PART 1

The Migration and Growth of Juvenile Salmon in the Susitna River

THE MIGRATION AND GROWTH OF JUVENILE SALMON IN THE SUSITNA RIVER

Report No. 7, Part 1

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ABSTRACT

Studies of salmon spawning, embryo incubation, and juvenile rearing are all critical in understanding the current life history and habitat dynamics of salmon in the Susitna River. However, the final measure of the value of a reach of river to the freshwater life stages of salmon is the number and condition of the fry which outmigrate from the reach to the ocean. Baseline data on salmon outmigration have been collected at Talkeetna Station (river mile 103.0) for the past three years. The data from 1982 and 1983 have shown that a substantial number of chinook, coho, and sockeye fry outmigrate from the middle river during their first summer. Because the majority of returning adults have spent at least one winter rearing in freshwater, an important question was whether these age 0+ fish overwintered in the lower river or had a low survival rate. To help answer this question, outmigrant traps were also operated near the mouth of the Susitna River (RM 22.4) during 1984. Mark and recapture studies gave population estimates for chum and sockeye fry (marked by coded wire tags) in the Susitna River above Talkeetna Station (middle river) and for chinook fry (marked by cold branding) in Indian River and other rearing sites. The cold branding study also monitored outmigration timing from Indian River and obtained estimates of juvenile chinook residence time in mainstem rearing areas. The Talkeetna River and Deshka River were intermittently sampled to help explain the mainstem outmigrant trap data. A portion of the age 0+ chinook fry apparently outmigrate from the middle river upon reaching a critical size but a large number remain to overwinter and then outmigrate during their second summer. Coho fry outmigrate at a wider range of lengths than chinook fry so the cumulative biomass of coho fry lags behind the cumulative numbers of individuals by one or two weeks. Age 0+ chinook and coho fry grow about 30 mm in length during the

open-water season. Juvenile sockeye salmon appear to seek out lake-like rearing areas at a size of about 50 mm. The limited amount of this habitat type in the middle river is the major influence on their redistribution to the lower river. The estimated 1984 middle river population size was about 300,000 for age 0+ sockeye and 2,040,000 for chum fry. Chum fry rearing in the middle river was demonstrated by their growth and by analysis of stomach contents.

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1.0 INTRODUCTION

Studies of the migration and growth of juvenile salmon in the mainstem Susitna River are a part of the ongoing investigations being conducted by the Resident and Juvenile Anadromous Fish Project (RJ) of the Susitna River Aquatic Studies Program. The scope of these studies has been to describe the periods of freshwater residence, growth, and timing of outmigration for juvenile salmon in the Susitna River and to provide population estimates for the reach of river between the Chulitna River confluence and Devil Canyon. This report presents the results of juvenile salmon outmigration studies conducted on the Susitna River between Cook Inlet and Devil Canyon during the 1984 open-water season. Five Pacific salmon species are addressed in this report: chinook (Oncorhynchus tshawytscha), coho (O. kisutch), sockeye (O. nerka), chum (O. keta), and pink (O. gorbuscha).

Investigations of the distribution, abundance, and migration of juvenile salmon during 1982 and 1983 were focused primarily on the Susitna River reach above the Chulitna River confluence (ADF&G 1983a; Schmidt et al. 1984). These studies included the operation of stationary outmigrant traps at Talkeetna Station, river mile (RM) 103.0, during 1982 and 1983 and a mark-recapture program for post-emergent chum and sockeye salmon fry using half-length coded wire tags in 1983 (Roth et al. 1984). These techniques have provided valuable information on the success of previous spawning runs, the effect of discharge on redistribution of young-of-the-year salmon juveniles, and the population size and egg-to-outmigrant fry survival rates for chum and sockeye salmon fry.

During the 1984 open-water season, additional tasks were added to further describe juvenile salmon growth, migration timing, and response to changing habitat conditions. The study area was expanded to include the entire river between Cook Inlet and Devil Canyon. New tasks begun in 1984 were the addition of stationary and mobile outmigrant traps at Flathorn Station (RM 22.4), intermittent trapping of migrating chinook salmon juveniles in the Deshka and Talkeetna rivers, and mark-recapture by cold branding of juvenile chinook and coho salmon in the Curry Station to Devil Canyon reach.

Investigations of the migration and growth of juvenile salmon in the Susitna River above the Chulitna River confluence during 1982 and 1983 indicated extensive migration of pre-smolt juveniles of all species to areas below this reach. This migration of pre-smolt chinook salmon was also observed in the Deshka River in 1980 (Delaney et al. 1981). If this movement is common in the major tributaries entering the Susitna River, extensive rearing and growth of juvenile salmon, particularly chinook, may occur in habitats associated with the mainstem river. Small habitat changes in the reach of river below Talkeetna could impact large numbers of rearing salmon.

The combined studies of juvenile salmon growth and migration conducted during the 1984 open-water season were developed to provide data to meet the following objectives:

- Estimate the timing, relative abundance, and size of outmigrating juvenile salmon in the Susitna River above the Chulitna River confluence.

- Estimate the population size of outmigrating chum and sockeye salmon fry and egg-to-outmigrant fry survival in this reach of river.

- Estimate the timing and size of outmigrating chum salmon from the Talkeetna River.

- Estimate the timing and rate of movement of juvenile chinook and coho salmon out of Indian River and their residence time at selected macrohabitats associated with the mainstem Susitna River.

- Estimate the timing and rate of outmigration of chinook salmon juveniles from the Deshka River into the mainstem Susitna.

- Estimate the timing and rate of outmigration of juvenile salmon from the Susitna River into Cook Inlet.

- Estimate the rate of growth of juvenile chum and chinook salmon from the time they enter the lower river (below the Chulitna River confluence) until they enter the marine environment.

- Estimate the relationship of mainstem Susitna discharge and other environmental variables to juvenile salmon outmigration.

Sampling of chum salmon fry in the Talkeetna River was hindered by equipment failure; insufficient data were collected for this species, although some growth and relative abundance data for chinook salmon were collected.

Although initially designed as a survey of Portage Creek using a stationary outmigrant trap, the cold branding study was relocated to Indian River with minnow traps serving as the primary collection technique. The design of the original collection equipment did not lend itself well to the continually fluctuating hydraulic conditions present at Portage Creek. The low numbers of juvenile salmon observed in Portage Creek after June 15, combined with the comparative logistical inaccessibility of this stream, made Indian River a better choice.

The data presented in this report provide information that can be used to determine the size of the present fishery resource, potential changes caused by the proposed hydroelectric development, and mitigation requirements necessary to compensate for any reductions of the juvenile salmon populations in the Susitna River.

2.0 METHODS

2.1 Study Locations

Studies on the migration and growth of juvenile salmon in the mainstem Susitna River were conducted at survey sites from Flathorn Station (RM 22.4) upstream to Slough 22 (RM 144.3) during the 1984 open-water season (Fig. 1).

2.1.1 Flathorn Station

A stationary outmigrant trap was operated on the west bank of the Susitna River at Flathorn Station (RM 22.4) and a mobile outmigrant trap was used to sample a total of ten points along transects spanning three channels of the mainstem river at this station (Fig. 2). Five sampling points were located in the west channel (RM 22.8), one in the middle channel (RM 22.8), and four in the east channel (RM 23.9). A bottom profile of the Susitna River at these sampling points is provided in Fig. 3.

2.1.2 Deshka River

An outmigrant fyke net weir was operated in the Deshka River (RM 40.6) between tributary river mile (TRM) 2.5 and TRM 5.0 to estimate the timing and rate of outmigration for juvenile chinook salmon (Fig. 4).

2.1.3 Talkeetna River

A beach seine sampling site for outmigrants was located in the north channel of the Talkeetna River (RM 97.5) approximately one mile upstream from the river's mouth (Fig. 5).

2.1.4 Talkeetna Station

Two stationary outmigrant traps were deployed on the mainstem Susitna River above the Chulitna River confluence at Talkeetna Station (RM 103.0) at the same locations used in 1983. One trap was set off the east bank (Trap 1) and the other off the west bank (Trap 2) of the river (Fig. 5).

2.1.5 Coded wire tagging

Coded wire tagging sites were selected from those locations above the Chulitna River confluence where high density spawning by adults was recorded (Barrett et al. 1984), and from surveys of the availability of sufficient numbers of post-emergent chum and sockeye salmon fry for collection and tagging (Fig. 5). Specific coded wire tagging sites (Fig. 6) were:

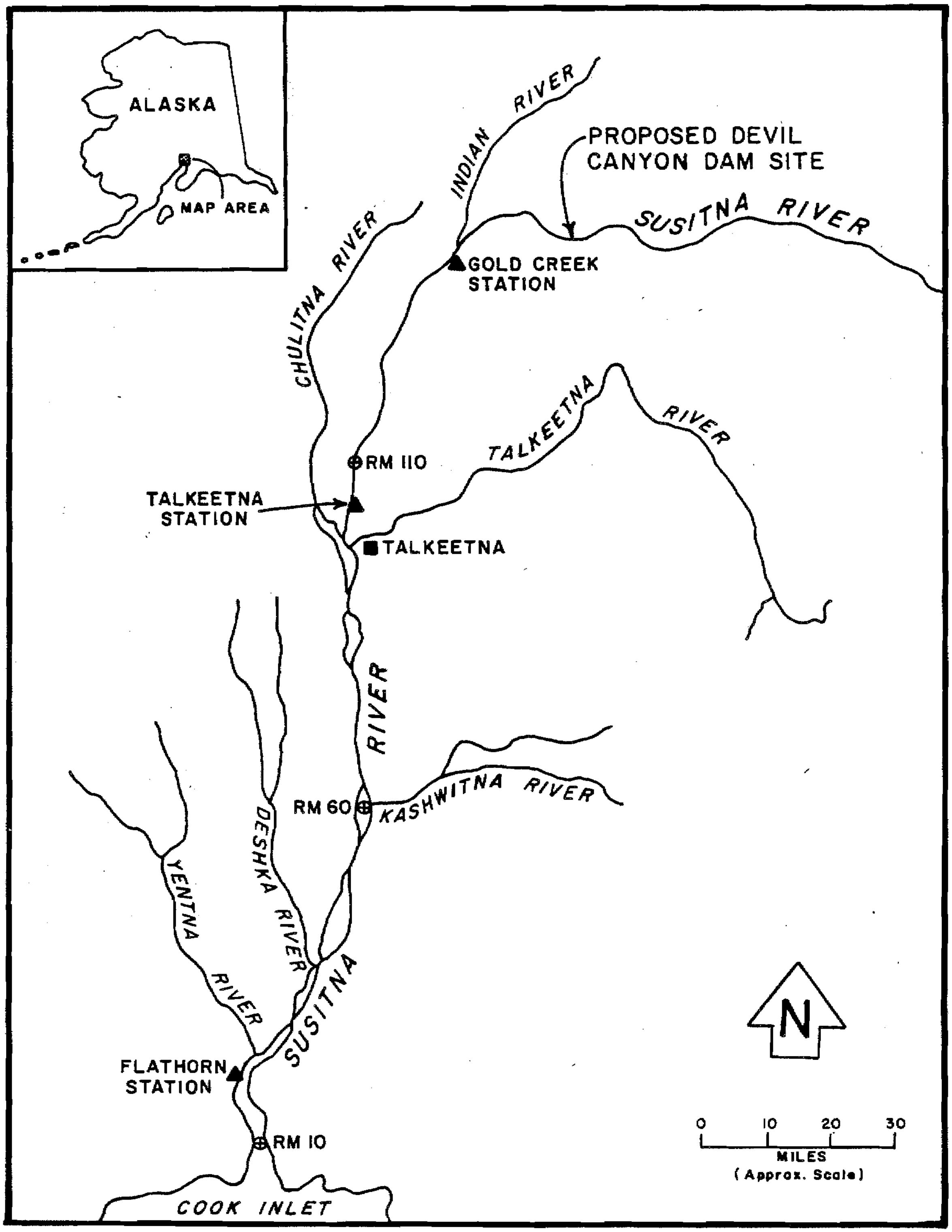


Figure 1. Map of juvenile salmon outmigration study field stations in the Susitna River basin, 1984.

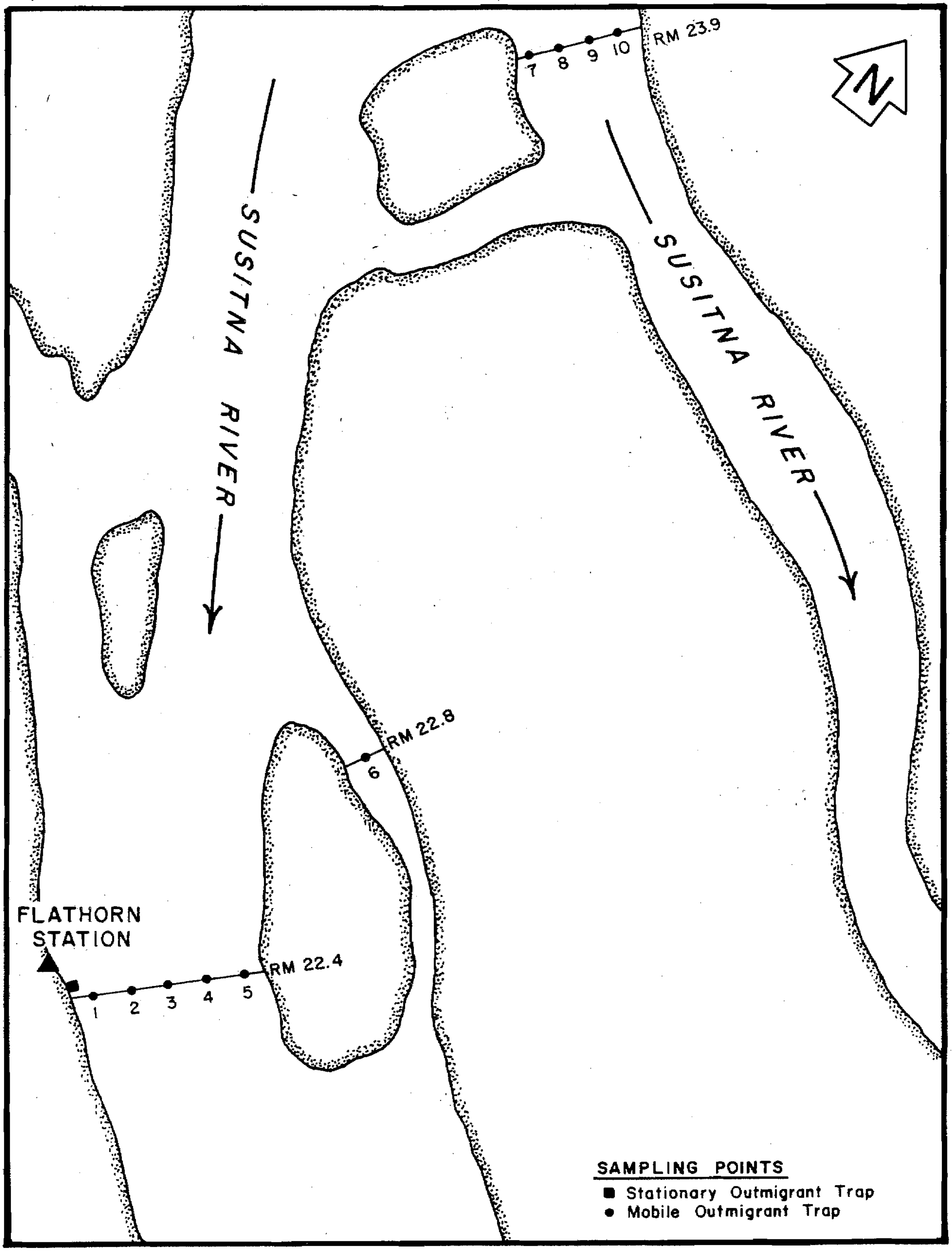


Figure 2. Map of the stationary outmigrant trap and the mobile outmigrant trap sampling points on the Susitna River at Flathorn Station, 1984.

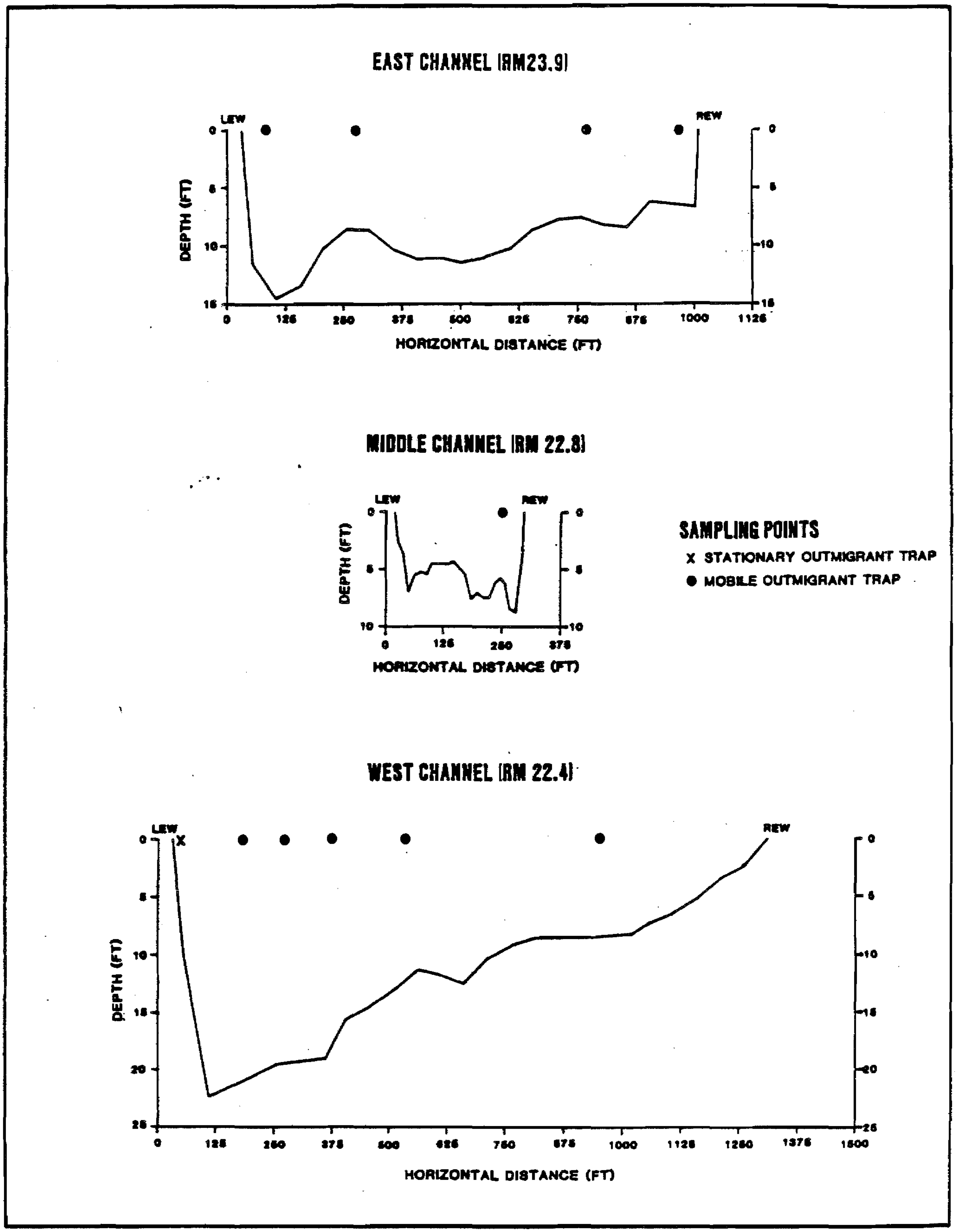


Figure 3. Bottom profile of the Susitna River at the stationary and mobile outmigrant trap sampling points at Flathorn Station. Measured on August 23, 1984 at a mainstem discharge of 114,000 cfs at the USGS gaging station at Susitna Station.

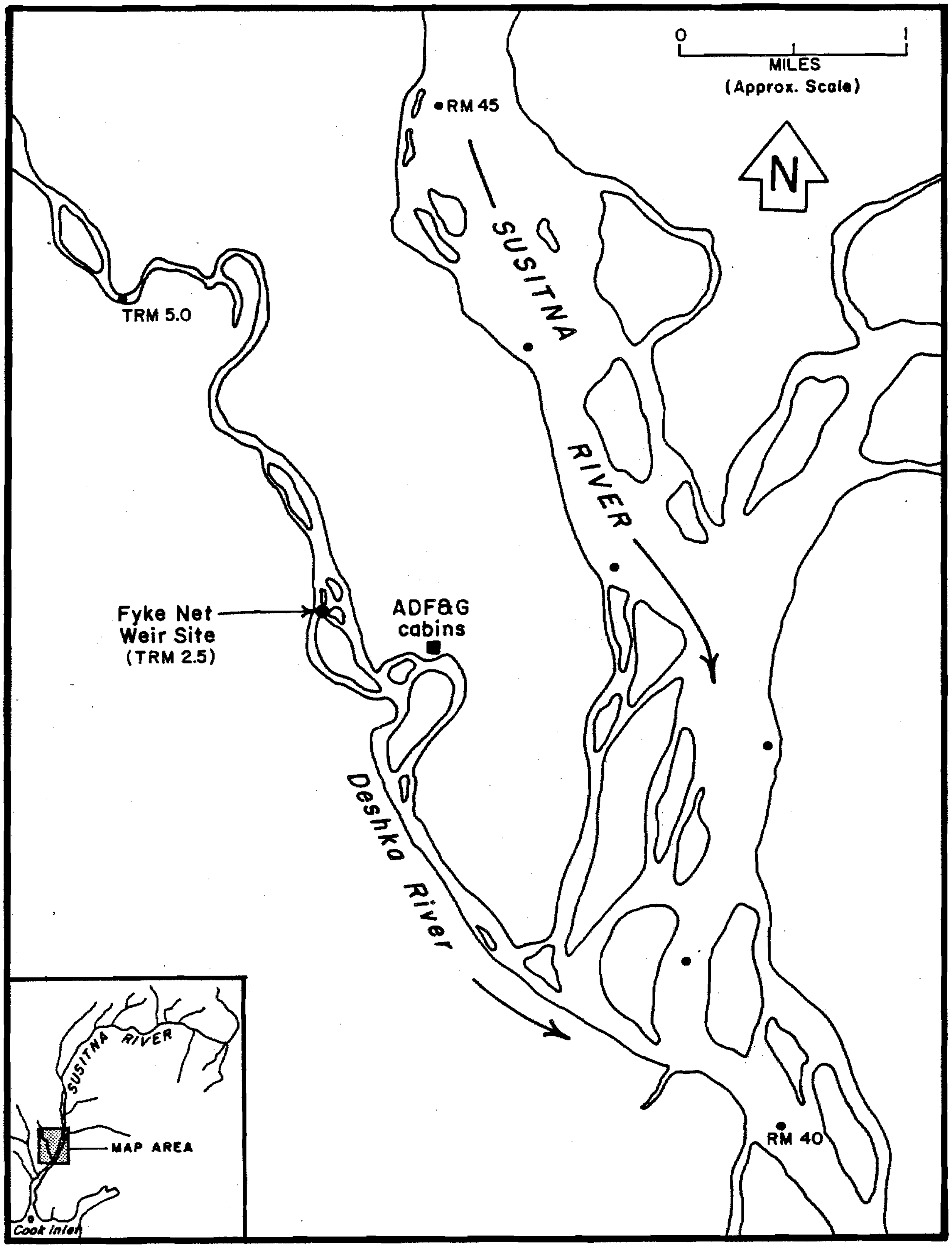


Figure 4. Map showing the location of the fyke net weir on the Deshka River, 1984.

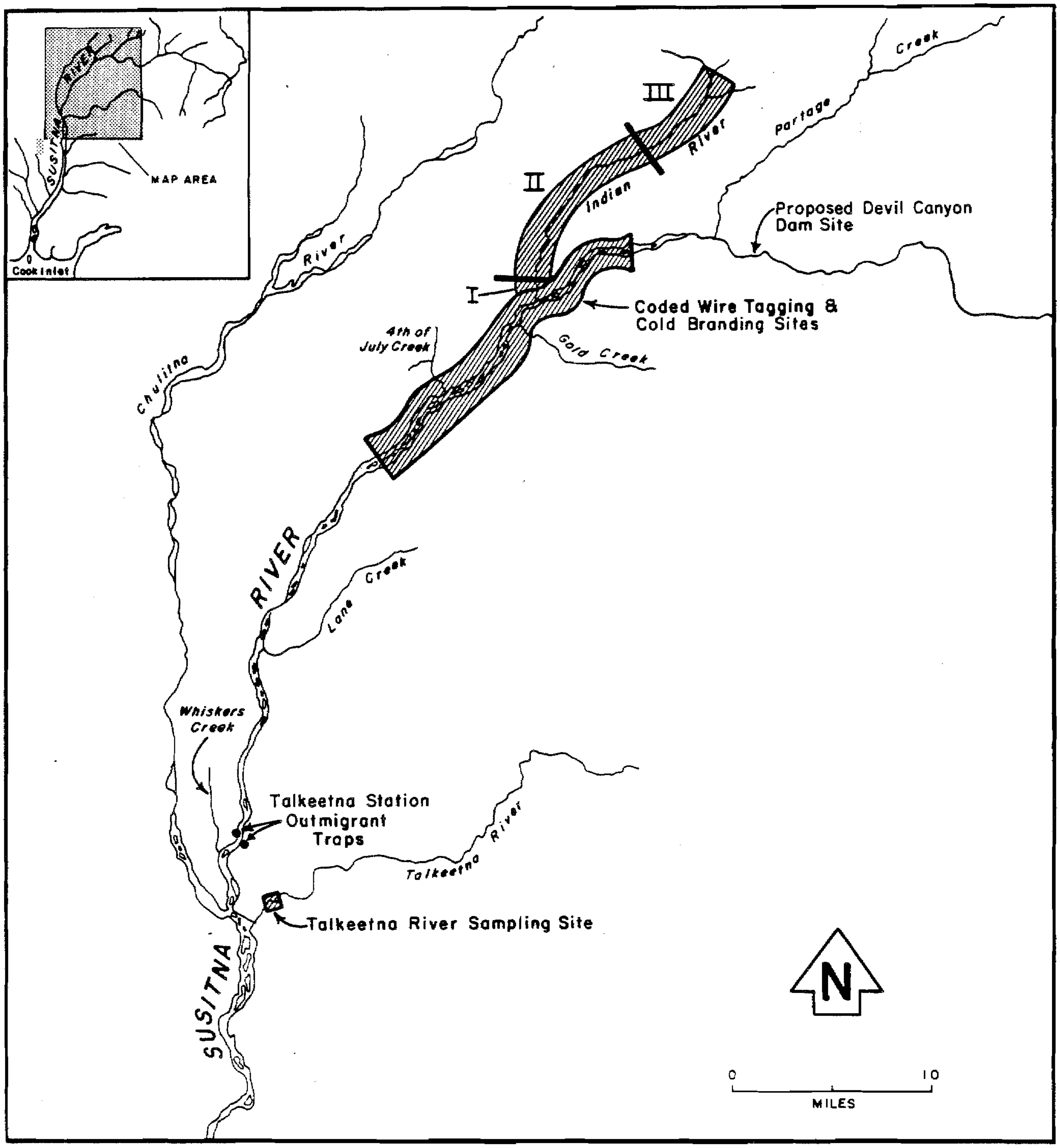


Figure 5. Map showing the reach where juvenile salmon mark-recapture sites are located (RM 122.2 to 144.8 and Indian River) and the locations of the Talkeetna stationary outmigrant traps (RM 103.0), and the Talkeetna River sampling site (TRM 1.0), 1984.

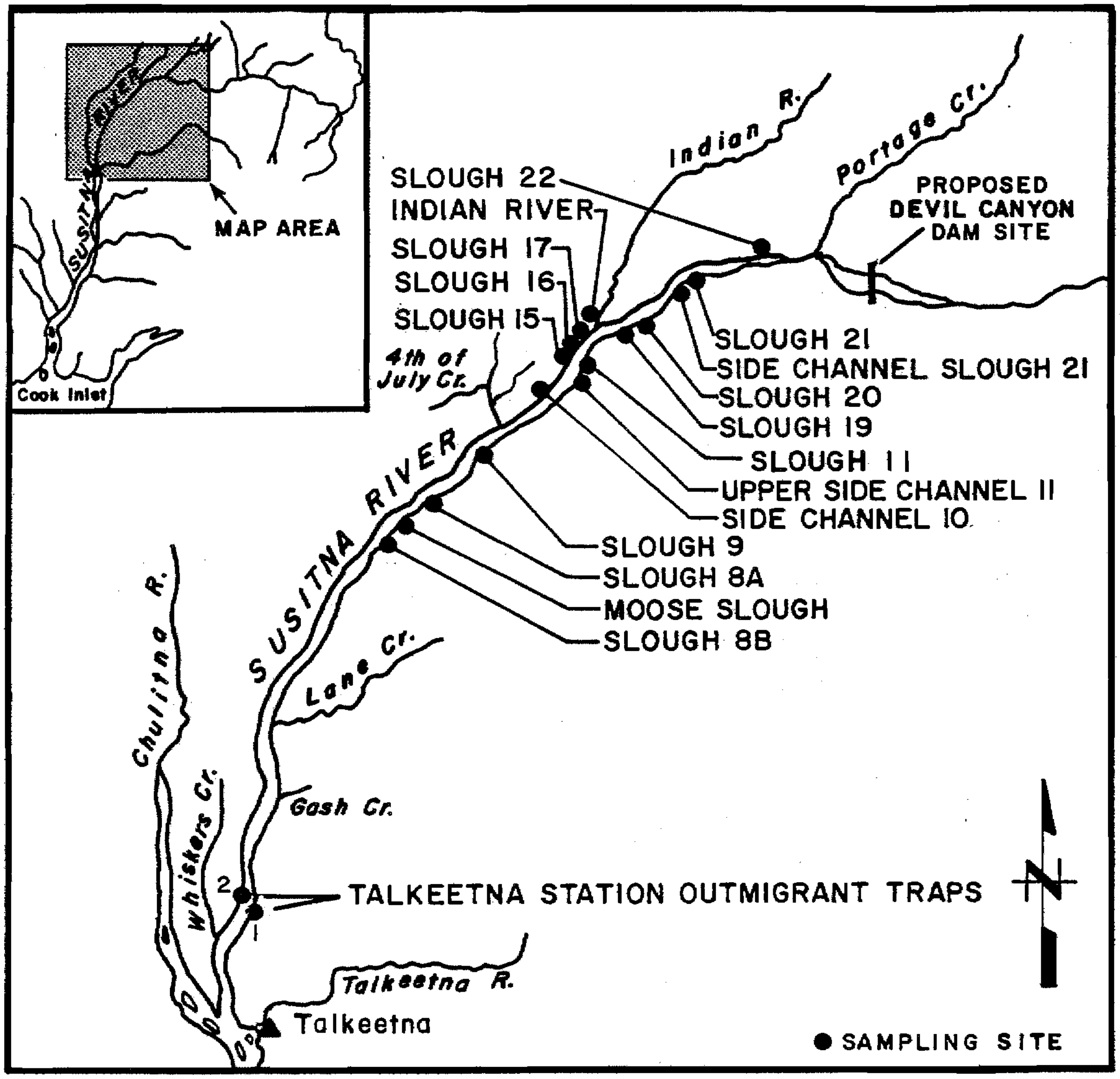


Figure 6. Map of coded wire tagging and cold branding sites in the middle reach of the Susitna River, 1984.

CODED WIRE TAGGING SITES	RIVER MILE
Slough 8B	122.4
Slough 8A	125.3
Slough 9	129.2
Slough 11	135.3
Slough 15	137.3
Indian River	138.6
Slough 20	140.1
Slough 21	142.0
Slough 22	144.3

2.1.6 Cold branding

A cold brand mark-recapture study was conducted at the mouth and at numerous side channels and side sloughs of Indian River (RM 138.6) which were found to contain large concentrations of juvenile chinook and coho salmon. Indian River was divided into three sections for this study. Section I included the mouth upstream to TRM 0.5, Section II was the portion of Indian River from TRM 0.5 to 7.5 and Section III was from TRM 7.5 upstream to TRM 12.3 (Fig. 5).

Cold branding was also used to estimate the populations and study the movements of juvenile salmon at the following study sites (Fig. 6):

COLD BRANDING SITES	RIVER MILE
Moose Slough	123.2
Side Channel 10	133.8
Lower Side Channel 11A	135.9
Slough 16	137.7
Slough 17	138.9
Slough 19	139.7
Slough 20	140.1
Side Channel 21	141.1
Slough 22	144.3

2.2 Field Data Collection and Recording

2.2.1 Flathorn Station outmigrant traps

The stationary outmigrant trap on the west bank of the Susitna River at Flathorn Station (RM 22.4) was operated from May 20 through October 1, 1984. A description of this outmigrant trap is provided in ADF&G (1985). The trap was checked at least twice each day to remove the captured fish and to clean the trap.

The mobile outmigrant trap at Flathorn Station was operated for 43 days during the period July 12 through September 13, 1984. A description of the trap and its operation is presented in ADF&G (1985). The trap was fished for 20-minute periods at ten different transect points during a fishing day.

Habitat and biological data recorded for each check of the stationary outmigrant trap included fishing effort (hours), trap depth (feet), distance from shore (feet), and catch by species and age class. Mainstem stage was recorded once each day. The first 25 fish of each species and age class collected daily were measured for total length (tip of snout to tip of tail) in millimeters (mm).

Biological and habitat data for the stationary trap were entered directly into an Epson HX-20 microcomputer in the field. Operational procedures for the microcomputer and the associated data form program are presented in ADF&G (1985). Computer entries were made for each trap check throughout the field season. Printouts and cassettes were periodically transferred to Data Processing to be entered into a mainframe computer for later data retrieval and analysis.

Transect number, fishing effort, total water column depth, set velocity, and drift velocity (if the trap was not held stationary during the set) were recorded for each individual transect point at which the mobile outmigrant trap was fished. Total catch by species and age class was also recorded, and total length measurements were taken for all captured fish. Data were recorded on a field data form for later analysis.

2.2.2 Deshka River outmigrant weir

A weir was established on the Deshka River (RM 40.6) using a fyke net (3/16 inch square mesh) to block a portion of the river. The fyke net is described in ADF&G (1985). The weir was operated at varying tributary miles (TRM 2.0 - 5.0) periodically from May 10 through June 22. The weir was moved to TRM 2.5 on July 11 and was fished periodically through September 18. Minnow traps were fished intermittently from late June through mid October to supplement the weir data.

Fishing effort and total catch by species and age class were recorded for the outmigrant weir and the minnow traps. A sample of each species and age class captured were measured for total length and scale samples were collected for age determination.

2.2.3 Talkeetna River beach seining

Beach seining (1/8 inch square mesh) was conducted one to two times each week from June 5 through September 15. Sampling was conducted to obtain a sufficient sample for comparative length and outmigration timing data. An attempt was made to use a Fyke net weir in late May and June. This did not work, so we changed to a beach seine.

Total catch by species and age class was recorded. All captured fish were measured for total length and released.

2.2.4 Talkeetna Station outmigrant traps

Two inclined plane outmigrant traps were operated continuously in the mainstem Susitna River at Talkeetna Station (RM 103.0) from May 14 through October 6, 1984 using the methods outlined by Roth et al. (1984).

Measurements of the following habitat parameters were recorded daily at the outmigrant traps: air and surface water temperature (°C), turbidity (NTU), water velocity (ft/sec), and mainstem stage data. The equipment and methods used to collect the habitat data are given in ADF&G (1985).

Trap fishing depths and distances from shore were adjusted to maximize catches while maintaining trap efficiency. All juvenile fish captured were anesthetized using MS-222 (Tricaine methanesulfonate). Field specimens were identified using the guidelines set forth by McConnell and Snyder (1972), Trautman (1973), and Morrow (1980). Juvenile chinook and coho salmon collected at the traps were checked for a cold brand mark and all recovered marks were recorded. Chum and sockeye salmon juveniles with a clipped adipose fin were passed through a detector to verify the presence of a coded wire tag. All coded wire tagged fish recovered at the traps were preserved and tags were later removed and decoded using a reading jig and a binocular microscope. All other fish recovered at the traps were held until anesthetic recovery was complete and then released downstream of the traps.

Scales were collected from a sub-sample of fish captured for comparison to length frequency data for final age class determination. Biological and habitat data were entered directly into an Epson HX-20 microcomputer.

Length and weight relationship data were also collected from samples of juvenile chinook, coho, and sockeye salmon collected in the outmigrant traps at Talkeetna Station. Total length was recorded to the nearest millimeter and live weights were determined to the nearest 0.1 gram.

2.2.5 Coded wire tagging

The coded wire tagging was conducted at Slough 11 (RM 135.3) from May 16 through June 20, 1984. The fish were transported from the collection areas to Slough 11 in an aerated tub, tagged, held for at least 24 hours, and then returned to the collection areas. The fish were also held overnight at the collection areas prior to release.

Beach seines were used to weir off the downstream end of the collection area and were checked at least once each day to collect fish and remove debris. Beach seining and dip netting supplemented the weir catches at sites where weiring alone did not provide enough fish for the tagging operation.

The coded wire tagging equipment and implantation procedures are similar to those outlined by Roth et al. (1984) using the guidelines provided by Koerner (1977) and Moberly et al. (1977). One-half length binary coded wire tags measuring 0.02 inches (0.533 mm) in length and 0.01 inches (0.254 mm) in diameter were used in the study. Separate head molds were required for each species and length class of fish. Fifty fish of each group were measured to determine mean length and the proper head molds for the tagging procedure. The adipose fin was clipped from each fish prior to tagging to provide a visual indicator of the presence of a coded wire tag. At the end of each tagging day, a subsample of 100 tagged fish were anesthetized and passed through the quality control device to determine the tag retention rate. Mortalities were recorded the following day and again just prior to release. A single tag code was used for each species tagged and for each collection site. Six distinct tag codes were used for juvenile sockeye salmon and fourteen distinct tag codes were used for juvenile chum salmon.

Coded wire tagging data recorded at each site included date tagged, tag code, species, number of fish tagged, percent tag retention, mortality, and date and time of release. Total numbers of fish tagged by species, collection site, and release date as well as final tag retention and mortality were tabulated for each tag code.

2.2.6 Cold branding

Mark-recapture studies of chinook and coho salmon populations were conducted from July through mid October. Cold branding was used as a marking technique because it is less expensive than coded wire tagging. Cold branding was not used on chum and sockeye because it has not been proven effective on these fish at the post-emergent stage. Sites in Indian River were sampled twice a month and fish were captured, branded, and released continually throughout the field season. Sampling in the sloughs and side channels of the Susitna River was conducted for five consecutive days and captured fish were either branded and released the same day or held until the end of the five day period before release.

Minnow traps, beach seines, and dip nets were used to capture fish which were then transported from the areas of collection to the Gold Creek field camp for cold brand marking. Cold branded fish from all sites except Indian River were held for 24 hours to determine marking mortality before being released at the area of collection. Fish collected in Indian River were marked, held for 24 hours, and then released at a side slough at TRM 7.2.

