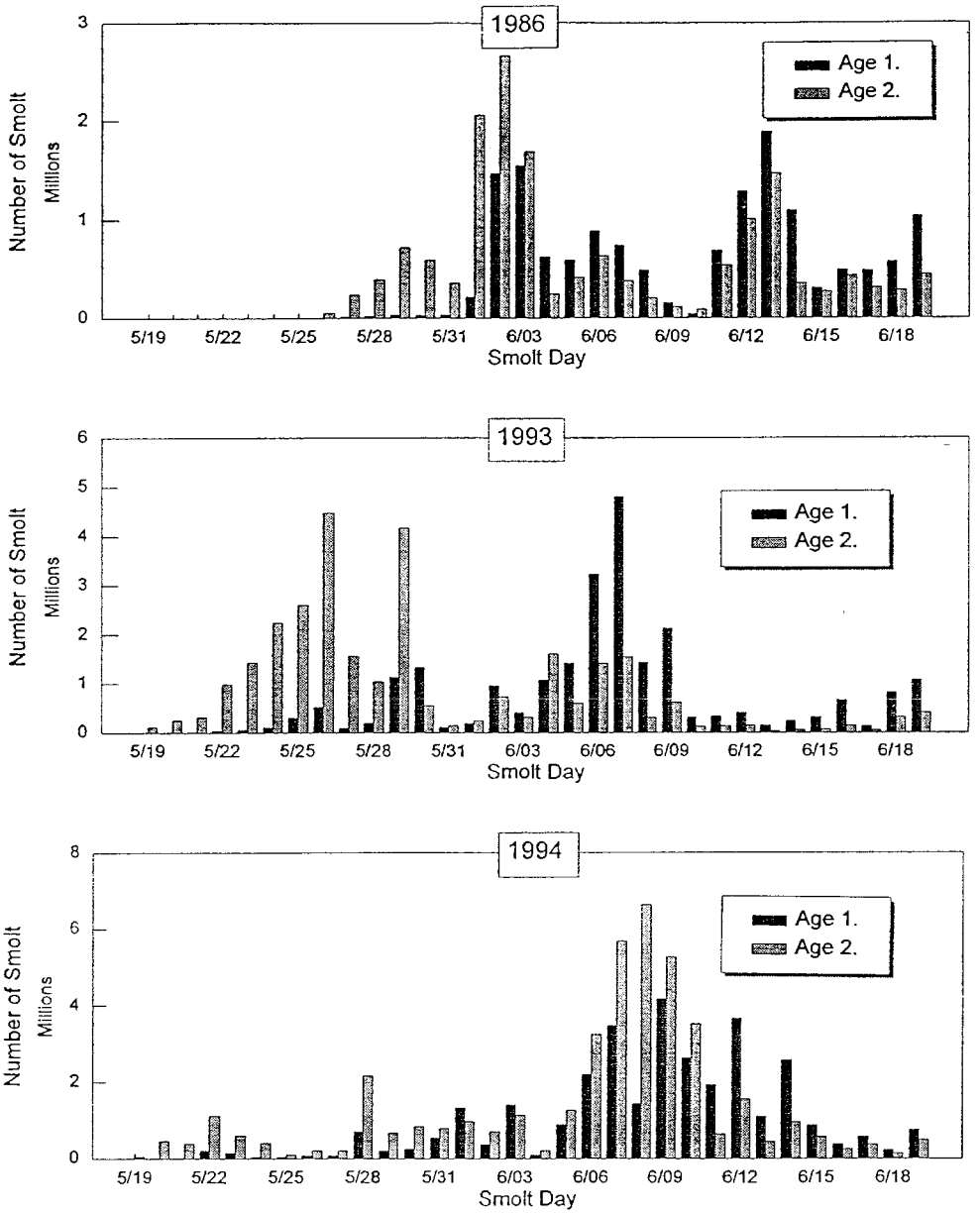
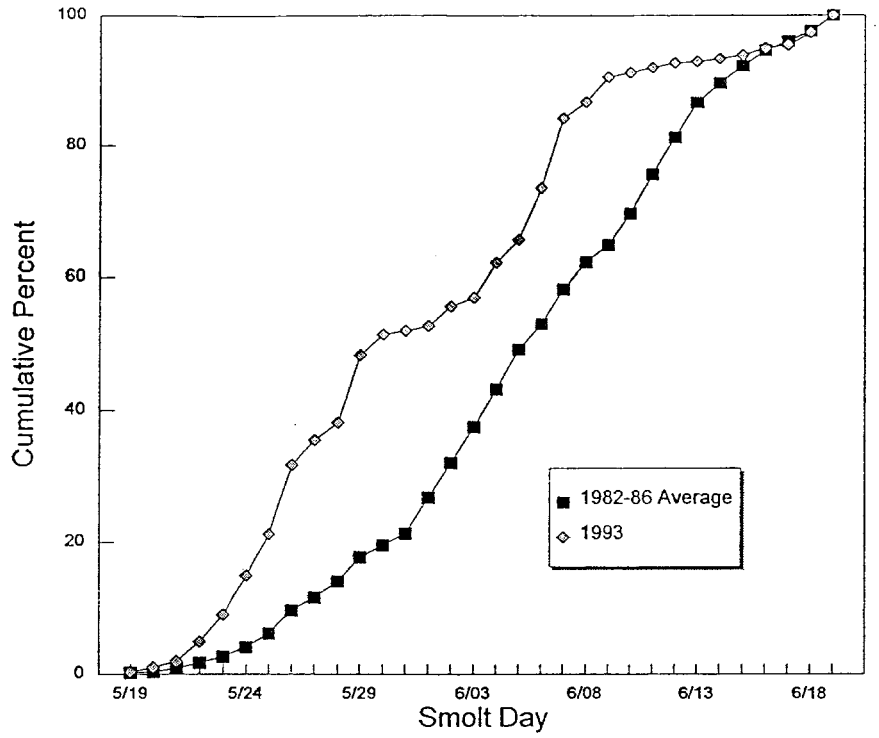