The brands consisted of single brass letters or symbols measuring approximately three millimeters in height which were soldered onto threaded brass caps. Liquid nitrogen was used as the cooling agent and branding procedures were similar to those outlined by Raleigh et al. (1973). The cold branding equipment is described in ADF&G (1985).

Juvenile chinook and coho salmon were marked with a distinctive brand to signify the collection site and date of their capture. Fish were marked on one side of the body at one of three target branding areas (Fig. 7), and a branding time of two seconds was used.

Date, collection site, gear type, fishing effort, species, number of fish captured, and brand symbol were recorded for each site. The number of recaptures by species and the symbols for previously marked fish were also recorded. Total length was measured for 50 fish of each species during each sampling trip.

2.3 Data Analysis

2.3.1 Juvenile salmon catch per unit effort

The catch per unit effort (CPUE) data collected for juvenile salmon at the stationary outmigrant traps are presented as the average catch per hour for each calendar day of sampling effort. The catch was expanded to 24-hour intervals by dividing the number of hours fished on a given day into 24 and then multiplying this ratio by the catch for each species and age class.

The catch rates plotted for each species and age class of juvenile salmon collected at the stationary traps were smoothed using the von Hann linear filter (Dixon et al. 1981). The equation is:

$$Z_{(t)} = \tfrac{1}{4}Y_{(t-1)} + \tfrac{1}{2}Y_{(t)} + \tfrac{1}{4}Y_{(t+1)}$$

where: $Z_{(t)}$ = smoothed catch per hour for day (t) and

$Y_{(t)}$ = observed catch per hour for day (t)

This is similar to a three day moving average except that the current day is weighted twice as heavily as the preceding and subsequent days.

The cumulative catch totals were adjusted for days not fished by tabulating the mean of the total catches recorded for the three days preceding and the three days following an unsampled day.

Length frequency distribution and scale analysis data were used to determine the age class composition of chinook, coho, and sockeye salmon juveniles.

A regression was done on the natural logarithm of weight versus the natural logarithm of length for chinook, coho, and sockeye salmon. The regression equations were used to provide estimates of the total biomass passing the Talkeetna and Flathorn station outmigrant traps by sampling period through the season.

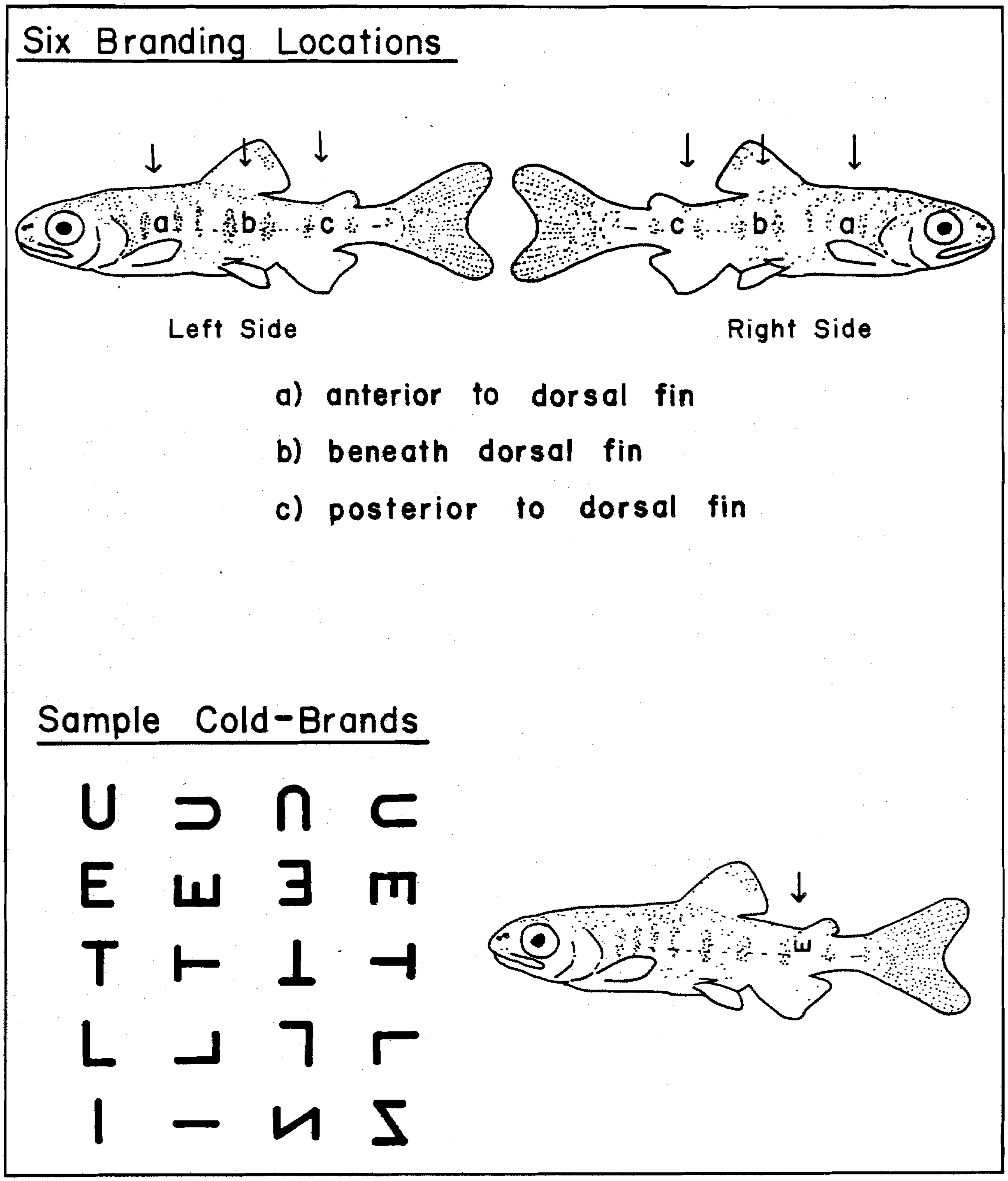


Figure 7. Branding locations and sample brands used for cold branding chinook and coho salmon juveniles, 1984.

2.3.2 Population and survival estimates

Potential egg deposition for chum and sockeye salmon was calculated by multiplying the average fecundity for each species by the estimated number of female spawners that passed Curry Station in 1983 (Barrett et al. 1984). The chum, sockeye, and chinook salmon adult population estimates were reduced by 40%, 39%, and 7% respectively, to account for milling fish which eventually spawned below the Chulitna River confluence (Barrett 1984; Barrett et al. 1984). The following formula was used to determine egg deposition:

$$\text{Total potential egg deposition} = (E) \times (1-M) \times (P) \times (F)$$

where:

E = Adult population estimate at Curry Station
M = Proportion milling
P = Proportion females
F = Average fecundity

Population estimates for chum and sockeye outmigrants were calculated by the Schaefer (1951) method (Appendix B). Estimates of survival for both species were determined by dividing the population estimates by the calculated potential egg deposition for each species. Only valid tagged fish were used in the calculations. The total number of valid tagged fish was determined by subtracting the mortalities for each day of tagging from the total number of fish tagged and then multiplying this by the tag retention rate. Total tag recoveries at the Talkeetna Station outmigrant traps include only those fish with a coded wire tag. Fish having a clipped adipose fin but no tag were not considered in the population estimates.

Population estimates for chinook salmon were calculated from the data collected during the cold branding study by using the Petersen, Schaefer, or Jolly-Seber methods (Ricker 1975). The Schaefer and Jolly-Seber methods were used at sites where conditions allowed five consecutive days of sampling. The Peterson method was used when there was one marking period and one recapture period. Confidence limits for the Jolly-Seber estimate of population size were developed using the method of Manly (1984). The Jolly-Seber model was run on a commercial spreadsheet program for microcomputers. The potential egg deposition for chinook salmon in Indian River was determined using the technique listed above except that the estimate was reduced to represent the percentage of chinook (determined from peak spawning counts) which spawned in Indian River. Fecundities used were those measured by Healy and Heard (1984) for Kenai River chinook salmon.

2.3.3 Time series analysis

The 1983 and 1984 discharge, turbidity, and age 0+ chinook and sockeye salmon outmigration time series are analyzed in Appendix C.

3.0 RESULTS

The results of the juvenile salmon outmigration studies are presented by species. The catch per unit effort (CPUE) data are presented as a percentage of the highest CPUE (after smoothing) recorded at the stationary traps during 1984. The cumulative catch data are presented as a percentage of the total adjusted cumulative catch after application of the smoothing functions. Juvenile salmon length data collected at Flathorn Station are from both the stationary and mobile traps and the length information presented for Talkeetna Station is from both stationary traps located at this site.

3.1 Chinook Salmon

3.1.1 Catch per unit effort

3.1.1.1 Age 0+

Chinook salmon fry collected incidentally during the coded wire tagging study in May and June were observed to be most abundant at Slough 22 and Indian River.

The cold branding study captured 26,823 chinook salmon fry in Indian River from July 1 through October 15. Fifty-eight percent of this catch was recorded near the mouth of the river (section I), 30% in the lower portion (section II) and 12% in the upper portion (section III). Beach seining of sections II and III during July captured 3,280 chinook salmon fry; 66% in section III and 34% in section II. Minnow trapping begun in Indian River in late July collected a total of 23,543 chinook fry during 947 minnow trap days (defined as one trap day for each overnight minnow trap set) for a season average of 24.9 fish per trap day.

Catch rates in Indian River (Fig. 8) were generally highest in section II except during late August when high and turbid water conditions reduced trapping effectiveness. The CPUE for chinook fry in Indian River for all sections combined was highest during late July (average of 36 fish per trap day) and steadily declined through the season to a low of 15 fish per trap day in early October.

A total of 11,875 chinook salmon fry were captured in sloughs and side channels in the middle reach of the Susitna River during the cold branding study from July 1 through October 15. Sloughs accounted for 84% of the catch while the remaining 16% were collected in side channels. Beach seining during July and August collected 39% of the total catch at these sites while minnow trapping begun in early September captured 61% of the chinook fry.

The 7,291 chinook salmon fry captured by minnow trapping at slough and side channel sites in the middle river were collected during 378 minnow trap days for an average of 19 fish per trap day. Mean CPUE by study site ranged from a high of 48 fish per trap day at Slough 22 during early October to a low of 3 fish per trap day at Side Channel 21 in late September.

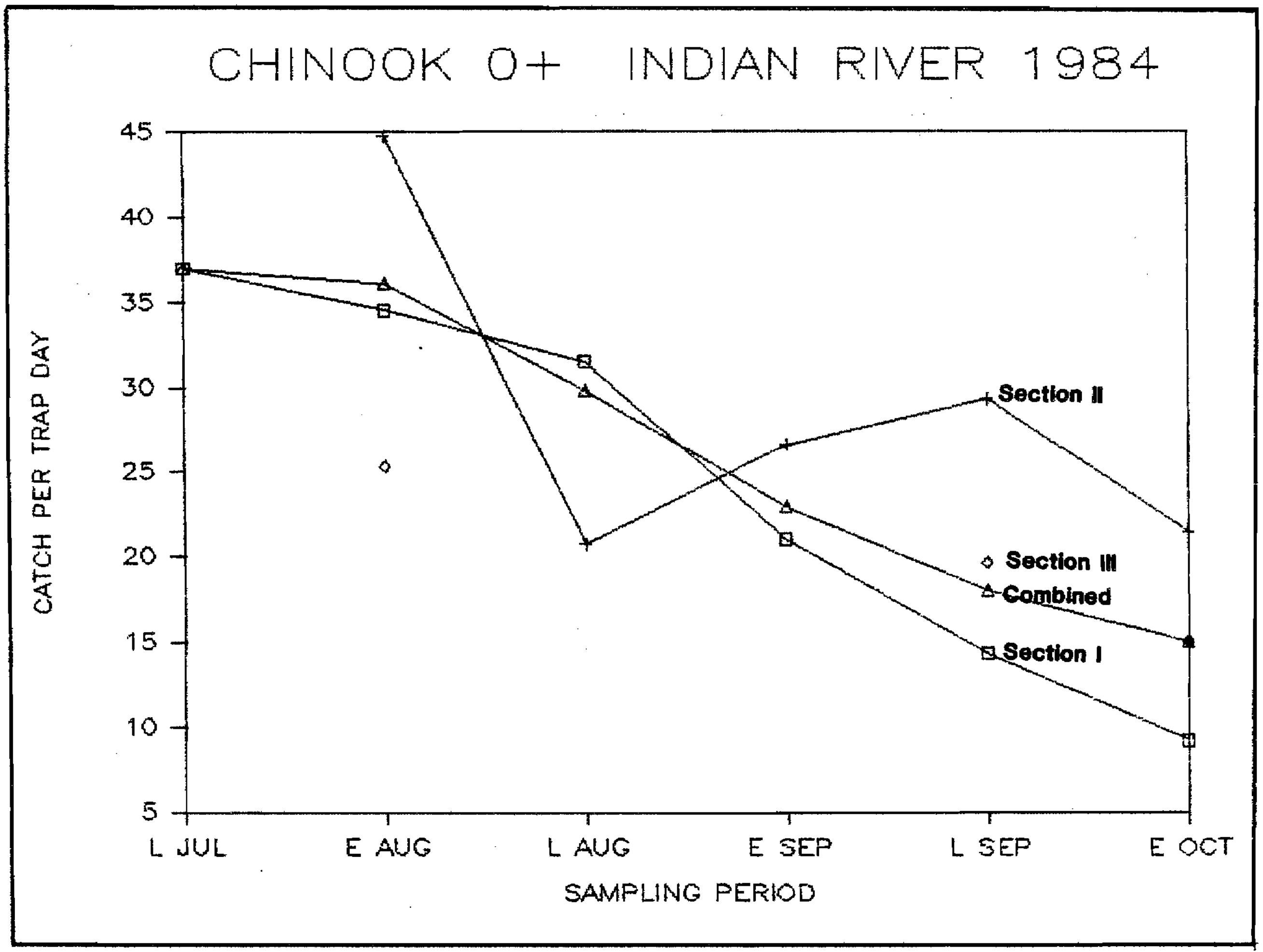


Figure 8. Chinook salmon (age 0+) average catch per minnow trap by sampling period and survey section in Indian River, 1984.

A total of 14,110 chinook salmon fry were collected at the Talkeetna Station outmigrant traps. Peak catches were recorded from late June through early August and the highest catch rate of 17.3 chinook fry per hour was recorded on July 26 (Fig. 9). Fifty percent of the catch was recorded by July 20. Catches decreased after early August and the last capture of chinook fry at this site was recorded on September 29.

A total of 2,118 chinook salmon fry were captured in the stationary outmigrant trap at Flathorn Station. Catch rates were greatest between late June and late August (Fig. 10). The chinook fry catch rate at this site peaked at 7.8 fish per hour on July 23, 50% of the captures were recorded by July 13, and the last capture was recorded on September 30.

The highest catch rate of the Flathorn Station mobile trap was 16.2 fish per hour, recorded on July 23 (Fig. 11). Of the 189 chinook fry collected in the mobile trap during 1984, 60% were captured at bank transect sampling points and the remaining captures occurred at center channel sampling sites (Fig. 12).

The Deshka River weir captured 1,808 chinook salmon during 1984 (Appendix Table A-1). Eighty-eight percent of the captures were recorded during July and the peak catch rate of 21.2 fish per hour was recorded on July 25. Minnow trap catches at this site were highest during late June at 8.7 fish per trap (Appendix Table A-2).

A total of 1,356 chinook salmon fry were collected in the lower reach of the Susitna River by the Juvenile Aquatic Habitat Studies (JAHS) surveys from June through early October (see Part 2 of this report). Catch rates for all sites combined peaked in August and then decreased through early October (Fig. 13).

3.1.1.2 Age 1+

Age 1+ chinook salmon were captured incidentally during the coded wire tagging study in May and June and were most abundant at Indian River and Slough 11. No age 1+ chinook were captured during the cold branding study begun in July, as most of these fish had outmigrated by that time.

Peak catch rates of the 1,321 age 1+ chinook captured at the Talkeetna Station outmigrant traps were recorded during the deployment of the traps in mid May and again in mid and late June (Fig. 14). Fifty percent of the season catches occurred by June 23. The highest catch rate for this age class was 3.6 fish per hour recorded on May 15 and the last age 1+ chinook was captured in the traps on August 7.

Catch rates for the 346 age 1+ chinook salmon captured at Flathorn Station were highest during early June (Fig. 15). The highest CPUE of 6.4 fish per hour was recorded on June 14 (50% of the season total by this date) and the last age 1+ chinook was collected at this site on August 23.

Nine age 1+ chinook salmon were collected in the Deshka River during weir and minnow trap sampling, with the last capture recorded on October 10.

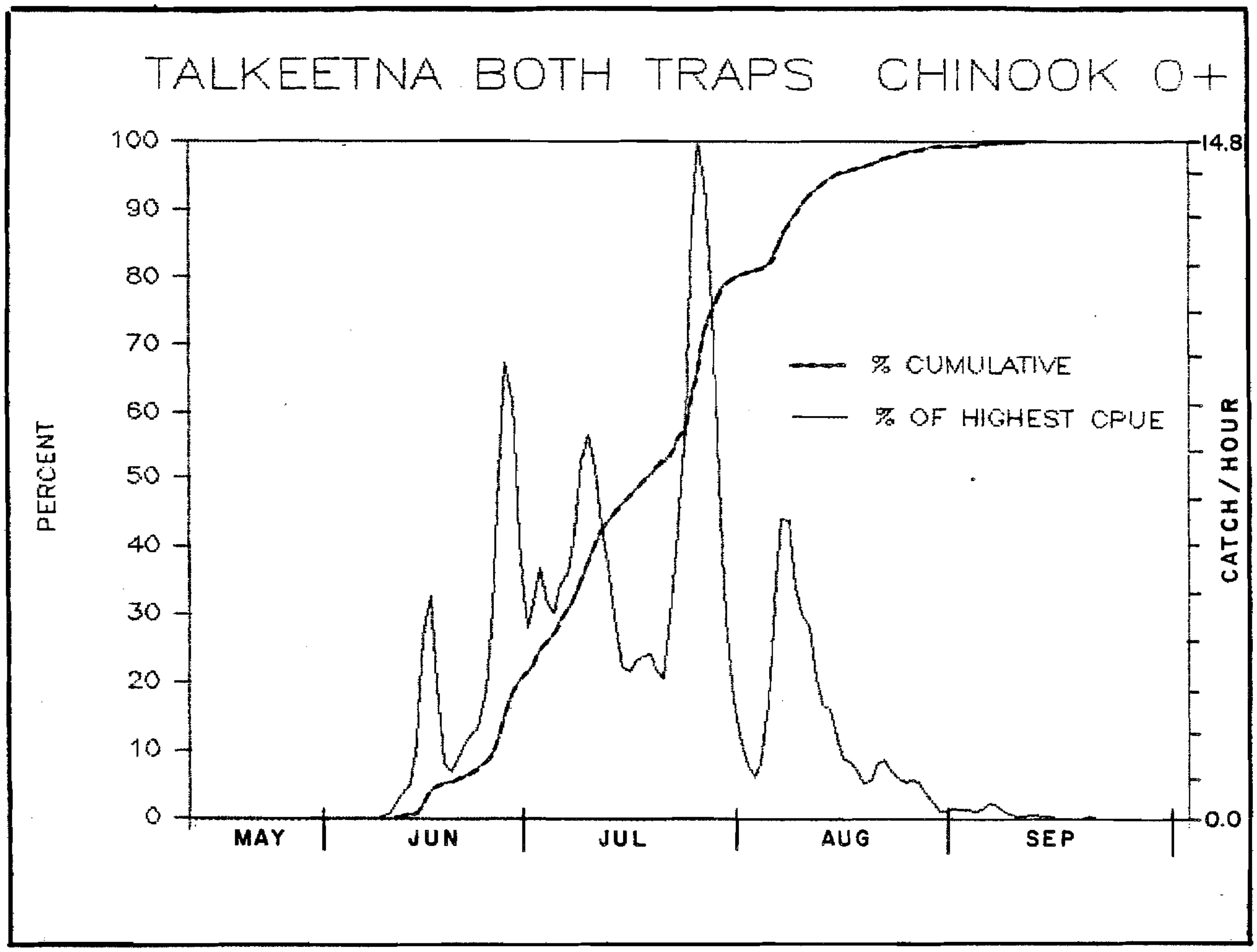


Figure 9. Chinook salmon (age 0+) smoothed daily catch per unit effort and adjusted cumulative catch recorded at the Talkeetna stationary outmigrant traps, May 14 through October 6, 1984.

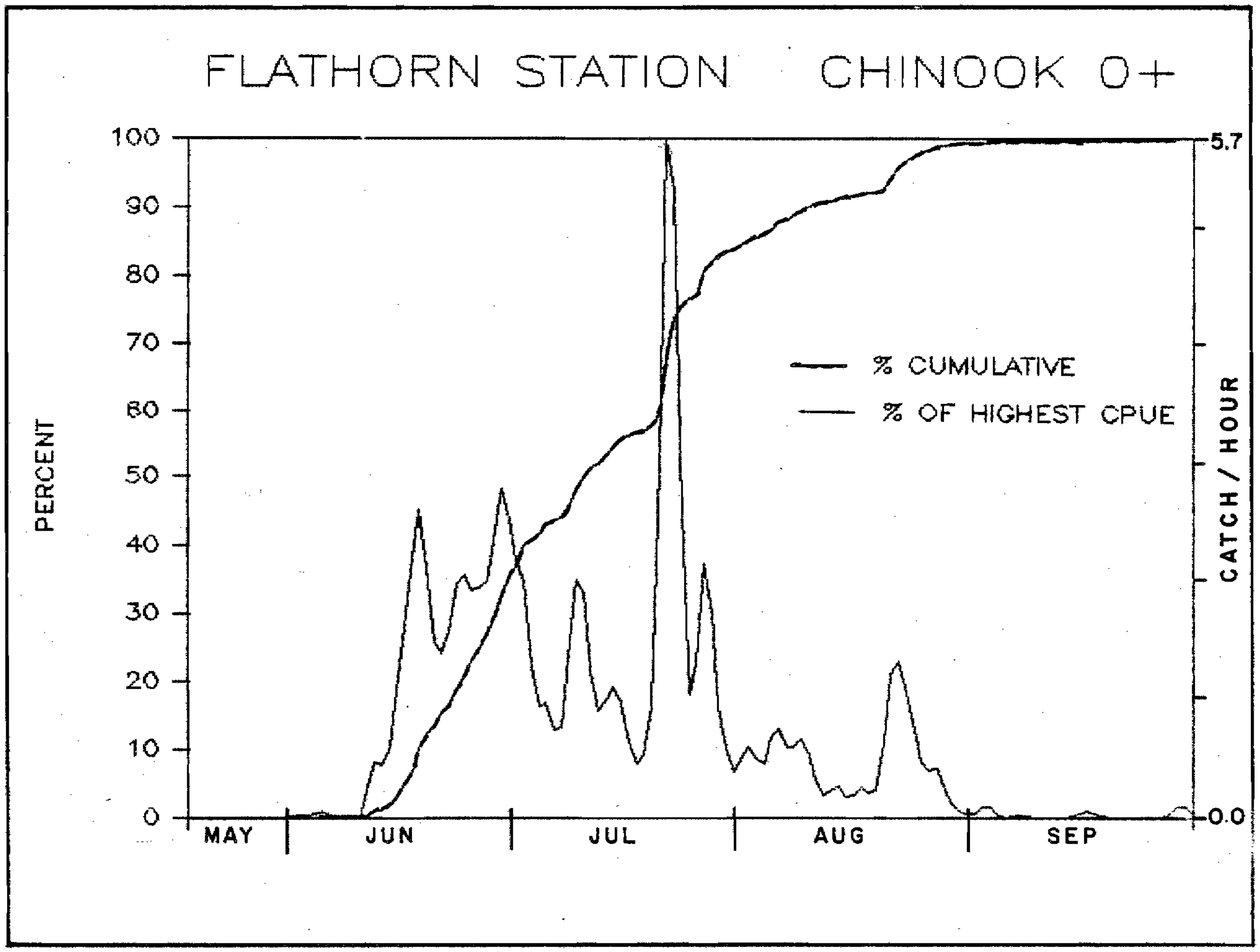


Figure 10. Chinook salmon (age 0+) smoothed daily catch per unit effort and adjusted cumulative catch recorded at the Flathorn stationary outmigrant trap, May 20 through October 1, 1984.

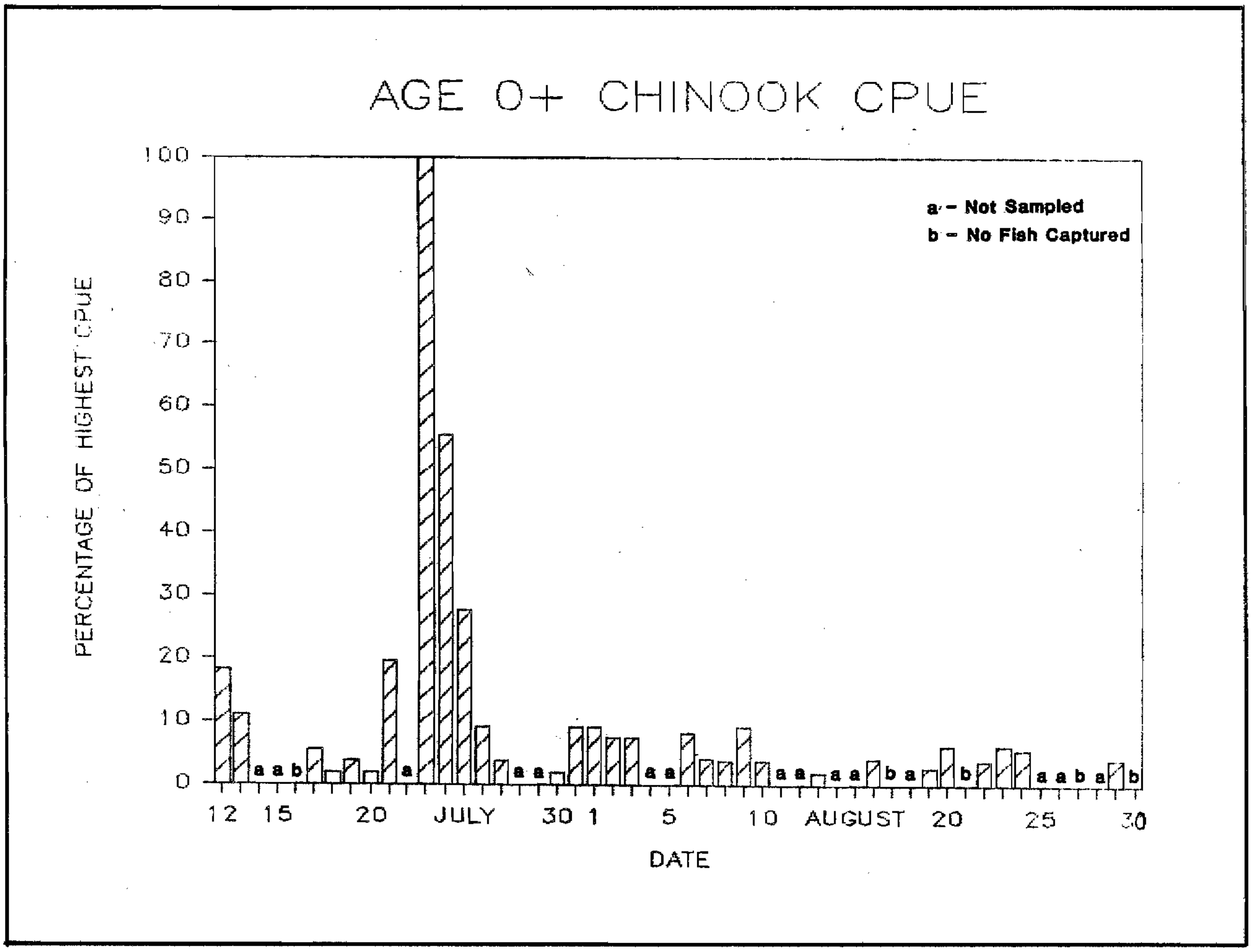


Figure 11. Chinook salmon (age 0+) daily catch per unit effort recorded at the Flathorn mobile outmigrant trap, July 12 through August 30, 1984.

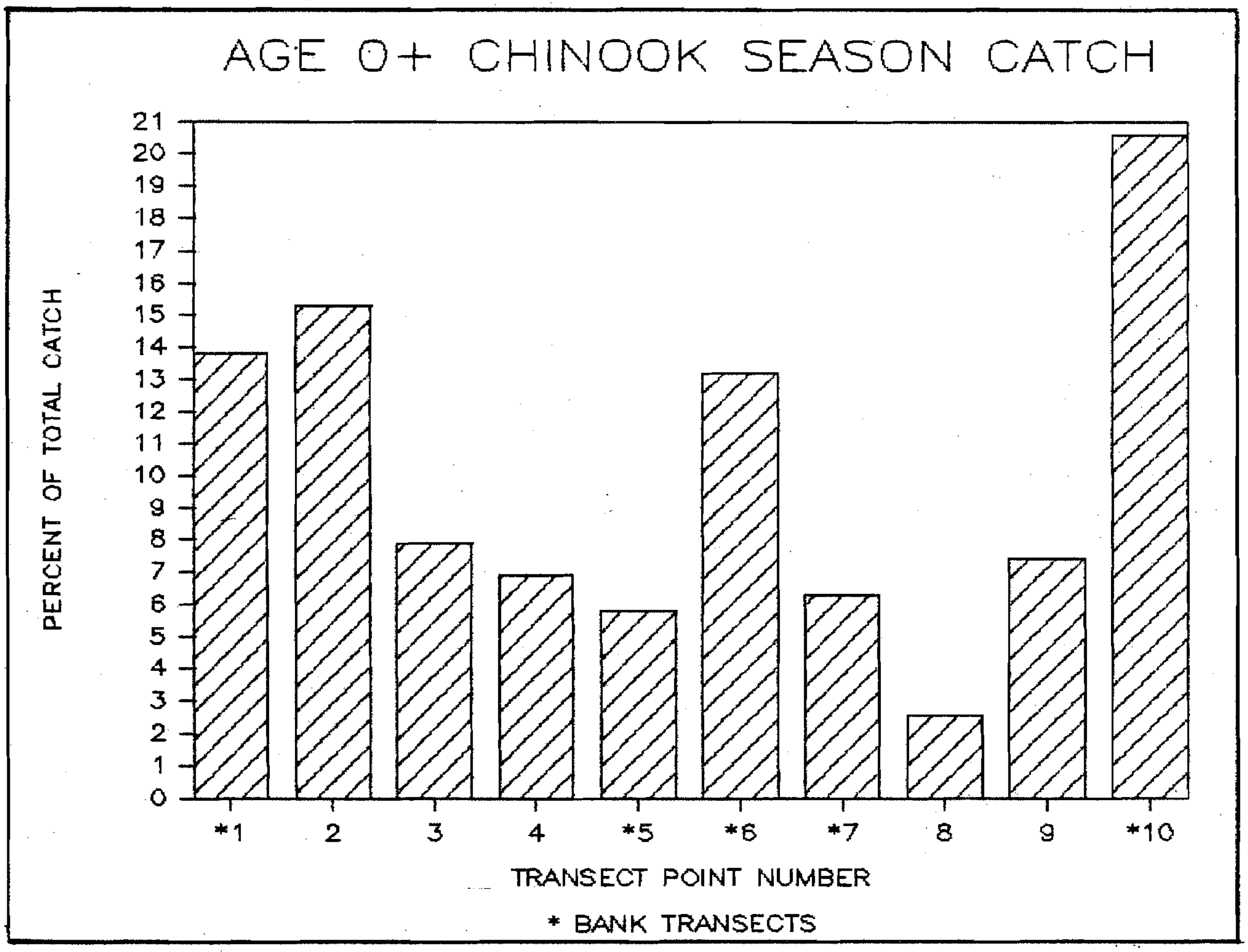


Figure 12. Chinook salmon (age 0+) percent of total catch by sampling point recorded at the Flathorn mobile outmigrant trap, 1984.

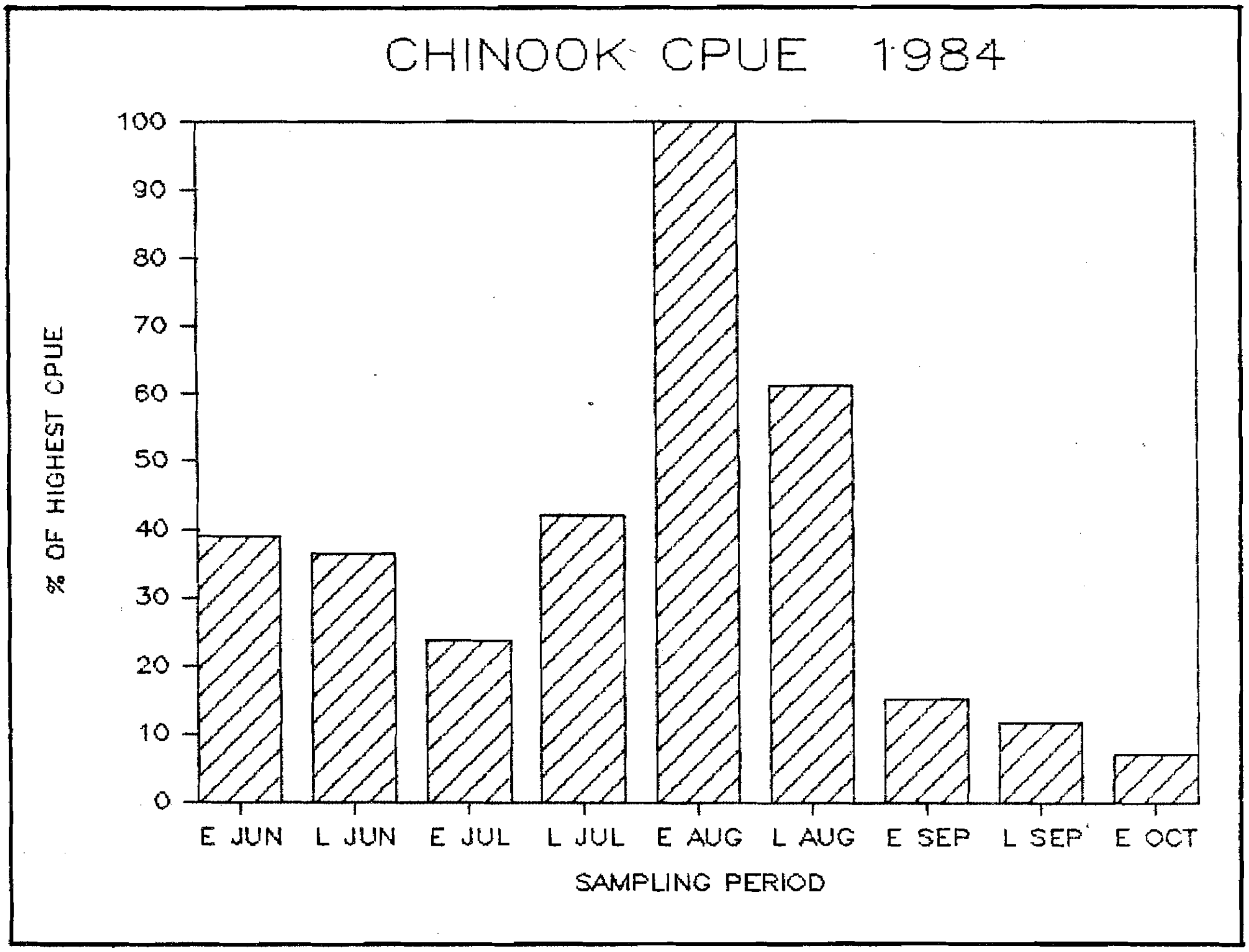


Figure 13. Chinook salmon (age 0+) catch per unit effort by sampling period recorded at JAHS sites in the lower reach of the Susitna River, 1984.

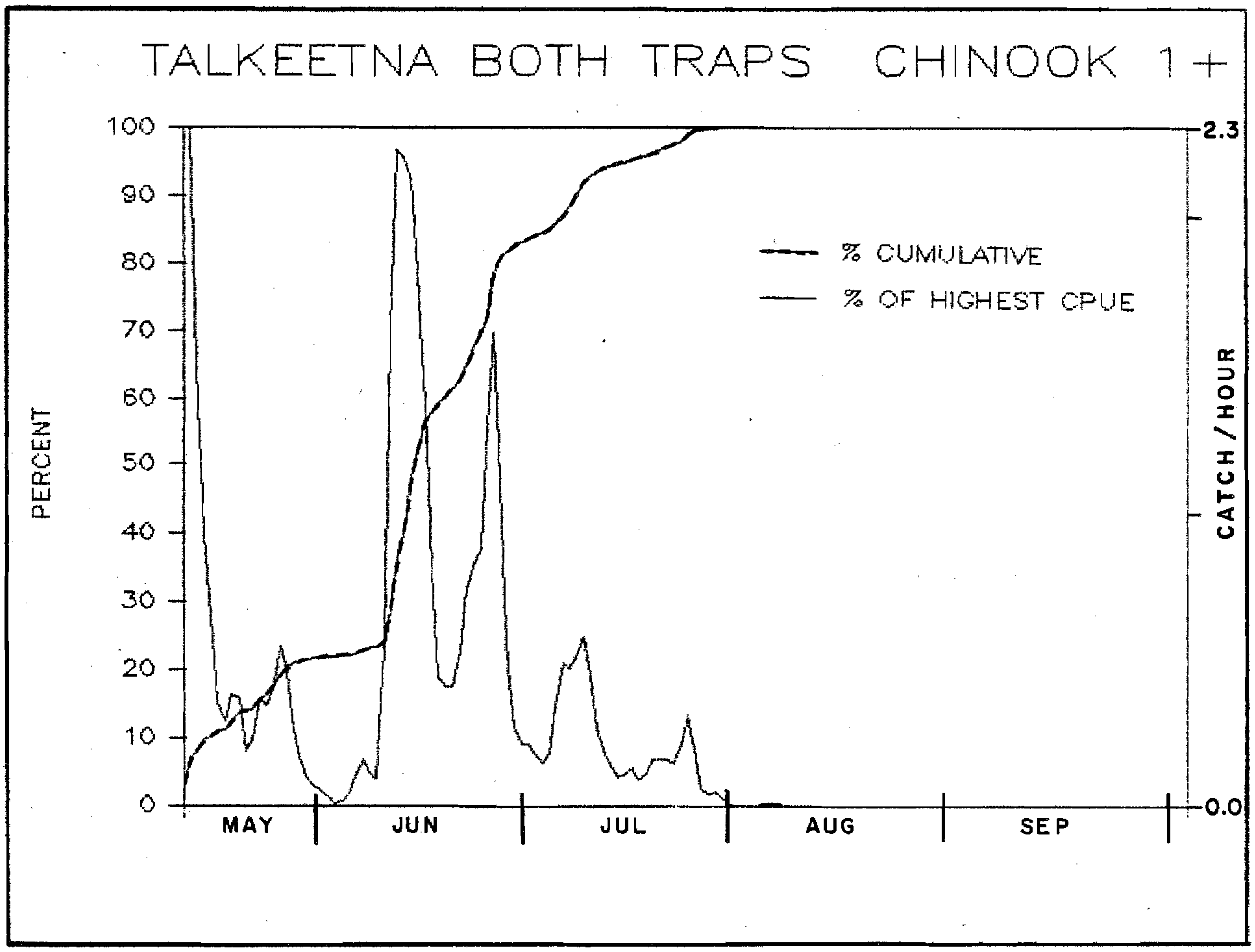


Figure 14. Chinook salmon (age 1+) smoothed daily catch per unit effort and adjusted cumulative catch recorded at the Talkeetna stationary outmigrant traps, May 14 through October 6, 1984.

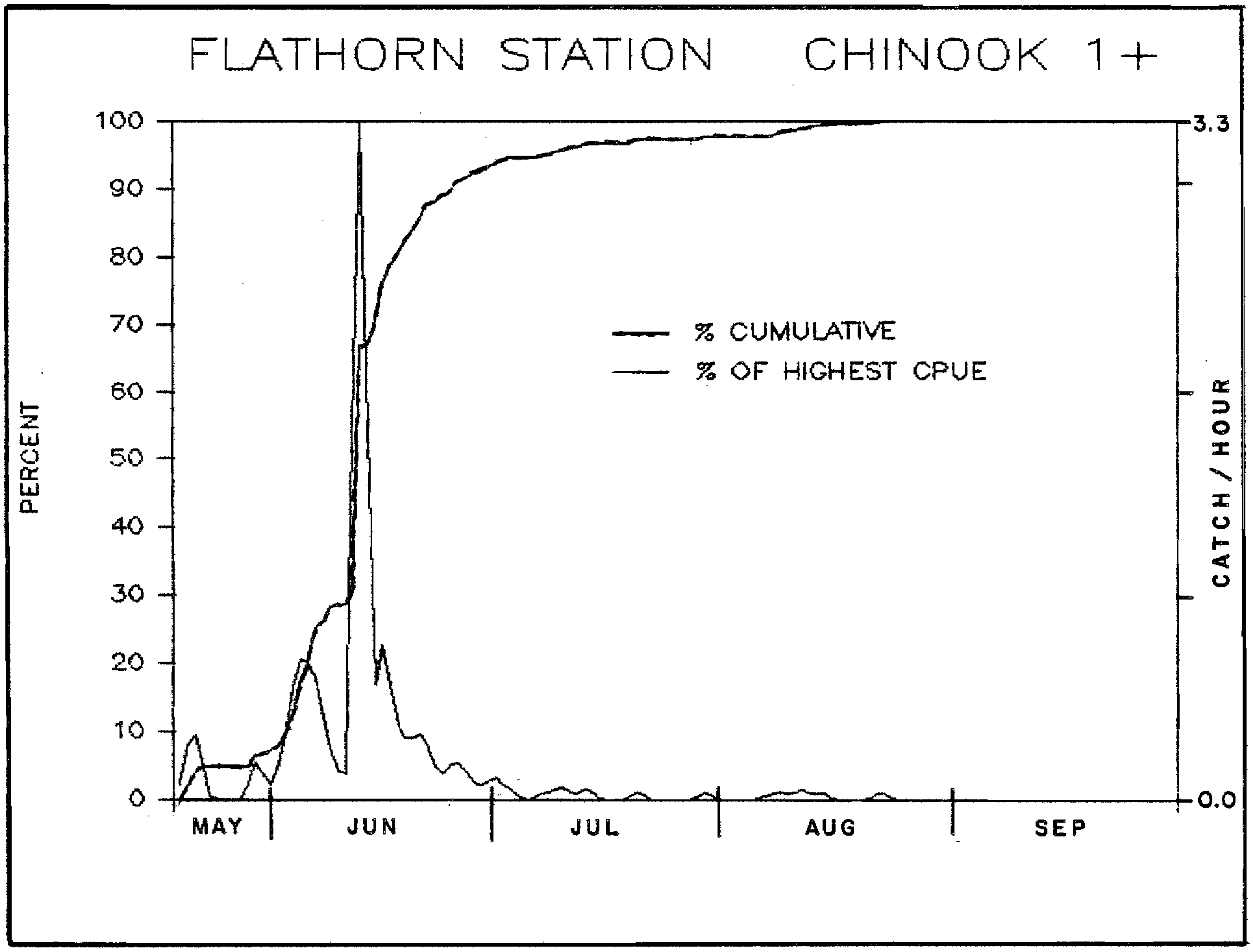


Figure 15. Chinook salmon (age 1+) smoothed daily catch per unit effort and adjusted cumulative catch recorded at the Flathorn stationary outmigrant trap, May 20 through October 1, 1984.

3.1.2 Growth

3.1.2.1 Age 0+

Chinook fry collected between the Chulitna River confluence and Devil Canyon (middle river) averaged 43 mm during late May and showed a steady growth through the season to a mean length of 64 mm by early October (Fig. 16). Age 0+ chinook collected between Cook Inlet and The Chulitna River confluence (lower river) during the same period averaged consistently larger than fry collected in the middle river. Chinook fry in the lower river increased from a mean length of 41 mm in late May to 75 mm in early October. The number of fish measured, mean length, and range of lengths by sampling period for chinook salmon fry are presented for each data collection area in Appendix Table A-3 and A-4.

3.1.2.2 Age 1+

Age 1+ chinook salmon for all sites sampled averaged 78 mm during May and the mean length increased to 90 mm during early June (Appendix Table A-5). Average lengths for this age class stayed the same through late July by which time most of the age 1+ chinook had migrated out of the Susitna River.

The length/weight relationship of juvenile chinook (both age classes) at Talkeetna Station is shown in Fig. 17.

3.1.3 Cold branding

A total of 23,406 chinook salmon fry were cold branded in Indian River between July 1 and October 15, 1984 (Table 1). One hundred forty-seven of these marked fish were later recaptured in Indian River, five were captured in the Talkeetna Station outmigrant traps, and five were captured below Indian River in side channels and sloughs associated with the mainstem Susitna River. The time between release of marked chinook fry in Indian River at TRM 7.2 and their subsequent recapture at the mouth of this tributary ranged from nine to 70 days with a mean of 30 days. The five chinook fry branded in Indian River which were collected in the outmigrant traps at Talkeetna Station averaged 17 days between release and recapture with a range from 8 to 26 days.

A total of 9,802 chinook salmon fry were cold branded in sloughs and side channels in the middle river between July 1 and October 15. Of these fish, 643 (6.6%) were later recaptured; 637 in the same slough where they were originally marked and released, seven fish in sloughs and side channels downstream from their release sites, four fish in the Talkeetna Station traps and two fish at sites upstream from their points of release. Of the 637 fry recaptured in the same slough where they were marked, 136 were caught 5 to 30 days later, and 113 were caught 30-60 days later. The branded chinook fry collected in the Talkeetna outmigrant traps averaged 12 days between release and recapture with a range from 8 to 17 days.

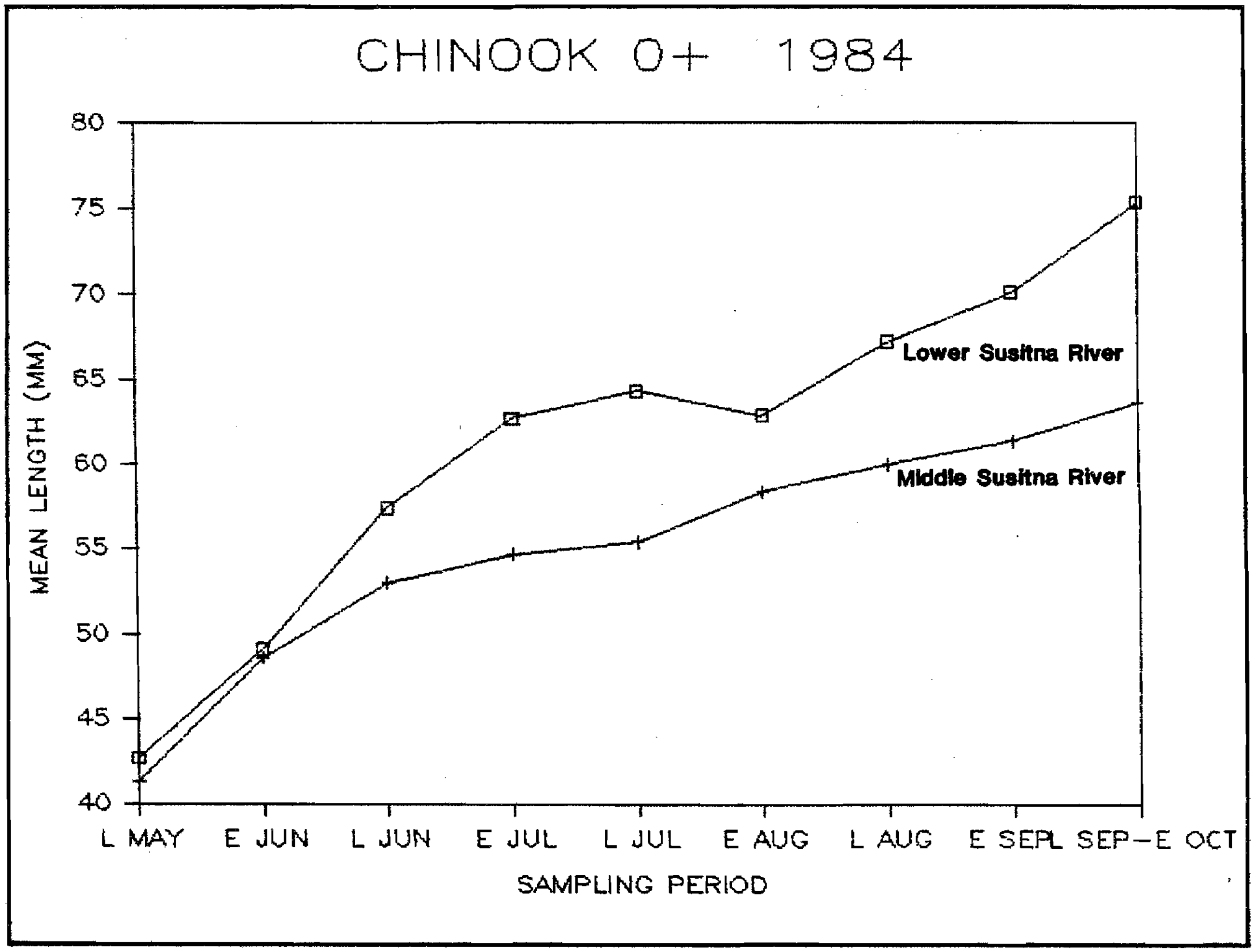


Figure 16. Chinook salmon (age 0+) mean length and range of lengths by sampling period for fish collected in the lower and middle reach of the Susitna River, 1984.

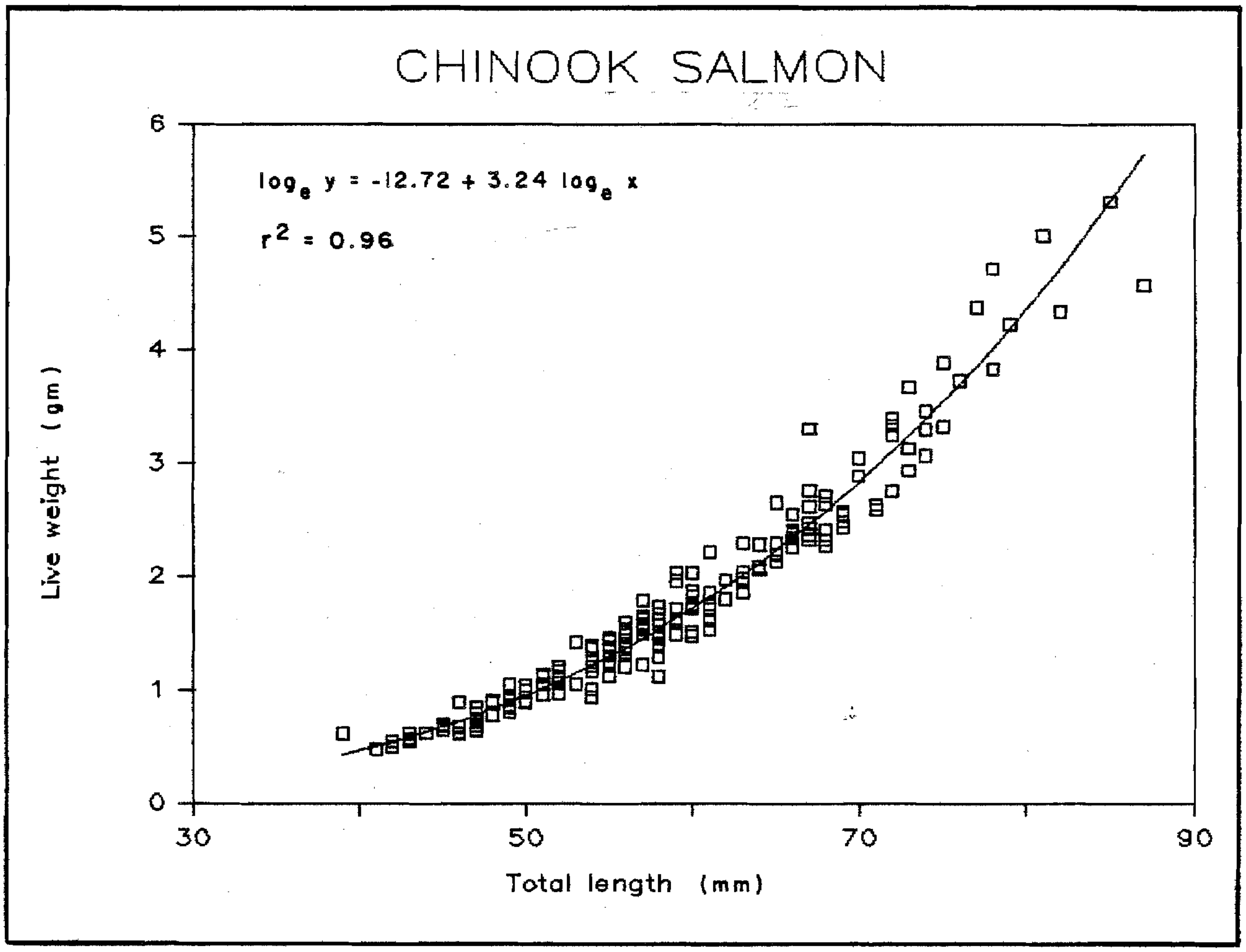


Figure 17. Weight/length relationship for juvenile chinook salmon collected at the Talkeetna stationary outmigrant traps, 1984.

Table 1. The number of chinook salmon fry marked and recovered in Indian River by sampling period, 1984.

Marking Period	Number of Fish Marked	Recapture Period July 16-31	August 1-15	August 16-31	Sept. 1-15	Sept. 16-30	Oct 1-15	Total
July 1-15	2,093	26	10	5	2	3	3	49
July 16-31	1,924	-	5	4	5	5	2	21
August 1-15	6,735	-	-	8	17	8	8	41
August 16-31	3,806	-	-	-	4	5	2	11
September 1-15	5,492	-	-	-	-	17	7	24
September 16-30	3,356	-	-	-	-	-	1	1
TOTALS	23,406	26	15	17	28	38	23	147

3.1.4 Population estimates

Using the mark-recapture data of Table 1 with the Schaefer method (Appendix B), there were an estimated 3,211,000 age 0+ chinook fry in Indian River after mid July. Females comprised 41.7% of the estimated population of 8,482 (9120-7% milling) adult chinook salmon (greater than 350 mm) which passed Curry Station in 1983 [95% confidence interval (C.I.) on estimate of 9120 of 6,148 to 14,212 fish; Barrett et al. 1984]. Indian River chinook comprised 27% of the peak spawning survey counts (Barrett et al. 1984). Using a fecundity estimate of 10,622 eggs per female (Healy and Heard 1984), an estimated 10,143,000 eggs were deposited in Indian River during 1983. It is not possible to calculate the egg to outmigrant survival rate because of unknowns in both the adult and the fry population estimates.

Population estimates were made at three sloughs and two side channels in the middle river during the cold branding study (Table 2). Populations were estimated at a high of 47,000 chinook fry in Slough 22 to a low of 3,400 in Lower Side Channel 11A. No Jolly-Seber estimate of population size was made for August 11 at Moose Slough because the head of site closed the night of August 11 and almost all of the fish left. Only one chinook fry was captured on August 12; there were no recaptures.

The effect of fluctuating discharge levels on the density (beach seine catch with constant effort) and total number (population estimate) of chinook fry in sloughs and side channels can be seen in Figs. 18 and 19. Estimates of population size were made using the Jolly-Seber method which allows for inmigration, recruitment, outmigration, and mortality. Recruitment does not occur, so all gains to the population were a result of migration into the site. Similarly, assuming that mortality during a five day period is negligible, all losses to the population were a result of migration from the site.

The total number of fry in Moose Slough during these five days paralleled the density of fry and the discharge level (Fig. 18). This pattern suggests that habitat quality was best at the highest observed flow and declined with a drop in discharge level. As the surface area of the site and the habitat quality decreased, so did the total number of fish at the site. Evidently, the site is of little rearing value to chinook salmon when the head of the site is not breached. A partial explanation is that the water clears when the head is closed; there is little cover other than turbid water at this site. The marked/unmarked ratio for each day was diluted by the entry of new fish into the site through the slough head, until the head closed. By that time, most of fish that had been at the site the previous four days had left. Residence time in this slough was low. This site probably acts mainly as an outmigration corridor and temporary rearing area.

At Lower Side Channel 11A, the density of fry stayed relatively constant over the five days even though the discharge level steadily decreased (Fig. 19). Meanwhile, the total number of fry at the site declined with the lowering in discharge level. The table of recaptures (Fig. 19) indicates a longer residence time than at Moose Slough. This fact, and the fairly constant density, suggests that the habitat quality at this

Table 2. Chinook salmon fry population estimates by site for middle Susitna River sloughs and side channels and for Indian River, 1984.

Sampling Site	Branding Dates	Recapture Dates	Estimate Method	Population Estimate	95% Confidence Interval
Lower Side Channel 11A	7/29 - 8/1	7/30 - 8/2	Schaefer	3,420	-
		7/30	Jolly-Seber	4,962	2,466 - 14,441
		7/31	Jolly-Seber	1,370	1,038 - 2,106
		8/1	Jolly-Seber	1,245	958 - 1,874
Side Channel 10	7/16 - 7/19	7/17 - 7/20	Schaefer	7,630	-
Moose Slough	8/8 - 8/11	8/9 - 8/12	Schaefer	4,990	-
		8/9	Jolly-Seber	5,884	3,888 - 11,141
		8/10	Jolly-Seber	1,455	1,159 - 2,071
Slough 22	9/8 - 9/13	10/8	Petersen	47,050	39,000 - 56,750
			Schaefer	43,761	-
Slough 19	8/29	9/26	Petersen	4,550	3,200 - 6,700
Indian River	7/1 - 9/30	7/15 - 10/15	Schaefer	3,211,000	-

		RECAPTURE				
DATE	NO. MARKED	8/9	8/10	8/11	8/12	TOTAL
8/8	238	25	25	11	0	61
8/9	480	-	50	21	0	71
8/10	212	-	-	22	0	22
8/11	137	-	-	-	0	0

MARKING

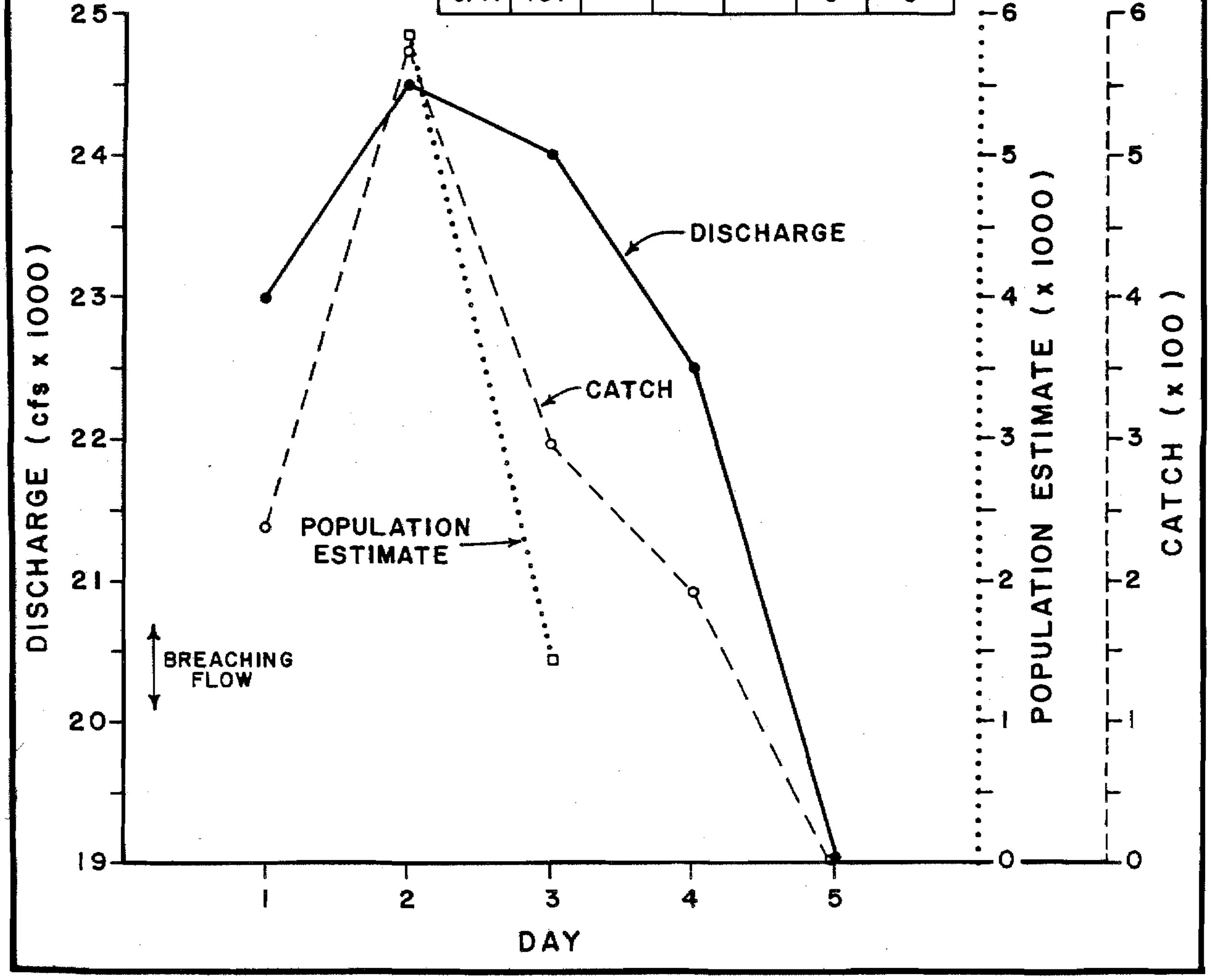
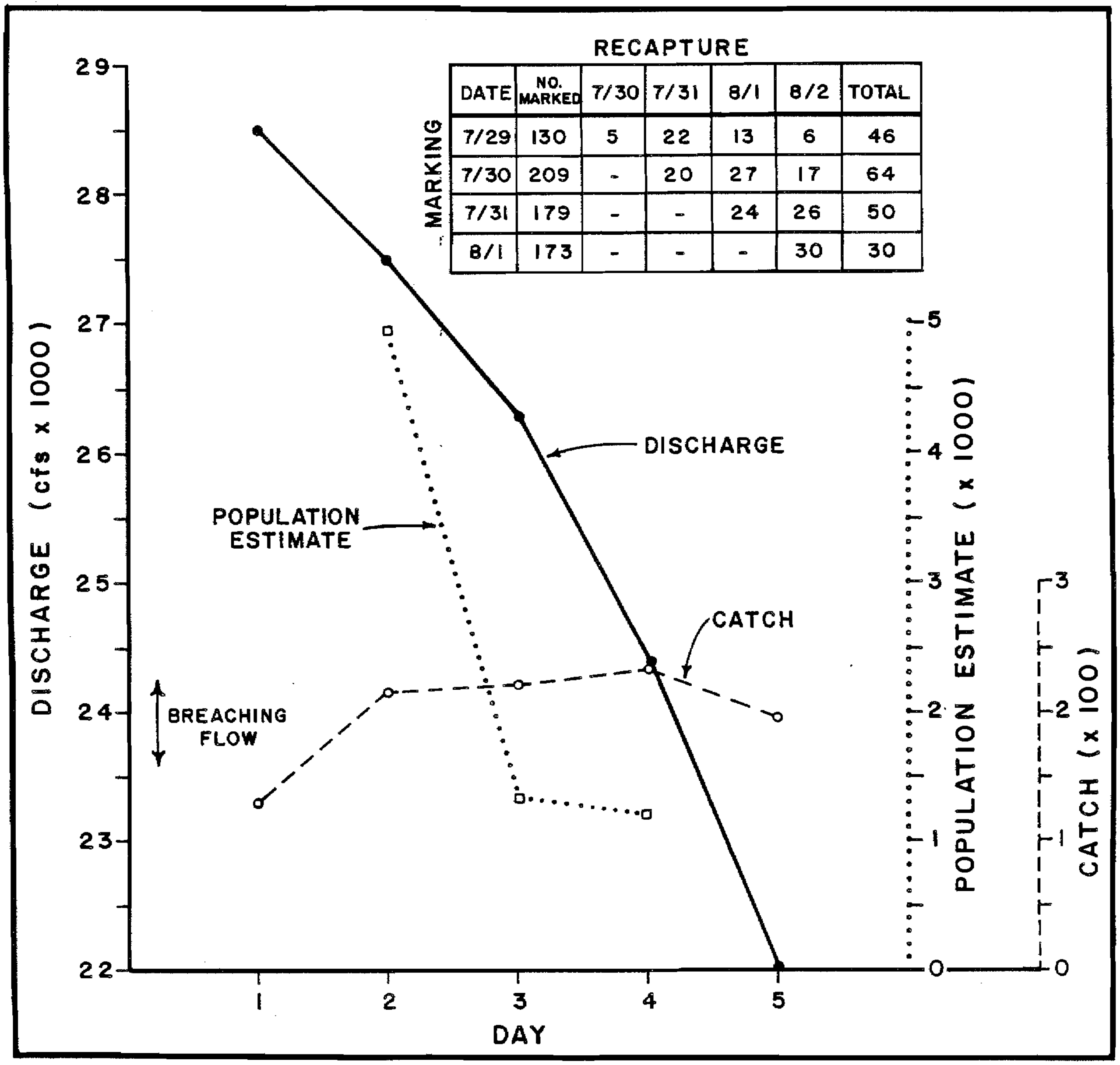


Figure 18. Catch, estimated population size, and mainstem discharge level at Moose Slough, August 8 - August 12, 1984.



DATE	NO. MARKED	7/30	7/31	8/1	8/2	TOTAL
7/29	130	5	22	13	6	46
7/30	209	-	20	27	17	64
7/31	179	-	-	24	26	50
8/1	173	-	-	-	30	30

Figure 19. Catch, estimated population size, and main-stem discharge level at Lower Side Channel 11A, July 29 - August 2, 1984.

site is relatively unaffected by changes in level of discharge. However, the total number of fry at the site necessarily declines with a lowering discharge level because the amount of habitat (surface area) available decreases. The constant density of fry even after the head of the site closed is perhaps attributable to a greater amount of object cover at this site than at Moose Slough.

3.2 Coho Salmon

3.2.1 Catch per unit effort

3.2.1.1 Age 0+

Juvenile coho salmon were observed during the coded wire tagging study to be most abundant at Indian River. Catch rates were not recorded. The cold branding study collected 1,548 coho salmon fry in Indian River from July 1 through October 15. Of this catch, 31% of the coho were captured in Section I, 44% in section II and 26% in section III. Beach seining of sections II and III during July captured 444 juvenile coho salmon; 76% in section II and 24% in section III. Minnow trapping begun in late July captured 1,129 juvenile coho salmon during 947 minnow trap days for a season average of 1.2 coho per trap day. Of these catches, 43% were recorded in the lower section, 31% in the middle section, and 26% in the upper section.

The catch per unit effort for all Indian River sections combined was steady through the season ranging from 1.1 to 1.5 fish per trap day (Fig. 20). Coho fry catches were highest in section III with an average of 5.0 coho per trap day over the season. Season average CPUE in section II was 1.4 coho per trap day and Section I averaged 0.8 coho per trap day.

A total of 90 coho salmon fry were captured during the cold branding study in sloughs and side channels in the middle Susitna River. Ninety-five percent of the coho catch was recorded in slough habitats in this reach. Beach seining during July and August captured 40% of the season's total catch while minnow trapping during September and early October collected the remaining 60% (average of 0.2 coho per trap day). Daily minnow trap CPUE ranged from a low of 0.01 at Slough 22 and Side Channel 21 in September to a high of 7.6 coho per trap day at Slough 14 on September 10.

Peak catches for the 1,830 age 0+ coho salmon collected at the Talkeetna Station outmigrant traps were recorded during late July and August, and the highest catch rate of 2.9 coho fry per hour was recorded on July 30, by which time 50% of the season total had been recorded (Fig. 21). The last coho fry was captured in the traps on October 4.

A total of 441 age 0+ coho salmon were captured at the Flathorn stationary outmigrant trap during 1984. Catch rates were highest during late August and late September and the peak catch rate of 1.5 fish per hour was recorded in the trap on September 30 (Fig. 22). Fifty percent of the catch at this site occurred by August 26. Only 16 age 0+ coho were captured in the mobile trap at Flathorn Station.

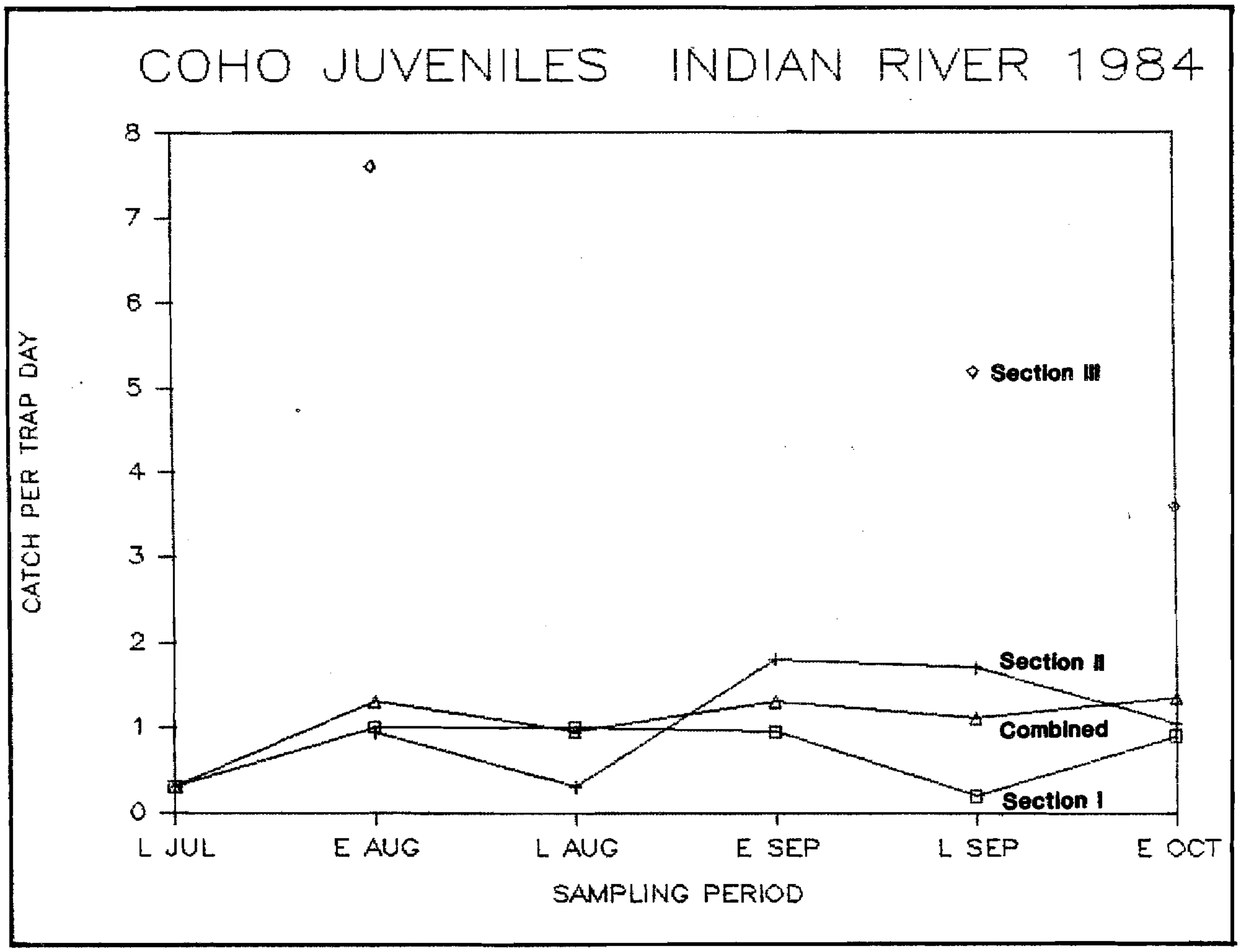


Figure 20. Coho salmon (age 0+) average catch per minnow trap by sampling period and survey section in Indian River, 1984.

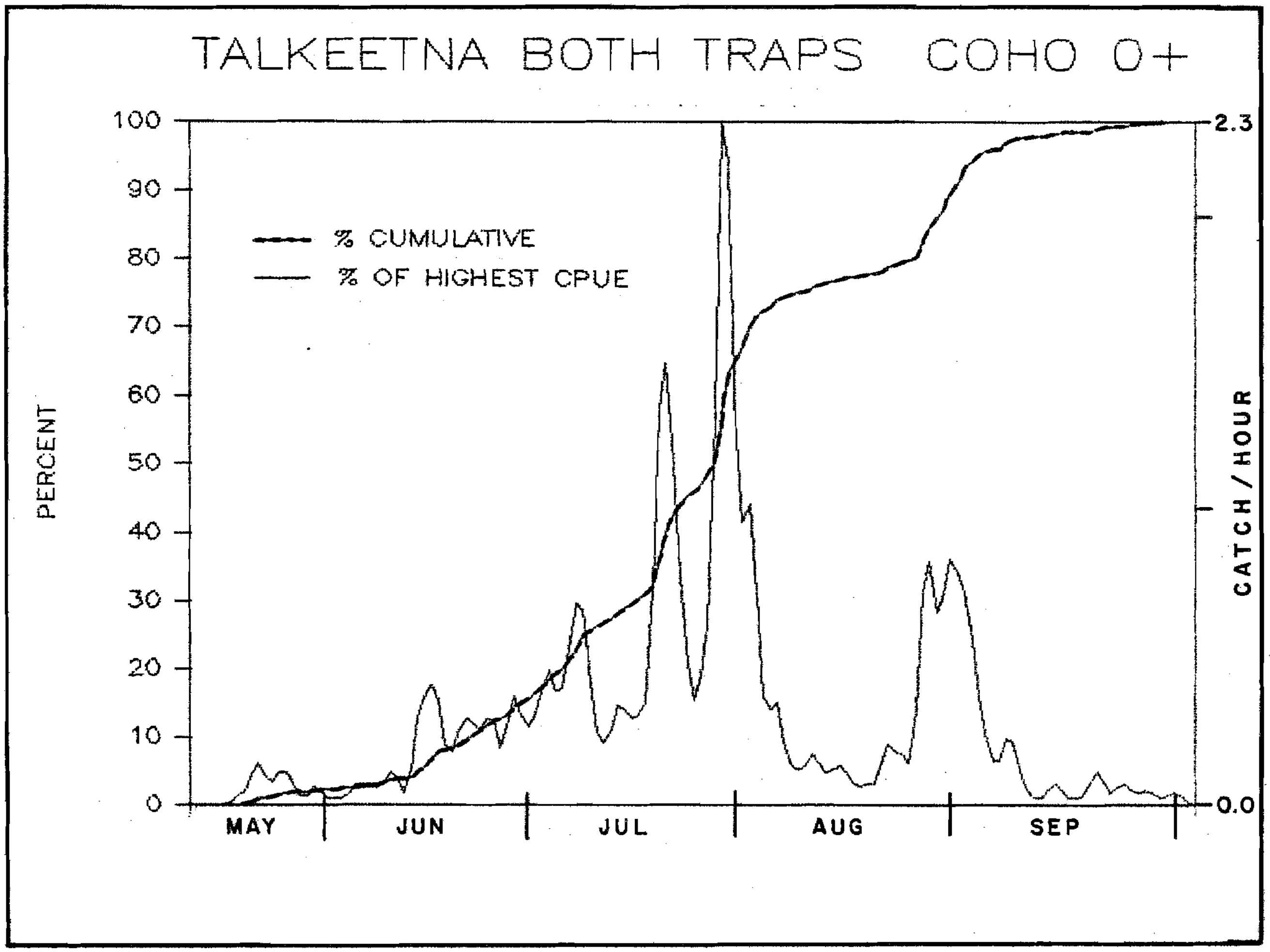


Figure 21. Coho salmon (age 0+) smoothed daily catch per unit effort and adjusted cumulative catch recorded at the Talkeetna stationary outmigrant traps, May 14 through October 6, 1984.