Figure 14. (p 2 of 2)



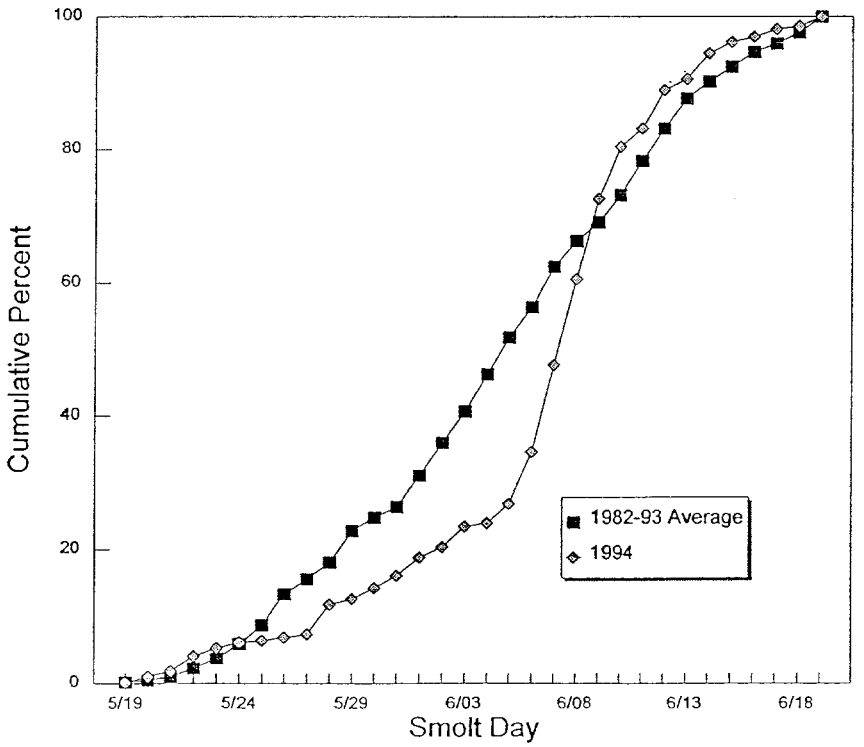


Figure 15. Comparison of 1993 and 1994 Naknek River smolt sonar counts, cumulative percent by smolt day, with previously observed averages.