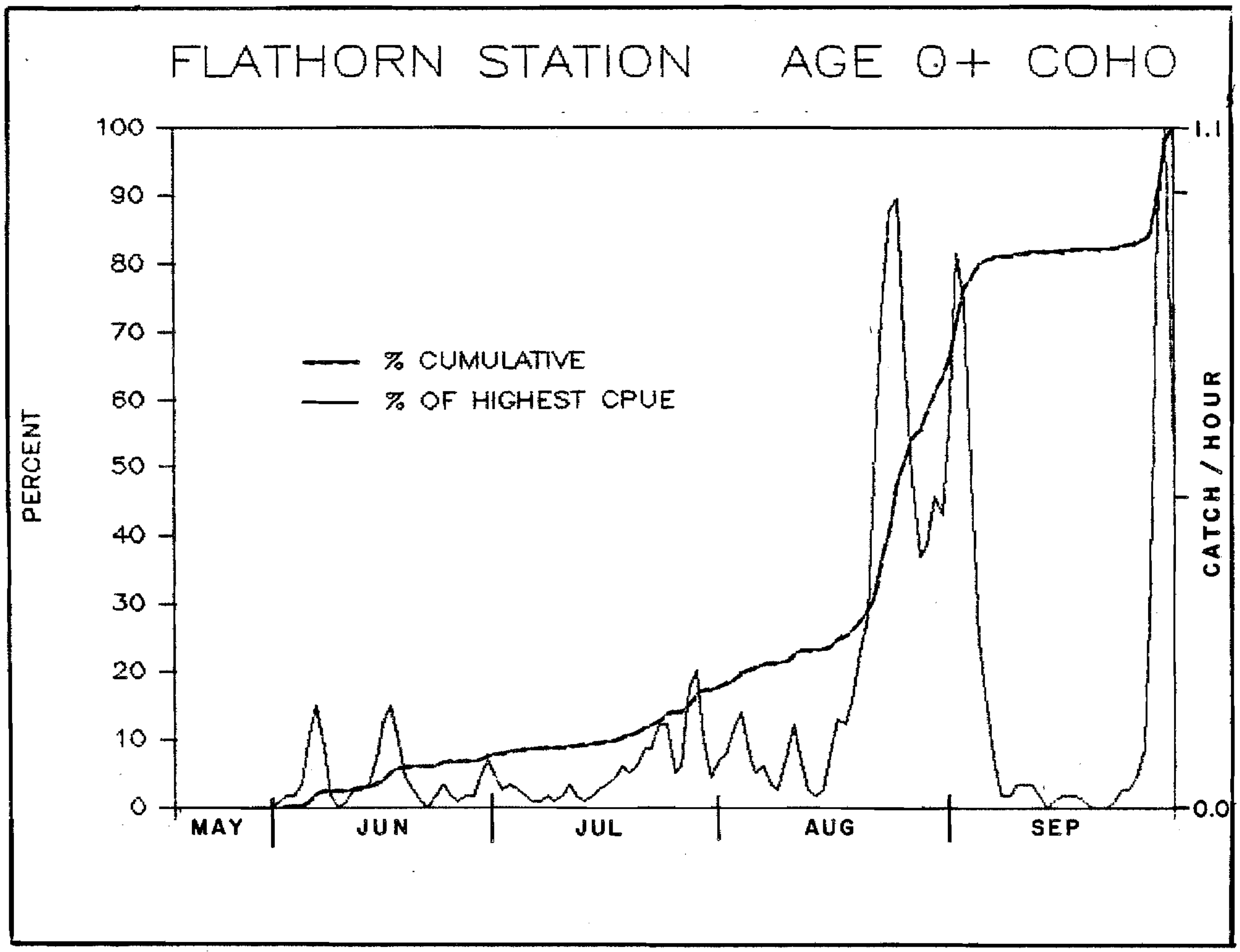


Figure 22. Coho salmon (age 0+) smoothed daily catch per unit effort and adjusted cumulative catch recorded at the Flathorn stationary outmigrant trap, May 20 through October 1, 1984.

A total of 380 age 0+ coho salmon were captured in the lower Susitna River during the JAHS study (see Part 2 of this report). Catch rates were highest during the late summer sampling and the peak catch rates were recorded in early October (Fig. 23).

The Deshka River weir captured 95 coho salmon fry during 1984; the peak catch rate of 1.3 fish per hour was recorded on July 25 (Appendix Table A-1). Minnow trap catches at this site were highest during late August at 2.6 coho per trap (Appendix Table A-2).

3.2.1.2 Age 1+ and older

Age 1+ coho salmon were collected sporadically during the coded wire tagging study in May and June with the highest concentrations observed in Slough 11 and Indian River. The cold branding study from July through early October captured 25 age 1+ coho at Indian River and 18 at middle river slough and side channel sites during the season.

Peak catches for the 1,425 age 1+ coho salmon juveniles captured at the Talkeetna Station outmigrant traps were observed in mid June and were again high in late July and late August (Fig. 24). Fifty percent of the catch was recorded by June 25. The highest catch rate for these age classes was 1.6 fish per hour recorded on June 18 and the last capture was on October 2.

Catch rates for the 291 age 1+ coho salmon juveniles captured at the Flathorn stationary outmigrant trap were highest during late August and September (Fig. 25) and the highest CPUE of 0.8 coho per hour was recorded on September 3. Fifty percent of the total catch was recorded by August 30 and the last capture of these age classes was October 1. The mobile outmigrant trap captured 10 age 1+ coho salmon during the season.

The JAHS study in the lower river collected 62 age 1+ coho salmon juveniles with most of the captures being recorded at tributary sites in this reach.

The Deshka River weir collected 26 age 1+ coho while minnow trapping at this site captured 119 fish. Catches were observed throughout the season with a peak rate of 6.2 coho per trap recorded in late August.

A total of 44 age 2+ coho salmon juveniles were collected during the 1984 studies. Talkeetna Station, Flathorn Station, and the Deshka River accounted for 95% of the captures of this age class.

3.2.2 Growth

3.2.2.1 Age 0+

Coho fry collected in the lower river were consistently larger than the fry collected in the middle river throughout the season (Fig. 26). Coho fry collected in the middle river averaged 40 mm total length during late May and showed a steady growth to a mean of 58 mm by late August. Coho fry in the lower river averaged 42 mm in early June and had grown

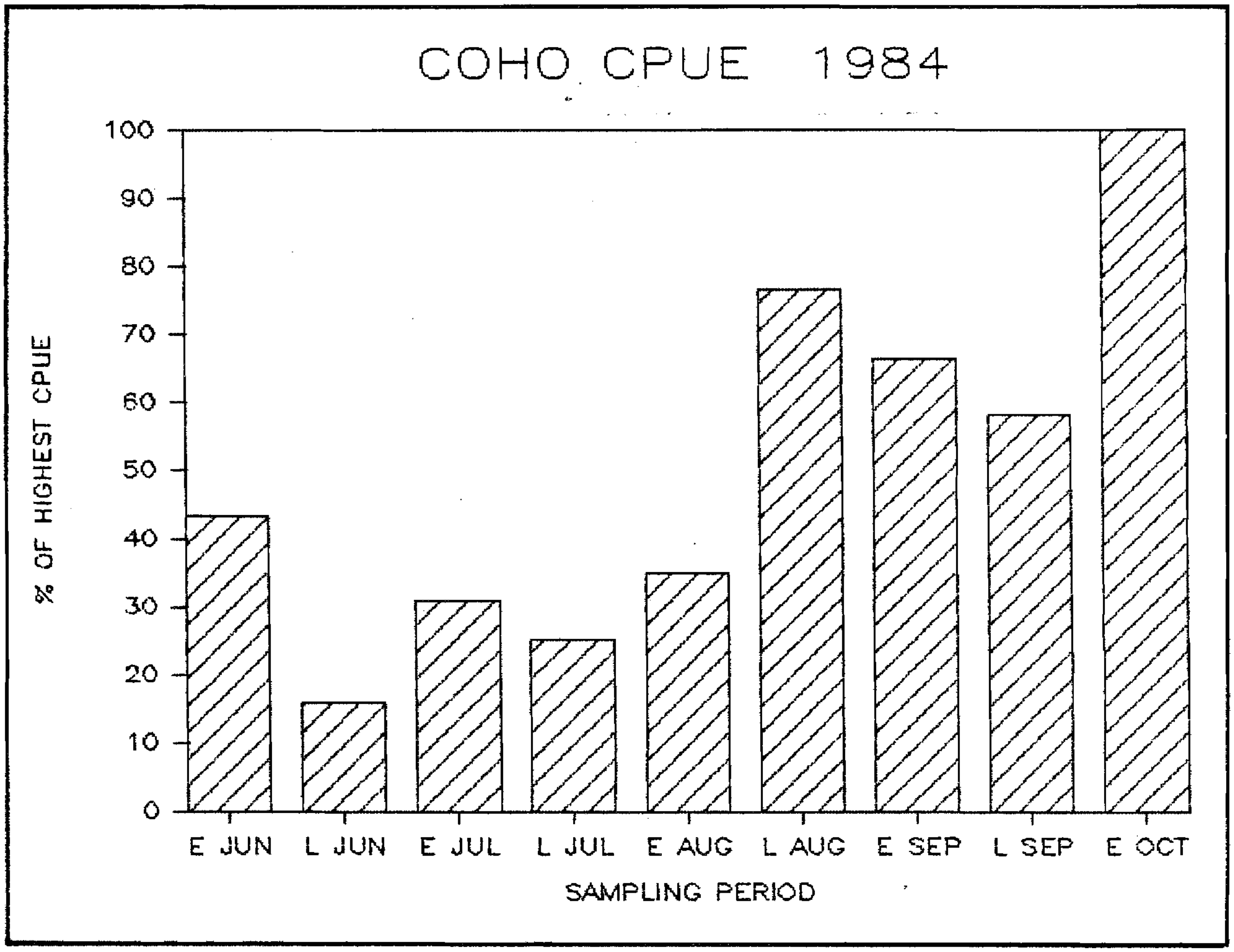


Figure 23. Coho salmon juvenile catch per unit effort by sampling period recorded at JAHS sites in the lower reach of the Susitna River, 1984.

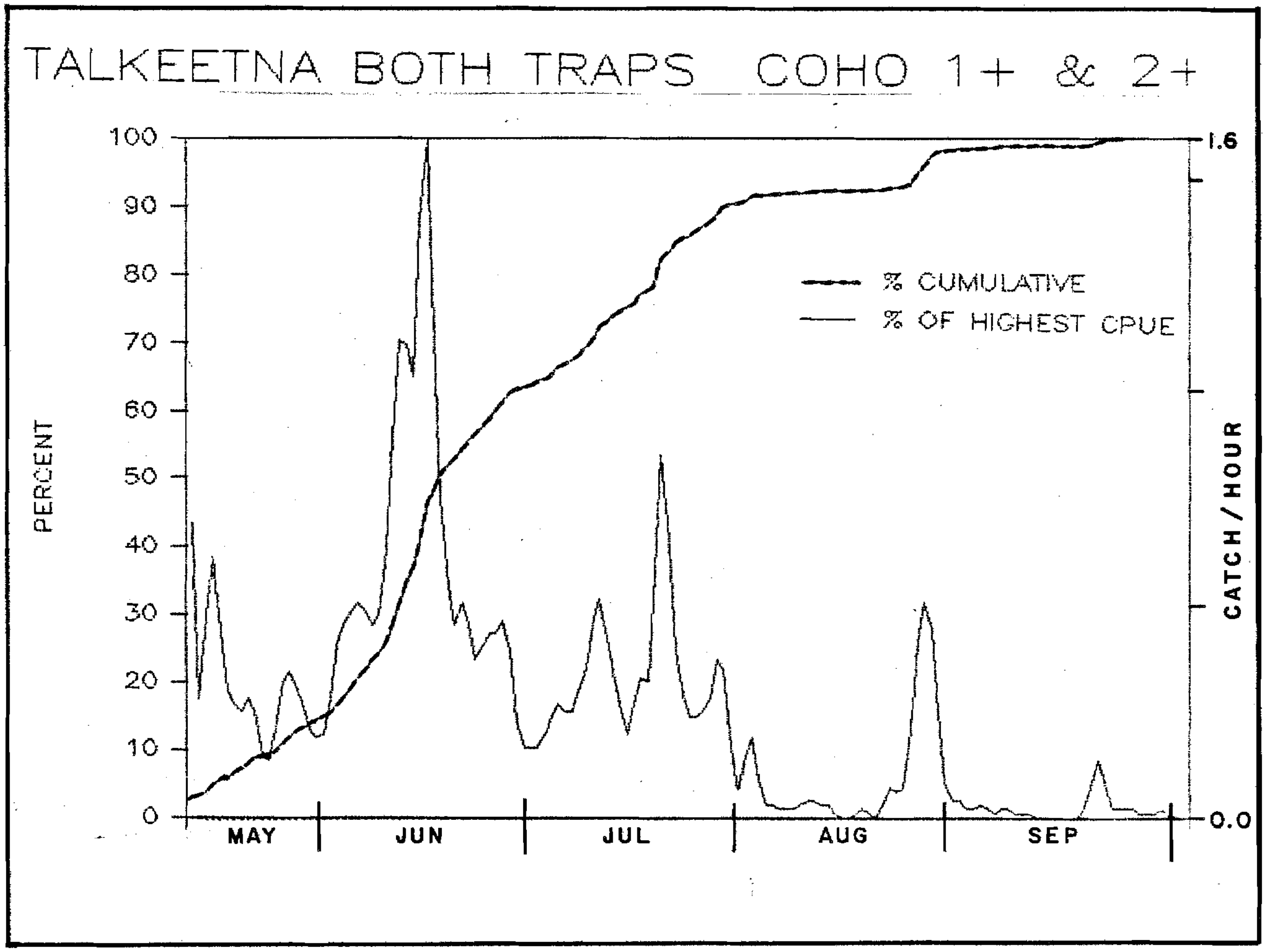


Figure 24. Coho salmon (age 1+ and older) smoothed daily catch per unit effort and adjusted cumulative catch recorded at the Talkeetna stationary outmigrant traps, May 14 through October 6, 1984.

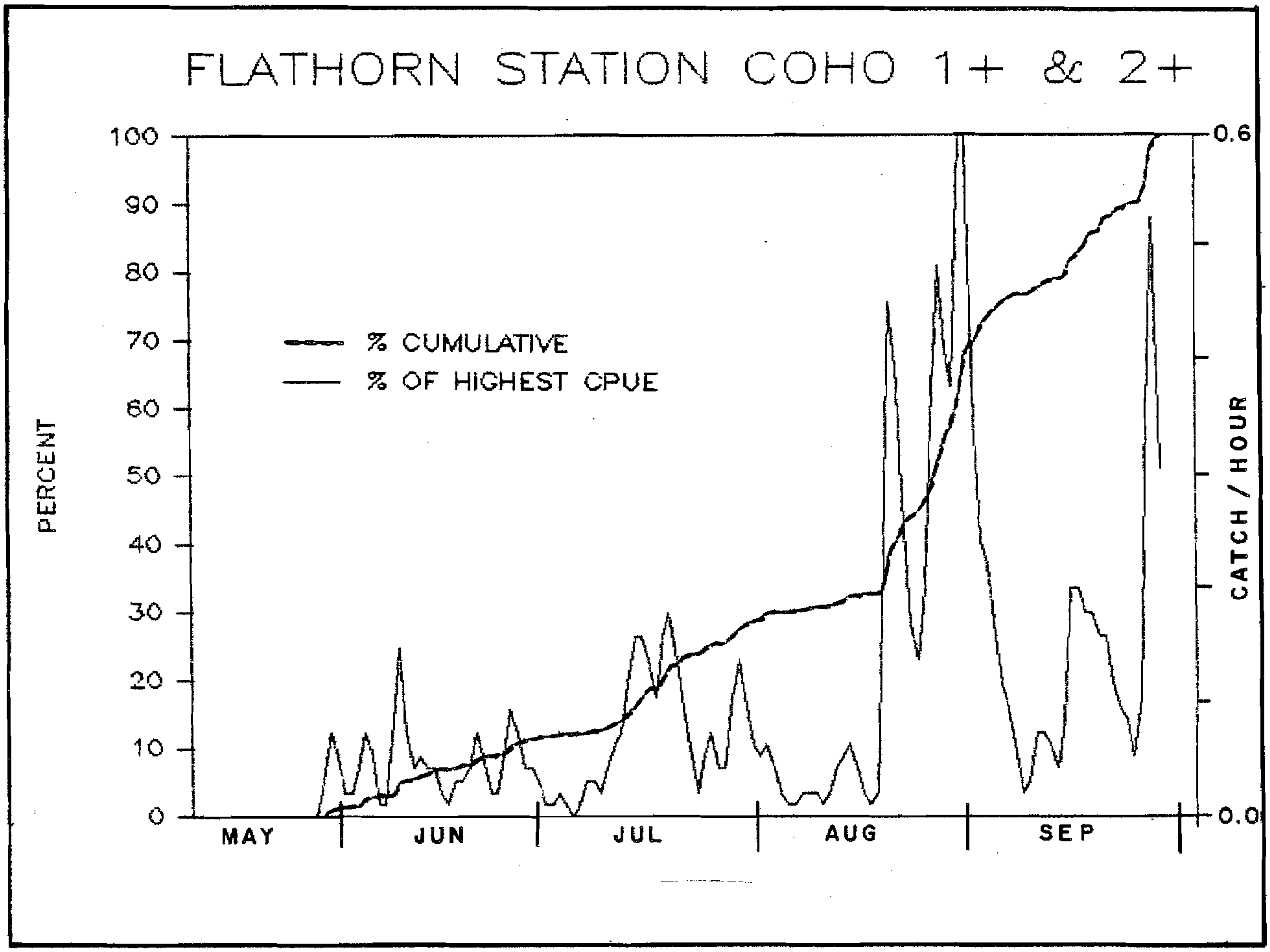


Figure 25. Coho salmon (age 1+ and older) smoothed daily catch per unit effort and adjusted cumulative catch recorded at the Flathorn stationary outmigrant trap, May 20 through October 1, 1984.

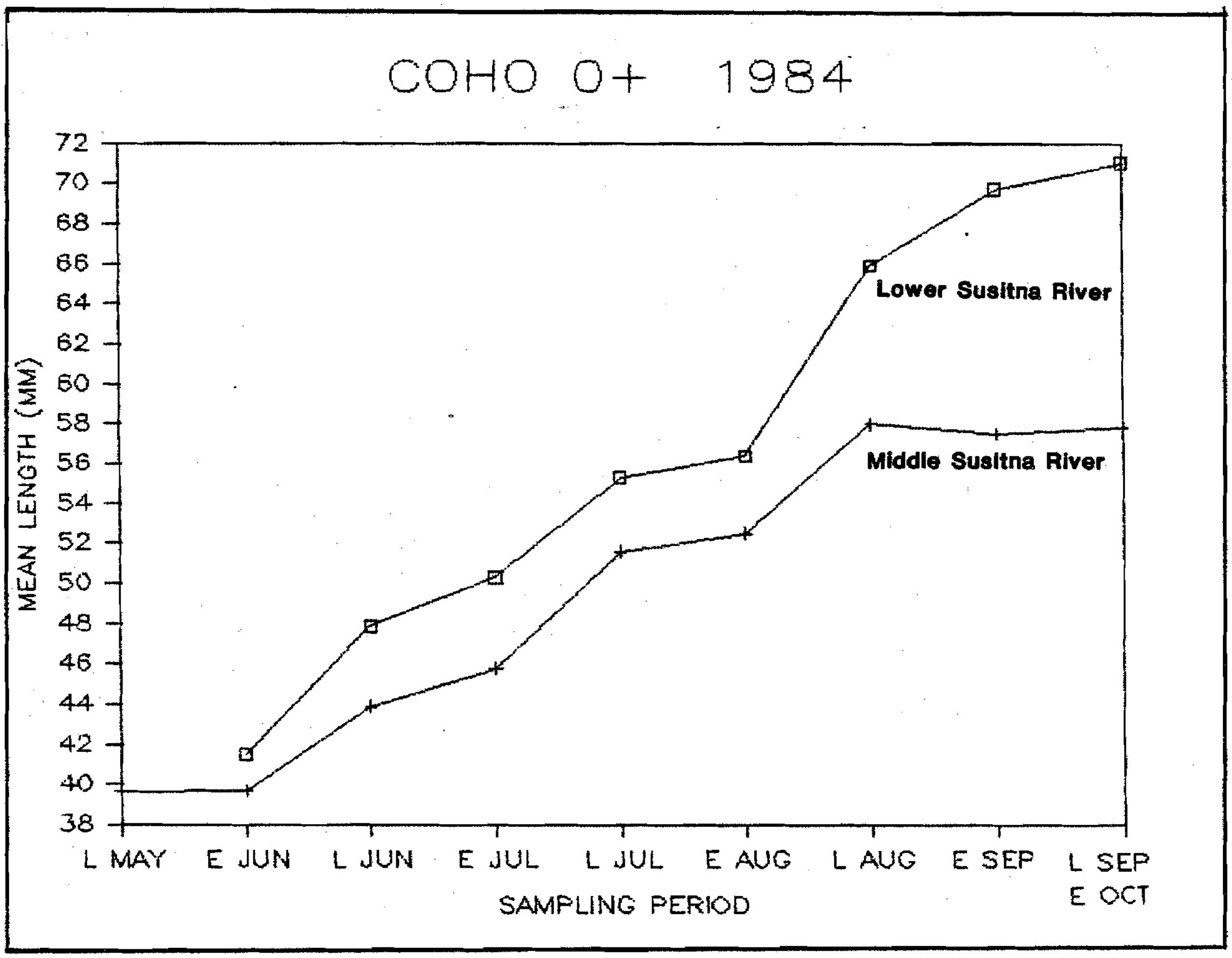


Figure 26. Coho salmon (age 0+) mean length and range of lengths by sampling period for fish collected in the lower and middle reach of the Susitna River, 1984.

to a mean length of 71 mm by late September. The number of fish measured, mean length, and range of lengths by sampling period for coho fry are presented for each data collection area in Appendix Table A-6 and A-7.

3.2.2.2 Age 1+ and older

The average length of age 1+ coho salmon juveniles collected in the lower river during the open water season was greater than that of fish of the same age class collected in the middle river (Fig. 27). Age 1+ coho averaged 70 mm total length in both reaches during May and increased to 104 mm in the middle river and 111 mm in the lower river by early October. Length data by collection area and sampling period are provided in Appendix Table A-8 and A-9.

Age 2+ coho salmon juveniles collected during the 1984 studies averaged 137.1 mm and ranged from 114 to 176 mm (Appendix Table A-10).

A sample of juvenile coho salmon were measured at Talkeetna Station to provide a relationship between length and weight for fish passing this site (Fig. 28).

3.2.3 Cold branding

A total of 1,480 juvenile coho salmon were cold branded in Indian River from July 1 through October 15. Of these fish, five were recaptured in Indian River and two were recovered at the Talkeetna Station outmigrant traps. The marked coho recaptured in Indian River were branded and released at TRM 11.5 on July 17 and recaptured at TRM 2.2 between September 9 and 11, for an average of 55 days between release and recovery. The two branded coho recovered at Talkeetna Station were released in Indian River on August 12 and were recovered in the outmigrant traps on August 31 and September 22; 19 days and 41 days, respectively, between release and recovery.

A total of 106 juvenile coho salmon were cold branded at slough and side channel sites, and the only recapture was recorded at Talkeetna Station. The recaptured fish was marked and released at Slough 14 on September 10 and was recovered in the traps on September 16.

3.2.4 Population estimates

Since only 100 to 200 of the estimated 750 adult coho passing Curry Station in 1983 entered Indian River, and since juvenile coho of the same brood year outmigrate as age 0+, 1+, and 2+ fish, few juvenile coho salmon were captured for marking during the 1984 cold branding studies. Too few branded coho salmon were recaptured to provide population estimates for any of the sites surveyed.

3.3 Sockeye Salmon

3.3.1 Catch per unit effort

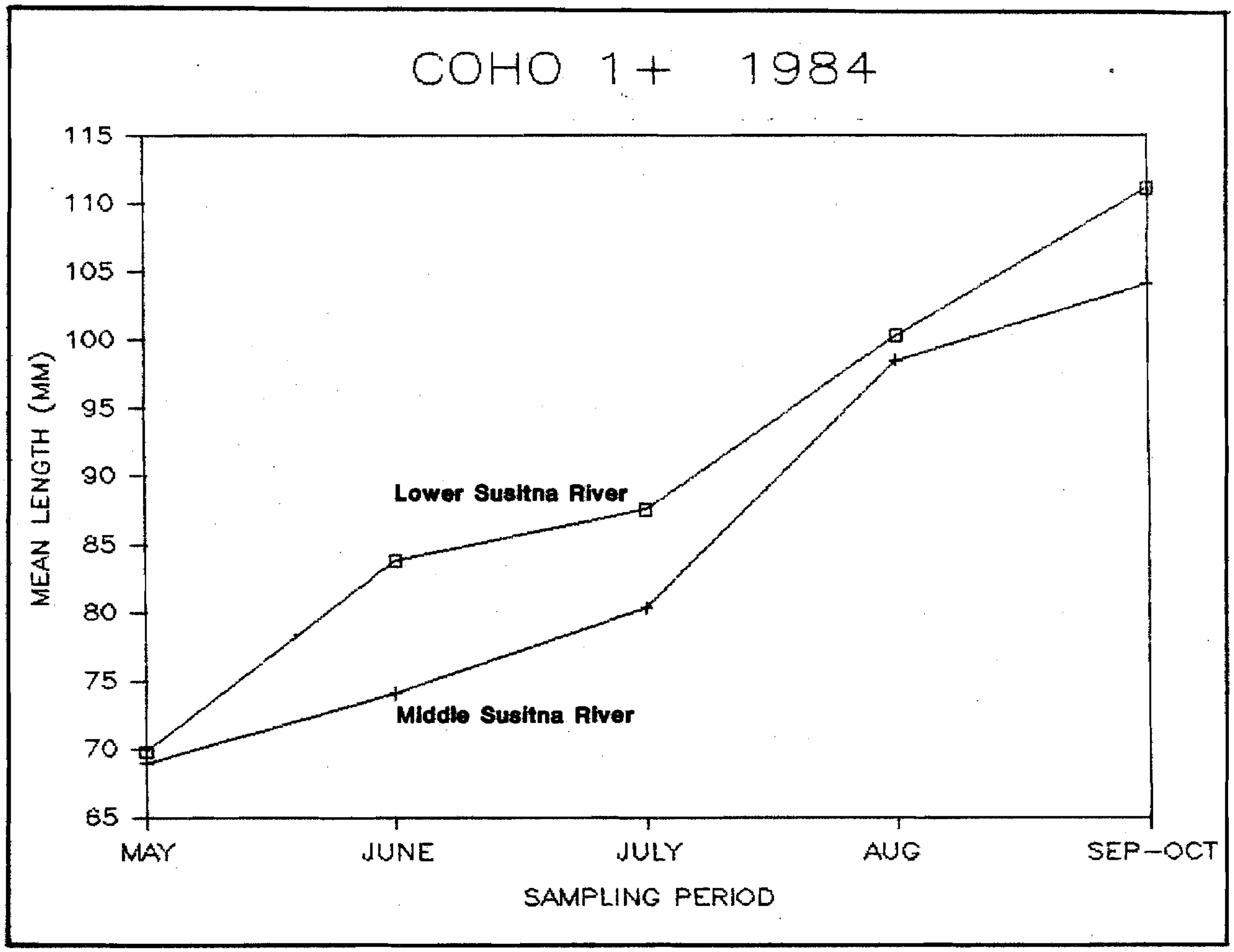


Figure 27. Coho salmon (age 1+) mean length by month for fish collected in the lower and middle reach of the Susitna River, 1984.

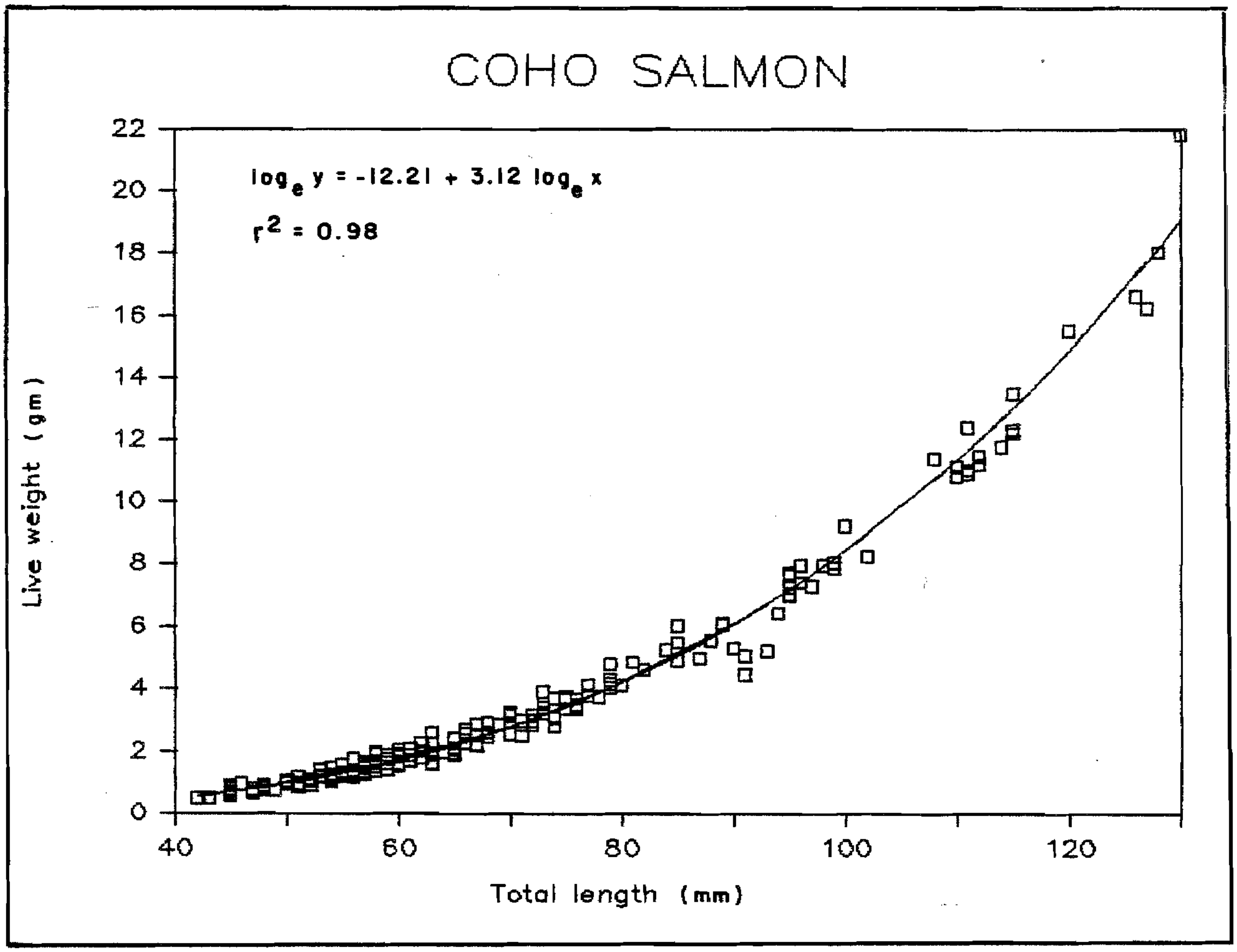


Figure 28. Weight/length relationship for juvenile coho salmon collected at the Talkeetna stationary outmigrant traps, 1984.

3.3.1.1 Age 0+

Sockeye salmon fry were collected during the coded wire tagging study in May and June at sloughs 8A, 9, 11, and 21 but catch rates were recorded only for Slough 21. These data were determined from 24 hour fyke net catches and are presented in Appendix Table A-11.

A total of 248 sockeye salmon fry were captured at slough and side channel sites in the middle river and in Indian River during beach seine sampling conducted in July and August. Of these fish, 94% were collected in sloughs and the remaining 6% were collected in Indian River and at mainstem side channels.

Peak catch rates for the 7,484 age 0+ sockeye salmon fry collected at the Talkeetna Station outmigrant traps were recorded in mid June and early July with the highest daily catch rate of 13.0 sockeye fry per hour occurring on June 18 (Fig. 29). The major downstream redistribution of sockeye fry in this reach had occurred by mid July (50% by July 4). The last sockeye fry at Talkeetna Station was observed on October 4.

Juvenile sockeye catches at the Flathorn stationary outmigrant trap were greatest during May and June but the downstream movement of sockeye fry continued through the open water season (Fig. 30). A total of 2,315 sockeye fry were collected in the trap during 1984, and the peak catch rate of 4.6 fish per hour was recorded on June 8. Fifty percent of the catches had occurred by June 29 and the last capture was October 1.

Mobile trap catches of sockeye fry at Flathorn Station were highest during June and the peak catch rate of 5.4 fish per hour was recorded on July 12 (Fig. 31). Of the 114 sockeye collected in the mobile trap during 1984, 59% were captured at bank transect points (Fig. 32).

A total of 412 sockeye salmon fry were collected in the lower river during JAHS surveys from June through October (see Part 2 of this report). Catch rates at JAHS sites peaked in late June and then were low throughout the remainder of the season (Fig. 33). An increase in catch rates was recorded at some sites including Rolly Creek (RM 39.0) and Beaver Dam Slough (RM 86.3) in late August and September, indicating the movement of sockeye into these sites during late summer.

3.3.1.2 Age 1+

A total of 90 age 1+ sockeye salmon juveniles were collected. Nineteen were captured at Talkeetna Station and 63 were collected at Flathorn Station.

Ninety-six percent of the catch for age 1+ sockeye collected at the outmigrant traps (Talkeetna and Flathorn combined) was recorded during May and June (Fig. 34). The last age 1+ sockeye was captured at Talkeetna Station on July 29.

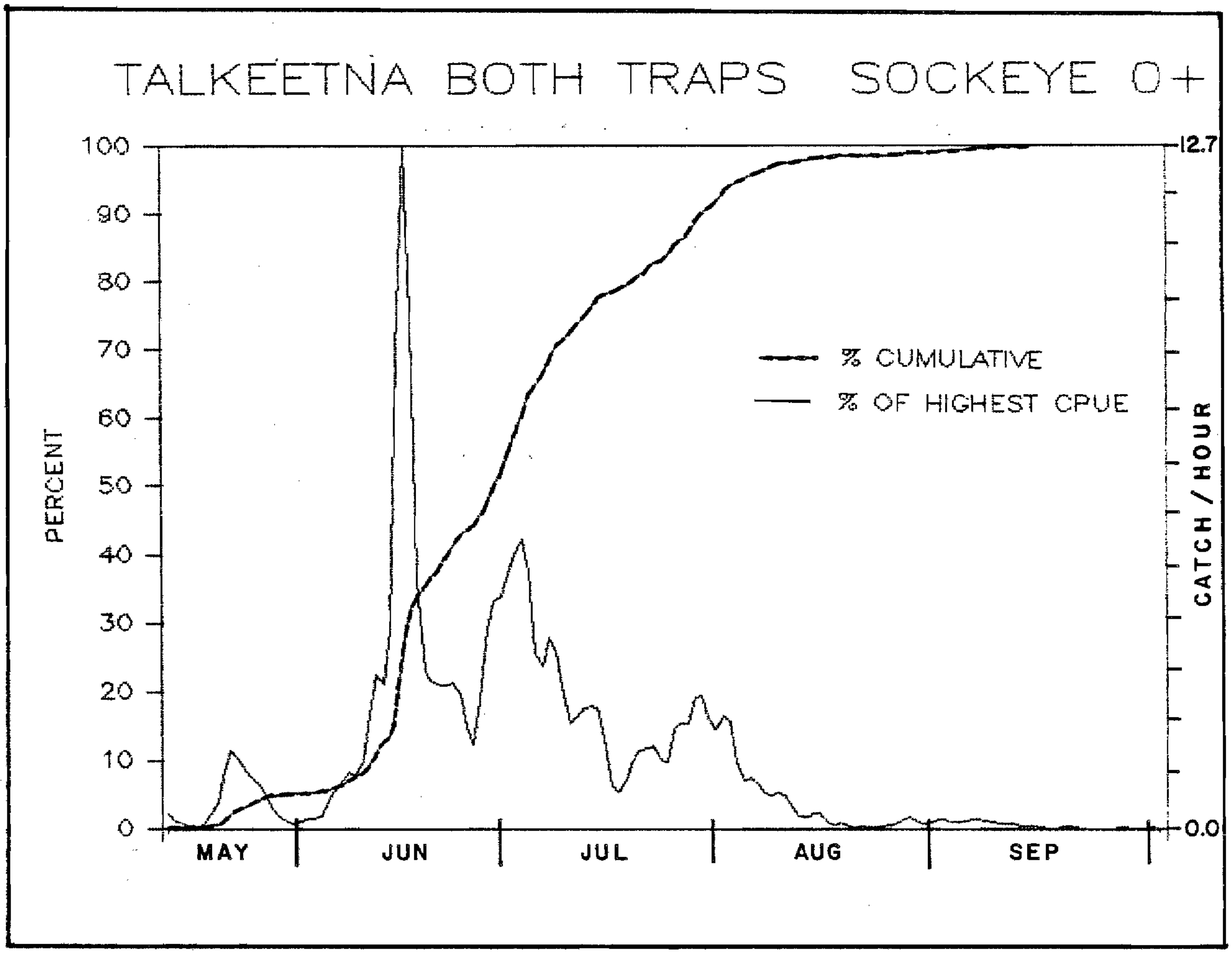


Figure 29. Sockeye salmon (age 0+) smoothed daily catch per unit effort and adjusted cumulative catch recorded at the Talkeetna stationary outmigrant traps, May 14 through October 6, 1984.

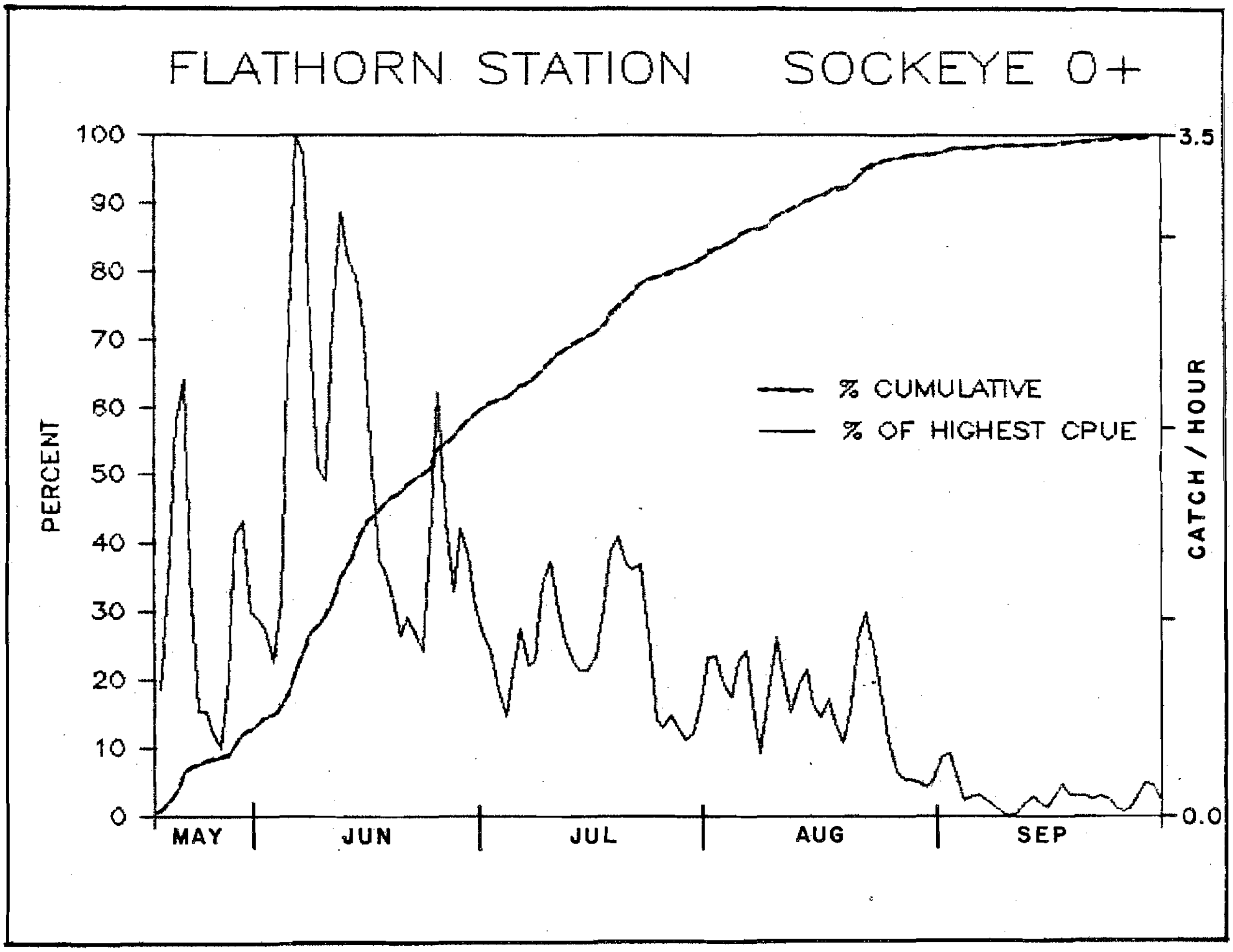


Figure 30. Sockeye salmon (age 0+) smoothed daily catch per unit effort and adjusted cumulative catch recorded at the Flathorn stationary outmigrant trap, May 20 through October 1, 1984.