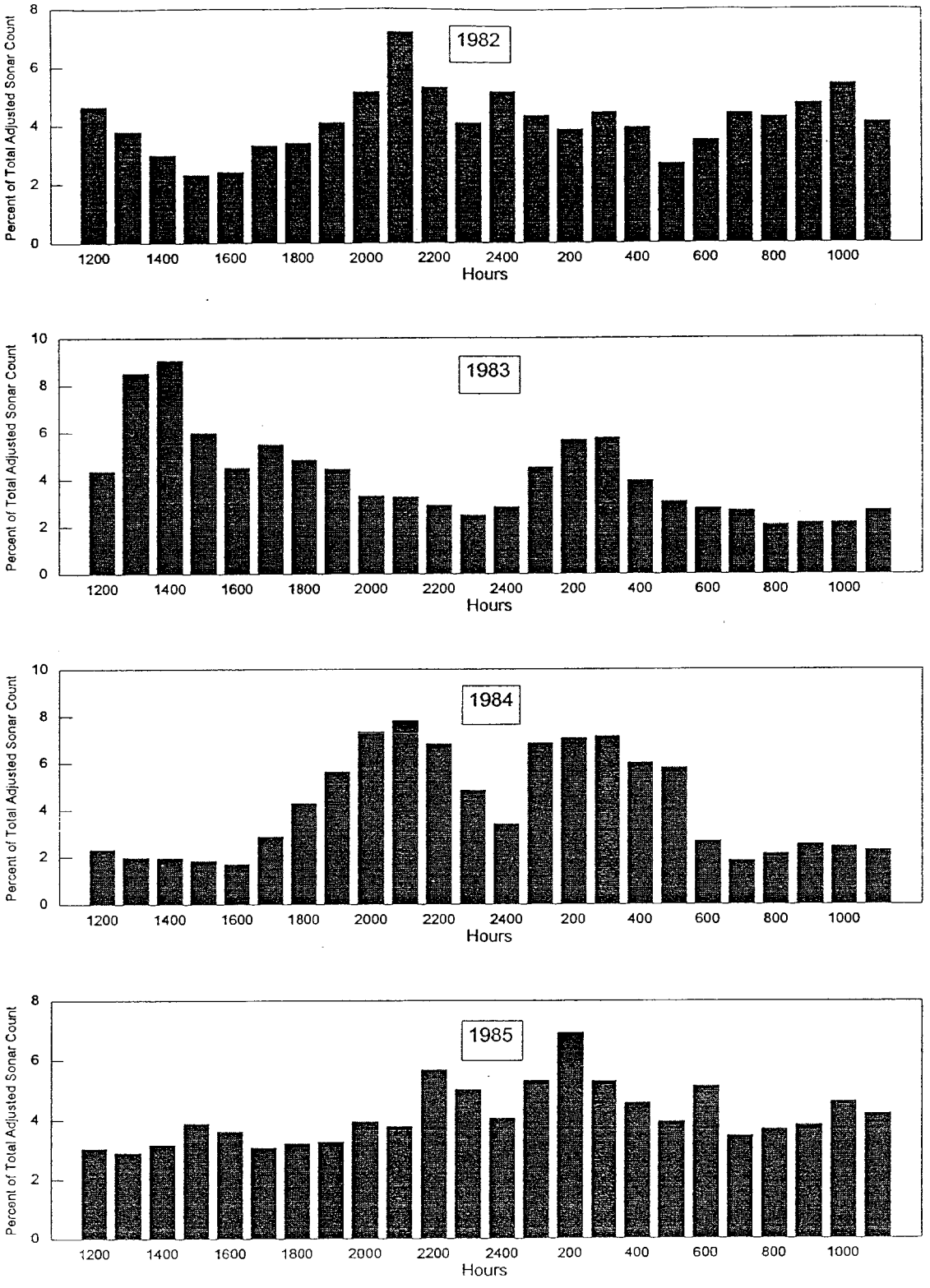
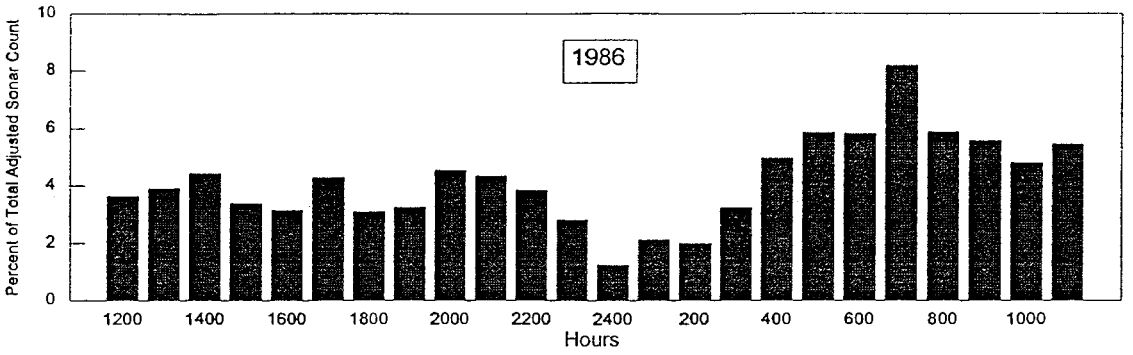
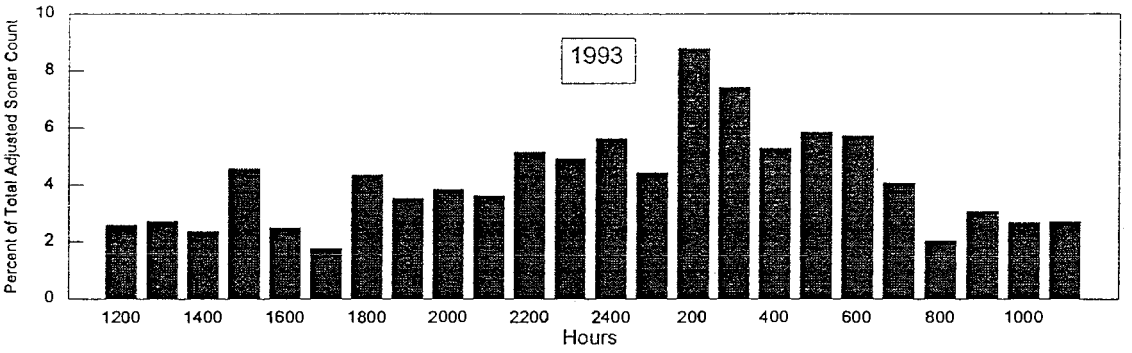


Figure 16. Percent of total adjusted sonar counts summarized by hour, Naknek River smolt project, 1982-1986 and 1993-1994.





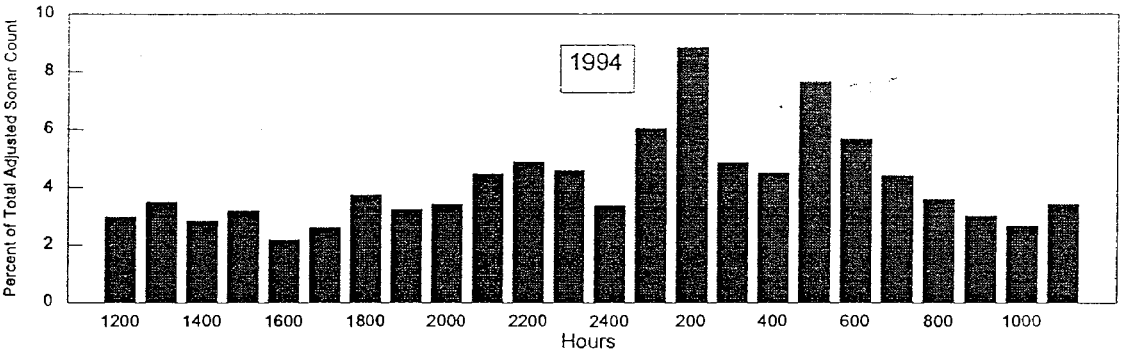


Figure 16. (p 2 of 2)

According to climatological data collected by the National Weather Service (1991), there were no abnormally severe storms in the summer/fall of 1991 that would have contributed to increased sockeye salmon egg mortality due to stream flooding (Appendix A.1). The precipitation in July and August was below normal, which may have reduced access to and the availability of suitable spawning areas. However the precipitation from September through November was normal and should not have greatly impacted sockeye salmon egg mortality.

Monthly summaries of climatological data show that the King Salmon area experienced some colder than normal temperatures during the winter of 1991-1992 (Appendix A.2) that may have contributed to increased mortality of sockeye salmon eggs. Below normal temperatures prevailed during the following three periods: from January 26 to February 7 (13 d) temperatures ranged from -3 to -32 °F below normal, from February 15 to February 23 (9 d) temperatures ranged from -9 to -20 °F below normal, and from February 28 to March 6 (8 d) temperatures ranged from -8 to -32 °F below normal. However, with the exception of February, the average monthly temperature for all other months during the winter of 1991-1992 were warmer than or equal to the 30-year average monthly temperatures (Appendix A.1). February 1992's temperature was -12°F below the 30-year average temperature for that month.

During the winter of 1991-1992 the Bristol Bay area received a better than average snow fall in November, December, February, and March (Appendix A.1). Deeper snow cover probably insulated the ice from colder temperatures and prevented it from penetrating to depths that were harmful to incubating salmon eggs.

According to observations collected from local bush pilots in King Salmon, Naknek Lake froze up on January 20, 1992 and the ice broke up on May 22, 1992 for an estimate of 122 days of total ice cover (Appendix A.3). This 1991 freeze-up date was similar to the average freeze-up date (e.g., January 22) reported between 1974 and 1994. The 1992 break-up date was about 2.5 weeks later than the average date of May 4.