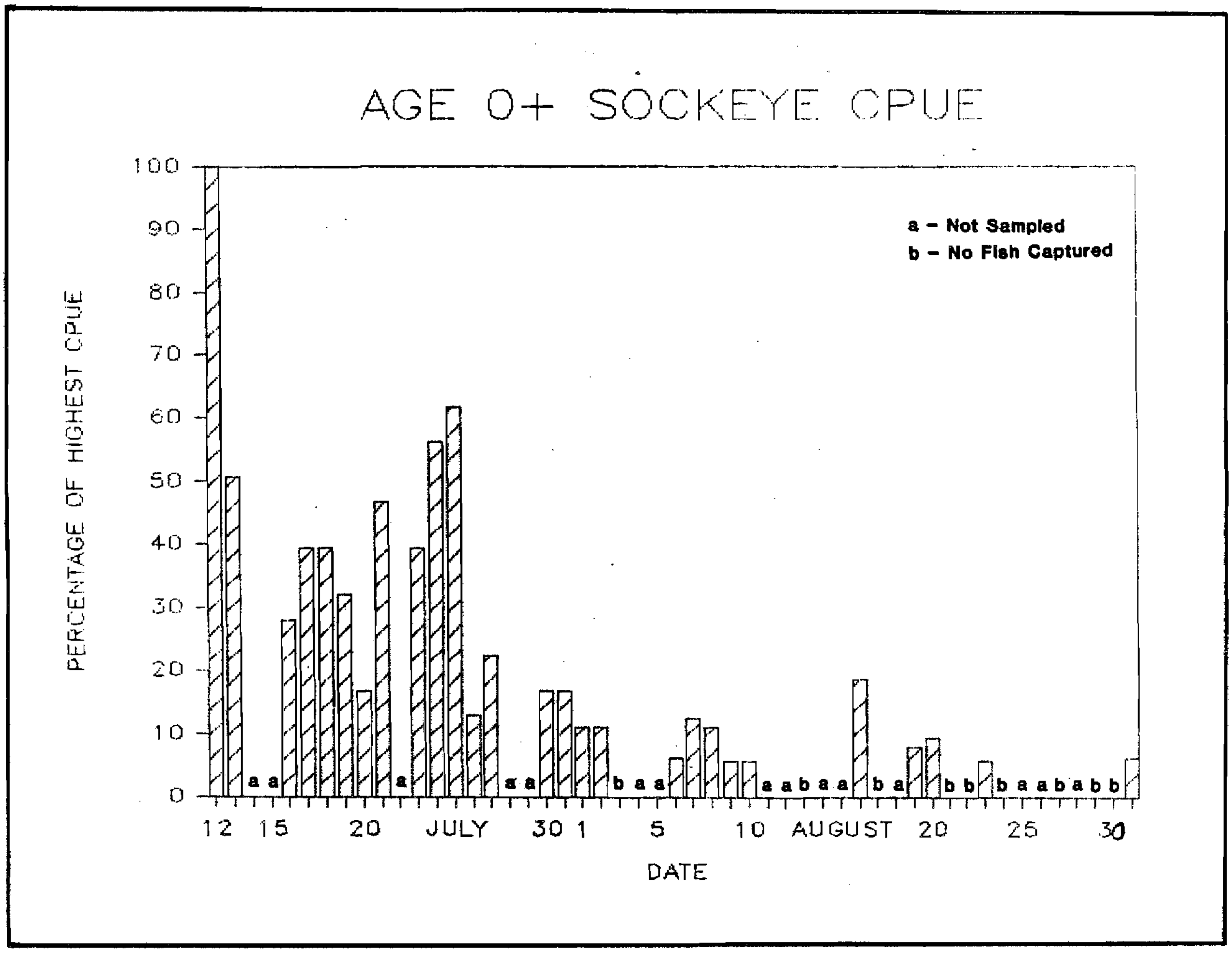


Figure 31. Sockeye salmon (age 0+) daily catch per unit effort recorded at the Flathorn mobile outmigrant trap, July 12 through August 31, 1984.

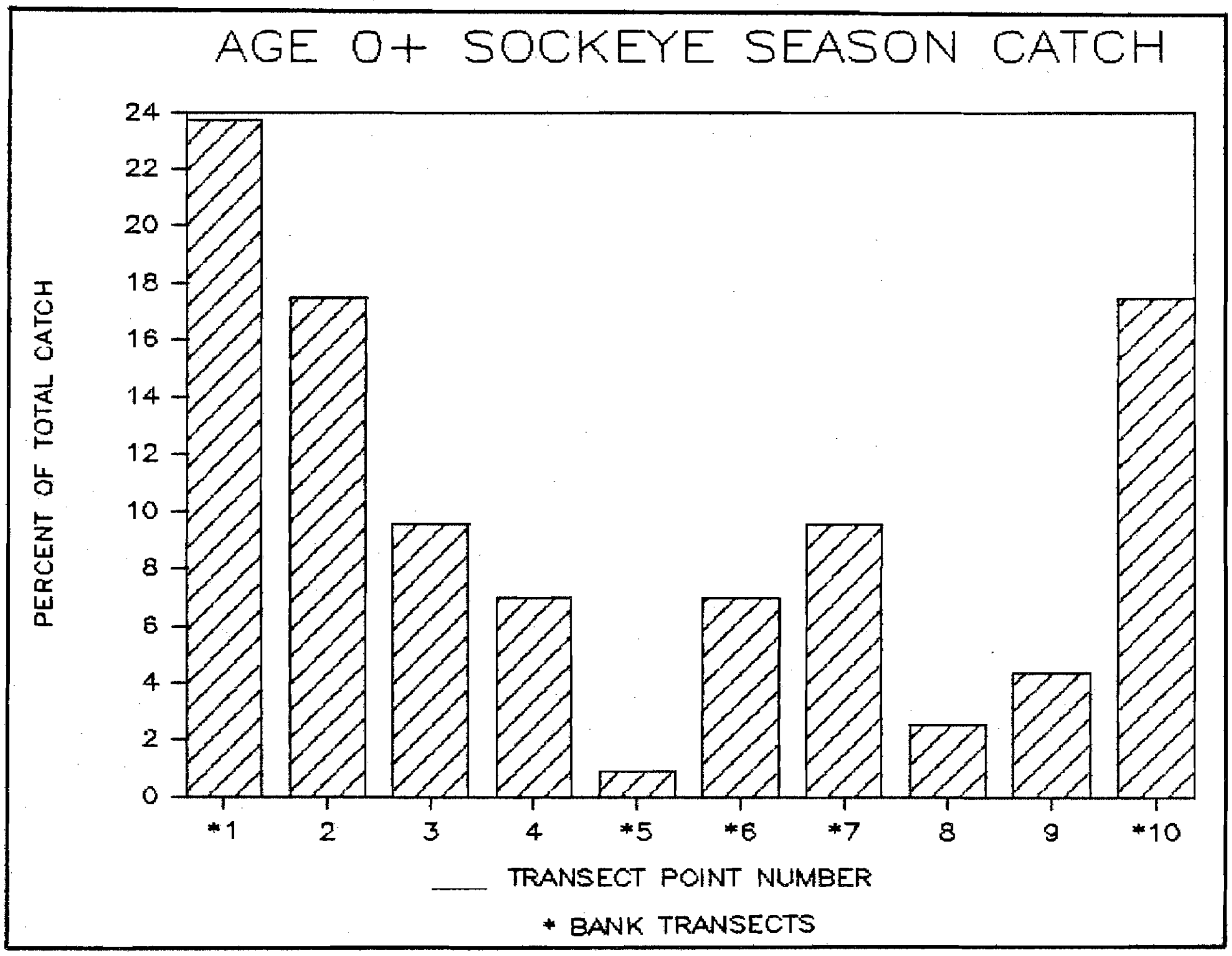


Figure 32. Sockeye salmon (age 0+) percent of the total catch by sampling point recorded at the Flathorn mobile outmigrant trap, 1984.

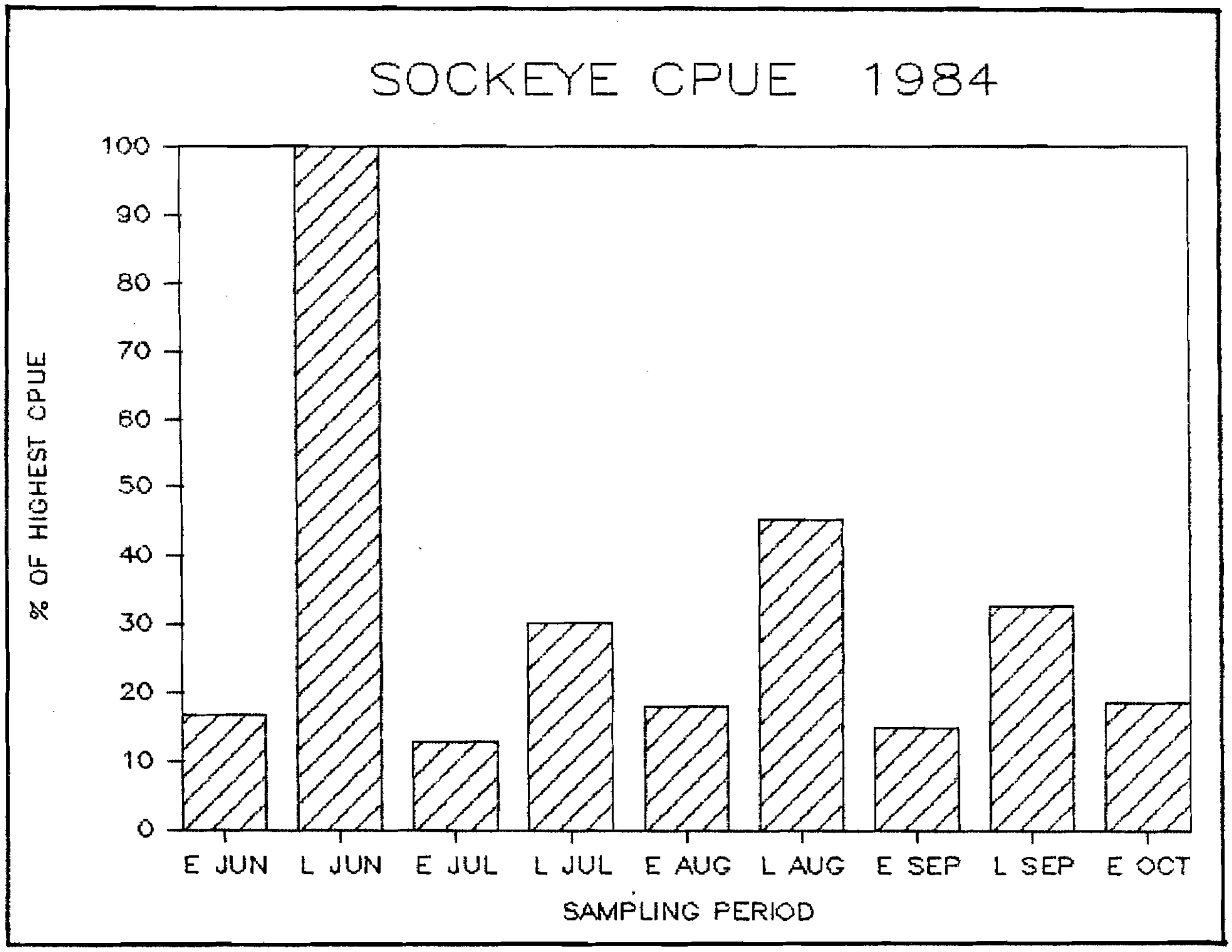


Figure 33. Sockeye salmon juveniles catch per unit effort by sampling period recorded at JAHS sites in the lower reach of the Susitna River, 1984.

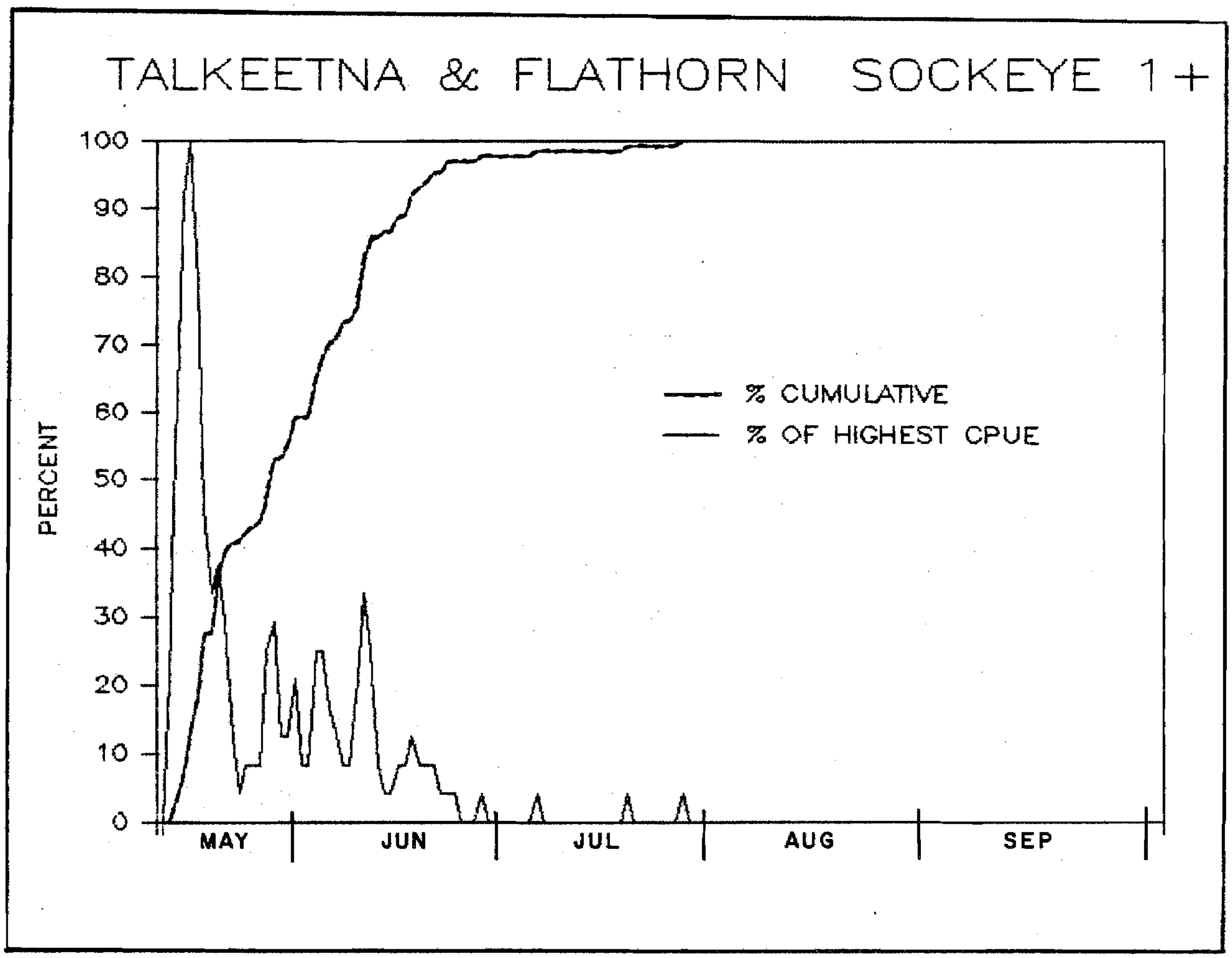


Figure 34. Sockeye salmon (age 1+) smoothed daily catch per unit effort and adjusted cumulative catch recorded at the Flathorn and Talkeetna stationary outmigrant traps, May 14 through October 6, 1984.

3.3.2 Growth

The mean length and range of lengths for age 0+ sockeye salmon by reach of river and sampling period is presented in Fig. 35. During May and June, sockeye fry collected in the middle river reach had a smaller mean length than the same age class sockeye collected in the lower river. By early July, sockeye fry averaged the same length (49 mm) in both reaches, and by late August, middle river sockeye fry were averaging larger than fish collected in the lower river. This trend continued through the remainder of the season. The number of fish measured, the mean length and range of lengths by sampling period for sockeye salmon fry are presented for each of the data collection areas in Appendix Table A-12.

The 90 age 1+ sockeye salmon collected during 1984 ranged from 56 to 102 mm total length (Appendix Table A-13). A coded wire tagged sockeye fry released in 1983 and recaptured in 1984 had increased from 32 mm to 81 mm.

A sample of juvenile sockeye were measured at Talkeetna Station to provide a relationship between length and weight for fish passing this site (Fig. 36).

3.3.3 Coded wire tagging and recovery

A total of 14,532 tagged sockeye salmon fry averaging 33 mm total length were released between May 22 and June 22, 1984 (Table 3). Tag retention rates for sockeye fry averaged 97.1% and ranged from 92.3 to 99.0%. Tagging mortality ranged from 0.6 to 2.6% and averaged 1.3%.

A total of 366 tagged sockeye salmon fry (2.5% of the total tagged sockeye released) were recovered from the 7,484 age 0+ sockeye captured and examined for tags at the Talkeetna Station outmigrant traps during 1984. In addition, 15 sockeye fry with clipped adipose fins but no coded wire tags were recovered in the traps. When compared to the total tagged sockeye salmon fry recovered, this provides a tag retention rate at the traps of 96.1%.

Trap recoveries of coded wire tagged sockeye fry were made from 0 to 109 days (mean = 35 days) following their release at the tagging sites (Fig. 37). In addition, one tagged sockeye fry which was released from Slough 21 on May 28 was recaptured at Flathorn Station on July 7. Seven coded wire tagged sockeye fry were recovered during the cold branding study in early August (Table 4). Six of these fish were recovered at Moose Slough (RM 123.2) and one tagged sockeye fry was recovered at a side channel below Slough 11 (RM 135.2).

A single coded wire tagged sockeye salmon marked and released during 1983 was recovered during the 1984 sampling season. This fish was released June 8, 1983 at Slough 11 and was recovered at Talkeetna Station on July 21, 1984.

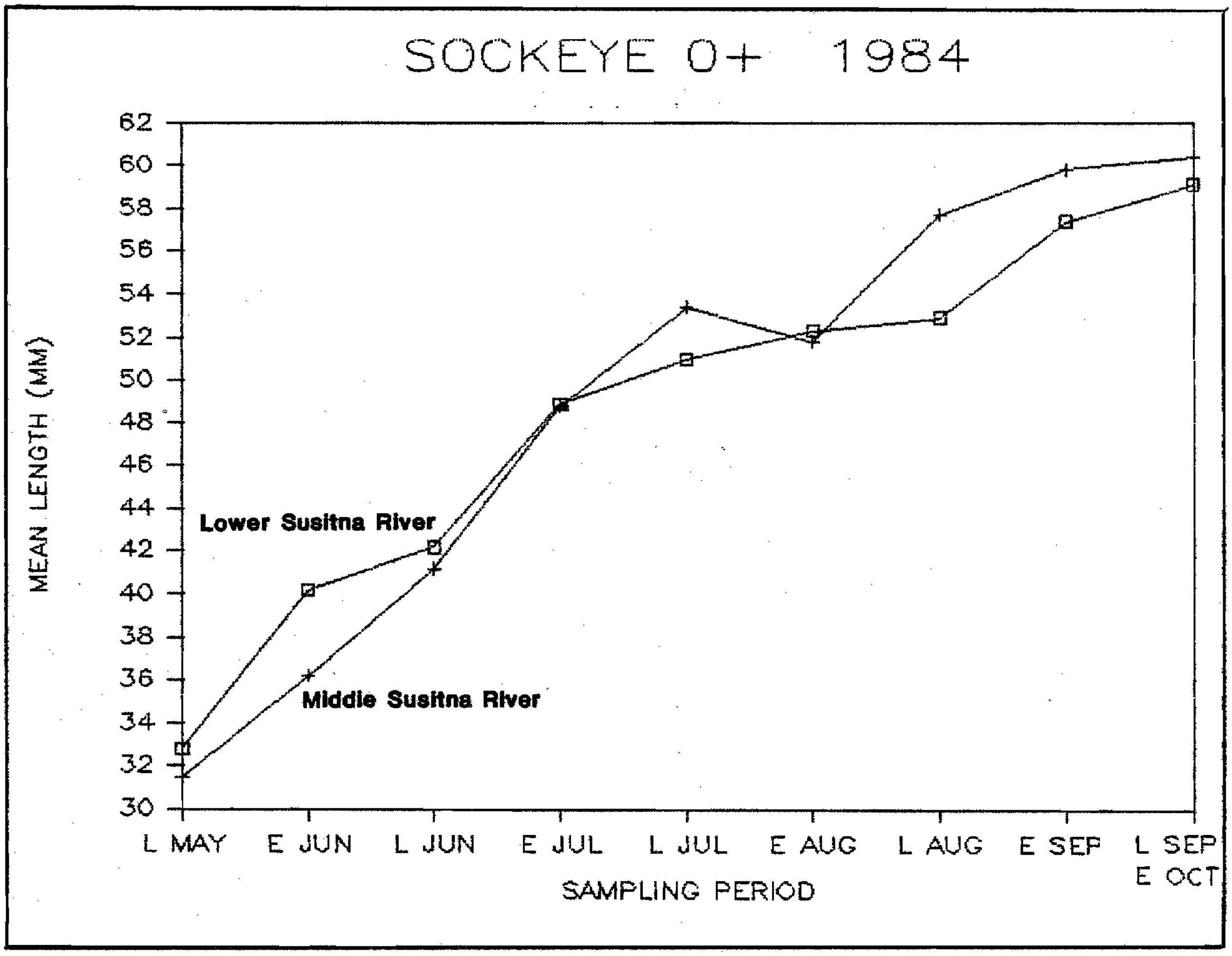


Figure 35. Sockeye salmon (age 0+) mean length and range of lengths by sampling period for fish collected in the lower and middle reach of the Susitna River, 1984.

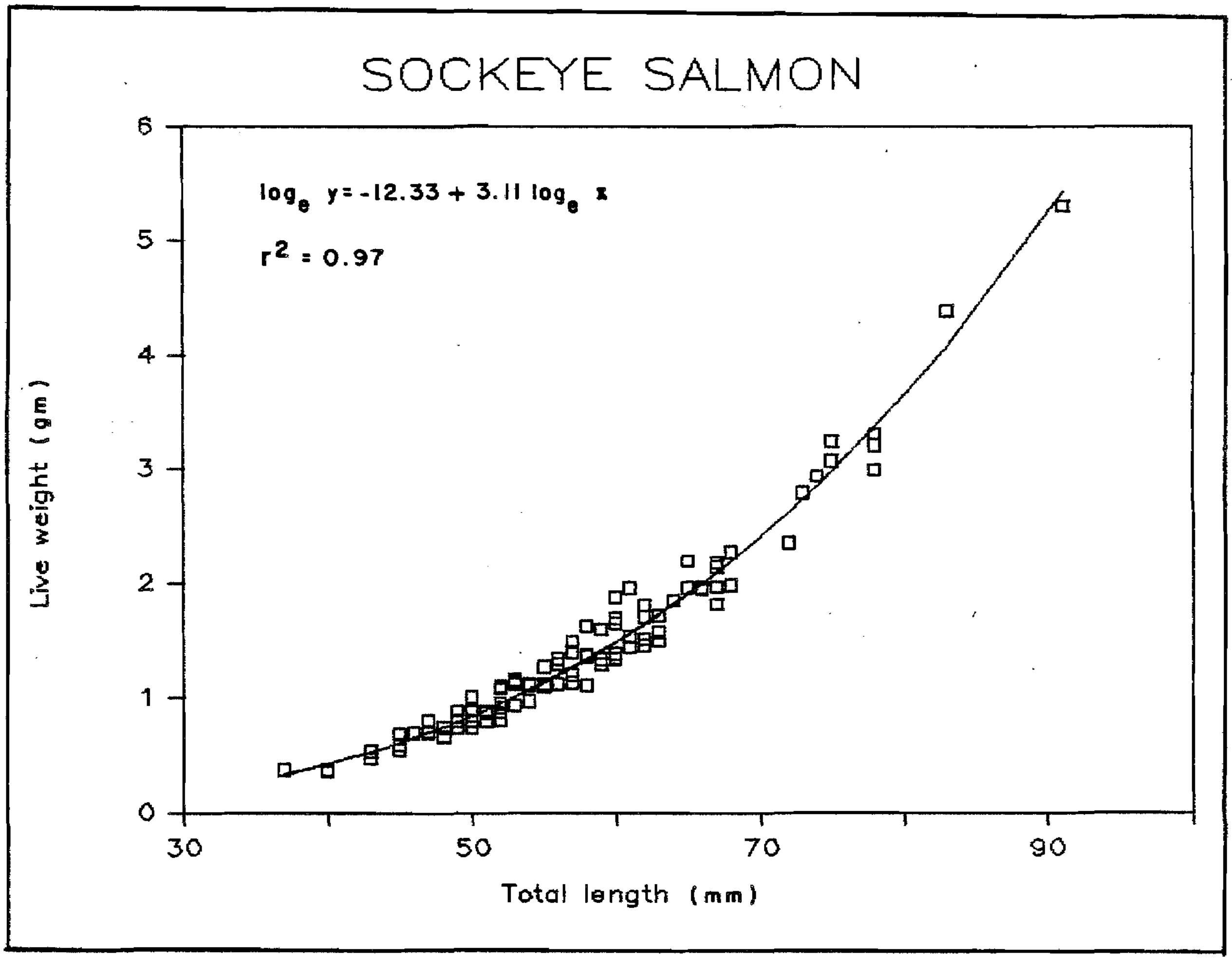


Figure 36. Weight/length relationship for juvenile sockeye salmon collected at the Talkeetna stationary outmigrant traps, 1984.

Table 3. Coded wire tag release data for sockeye salmon fry on the Susitna River by tagging site and release date, 1984.

Tagging Site (River Mile)	Number of Fish Tagged	Date of Release	Percent Tag Retention	Percent Mortality
Slough 21 (RM 142.0)	3,736	5/28	97.9	2.6[a]
Slough 11 (RM 135.3)	2,327	5/22	92.3	1.1
	2,732	5/24	97.7	0.7
	1,537	6/22	96.6	1.1
Slough 9 (RM 128.3)	2,052	6/9	99.0	1.0
Slough 8A (RM 125.3)	2,148	6/19	99.0	0.6
TOTAL - ALL SITES	14,532	5/22-6/22	97.1	1.3

[a] Mortality due to handling, thermal, and anesthetic stresses.

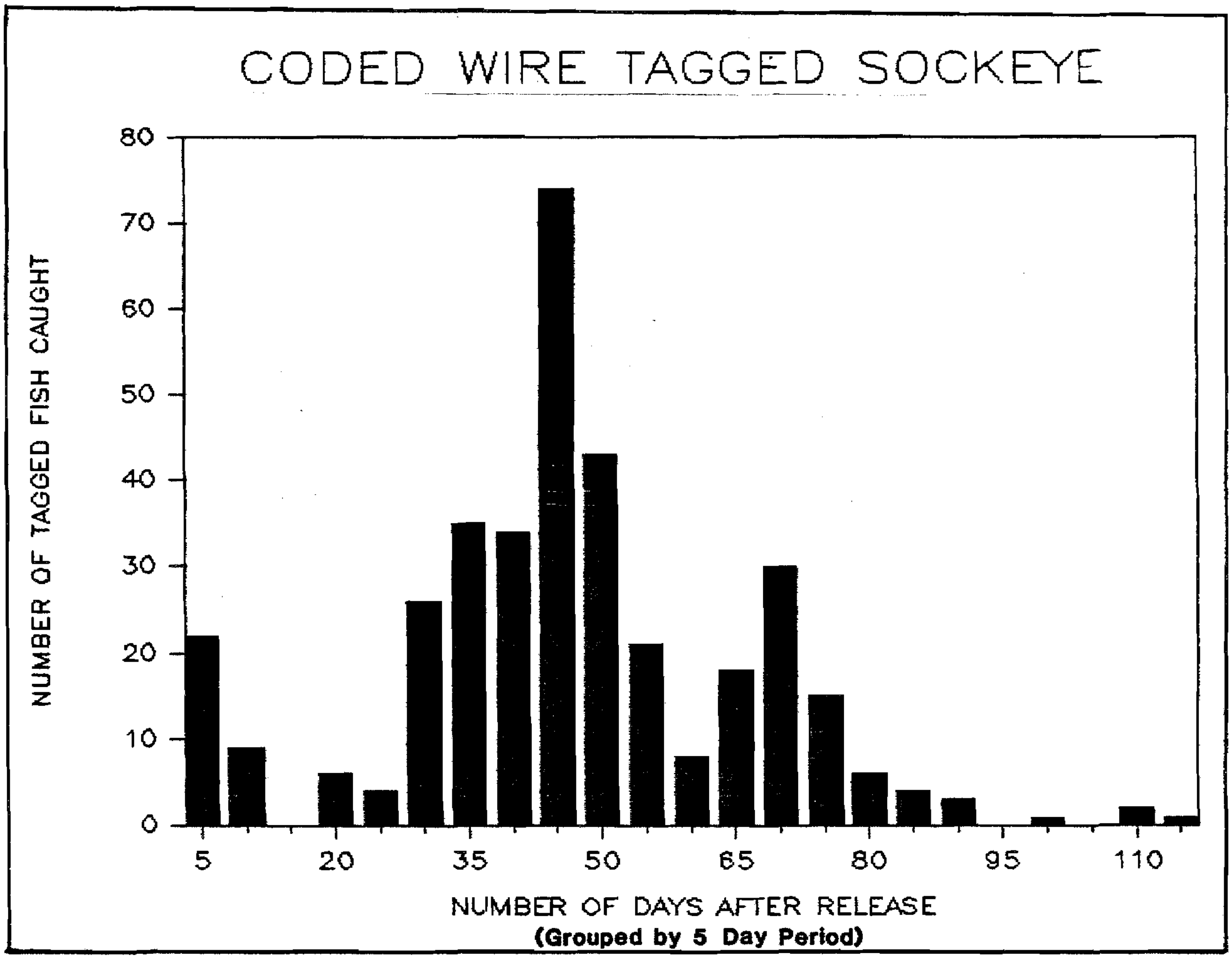


Figure 37. Length of time between the mark and recapture of coded wire tagged sockeye salmon juveniles in the middle reach of the Susitna River, 1984.

Table 4. Recoveries of coded wire tagged sockeye salmon fry at mainstem river sites between Talkeetna and Devil Canyon, 1984.

Collection Site	Collection Date	Release Site	Release Date
Moose Slough[1]	8/8	Slough 21	5/28
Moose Slough	8/8	Slough 21	5/28
Moose Slough	8/8	Slough 11	6/22
Moose Slough	8/8	Slough 9	6/9
Moose Slough	8/8	Slough 8A	6/19
Moose Slough	8/8	Slough 8A	6/19
Slough 11 Side Channel[2]	8/3	Slough 21	5/28

1 River Mile 123.2

2 River Mile 134.9

The ratio of coded wire tagged sockeye fry to total sockeye fry was the same (0.05:1.00) in both traps at Talkeetna Station. This indicates that the coded wire tagged fish were uniformly mixed in the total population by the time they migrated past the traps.

3.3.4 Population estimates and survival rates of outmigrants

Females comprised 38.5% of the population of 1,900 adult sockeye salmon estimated past Curry Station in 1983 (95% C.I. - 1,600 to 2,300 adults) and the fecundity of Susitna River sockeye averaged 3,350 eggs per female, with a 95% C.I. of 3131 to 3569 (Barrett et al. 1984). Milling activity was estimated at 30% (Barrett 1984). These data provided a calculation of total potential egg deposition for sockeye salmon of 1,715,000 eggs during 1983.

Using the method outlined by Schaefer (1951), the number of age 0+ sockeye salmon fry above Talkeetna Station during 1984 was estimated to be 299,000 (Appendix Table B-1 and B-2). A comparison of this estimate to the calculated potential egg deposition (dividing the estimated number of fry by the number of eggs) gave an egg-to-outmigrant fry survival rate of 17%. The reliability of this estimate is not currently known because there is no way to estimate the variance of the adult milling estimate and because we do not currently have a method of estimating the variance on the Schaefer estimate of the fry population size.

3.4 Chum Salmon

3.4.1 Catch per unit effort

Chum salmon were collected during the coded wire tagging study in May and June and during beach seine sampling of Indian River in July. Catch rates were not generally recorded during these studies except for 24 hour fyke net sets at Slough 21 (Appendix Table A-10).

Peak catches of chum fry collected at the Talkeetna Station outmigrant traps were recorded during late May and mid June, with the highest daily catch rate of 8.0 fish per hour occurring on June 14 (Fig. 38). Ninety-five percent of the 3,590 chum fry captured at Talkeetna Station were recorded by July 15. The major outmigration had occurred by the end of June (50% by June 13), although the migration continued until September 11.

Chum salmon fry catches at Flathorn Station were greatest during June with a peak catch rate of 10.9 fish per hour recorded on June 14 by which time 50% of the season catch had occurred (Fig. 39). By July 1, 97% of the chum fry collected at this site had been captured; the last chum fry was captured on July 22.

Beach seining and electrofishing at side channel, slough, and tributary sites in the lower river reach collected chum salmon fry during June and July (see Part 2 of this report). Chum fry were abundant in this reach during early June but catches steadily decreased through July (Fig. 40).

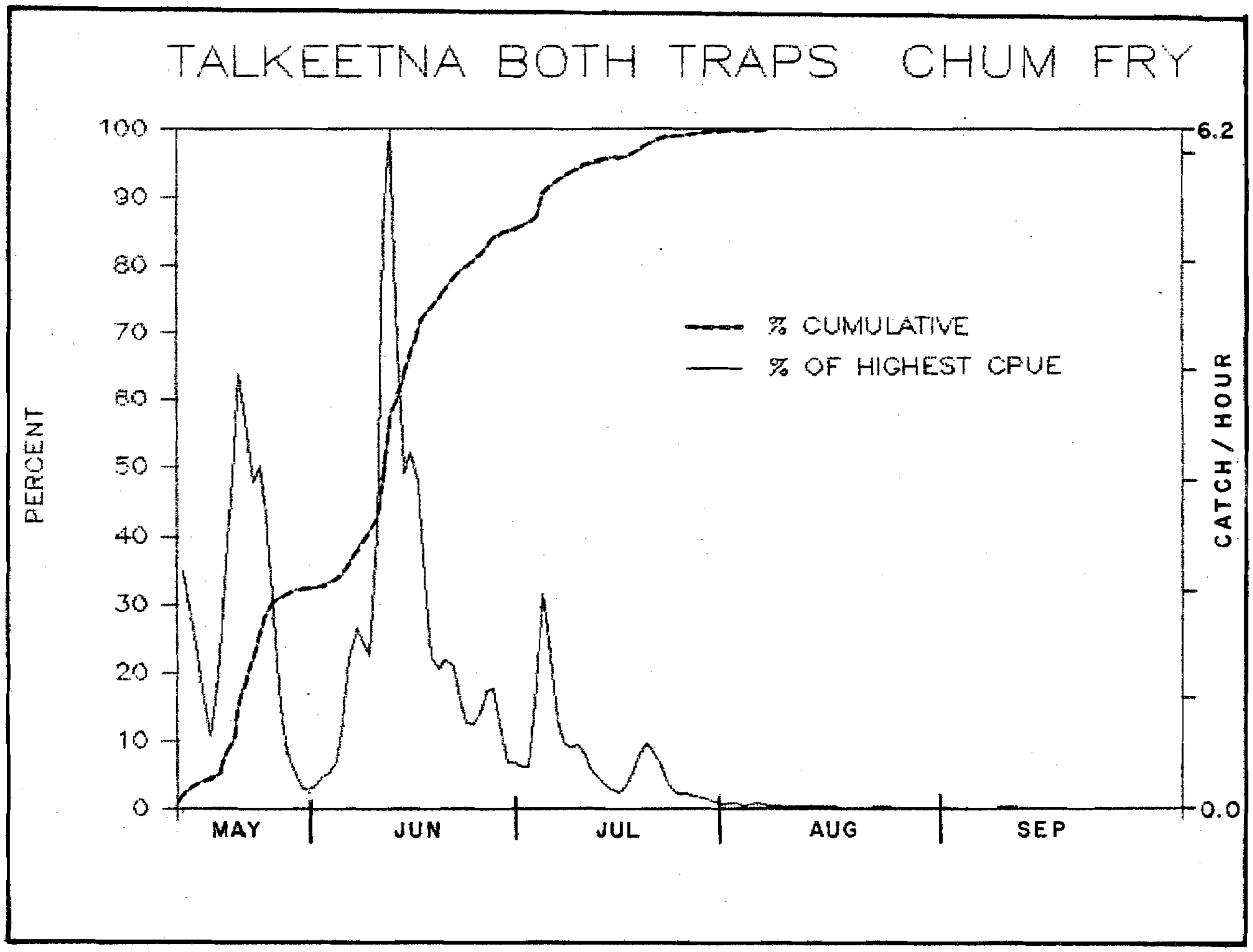


Figure 38. Chum salmon fry smoothed daily catch per unit effort and adjusted cumulative catch recorded at the Talkeetna stationary outmigrant traps, May 14 through October 6, 1984.