Temperature profiles of Naknek drainage lakes measured annually in late July and early August between 1990 and 1992 exhibited no thermocline in these lakes (LaPerriere *In prep*). The strong winds common to this area are believed to circulate the water in these lakes to the bottom, allowing warmer surface waters to be mixed deep into these lakes. The mixing and warming of the lake waters may produce better growth of aquatic organisms in the Naknek drainage lakes than those at similar latitudes that stratify in summer and maintain a cold hypolimnion.

In summary, there appeared to be no extraordinary weather events that would explain the low smolt per spawner production from the record spawning escapement in 1991.

Spawning Distribution

Another factor which may have affected the freshwater survival of salmon from the 1991 brood year was the distribution of spawners on the spawning grounds.

The historical aerial survey data base of salmon spawning grounds in the Naknek River drainage is sporadic and inconsistent. ADF&G and NPS personnel have identified only six major spawning

areas in the Naknek River drainage (e.g., American Creek, Hardscrabble Creek, Margot Creek, Idavin Creek, Brooks River, and Headwaters Creek). Salmon spawning has been documented in other small streams in this drainage; however, most are very difficult or nearly impossible to evaluate more than a few hundred yards in the lower reaches by aerial survey due to dense overhanging vegetation and/or meandering of the creek bed (D. Bill, NPS, King Salmon, personal communication).

Despite the lack of a good aerial survey spawner distribution data for this system, the observer who flew the Naknek drainage on August 20-21, 1991 documented numerous concentrations of salmon in places where they had not been reported in the past (J. Regnart, ADF&G, King Salmon, personal communication; Appendix B.1). In addition, although the traditional spawning areas appeared to be utilized fully at the time of the surveys, large numbers of schooling salmon observed at the mouths of creeks and in the lower reaches of tributaries suggested that egg superimposition may have been a major problem in 1991 as subsequent waves of fish moved in to spawn on top of existing redds (J. Regnart, ADF&G, King Salmon, personal communication). Therefore, sockeye salmon egg survival may have been reduced in 1991 by the limited availability of suitable spawning areas.

Juvenile Survival

Other factors which could have affected the freshwater survival of juvenile salmon were shortages of food, lack of suitable rearing habitat, disease, and predation. No specific studies were conducted to evaluate freshwater survival of different salmon life stages in the Naknek River drainage following the 3.6 million escapement in 1991.

Age and size composition estimates of smolt from the 1991 brood escapement did not indicate that freshwater growth was less than average for the progeny of the 1991 escapement. The mean length and mean weight of the age-1. and -2. smolt from the 1991 brood year were not significantly smaller than what has been observed in the past. Also the proportion of age-2. smolt from the 1991 brood year was not significantly higher than past brood years. However, the mean length and mean weight of age-1. smolt from the 1992 brood year was slightly below average ($p=0.06$). This may be an indication of negative brood year interaction between brood years 1991 and 1992.

Mathisen and Farley (1995) concluded from their studies of Becharof Lake and Ugashik Lakes (e.g., neighboring Bristol Bay lakes) that large escapements in one year or small escapements in another year should not cause concern. The sockeye salmon spawning escapement goal of 1.0 million fish for the Naknek River system has been greatly exceeded only once (e.g., in 1991 due to a commercial fisherman's strike, Table 14). Prior to and after the 3.6 million escapement in 1991 the escapements to the Naknek River drainage have been relatively constant The 1981-1990 (10-year) spawning escapement range was 0.9 to 2.1 million fish with an average of 1.4 million fish. Since 1991, the spawning escapements to the Naknek River drainage have ranged from 1.0 to 1.6 million fish and the average is 1.3 million fish. Mathisen and Farley (1995) went on to say that more important changes come when there is a series of consecutive large or small escapements.

Freshwater Nutrient Additions

Water quality studies conducted annually in late July and early August of 1990-1992 in six large lakes and selected inlets and streams of the Naknek River drainage by LaPerriere (*In prep*) reported that total nitrogen and total phosphorus were both elevated in 1991 in two Brooks Lake inlet streams (e.g., Headwaters Creek and Up-a-Tree Creek) when a record escapement of sockeye salmon returned to the Naknek drainage. However, nutrient data collected in Brooks, Naknek, and Coville lakes in 1991, suggested that these lakes may be nitrogen limited (LaPerriere *In prep*). LaPerriere's (*In prep*) nitrogen values were lower in 1991 than in 1992 and phosphorus values were slightly but not significantly higher.

In 1991, a record number of sockeye salmon spawners entered the Naknek River drainage. After these fish spawned and died, a record number of salmon carcasses remained in the lakes and streams. No direct measurements were made of the effects that this large number of carcasses had upon the availability of nutrients for fish populations. However, Mathisen and Farley (1995). analysis of smolt samples collected from nearby Becharof Lake in 1992 for marine derived nitrogen (Delta N-15) suggested that the value of salmon carcasses as lake fertilizers was small compared to other lakes like Lake Iliamna (Kline et al. 1993). Without a similar marine derived nitrogen analysis of smolt from the Naknek River drainage, it is difficult to quantify the value of sockeye salmon carcasses as fertilizer in this drainage or to evaluate their effect upon production.

Salmon Fishery Management Implications

The current point escapement goal for the Naknek River is 1.0 million sockeye salmon and the escapement goal range is 0.8 million to 1.4 million. Actual escapements into the Naknek River have averaged 1.7 million for the past 10 years. The current escapement goal was established in 1984 and was based on historical spawner-recruit data, limited smolt data, and studies of available spawning habitat.

Updated spawner-recruit and juvenile information are continuously analyzed and escapement goals for all Bristol Bay rivers are periodically reviewed to determine if they remain appropriate or if adjustments are required. The point escapement goal and ranges for the Naknek River were most recently re-evaluated during a 1994 workshop sponsored by ADF&G. During that workshop all available spawner-recruit and smolt data were analyzed. Stock-recruitment models did not adequately explain the observed relationships between spawners and returns, consequently a precise estimate of the numbers of spawners required to produce maximum sustained yield (MSY) was not possible. However, spawner-return and smolt information did indicate that high production was sustainable when the numbers of spawners ranged from 0.8 million to 2.0 million.

The results of the 1993-1994 Naknek River smolt enumeration studies were presented and discussed at the 1994 Bristol Bay sockeye escapement goal workshop. The significantly fewer numbers of smolt per spawner from the 1991 brood year indicated that sockeye production was

reduced from an escapement of 3.6 million. If the trend of reduced smolt production for the 1991 brood year is substantiated by return information in 1995-1997, it will give additional evidence that escapements greater than 2.0 million produce lower overall returns and less yield than escapements in the 1.0 million to 2.0 million range. However, the size and age composition of smolt from the 1991 brood year were not statistically different from historical means; therefore, there is some question whether the estimates of the numbers of smolt were accurate. Because of the potential error in the estimate of smolt numbers, workshop participants thought it prudent to wait for the actual returns from the 1991 brood escapement prior to evaluating production from 3.6 million spawners.

Participants in the 1994 escapement goal workshop recommended no changes to the Naknek River sockeye escapement goal. They felt that the current escapement range was for the most part supported by spawner-recruit and smolt information. They also agreed that the available spawner-recruit data suggested that the point goal and/or the range could possibly be increased, however the group recommended waiting until returns from recent high escapements could be analyzed before making any changes. Because the 1991 escapement was the greatest observed escapement for the Naknek River, it will be a very influential data point when fitting production curves to estimate optimum escapements. The estimates of smolt production from the 1991 escapement will increase the accuracy and precision of Naknek River forecasts for returning runs in 1995 through 1997.

Evaluating escapement goals is an ongoing process for the Alaska Department of Fish and Game. Procedures for establishing, reviewing, modifying, and documenting escapement goals are outlined in the Department's salmon escapement goal policy. Escapement goals are reviewed as new scientific information or techniques become available, or as new user groups or allocative issues arise. The Department's escapement goal policy states that the Department, unless otherwise directed by regulation, will manage Alaska's salmon fisheries, to the extent possible, for MSY. However, as fishery scientists around the State move towards ecosystem management, the needs of all users of Naknek River salmon, human and dependent biota, should be given consideration when setting escapement goal levels.

Future Study Needs

The Naknek River smolt sonar program should be repeated on an annual basis over a 10-15 year period to properly evaluate the trends between spawning escapements, smolt production, and adult salmon returns in this drainage.

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Appendix A.1. Meteorological data for King Salmon, Alaska, July 1991 - June 1992.