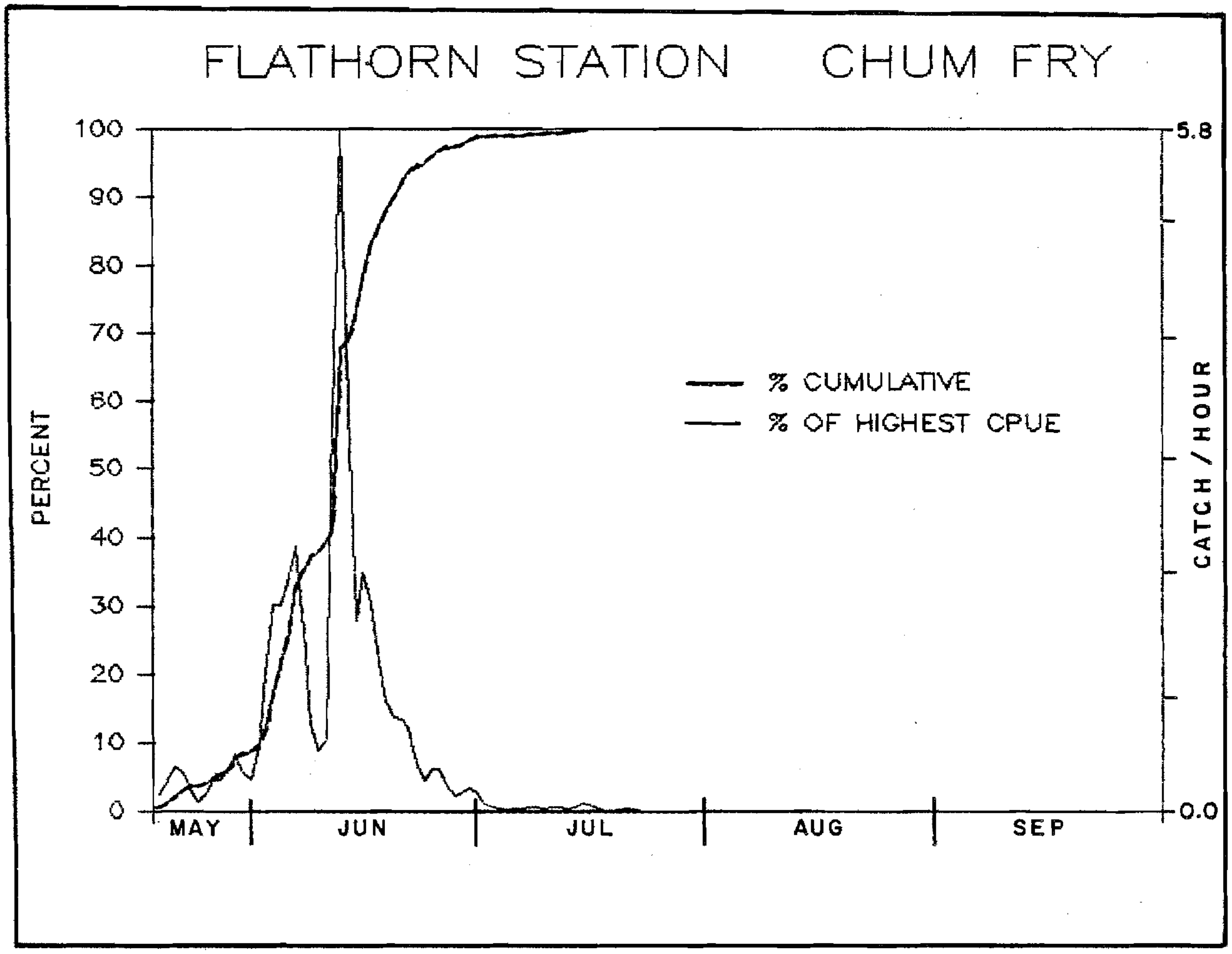


Figure 39. Chum salmon fry smoothed daily catch per unit effort and adjusted cumulative catch recorded at the Flathorn stationary outmigrant trap, May 20 through October 1, 1984.

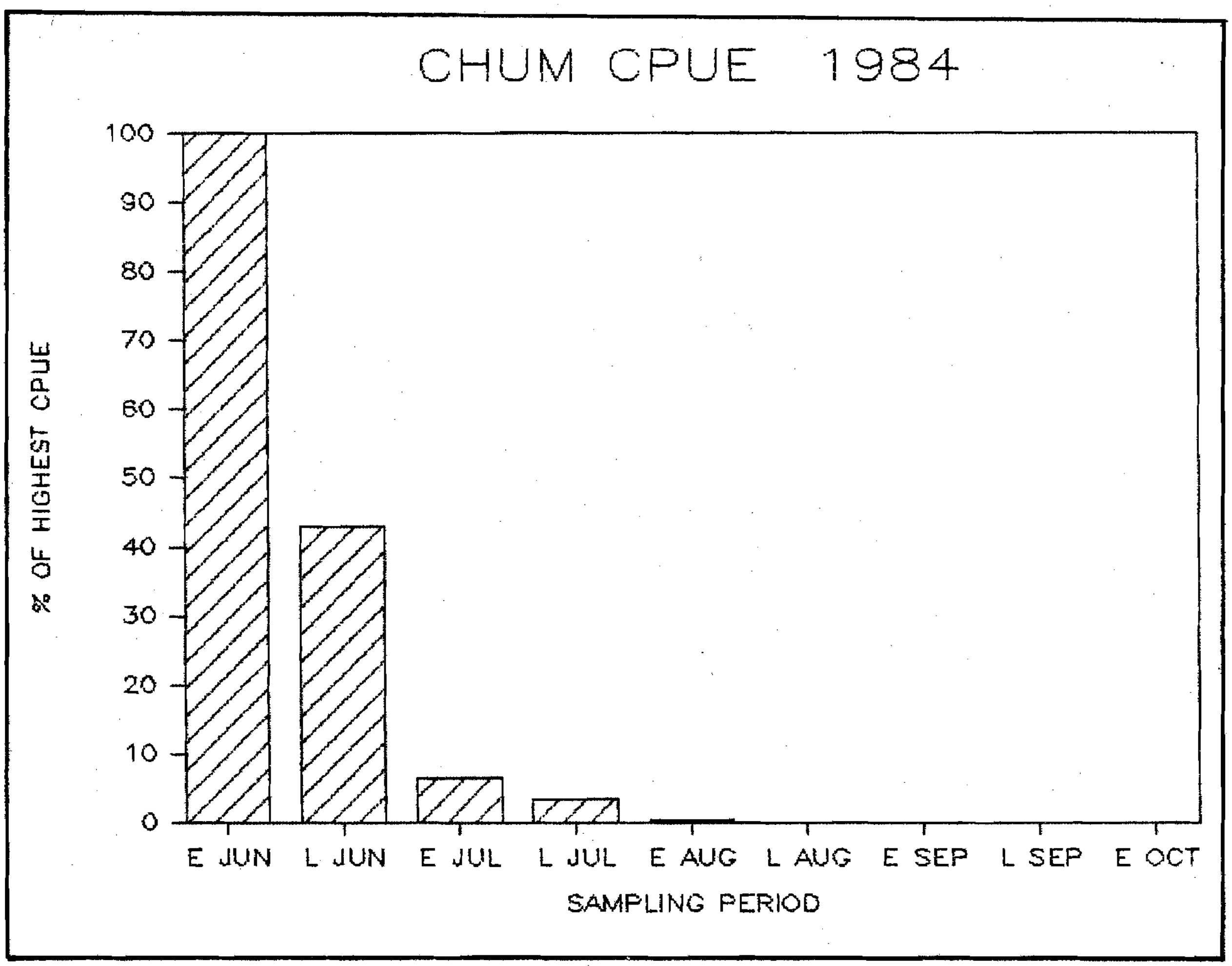


Figure 40. Chum salmon fry catch per unit effort by sampling period recorded at JAHS sites in the lower reach of the Susitna River, 1984.

3.4.2 Growth

At both Talkeetna and Flathorn Stations, chum length ranged from emergent lengths (less than 35 mm) to lengths greater than 60 mm for May, June, and July (Appendix Table A-14). Chum salmon spawn in both tributaries and sloughs and there is a wide range in emergence timing. The fish caught at 30-40 mm are probably recent emergents. The 50-60+ mm fish have gained over 20 mm in length.

During June, Indian River chum fry averaged 40 mm and had increased to a mean length of 48 mm by early July. Limited sampling of the Talkeetna River during June and July indicated a mean length of 43 mm for chum fry outmigrating from this tributary.

3.4.3 Coded wire tagging and recovery

A total of 31,396 tagged chum fry averaging 43 mm total length were released between May 22 and June 22, 1984 (Table 5). Tag retention rates ranged from 93.0 to 100% and averaged 96.4%. Mortality rates between tagging and release averaged 0.9% and ranged from 0.0 to 2.7%.

Fifty-one tagged chum salmon fry (0.2% of the total tagged chum released) were recovered from the 3,590 chum salmon fry captured and examined for tags at the Talkeetna Station outmigrant traps during 1984. In addition, two chum fry with clipped adipose fins but no coded wire tags were recovered in the traps. When compared to the total tagged chum salmon fry recovered, this provides a tag retention rate at the traps of 96.2%.

Trap recoveries of tagged chum fry were made from 0 to 29 days (mean = 8 days) following their release at the tagging sites (Fig. 41).

The ratio of coded wire tagged chum fry to the total number of fish caught at each trap at Talkeetna Station was 0.016:1 at Trap 1 and 0.013:1 at Trap 2, indicating that the tagged chum fry were randomly distributed with the untagged population by the time they migrated past the traps.

3.4.4 Population estimates and survival rates of outmigrants

Adult population estimates at Curry Station during 1983 were 21,100 chum salmon with 95% confidence limits of 19,200 to 23,500 adults. Females comprised 34.5% of these fish and chum salmon milling was estimated at 40% (Barrett et al. 1984). Fecundity of Susitna River chum salmon was determined during 1983 to be 2,850 eggs per female (95% confidence limits of 2,666 to 3,034). These data provided an estimated total potential egg deposition of 12,448,000 eggs.

The population estimated using the Schaefer (1951) method was 2,039,000 chum salmon fry outmigrating past Talkeetna Station during 1984 (Appendix Table B-3 and B-4). Using the above data, an egg-to-outmigrant fry survival rate of 16% was calculated for chum salmon. As with sockeye salmon, there is no way of knowing the reliability of the estimate

Table 5. Coded wire tag release data for chum salmon fry on the Susitna River by tagging site and release date, 1984.

Tagging Site (River Mile)	Number of Fish Tagged	Date of Release	Percent Tag Retention	Percent Mortality
Slough 22 (RM 144.3)	2,383	6/7	98.0	0.5
Slough 21 (RM 142.0)	2,201	6/3	96.6	1.4
Slough 20 (RM 140.1)	1,255	6/11	96.9	0.6
Slough 15 (RM 137.3)	351	6/14	100.0	0.0
Indian River (RM 138.6)	4,612	6/1	94.5	0.7
	341	6/1	93.0	0.0
	4,592	6/21	93.8	2.7[a]
	2,511	6/22	95.0	0.4
Slough 11 (RM 135.3)	2,031	5/22	97.7	0.1
	2,203	5/24	93.9	0.3
	572	5/24	99.0	0.2
	1,916	6/16	98.0	0.4
Slough 9 (RM 128.3)	5,122	6/6	99.4	0.7
Slough 8B (RM 122.4)	1,306	6/13	98.0	0.8
TOTAL - ALL SITES	31,396	5/22-6/22	96.4	0.9

[a] High mortality due to injury from improper headmold.

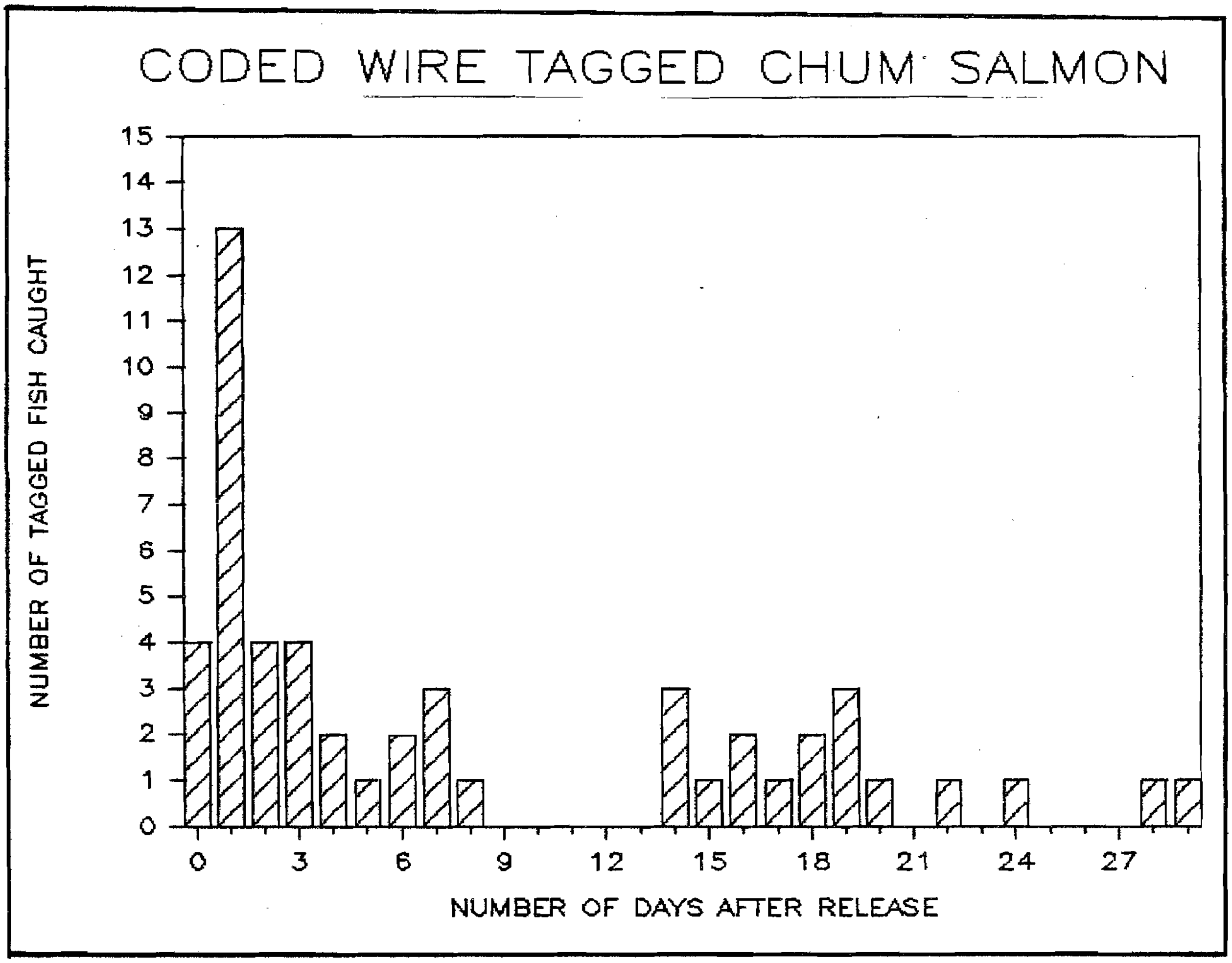


Figure 41. Length of time between the mark and recapture of coded wire tagged chum salmon juveniles in the middle reach of the Susitna River, 1984.

because the variance of the adult milling estimate and the variance of the fry population estimate are not known.

3.5 Pink Salmon

Sixty-eight pink salmon fry were captured between May 15 and July 18 at the Talkeetna Station outmigrant traps during 1984, with the peak catch rate of 0.8 fish per hour being recorded on June 18 (Fig. 42). Pink fry migrating past Talkeetna Station averaged 36 mm total length with a range from 29 to 53 mm.

A total of 405 pink salmon fry were collected in the stationary outmigrant trap at Flathorn Station. Catches occurred from May 21 through July 6 and the peak catch rate of 4.0 fish per hour was recorded on June 5 (Fig. 43). Fifty percent of the catches at this site were recorded by June 11. Pink fry collected at Flathorn Station averaged 34 mm and ranged in length from 25 to 46 mm.

No pink salmon fry were collected during the cold branding studies in the middle river, during sampling of the Deshka River, or at JAHS sites in the lower river during 1984.

3.6 Descriptive Statistics for Catch and Environmental Variables

Summary statistics for Talkeetna Station catch are given in Table 6 and for environmental variables in Table 7. Flathorn data are summarized in Table 8. The influence of discharge peaks on the level of outmigration can be seen by comparing the seasonal discharge level (Fig. 44; Fig. 45) with the outmigration plots presented earlier. Results of a statistical time series analysis of 1983 and 1984 discharge, turbidity, and age 0+ chinook and sockeye salmon outmigration are presented in Appendix C.

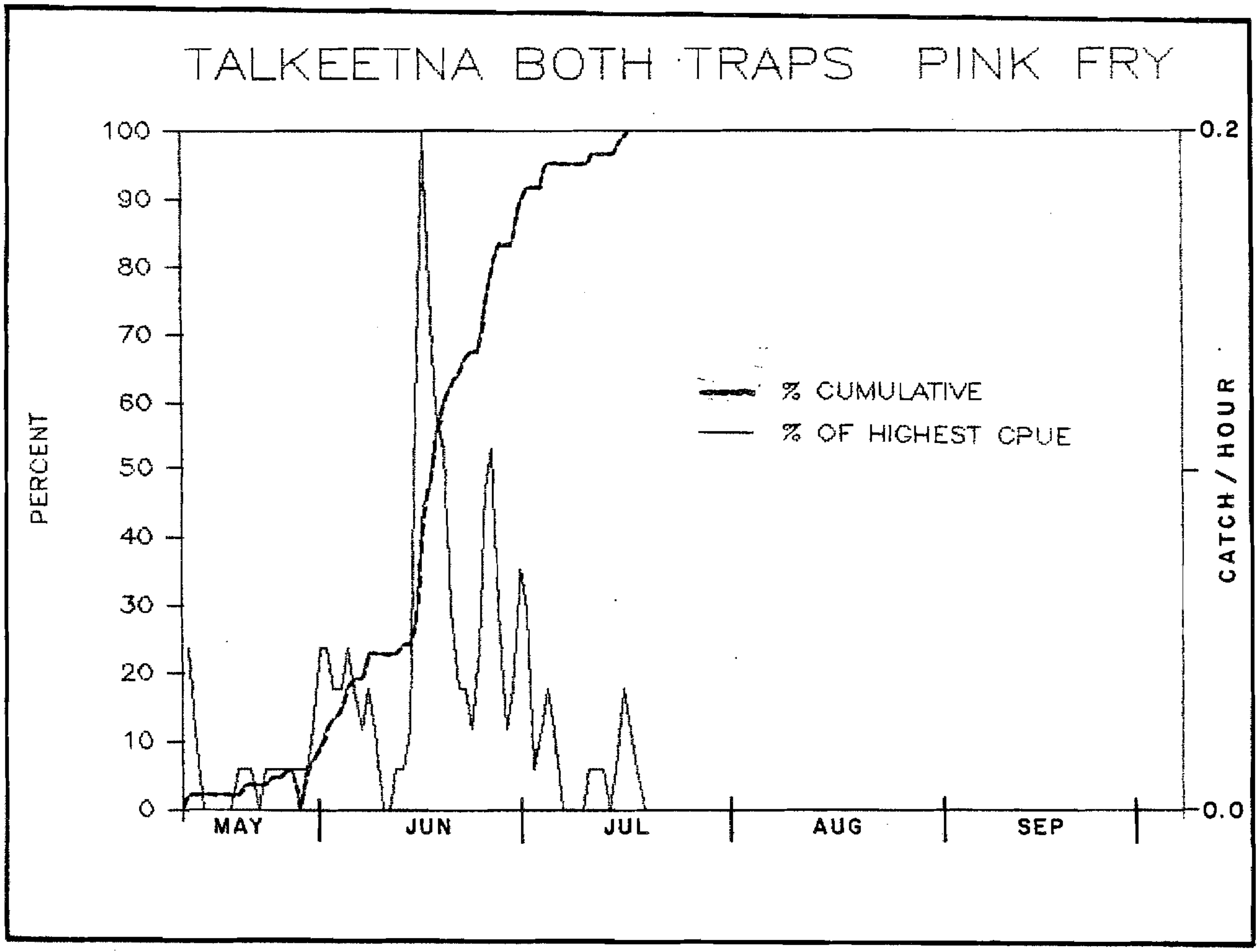


Figure 42. Pink salmon fry smoothed daily catch per unit effort and adjusted cumulative catch recorded at the Talkeetna stationary outmigrant traps, May 14 through October 6, 1984.

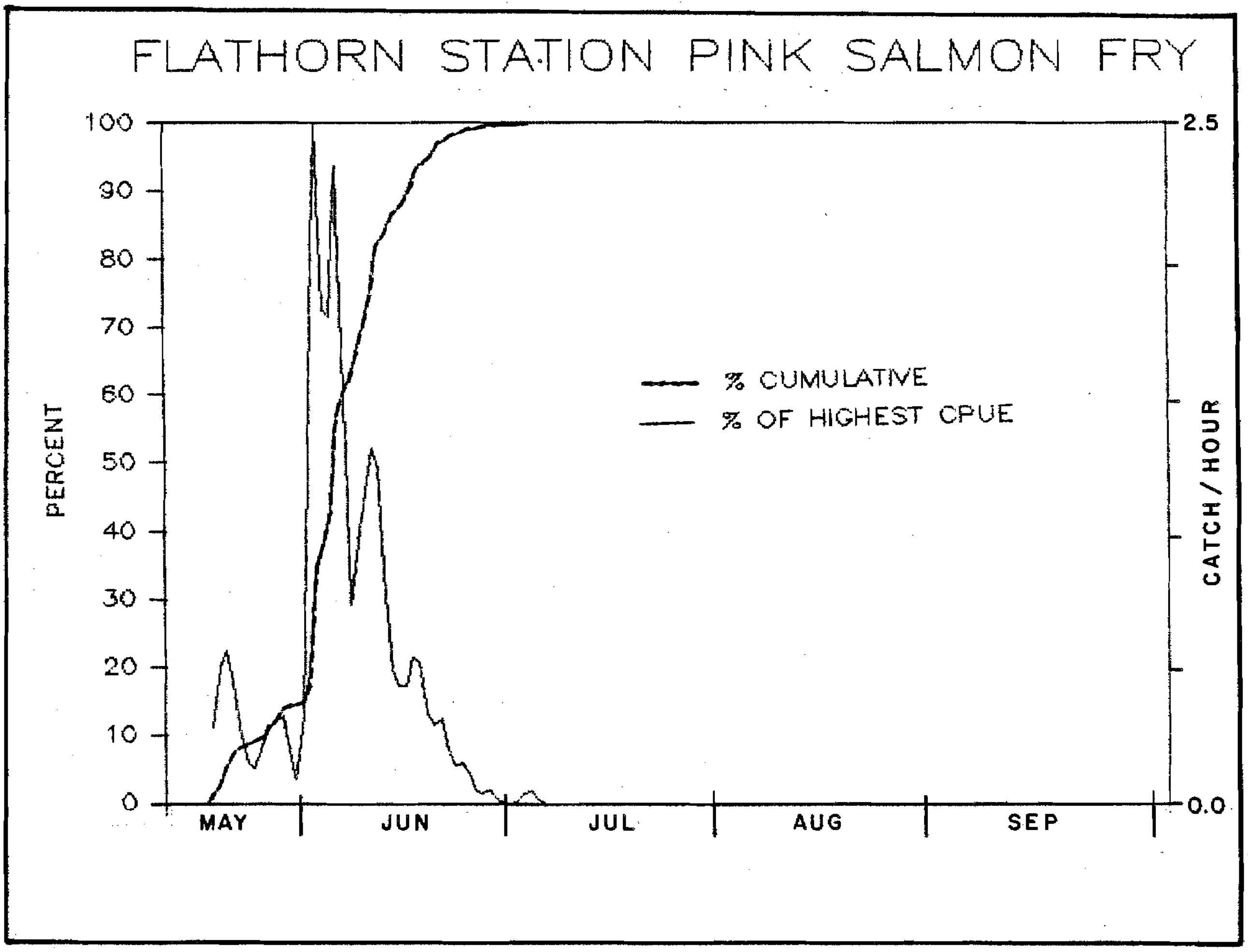


Figure 43. Pink salmon fry smoothed daily catch per unit effort and adjusted cumulative catch recorded at the Flathorn stationary outmigrant traps, May 20 through October 1, 1984.

Table 6. Summary statistics for juvenile salmon catch per hour by species and age class recorded at the Talkeetna Station outmigrant traps, May 14 through October 6, 1984.

	Catch Per Hour, Both Traps[a]			
	Min	Max	Mean	Std. Dev.
Chinook 0+	0.0	17.2	2.2	3.2
Chinook 1+	0.0	3.5	0.3	0.6
Coho 0+	0.0	2.9	0.3	0.4
Coho 1+[b]	0.0	1.7	0.3	0.3
Sockeye 0+	0.0	13.0	1.2	1.8
Sockeye 1+	0.0	0.3	0.0	0.0
Chum	0.0	8.0	0.7	1.2

[a] n = 146

[b] includes all juvenile coho age 1+ or older.

Table 7. Summary statistics for habitat variables recorded on the Susitna River between the Chulitna River confluence and Devil Canyon, May 14 through October 6, 1984.

	Min	Max	Mean	Std. Dev.	n
Discharge (ft^3/sec)[a]	6,780	52,000	19,405	8160.0	146
Water Temperature (°C)[b]	2.0	13.5	8.8	3.0	145
Turbidity (NTU)[b]	13	400	115	92.0	145

[a] USGS provisional data at Gold Creek, 1984.

[b] ADF&G data at Talkeetna Station outmigrant traps, 1984.

Table 8. Summary statistics for juvenile salmon catch per hour by species and age class recorded at the Flathorn Station outmigrant traps, May 20 through October 1, 1984.

Catch Per Hour[a]	Min	Max	Mean	Std. Dev.
Chinook 0+	0.0	7.8	0.7	1.1
Chinook 1+	0.0	6.5	0.1	0.6
Coho 0+	0.0	1.5	0.1	0.3
Coho 1+[b]	0.0	0.8	0.1	0.1
Sockeye 0+	0.0	4.6	0.8	0.8
Sockeye 1+	0.0	0.4	0.0	0.1
Chum	0.0	10.9	0.3	1.1
Pink	0.0	4.0	0.2	0.5
Discharge (ft^3/sec)[c]	40,800	166,000	93,122	28,887.5

[a] n = 134.

[b] Includes all juvenile coho age 1+ or older.

[c] USGS provisional data at Susitna Station, 1984.

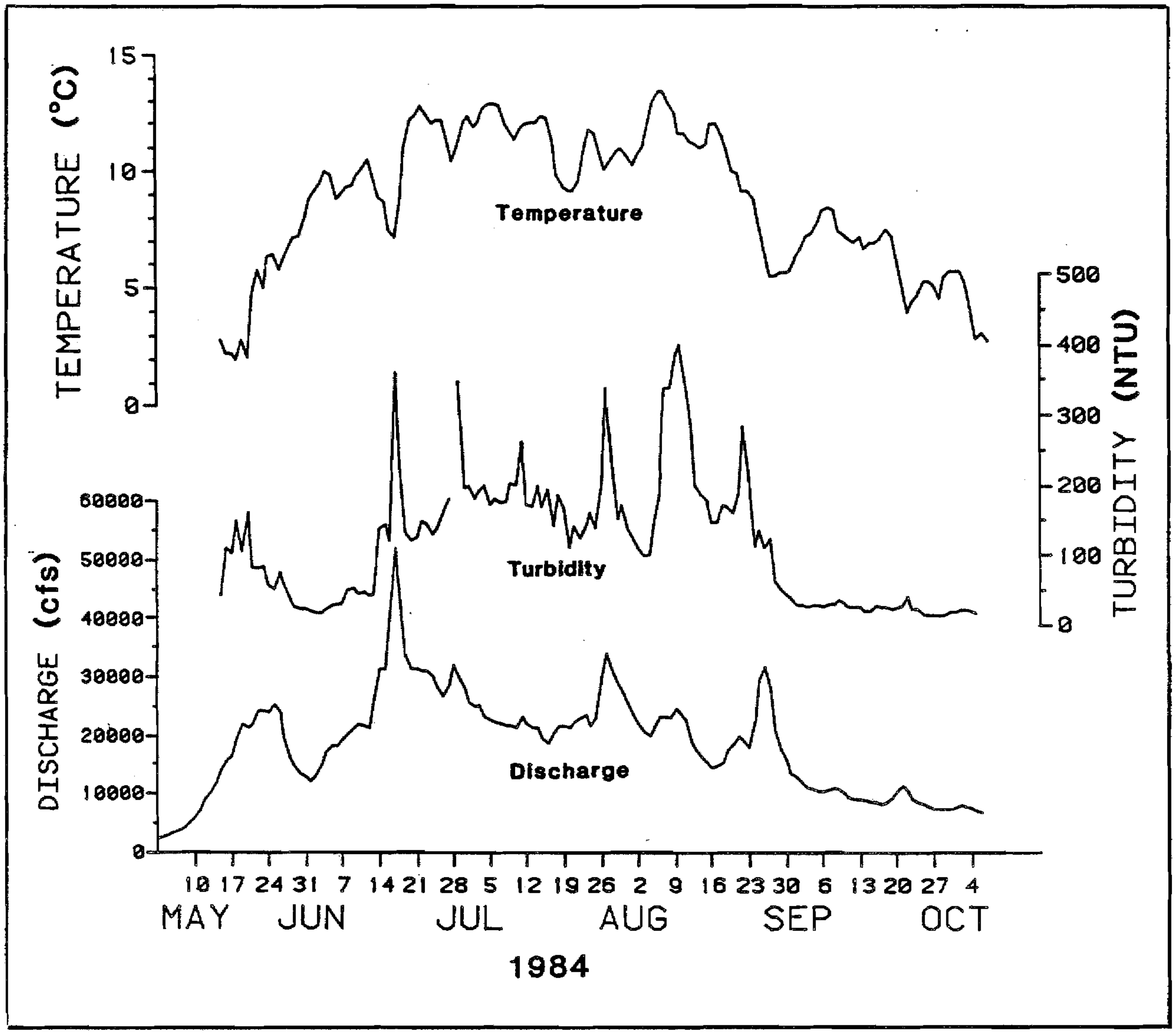


Figure 44. Mainstem discharge, water temperature, and turbidity in the middle reach of the Susitna River, 1984. Discharge was measured at the USGS gaging station at Gold Creek. Water temperature and turbidity were measured at Talkeetna Station.

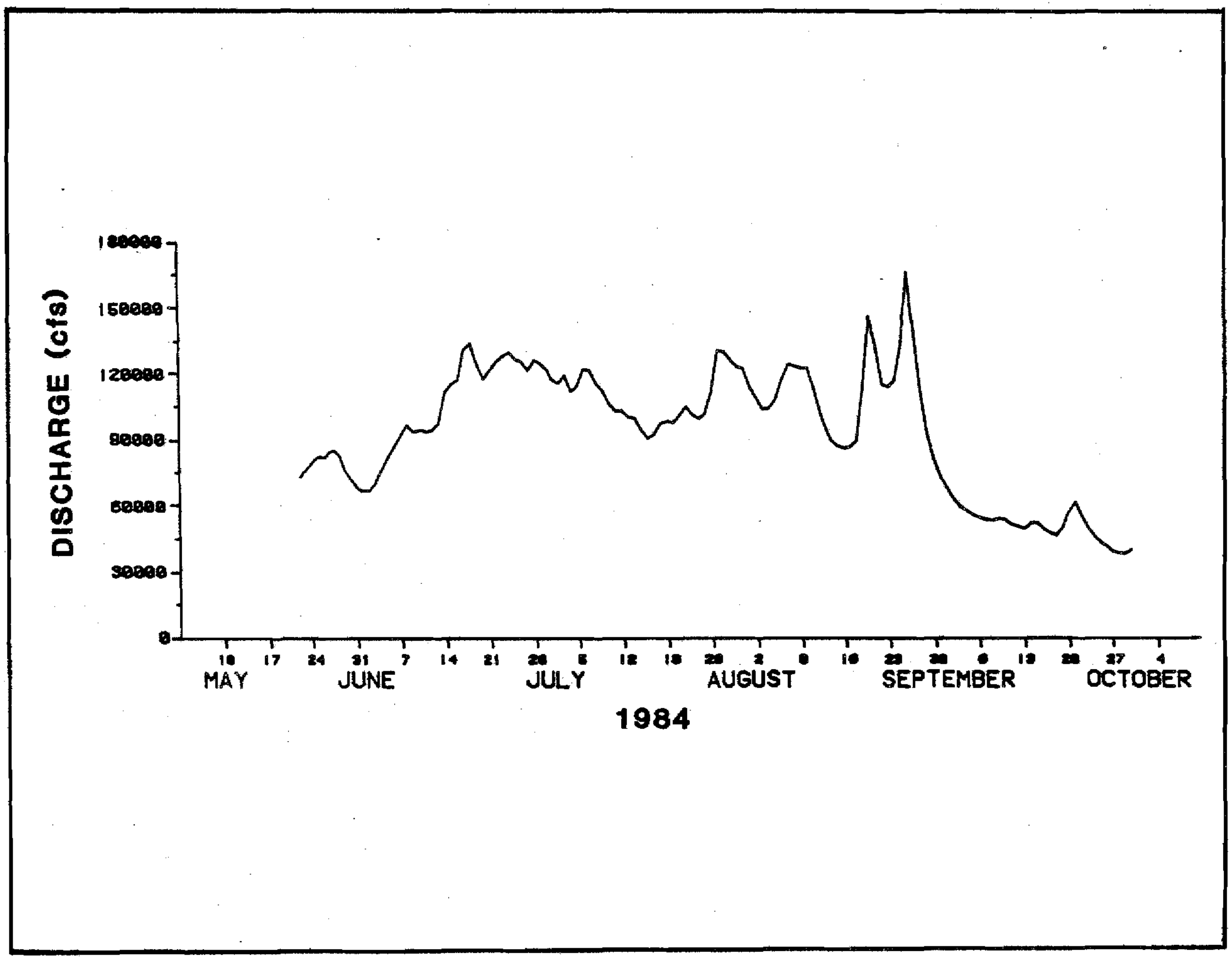


Figure 45. Mainstem discharge in the lower reach of the Susitna River measured at the USGS gaging station at Susitna Station, 1984.

4.0 DISCUSSION

4.1 Chinook Salmon

4.1.1 Outmigration

Fifty percent of the outmigration of age 0+ chinook salmon past Talkeetna Station during both 1983 and 1984 had occurred by mid July, but the rates and timing were different between the two years (Fig. 46). During 1983, two pulses of chinook fry movement were recorded, one in late June and the second in mid August. Conversely, the 1984 outmigration did not start until mid June and was then relatively steady through late August.

Low tributary flows during July of 1983 trapped chinook fry in pools and side channels in Indian River until high tributary flows from heavy rainfall in mid August allowed access or flushed fry to the Susitna River (Roth et al. 1984). In 1984, minnow trap catches of marked and unmarked chinook in Indian River during the cold branding study showed the movement of chinook fry out of this tributary continued from July through early October.

In 1984, age 0+ chinook salmon in the middle river that had outmigrated from the tributaries were found predominately in shallow, turbid, rocky bottom areas in breached sloughs and side channels during July and August. Not until mid August, when mainstem flows had decreased and many of these sloughs and side channels were no longer breached, did catches of juvenile chinook increase at clear water sloughs and side channels. In early September, juvenile chinook were concentrated at the mouths of clearwater sloughs and side channels, but as water temperatures and stage continued dropping through September and early October, these fish slowly dispersed within these sites with the major concentrations being found in areas with non-imbedded substrate and a groundwater source.

The rates of outmigration of age 1+ chinook salmon past Talkeetna Station were similar in 1983 and 1984 (Fig. 47), but the date by which half of the total seasonal outmigration occurred was ten days earlier in 1983 than in 1984, primarily because of the late start of outmigration in 1984.

The chinook fry appear to associate with the banks of the river during their downstream movement. Although juvenile chinook were captured across the entire river at Flathorn Station, 60% of the total mobile trap captures were recorded at bank transect sites.

4.1.2 Freshwater life history

Chinook salmon juveniles in the middle river appear to group into three separate categories. The first group are those juveniles which rear and overwinter in their natal tributaries and outmigrate to the ocean as age 1+ fish during the spring of their second year. The second group of chinook juveniles spend a portion of their first summer in their natal tributaries and then, probably because of density dependent interaction,

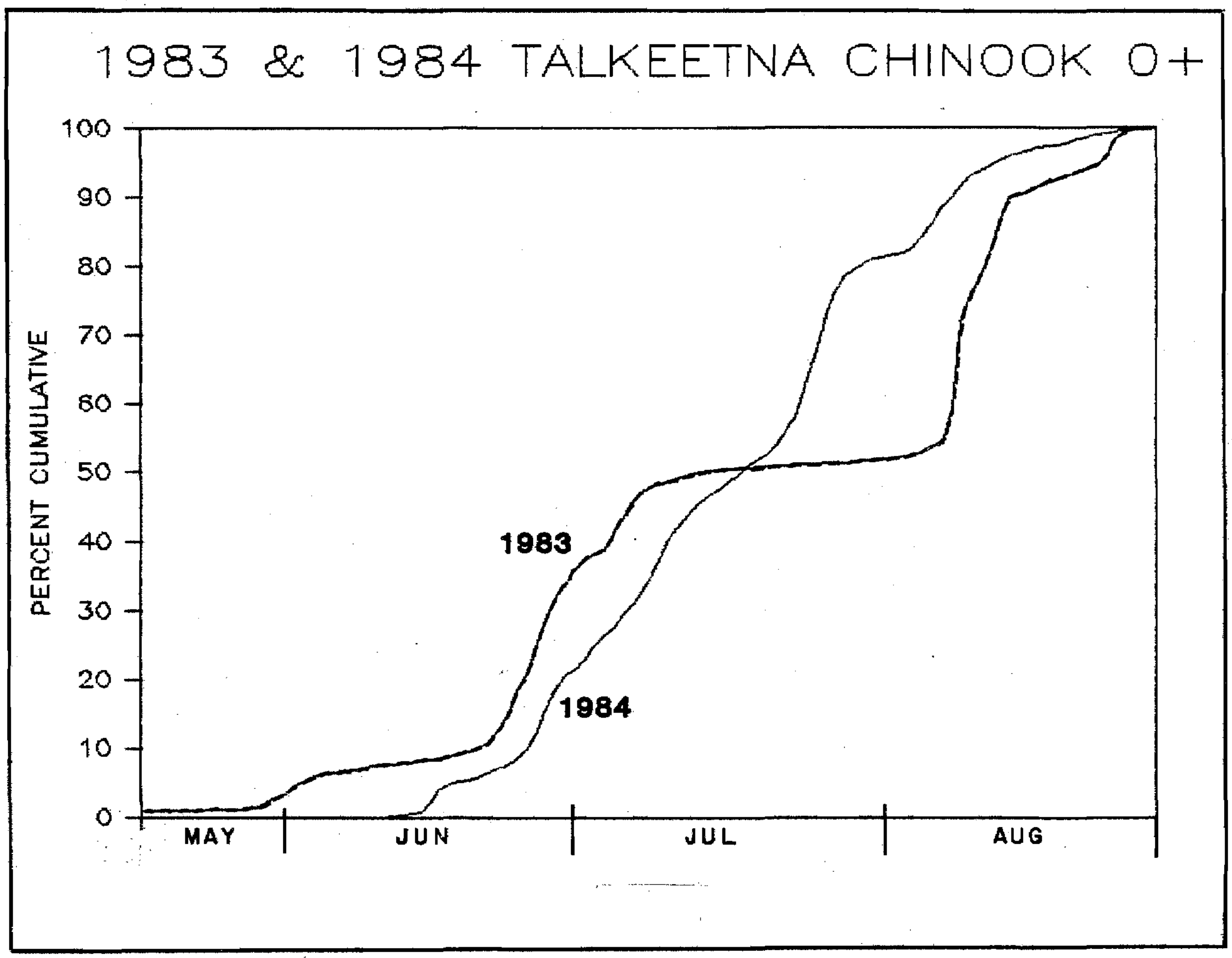


Figure 46. Chinook salmon (age 0+) adjusted cumulative catch recorded at the Talkeetna stationary outmigrant traps, 1983 and 1984.