	1991[a]						1992[b]					
	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Temperature (°F)												
Max	76.0	70.0	63.0	54.0	50.0	39.0	42.0	35.0	42.0	56.0	73.0	66.0
Avg	55.2	53.7	50.7	37.2	23.1	15.1	17.7	3.1	22.0	32.4	42.7	52.6
Min	41.0	32.0	34.0	13.0	-4.0	-18.0	-18.0	-31.0	-34.0	1.0	14.0	34.0
30-Year Mean	54.7	54.0	47.2	33.4	22.3	14.2	14.1	14.9	21.3	31.4	42.7	50.4
Percipitation (inches)												
Water Equivalent - Total	1.02	1.79	2.10	1.99	1.34	1.26	0.79	0.92	1.40	0.19	0.74	2.53
- Greatest (24 h)	0.46	0.36	0.45	0.91	0.36	0.41	0.23	0.28	0.55	0.12	0.36	0.61
- Date	30	18-19	9-10	2-3	23	1-2	29-30	23-24	23-24	17	29-30	27-28
30-Year Mean	2.17	3.1	2.86	2.10	1.47	1.25	1.04	0.88	1.08	0.93	1.21	1.55
Snow, ice, hail - Total	0.0	0.0	0.0	Trace	9.0	9.4	7.2	8.6	8.7	0.5	Trace	Trace
- Greatest (24 h)	0.0	0.0	0.0	Trace	3.6	1.5	2.3	2.8	2.9	0.3	Trace	Trace
- Date			30	23	23	9-10	29-30	23-24	23-24	10	13	22
30-Year Mean	0.0	0.0	Trace	3.1	6.2	8.6	7.8	6.8	7.4	4.7	1.0	Trace
Wind												
Resultant - Direction (!!)	202	207	131	083	041	122	051	360	082	019	339	147
- Speed (mph)	5.3	0.9	9.6	5.2	7.6	1.8	6.0	4.3	3.6	7.0	2.3	6.0
Average Speed	10.0	9.2	14.6	12.2	13.2	10.4	11.6	8.7	11.1	10.6	10.3	10.6
Fastest Obs. 1 Min.												
- Direction (!!)	15	17	11	11	12	15	09	23	11	09	13	09
- Speed (mph)	25	25	40	44	35	40	40	18	31	29	32	28
- Date	15	15	22	31	1	13	16	28	18	14	6	4
30-Yr Mean Direction & Speed	S 10.1	S 10.2	S 10.7	N 10.5	N 10.7	N 10.6	N 10.7	N 11.2	N 11.4	NNW 11.1	S 11.2	SW 10.9
30-Yr Fastest Obs. 1 Min												
- Direction (!!)	08	08	09	14	09	09	09	14	09	16	09	14
- Speed (mph)	49	46	62	53	71	55	48	53	69	46	48	48

[a] Source - National Weather Service (1991).
[b] Source - National Weather Service (1992).

Appendix A.2. Monthly temperature summaries for King Salmon, Alaska, January to March 1992. [a]

	January				February				March			
	Temperature (°F)				Temperature (°F)				Temperature (°F)			
Date	Max	Min	Avg	Departure from Normal	Max	Min	Avg	Departure from Normal	Max	Min	Avg	Departure from Normal
1	25	18	22	11	-9	-25	-17	-31	3	-34	-16	-32
2	29	18	24	13	-5	-23	-14	-28	16	-24	-4	-20
3	27	11	19	8	-5	-31	-18	-32	8	-15	-4	-20
4	20	-11	5	-6	21	-16	3	-11	0	-19	-10	-26
5	38	20	29	18	15	6	11	-3	8	-9	-1	-17
6	37	27	32	21	6	-16	-5	-19	18	0	9	-8
7	30	10	20	8	5	-19	-7	-21	42	17	30	13
8	32	12	22	10	32	1	17	3	41	23	32	15
9	24	18	21	9	35	30	33	19	41	31	36	19
10	27	11	19	7	31	9	20	6	41	30	36	19
11	34	15	25	13	20	4	12	-2	31	17	24	7
12	39	34	37	25	20	-2	9	-5	25	15	20	2
13	42	33	38	26	16	-7	5	-9	27	15	21	3
14	41	31	36	24	25	6	16	2	42	12	27	9
15	36	20	28	15	17	-5	6	-9	41	32	37	19
16	40	26	33	20	13	-5	4	-11	41	26	34	15
17	40	31	36	23	1	-10	-5	-20	39	33	36	17
18	32	17	25	12	2	-12	-5	-20	37	31	34	15
19	24	11	18	5	6	-12	-3	-18	40	34	37	17
20	15	3	9	-4	-1	-22	-12	-27	35	23	29	9
21	29	5	17	4	1	-10	-5	-20	27	19	23	3
22	37	14	26	13	1	-9	-4	-19	41	26	34	13
23	34	-1	17	4	10	-11	-1	-16	41	33	37	16
24	32	-4	14	1	20	7	14	-1	40	33	37	16
25	33	4	19	6	20	3	12	-3	33	25	29	7
26	5	-2	2	-11	18	10	14	-2	28	12	20	-2
27	-2	-13	-8	-21	19	10	15	-1	22	3	13	-10
28	1	-15	-7	-21	15	1	8	-8	30	-1	15	-8
29	0	-8	-4	-18	7	-30	-12	-28	36	2	19	-4
30	-1	-12	-7	-21					30	9	20	-4
31	-5	-18	-12	-26					40	21	31	7
Monthly			18	5			3	-12			22	3

[a] Source - National Weather Service (1992a, 1992b, 1992c)

Appendix A.3. Ice covered dates for Naknek Lake, 1970 - 1995.