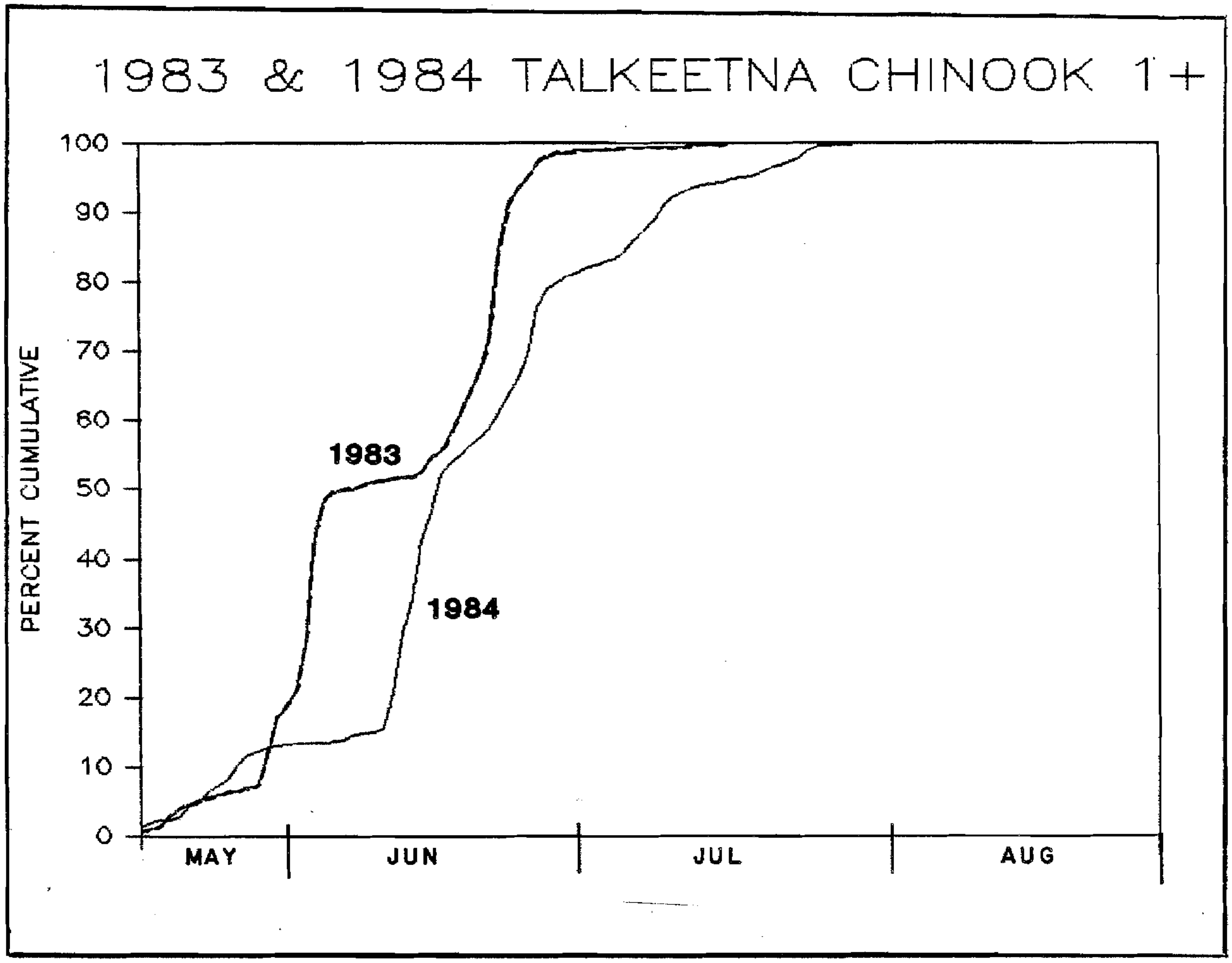


Figure 47. Chinook salmon (age 1+) adjusted cumulative catch recorded at the Talkeetna stationary outmigrant traps, 1983 and 1984.

behavioral changes related to downstream re-distribution, or flushing by high flows, enter the mainstem river. These fish actively search out suitable habitats as they move downstream. Many of the fish enter sloughs and side channels in the middle river to overwinter while others continue downstream to the lower river. Since 80% of the Talkeetna Station trap catch had occurred by August 1, and high catches were still being recorded at Indian River and selected sloughs above Talkeetna Station in August, September, and October, it appeared that a significant percentage of 1983 brood year chinook salmon belonged to one of these two groups. We do not know what this percentage was.

A third group of chinook salmon juveniles may be present in the Susitna River. Data collected at the Flathorn Station outmigrant trap showed that a portion of the age 0+ chinook were moving downstream past this site. Many of these were probably fry from the Deshka River. Although it is possible that these fish overwintered in freshwater habitats below Flathorn Station, it appeared that many of these fish entered the ocean as age 0+ fish because few rearing chinook fry were found at sites below the Deshka River during 1984 (see Part 2 of this report).

Intermittent operation of an outmigrant weir on the Deshka River during 1984 showed that a large number of age 0+ chinook fry were outmigrating from this tributary during July and August. Similar data were collected in 1980 by Delaney et al. (1981), who postulated that the observed outmigration was a size related response as the fish reached approximately 80 mm. It is not known whether these fish remain in habitats associated with the mainstem river or if they continue to the ocean as age 0+ fish.

Scale samples collected from returning adults at Sunshine Station and above indicated that the age 0+ class of outmigrants represented less than 3% of the middle river returning chinook during 1983 (Barrett et al. 1984) and less than 1% in 1984 (Barrett et al. 1985). However, no adult chinook scale samples were taken in 1984 at Flathorn Station, which did not begin operation until early July. It may be that a significant proportion of the adults bound for lower river tributaries such as the Deshka did outmigrate during their first summer.

Otherwise, if it is assumed that a significant percentage of Susitna River chinook salmon migrate to the ocean as age 0+ fish, then either the marine survival of this age class is very low or the freshwater life histories on adult scales were not interpreted correctly. Richards (1979) reported that a major portion (72%) of the adult scales analyzed from the Deshka River during 1978 indicated that the fish had migrated to the ocean during their first summer as age 0+ fish. Scale analysis from creel census samples collected in the Deshka River have classed these fish as predominantly age 1+ outmigrants (Kubik 1967; Kubik and Wadman 1978; Kubik and Delaney 1980).

There are many unanswered questions about chinook fry life history in the Susitna River. Aging of adult chinook at Flathorn Station during 1985 will help answer the question of whether there is a significant proportion of returning adults which outmigrated during their first summer. However, we still do not know the proportion of returning adults which, as fry, followed one or the other of the three life history strategies discussed above. The answer to this question is of major importance in assessing dam-related effects on the population.

4.1.3 Estimates of population size and residence time

The Schaefer population estimate of 3.2 million chinook salmon juveniles in Indian River in 1984 must be qualified. A successful method of sampling large numbers of juvenile chinook and a location containing large numbers were not found until mid July, at which time over 50% of the Talkeetna Station trap catch of age 0+ chinook fry had occurred. Therefore, this estimate is only for those fish in Indian River for the period July 15 to Oct. 15.

The efficiency of minnow traps decreases when flows are high. Because the marked fish were not randomly re-introduced into the system, we have to assume that the recapture was random. However, there is some reason to believe that the unmarked fish were more likely to redistribute downstream during high flows than were the marked fish, which were re-introduced into side sloughs.

Having two separate groups of juvenile chinook within Indian River, those fish which overwinter in Indian river and the middle Susitna River and those fish which migrate out of this reach, further complicates the population estimate. Most marked fish were marked near the mouth of Indian; it is likely that fish captured near the mouth were going to migrate out of Indian River during the first summer. Also, it has to be assumed that these fish, when transported back upriver, randomly mixed with the other fry. The estimate of 3.2 million fry for Indian River should be used as a rough approximation, obtained by an experimental project. Information gathered during the 1984 season will enable a more refined estimate for the 1985 season.

The chinook fry population estimates made for sloughs and side channels give a general idea of how many fry these sites can support. The day-to-day variation in total number of fish at these sites, which results from variation in discharge level, is striking. Another important result of this study is the residence time of rearing chinook fry at these sites because of the implications this has on the results of the IFIM and RJHAB models of rearing habitat (presented in Part 2 of this report). Habitat value from the models is measured by weighted usable area (WUA), which depends only on water depth, water velocity, cover, and substrate. The model will predict discharge levels at which habitat value of a site is high. However, there may not be many fish at a site, even when WUA is high, because of previous flushing of the site by a high discharge or because of a seasonal effect in level of outmigration. More importantly, if the fish are using a site only as an outmigration corridor, as appeared to be the case at Moose Slough in mid August, then it really doesn't matter if the WUA is high or low, because WUA measures only rearing habitat quality. On the other hand, if the fish have a longer residence time at a site, such as at Lower Side Channel 11A in late July, then the amount of WUA is important.

Of the 643 chinook fry which were captured in a slough or side channel, cold-branded, and later recaptured at the same site, 113 were still present 30-60 days later. This indicates that a substantial amount of chinook fry rearing occurs at these sites.

4.1.4 Growth

The increase in mean length of age 0+ chinook by sampling period for the combined data collected at the Talkeetna Station outmigrant traps during 1982, 1983 and 1984 is presented in Fig. 48. Chinook fry, which emerge from the gravel at an average length of approximately 37 mm, had increased to an average of 44 mm by early June. By the end of the open-water season, their mean length was 63 mm. Chinook fry collected in the lower river in 1984 averaged from two to ten mm larger than their counterparts in the middle river through the season (Fig. 16).

Chinook fry which overwinter in Indian River show little growth between late October (when they are a little less than 70 mm long) and late March (ADF&G, unpublished data). Outmigrating age 1+ fish at Talkeetna station averaged 90 mm during the peak of outmigration, so they had grown about 20 mm during April, May, and June.

Examination of the downstream redistribution of juvenile chinook salmon in the Susitna River by age class during 1984 shows that chinook fry in the middle river averaged approximately the same length (50 to 55 mm) throughout the period of peak outmigration (late June through early August). This results in very little separation between cumulative movements recorded for catch and biomass at Talkeetna Station (Fig. 49). The outmigration of chinook fry in the middle river appears to be triggered, in part, by the fish reaching a critical size. As they reach this critical size (estimated at 55 mm), chinook fry redistribute downstream to other rearing areas.

In the lower river, total biomass movements were delayed in comparison to the total number of chinook fry moving past Flathorn Station (Fig. 49). This was due to the growth occurring in the lower river and because of the mixed stocks present in this reach.

4.2 Coho Salmon

4.2.1 Outmigration

The downstream movement of coho salmon fry past Talkeetna Station is compared for 1983 and 1984 in Fig. 50. Although the outmigration from May through early July was slower during 1984, 50% of the total season outmigration was recorded ten days earlier in 1984 than in 1983. The delay in downstream movement observed during July of 1983 was due in part to low tributary water levels during this period, and the high rates of downstream movement recorded in mid August corresponded to a period of heavy rainfall and high tributary discharges.

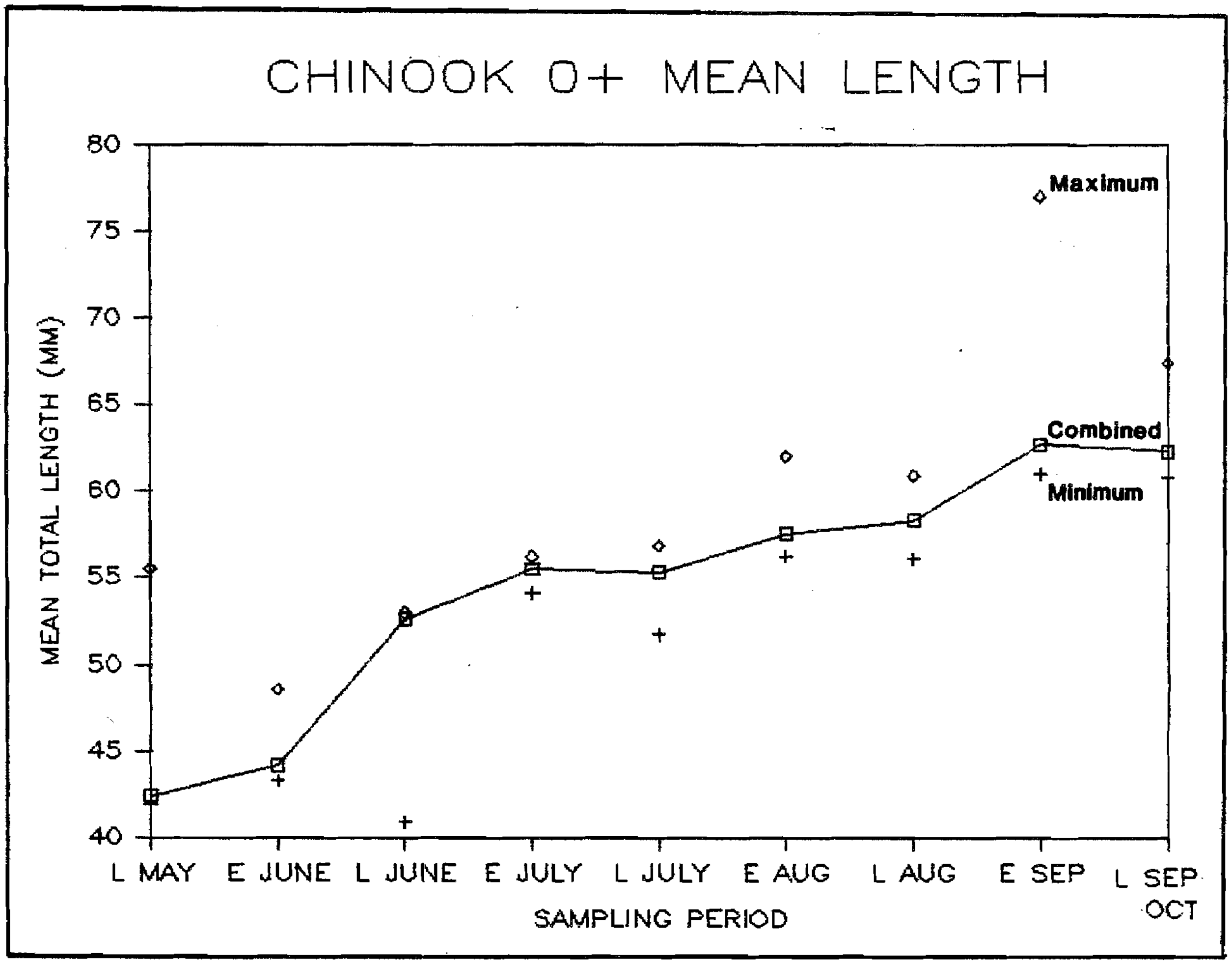


Figure 48. Chinook salmon (age 0+) mean length and range of mean lengths by sampling period recorded at the Talkeetna stationary outmigrant traps during 1982, 1983, and 1984.

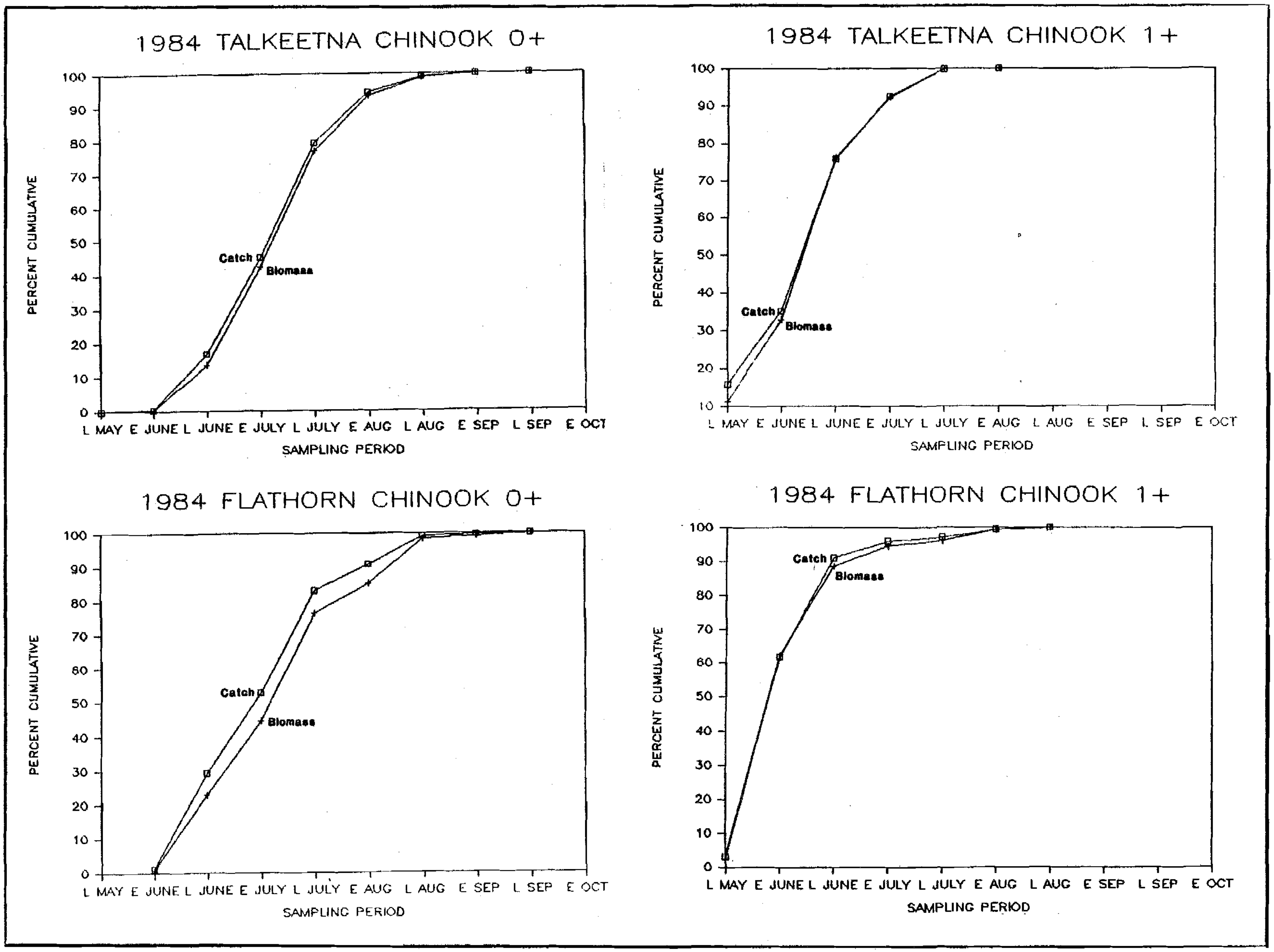


Figure 49. Chinook salmon adjusted cumulative catch and biomass by age class recorded at Talkeetna and Flathorn stations, 1984.

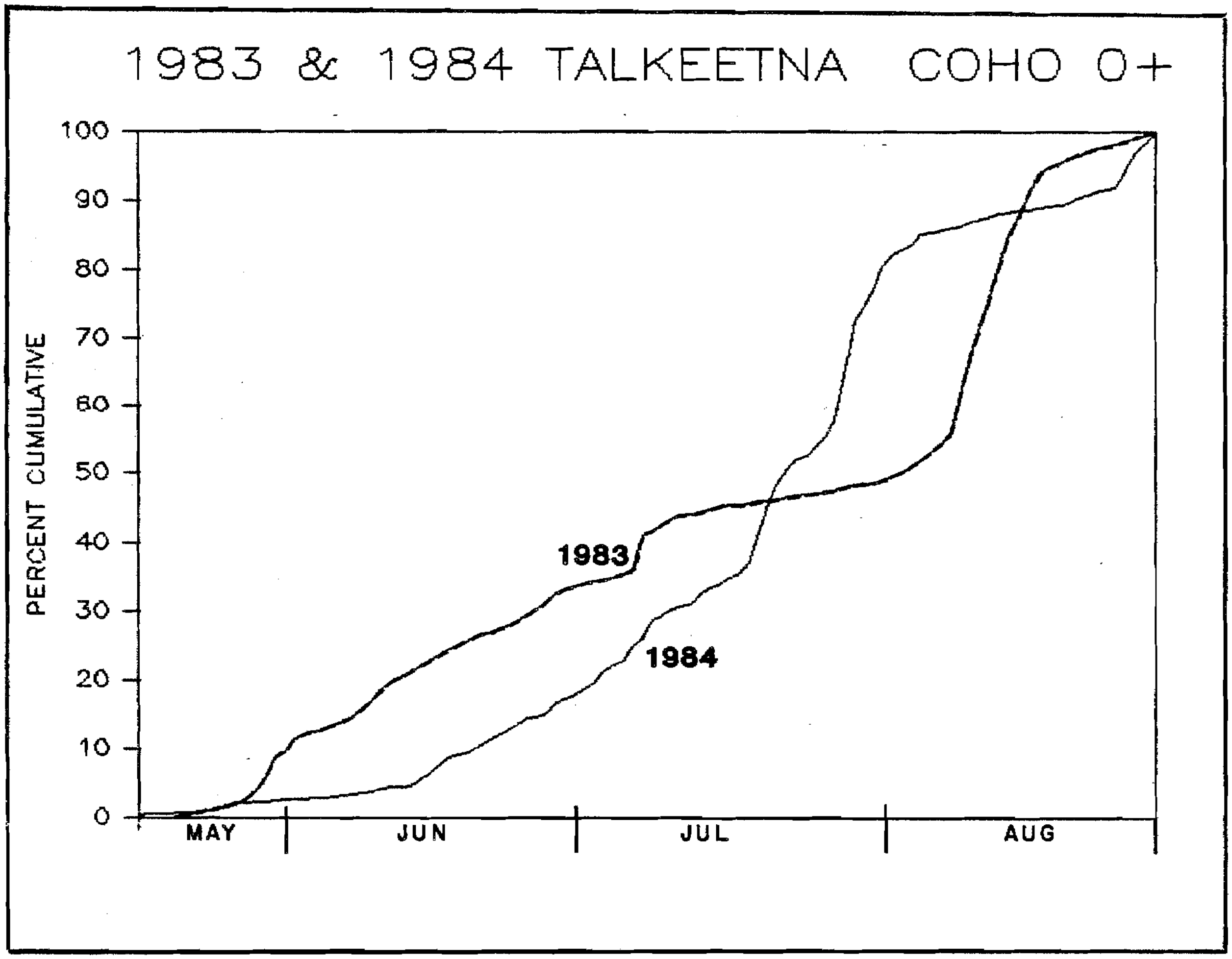


Figure 50. Coho salmon (age 0+) adjusted cumulative catch recorded at the Talkeetna stationary outmigrant traps, 1983 and 1984.

The downstream movement of age 1+ coho salmon past Talkeetna Station was approximately two weeks later in 1984 than in 1983 while the rates of movement were fairly stable throughout both seasons (Fig. 51).

4.2.2 Freshwater life history

Most coho salmon juveniles spend one or more years in the Susitna River before migrating to the ocean. Analysis of scales from returning adults indicate that most juvenile coho outmigrate as either age 1+ or age 2+ but the proportion of each age class has varied between years (ADF&G 1982; ADF&G 1983; Barrett et al. 1984; Barrett et al. 1985).

Coho salmon in the middle Susitna River spawn almost exclusively in the tributaries. The fry, after emergence, rear in their natal tributaries or enter the mainstem river in search of suitable habitats. Outmigrant trap data collected at Talkeetna Station have shown a downstream redistribution of juvenile coho occurring throughout the open-water season. During the fall, coho fry move into tributaries, sloughs, beaver ponds, or other habitats to overwinter. Similar redistributions of juvenile coho were observed by Delaney and Wadman (1979) and by Tschaplinski and Hartman (1983).

Trap catches recorded at Talkeetna Station during 1982 and 1984 showed that high catches of age 0+ and 1+ juvenile coho occurred during September or early October. It was presumed that these fish were redistributing to habitats in the lower river to overwinter, but the data collected at Flathorn Station in 1984 indicate that a portion of these fish may migrate to the ocean during the fall (Fig. 22).

4.2.3 Growth

The change in mean length for age 0+ coho by sampling period for the combined data collected at the Talkeetna Station outmigrant traps during 1982, 1983, and 1984 is presented in Fig. 52. Coho salmon in the middle river emerge from the gravel at approximately 35 mm and grow to 45 mm by early July. By the end of the open-water season, coho fry have obtained a mean length of approximately 68 mm. Throughout the season, age 0+ coho in the lower river averaged at least five millimeters larger than fish collected in the middle river (Fig. 26).

Age 1+ coho salmon in the middle river also showed a steady growth through the season (Fig. 53) increasing approximately 45 mm between late May and early October. Similar to age 0+ coho, age 1+ coho collected in the lower river averaged larger than fish captured in the middle river reach (Fig. 27).

The downstream redistribution (as shown by the cumulative biomass) of juvenile coho salmon in the Susitna River by age class during 1984 averaged one to two weeks later than the redistribution of the total number of individuals recorded at both the Talkeetna and Flathorn stations outmigrant traps (Fig. 54). The difference between the cumulative biomass movement and the movement of total numbers of fish results from the growth of juvenile coho occurring during the open-water

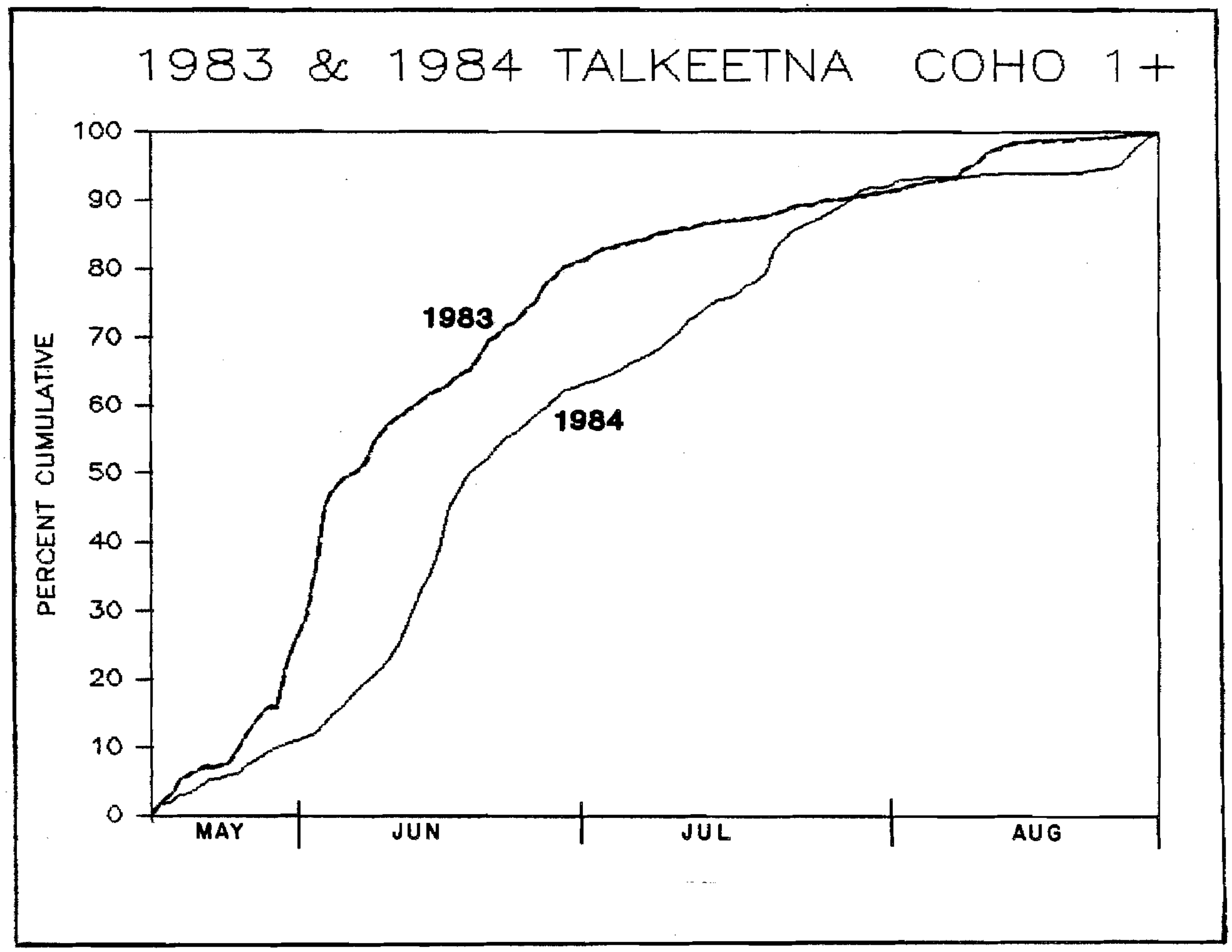


Figure 51. Coho salmon (age 1+) adjusted cumulative catch recorded at the Talkeetna stationary outmigrant traps, 1983 and 1984.

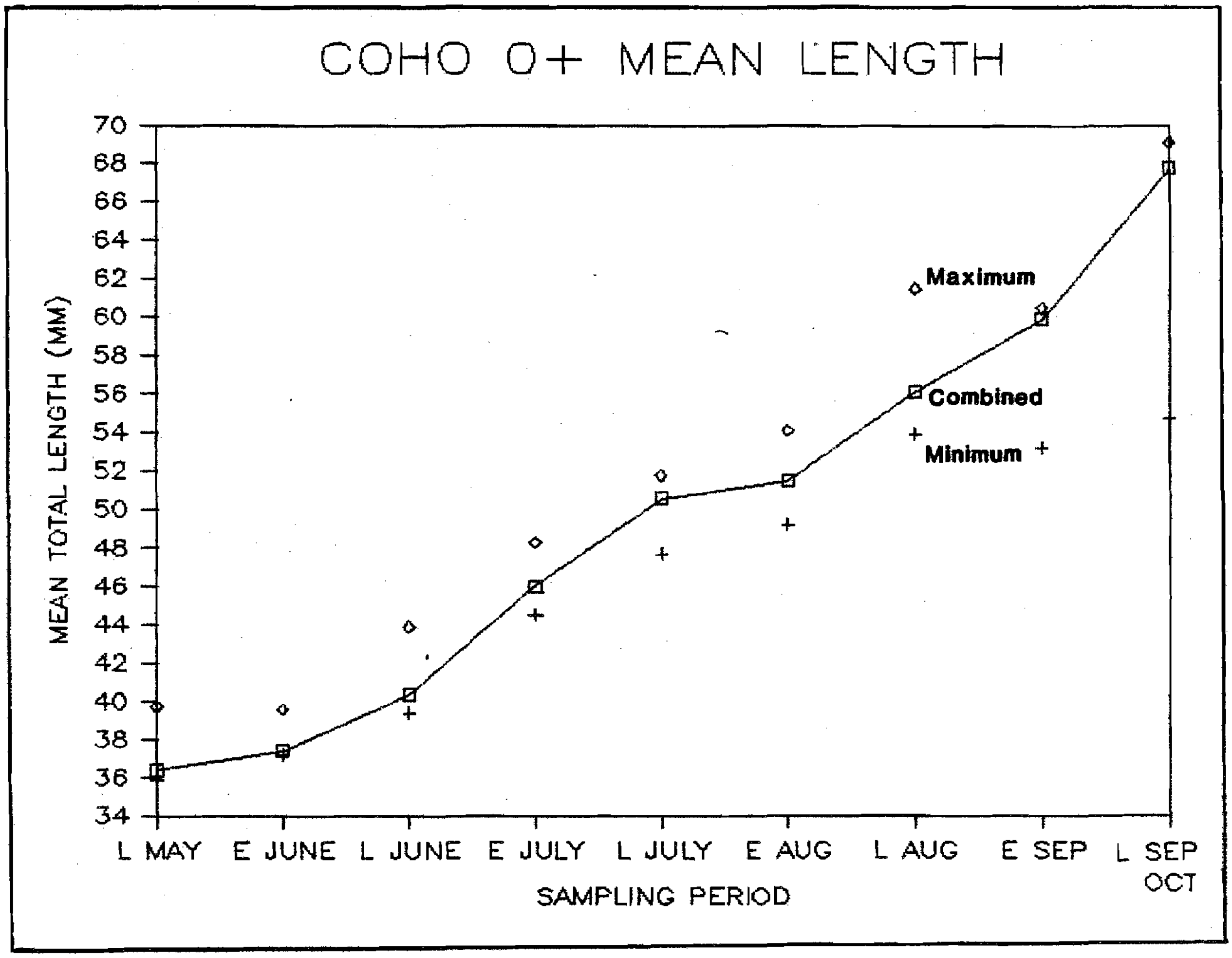


Figure 52. Coho salmon (age 0+) mean length and range of mean lengths by sampling period recorded at the Talkeetna stationary outmigrant traps during 1982, 1983, and 1984.

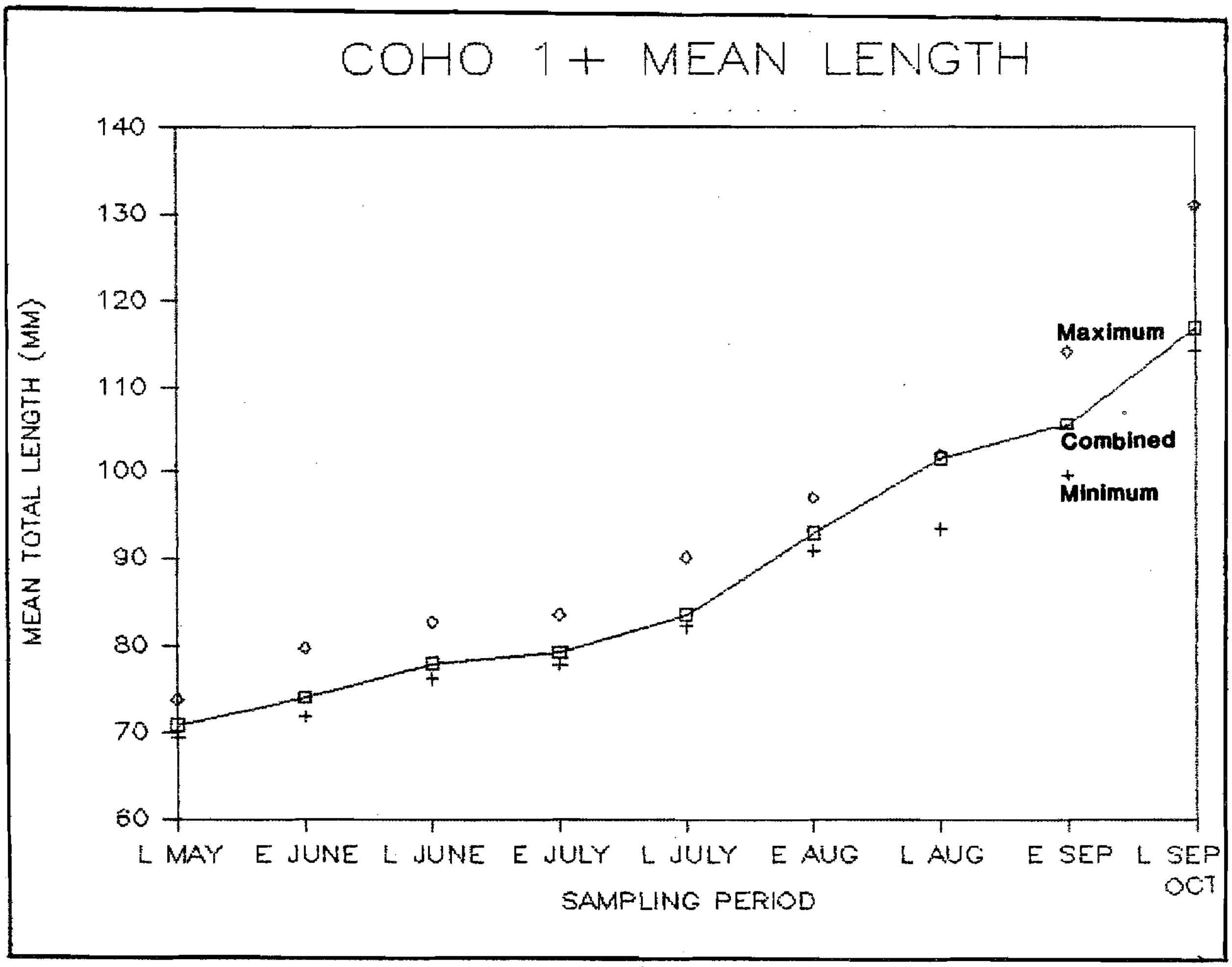


Figure 53. Coho salmon (age 1+) mean length and range of mean lengths by sampling period recorded at the Talkeetna stationary outmigrant traps during 1982, 1983, and 1984.