Winter Of	Freeze-up Date [a] (dd/mmm)	Julian Day	Break-up Date [a] (dd/mmm)	Julian Day	Total Days of Ice Cover	Comments [a]
1969-70						
1970-71						Long, cold winter.
1971-72						
1972-73			18-May	138		
1973-74						
1974-75	01-Feb	32				
1975-76	02-Jan	2				Still frozen 05-May
1976-77	27-Jan [b]	27	03-Mar	62	36	
1977-78						
1978-79						
1979-80						
1980-81						
1981-82	04-Dec	27	25-May	145	171	
1982-83						
1983-84	13-Feb	44				
1984-85	08-Feb	39	14-May	134	96	
1985-86	18-Jan	18	02-May	122	104	
1986-87	02-Jan	2				
1987-88						50% open 01-Feb
1988-89	23-Dec	8				
1989-90	26-Dec	5	22-May	142	146	
1990-91	02-Dec	29				
1991-92	20-Jan	20	22-May	143	122	
1992-93	20-Jan	20	27-Apr	117	97	70% open 07-Apr
1993-94	16-Feb	47	04-May	124	78	Partially frozen 09-Jan, but opened back up.
1994-95	19-Dec	12	27-Apr	117	128	
Total		332		1244		
Min	02-Dec		03-Mar		36	
Avg	22-Jan	22	04-May	124	109	
Max	16-Feb		25-May		171	

[a] Most data is anecdotal, provided by pilots from local air charter companies (R. Russell, Alaska Department of Fish and Game, King Salmon, personal communication).

[b] Last date area was observed with open water; may have frozen over even later.

Appendix B.1. Naknek River system sockeye salmon spawning distribution aerial survey estimated counts, August 20-21, 1991. [a]

Date	Location	Aerial Survey Estimate (Nos. of Fish) Schooling	Spawning	Dead	Total
8/20/91	Naknek Lake				
	NW shore, Ck mouth W of peninsula	350	-	-	350
	NW shore, beaches	-	0	-	0
	Idavan Ck, 70% of reach below the falls	4,200	18,400	1,130	23,730
	Bay of Islands Ck	-	0	-	0
	S shore, Bay of Islands to Naknek R	-	0	-	0
	S shore, Ck 7 mi. W of Dumpling Mt.	-	~500	-	~500
	Lakes Coville and Grosvenor				
	Waterway - most at Lk Grosvenor end	-	3,500	-	3,500
	Lake Coville				
	N shore, 1st Ck - heading E	-	1,000	-	1,000
	N shore, 2nd Ck - heading E	-	400	-	400
	N & S shore, beaches	-	0	-	0
	American Ck, flats below mouth [b]	6,700			6,700
	American Ck, mouth to Hammersly Lk [b]	15,900	40,800	35,230	91,930
	Hammersly Lake	-	0	-	0
	Ck adjoining Hammersly/Murray Lks - lower half [b]	-	300	650	950
8/21/91	Lake Grosvenor				
	NW beach, spawning site #1	-	2,000	-	2,000
	NW beach, spawning site #2	-	6,800	-	6,800
	NW beach, spawning site #3	-	1,200	-	1,200
	Hardscrabble Ck, mouth to 6 mi.	2,200	11,600	-	13,800
	Hardscrabble Ck, 6 mi.to headwaters	[c]	[c]	[c]	
	Grosvenor R, near outlet of Grosvenor Lk	1,200	-	-	1,200
	Savonoski River				
	Wolverine Ck - falls down to mouth	900	2,800	-	3,700
	Naknek Lake				
	Iliuk Arm, S shore beaches	-	0	-	0
	Iliuk Arm, Margot Ck	2,000	3,500	-	5,500
	Cabin Ck	-	1,800	-	1,800
	Brooks Lake				
	Brooks River	[d]	[d]	[d]	
	Headwaters Ck, mouth	400	-	-	400
	Headwaters Ck, in the creek	5,300	12,300	400	18,000

[a] Source - Jeff Regnart, ADF&G, King Salmon, personnel communiction.

[b] Recommend future surveys be flown on August 10 and August 20

[c] No survey conducted due to turbulance.

[d] National Park Service personnel request that this area not be surveyed. Brooks River know to be a major spawning area in the Naknek Lake system.