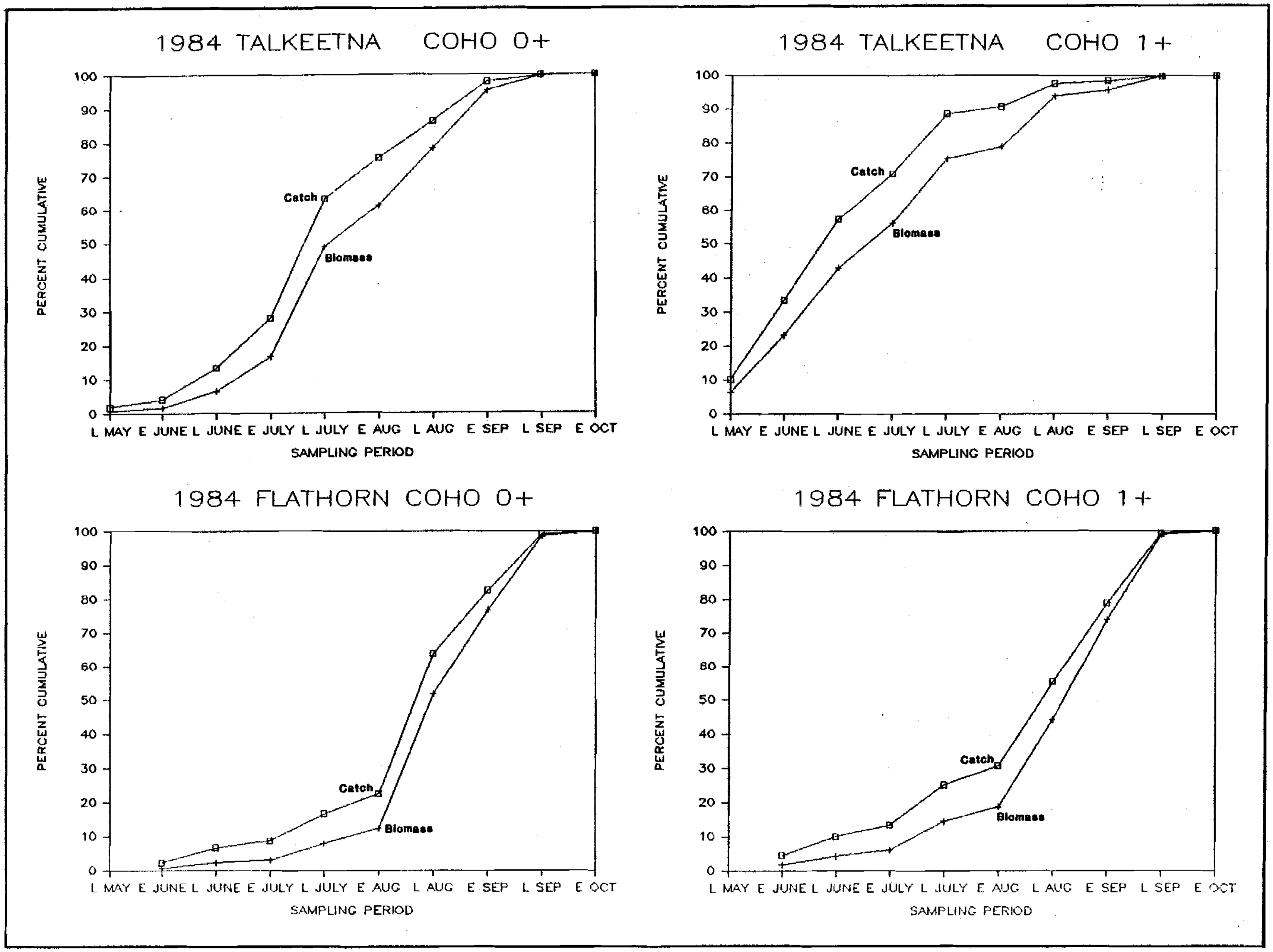


Figure 54. Coho salmon adjusted cumulative catch and biomass by age class recorded at Talkeetna and Flathorn stations, 1984.

season. The cumulative biomass curve is probably a better indicator of the value of coho rearing habitat in the reach than is the cumulative numbers curve. That is, the greater the amount of time the fry spend rearing in a particular reach of river, the greater the benefit they have gained from that particular reach. Not only are they larger, having consumed more food in this reach, they also have a higher probability of survival than smaller fry and therefore are of more value. Any management determination for these fish should consider the timing of movement of total biomass in the river rather than formulating actions only from the catch data.

4.3 Sockeye Salmon

4.3.1 Outmigration

The migration of sockeye salmon fry past Talkeetna Station during 1984 was similar to the timing recorded during 1983 (Fig. 55). Fifty percent of the total outmigration was recorded by the end of June during both seasons. Sockeye fry were steadily redistributing to areas below the sampling site from break-up through late August. Sampling of sloughs and side channels in the middle river during the cold branding study showed that sockeye fry were not actively outmigrating but were entering habitats along the margins of the river as they moved downstream. The fry probably remain at these sites until (1) they are displaced by flows or density interactions, (2) adequate food supplies are no longer available, (3) the habitats become otherwise unsuitable, or (4) the critical size is reached.

The tendency of sockeye fry to orient along the banks of the river during their downstream migration was observed at Flathorn Station where 59% of the total sockeye fry collected in the mobile trap were captured at bank transect points.

The rates of downstream movement for coded wire tagged sockeye fry during 1984 showed that fry in the middle river, after tagging, spent an average of 35 days (range from 0 to 109 days) in the middle river before migrating past Talkeetna Station.

4.3.2 Freshwater life history

Outmigrant trap data collected at Talkeetna Station during the past three seasons (1982-1984) show that a large number of sockeye fry migrate out of this reach as age 0+ fish, but scale analysis of adult sockeye collected at Curry Station showed that this age class represented only 6.4% of the returning adults during 1984 (Barrett et al. 1985). The largest percentage of returning adults were comprised of fish which had spent one winter in freshwater before going to the ocean. There fore, the majority of age 0+ fry from the middle river either rear in the lower river or have a low survival rate.

Bernard et al. (1983) analyzed scale patterns from samples of adult sockeye salmon collected from four different sites in the Susitna River watershed in an attempt to delineate the differences in scale patterns

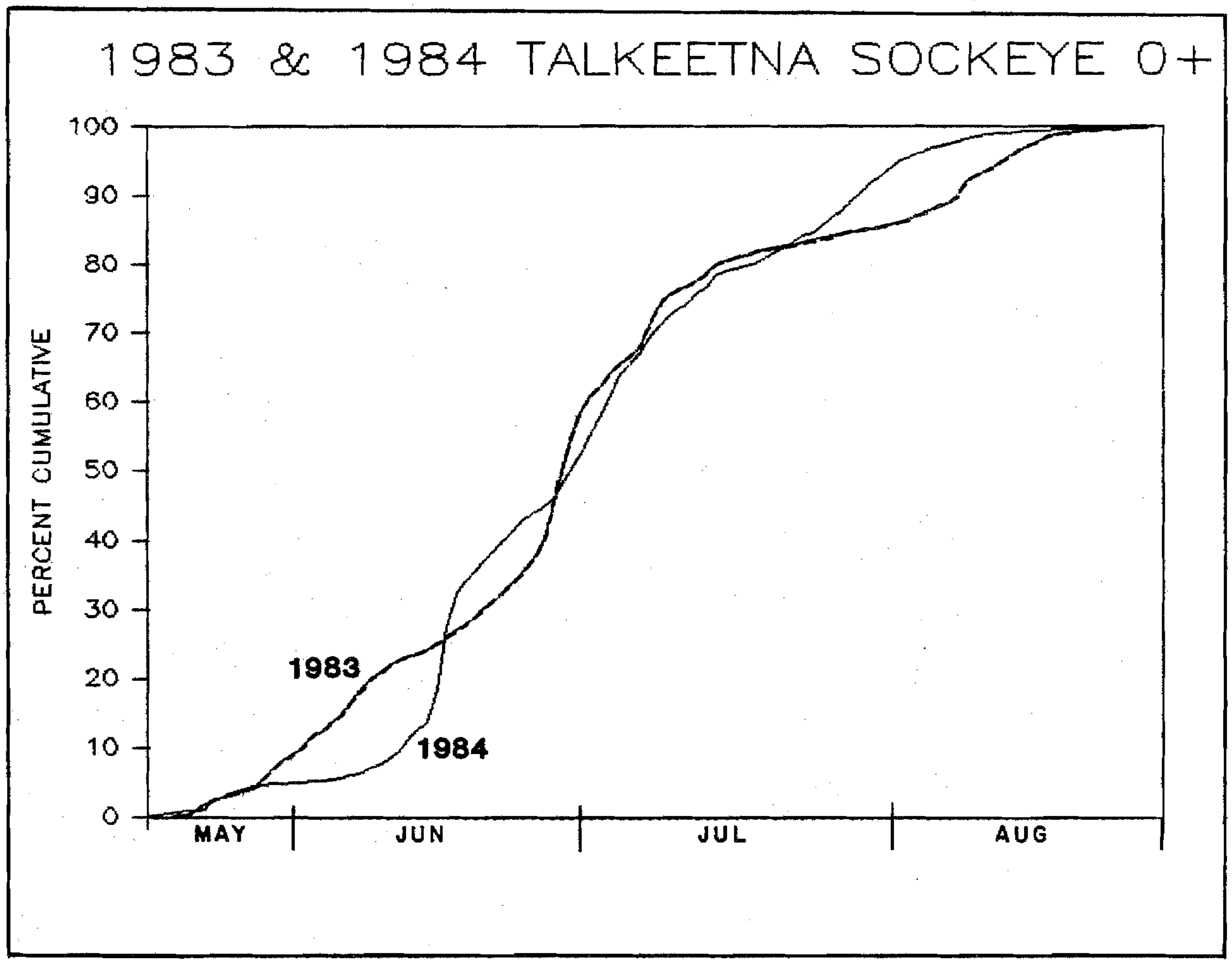


Figure 55. Sockeye salmon (age 0+) adjusted cumulative catch recorded at the Talkeetna stationary outmigrant traps, 1983 and 1984.

for the period of freshwater growth for each of the sites. Samples were collected from escapements of sockeye salmon at Curry and Talkeetna stations on the Susitna River, from the outlet of Larson Lake on the Talkeetna River, and from the Tokositna River which is a tributary to the Chulitna River. One of the results of this study was that sockeye salmon scale samples collected from the Susitna River sites could not be distinguished from those of Tokositna or Larson Lake fish.

Six hypotheses were suggested by Bernard et al. (1983) for the lack of unique differences in the scale patterns between Susitna River fish and those collected from the other sites. In general, these hypotheses can be placed into two groups: 1) The Susitna River fish are a unique stock but the fry rear in environments similar to those found in Larson Lake or the Tokositna River, or 2) the sockeye salmon spawning in the Susitna River are strays from either the Talkeetna or Chulitna watersheds and their fry move into these watersheds to rear or are displaced downstream and enter the ocean as age 0+ fish. If these fish enter the ocean as age 0+ fish, scale analysis of returning adults indicates that survival of these fish is very low.

However, the study conducted by Bernard et al. was based on the assumption that sockeye fry did not rear in the middle Susitna River. Data collected at the Talkeetna Station outmigrant traps during the past three years have shown that a significant amount of sockeye rearing occurs in this reach. The Susitna River samples collected by Bernard et al. were taken at the fishwheel sites rather than at the spawning grounds. Barrett (1984) has pointed out that a high percentage of these fish (30% estimated in 1983) are milling fish which eventually spawned in areas other than the middle Susitna River. Comparisons of the scales of fish collected at the spawning grounds in these rivers may provide more accurate differentiation of Susitna River fish from those observed in the Talkeetna and Chulitna rivers. Also, Bernard et al. analyzed scales from only 1.3 age fish (European formula); Barrett et al. (1984) have shown that multiple age classes are present in the middle Susitna River escapements. Juvenile sockeye salmon outmigrating from Larson Lake predominantly spend two winters in freshwater before outmigrating from the lake as smolts (Marcuson 1985).

Although it is possible that sockeye salmon which spawn in the middle reach of the Susitna River are strays from the stocks originating from the Talkeetna and Chulitna rivers, it is more likely that the Susitna sockeye are a separate and viable stock. However, the amount of rearing habitat in this reach is limited. The age 0+ fish which outmigrate from the middle reach of the Susitna probably imprint to their natal areas in the early stages after hatching and then later distribute to suitable habitats throughout the expanse of the lower river to overwinter. These fish then enter the ocean during their second year of life and finally return to their natal areas as adults to spawn. Also, a limited amount of overwintering by sockeye fry in the middle reach does occur, as shown by the capture of age 1+ fry at Talkeetna Station.

More definitive information on the viability of middle Susitna River sockeye may be obtained through the continued monitoring of returning adults at the fishwheel sites and during spawning ground surveys to collect returning fish which were marked with coded wire tags as fry.

Juvenile sockeye salmon life histories in the middle Susitna River can be grouped into three categories. The first group includes those fish which spend their entire freshwater period rearing in the middle river, overwintering in this reach and then migrating to the ocean during the spring of their second year (age 1+). The second group includes those fish which rear for a portion (one to four months) of their first summer in the middle river and then migrate to areas below the Chulitna River confluence to overwinter and then enter the ocean during the spring of their second year. The third group of juvenile sockeye spend a portion of their first summer rearing in the middle river and then begin a downstream migration, eventually entering the marine environment during their first summer or fall as age 0+ fish.

Currently, it is not known what contribution each group provides to the total outmigration of juvenile sockeye from the middle Susitna River. Outmigrant trap data collected at Flathorn Station during 1984 collected a large number of age 0+ sockeye; most of these fish were probably destined for the ocean as 0+ fish.

Although trap catches of age 1+ sockeye at Talkeetna Station have been low (only 19 fish during 1984), it is possible that this age class (group 1) migrates out of the middle river prior to the initiation of spring sampling or that they differ from their age 0+ counterparts in that they migrate further from shore and are not intercepted by the bank traps in proportion to their relative abundance. Also, the bank traps are less effective at capturing these larger fish (Roth et al. 1984).

4.3.3 Estimate of population and survival

The estimated 1983-1984 egg-to-emergent fry survival rate of 17%, based on an estimated 299,000 sockeye fry produced during 1984 from the approximately 1,900 adults which migrated past Curry Station in 1983, was lower than the 1982-1983 estimate of 42%, based on the 1,300 adult sockeye past Curry Station during 1983 which produced an estimated 575,000 fry. The substantial differences between the estimates of survival in 1983 and 1984 are due in part to the data used in the calculations. During both years, survival rates were calculated by dividing the number of fry produced by the estimated number of eggs carried by adults past Curry Station during the previous season. Barrett et al. (1984) pointed out that the estimates provided at Curry Station represent only the fish which passed this site but do not necessarily reflect the number of fish which actually spawned in the middle river reach. As sockeye salmon in this reach are almost strictly slough spawners, more reasonable estimates were calculated by Barrett et al. (1984) by comparing slough escapement counts to observation life data to estimate the total slough escapement in the middle river. During 1983, this comparison provided an estimate that 1,060 adult sockeye had spawned in sloughs in the middle river. The stream life data were then used to provide comparable estimates for 1982 showing approximately 1,500 sockeye had spawned in the sloughs that year. These data were then used to recalculate the sockeye egg-to-outmigrant survival rates. A survival rate of 22% was estimated for 1983-1984 and a rate of 35% was calculated for 1982-1983.

4.3.4 Growth

The weekly growth rate for sockeye fry which were coded wire tagged in 1983 and 1984 (Fig. 56) most accurately represent the growth rates for sockeye salmon fry in the middle river because the dates of release and recovery and the mean lengths for each period were known.

These fry grew approximately three millimeters each week until they reached a critical size and then the growth rates slowed (Fig. 56). Schmidt (1984) postulated that the cessation of sockeye growth after reaching a certain size was associated with evolved behavioral patterns and morphological changes. Schmidt suggested that the sockeye fry were able to rear in the middle river habitats for part of the summer but began a downstream migration in search of plankton rich environments after reaching a critical size. The small number of habitats which provide this type of environment in areas associated with the Susitna River is a major factor in controlling the production of sockeye in the middle river.

A comparison of the length data collected at Talkeetna Station during 1982, 1983, and 1984 and during the previous winter studies above Talkeetna in 1981 and 1982 show that Susitna River sockeye average approximately 32 mm total length at emergence, 35 mm by early June, and have increased to approximately 50 mm by late July (Fig. 57). From late July through August, no significant growth was observed for sockeye fry collected at Talkeetna Station, indicating that the critical size postulated by Schmidt (1984) may be 50 to 55 mm in the middle river. The apparent growth of sockeye fry after late August (Fig. 57) is attributed to the collection of fish which had continued rearing in the small number of sites in the middle river which provide the necessary food and habitat requirements. These fish were probably forced to migrate out of these areas as water levels and available habitat decreased. The number of sockeye collected after late August represent less than 2% of the total outmigration of age 0+ fish from this reach.

A comparison of the downstream redistribution of sockeye salmon in the Susitna River by age class during 1984 as the percent cumulative of the total catches recorded at Talkeetna and Flathorn stations compared to the calculated percent cumulative biomass moving past these sites, indicated that the redistribution by weight of sockeye in the Susitna River was up to two weeks later than the redistribution observed when comparing only total numbers of fish (Fig. 58).

Age 1+ sockeye salmon collected during 1984 averaged approximately 75 mm. This is approximately 10 mm longer than the average length of sockeye fry collected at the end of the open-water season indicating that the fry are growing through the winter and early spring prior to outmigrating as smolts. The average length of age 1+ sockeye migrating out of the Susitna River was approximately 10 mm smaller than the same

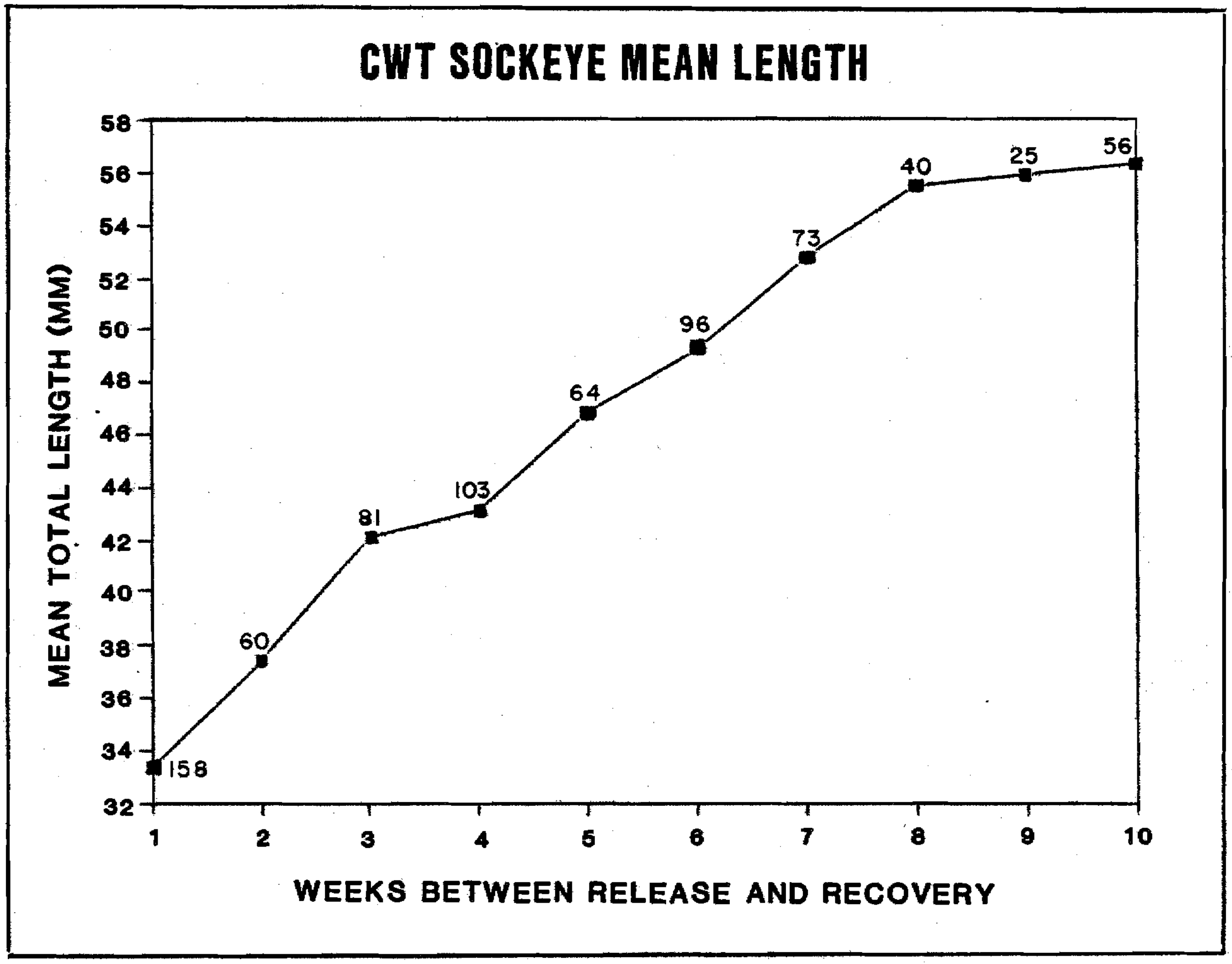


Figure 56. Mean length of coded wire tagged sockeye salmon fry at recovery sites in the middle reach of the Susitna River by week, 1984. Number of fish shown by data points.

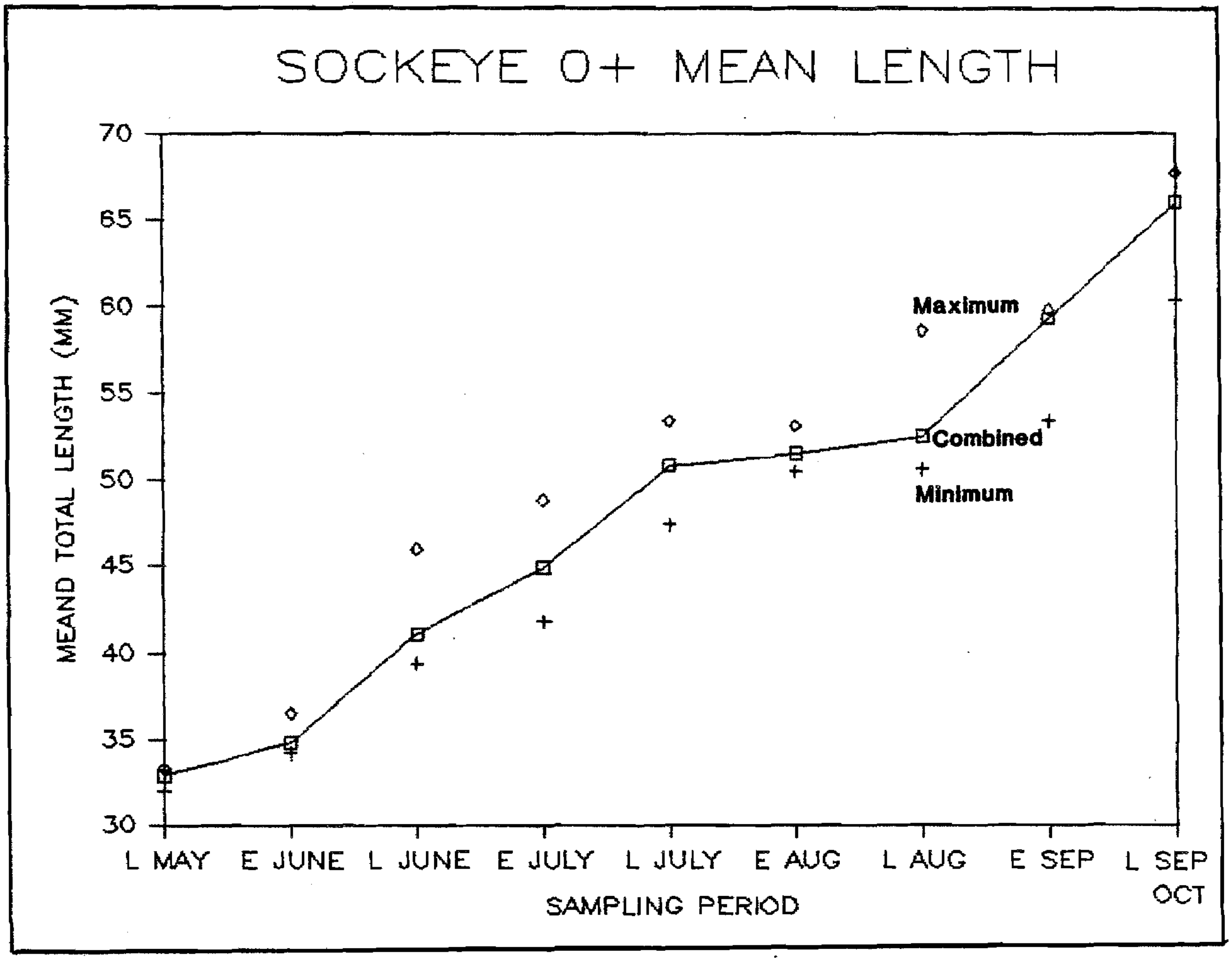


Figure 57. Sockeye salmon (age 0+) mean length and range of mean lengths by sampling period recorded at the Talkeetna stationary outmigrant traps during 1982, 1983, and 1984.

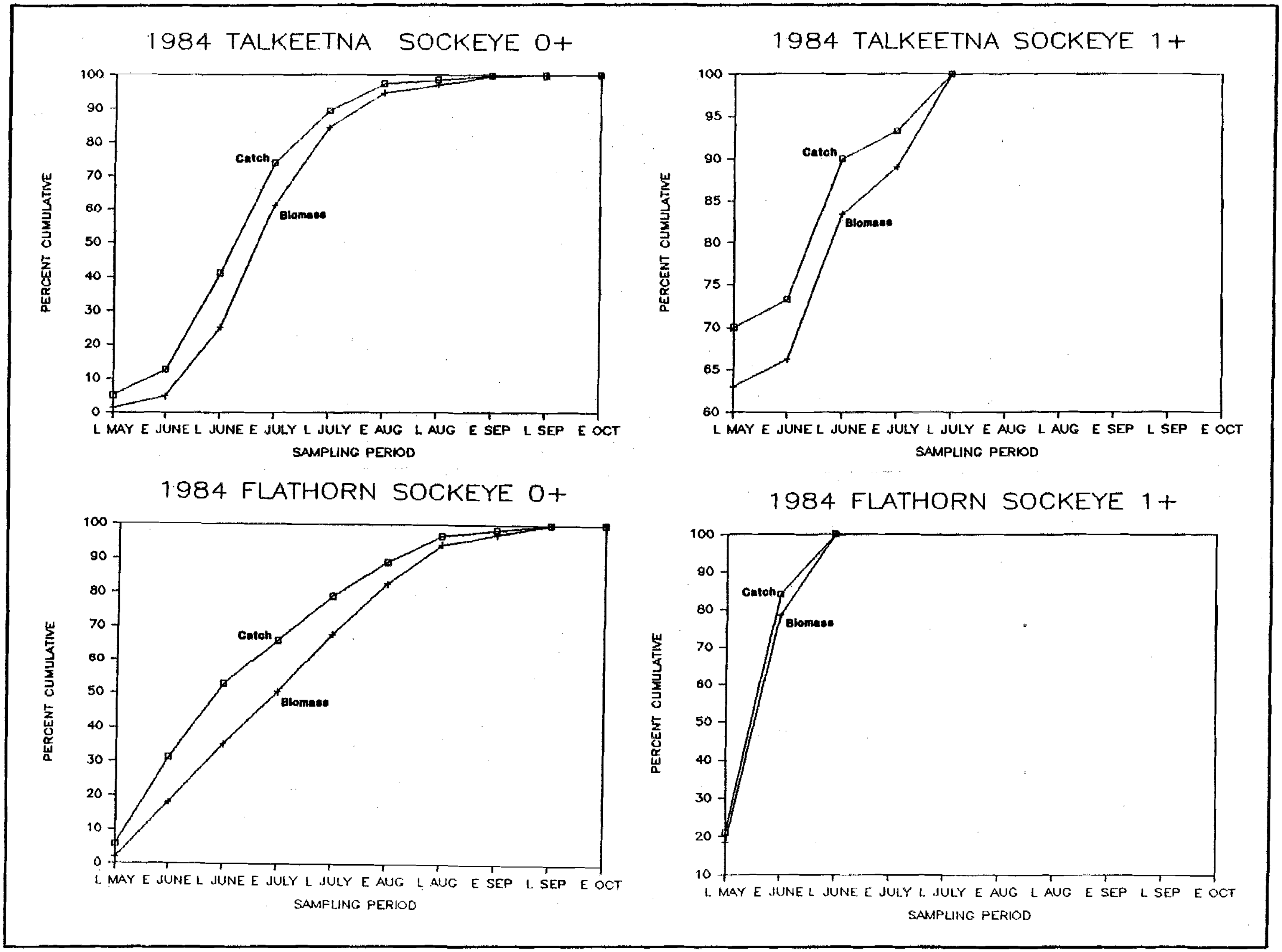


Figure 58. Sockeye salmon adjusted cumulative catch and biomass by age class recorded at Talkeetna and Flathorn stations, 1984.

age fish outmigrating during 1984 from Larson Lake, a major spawning site in the Talkeetna River (Marcuson 1985).

4.4 Chum Salmon

4.4.1 Outmigration

The migration of chum salmon fry past Talkeetna Station during 1984 was similar to the timing recorded during 1983 (Fig. 59). Fifty percent of the total outmigration past this site had occurred by mid June and over 95% of the chum fry had migrated out of the middle river by mid July. At Flathorn Station, the peak chum fry outmigration also occurred in mid June during 1984.

4.4.2 Freshwater life history

Chum salmon fry spend from one to eight weeks in the middle Susitna River before outmigrating from the reach. A portion of the population of chum fry probably begins outmigration shortly after emergence whereas other fry stay in the river to rear for a few weeks before outmigrating. It is not possible to determine the percentage which each group provides because of the difficulty in sampling outmigrant fishes prior to and during breakup, a time when many newly emerged chum fry may outmigrate.

4.4.3 Estimates of population and survival

The estimated 1982-1984 egg-to-outmigrant fry survival rate of 16%, based on an estimated 2,039,000 chum salmon fry produced during 1984 from the approximately 21,100 adults past Curry Station in 1983, was similar to the estimated 1982-1983 rate of 14%, based on the 17,600 adult chum which passed Curry Station during 1982 which produced an estimated 3,322,000 fry.

The calculation of survival rates is based upon the estimated number of parent spawners which is difficult to obtain because of the extent of tributary spawning by chum salmon. Also a substantial percentage of chum salmon passing Curry Station are milling fish which eventually spawn below this site, and although estimates have been provided for 1982 and 1983 (Barrett 1984), these percentages are, at best, only indicators of the amount of chum salmon milling occurring. As these estimates have a large influence on the calculated rates of survival, the rates presented for 1983 and 1984 should be used to compare differences between years rather than absolute values of middle river chum salmon survival.

4.4.4 Growth

Many chum fry from the middle reach move downstream at lengths not much longer than their emergence length (less than 35 mm), but there are also many that spend several weeks in freshwater and attain lengths of over 60 mm, an increase of more than 20 mm. The mean length by one-week periods of recovery after release for coded wire tagged chum fry which were tagged and recaptured during 1983 and 1984 (Fig. 60) most

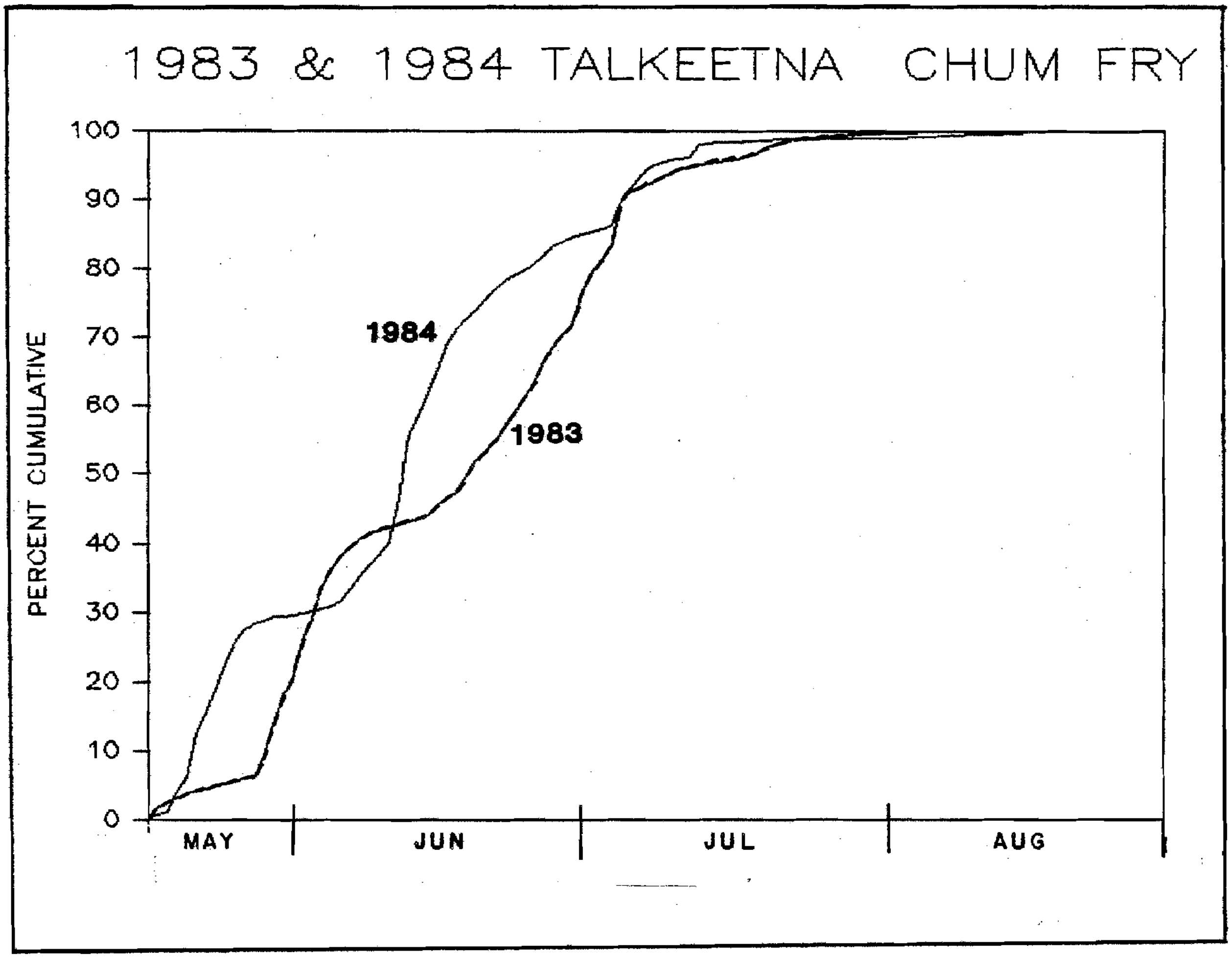


Figure 59. Chum salmon fry adjusted cumulative catch recorded at the Talkeetna stationary outmigrant traps, 1983 and 1984.

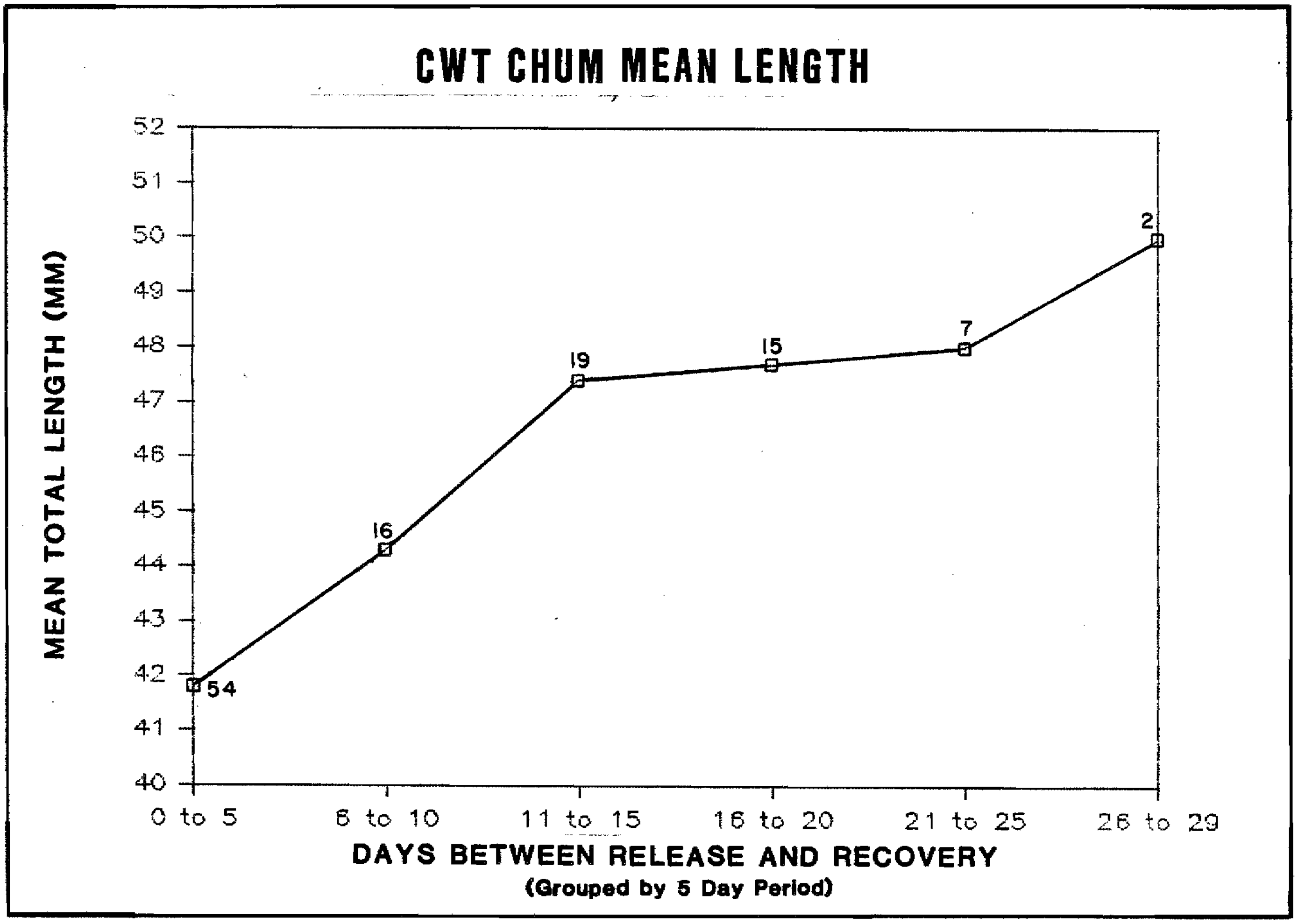


Figure 60. Mean length of coded wire tagged chum salmon fry at recovery sites in the middle reach of the Susitna River by 5 day period, 1984. Number of fish shown by data points.

accurately represent the growth rates of chum fry in the middle river because the dates of release and recovery and the lengths for the fish for each period were known. The 15% increase in length by fish captured more than 20 days after release (mean length significantly different from release length at 95% confidence level) would correspond to an even larger percentage increase in weight. The chum fry greater than 50 mm in length collected during the three years of this program had a noticeably greater girth than shorter fry. Similarly, chum fry in the Tokachi River of Japan grew 1.0 to 1.3 times in length and 1.0 to 3.1 times in weight during April and May (Kaeriyama et al. 1978).

These data indicate that the chum fry in the middle river are actively rearing after emergence. Chum fry rearing was also shown from the analysis of stomach samples from tagged fish recovered at Talkeetna Station during 1983. These fish had been eating various life stages of mayflies, stoneflies, blackflies, midges, and other dipterans.

4.5 Pink Salmon

4.5.1 Outmigration

The rates of downstream migration of pink salmon fry past Talkeetna Station for 1983 and 1984 were very similar between the two years but the timing was approximately two weeks later in 1984 than in 1983 (Fig. 61). Differences in spawning times, winter temperatures, and spring breakup account for the differences in timing between the two years.

The low catches of juvenile pink salmon recorded at Talkeetna Station during the past three seasons is due to the pattern and timing of outmigration. Pink salmon fry outmigrate shortly after emergence and most of the fry probably have migrated past the traps prior to the initiation of sampling. Those fish which are still in the middle river after breakup appear to outmigrate in association with center channels and high velocities.

4.5.2 Freshwater life history

Pink salmon fry in the Susitna River outmigrate to the ocean shortly after emergence during a relatively short (in comparison to the other species) timing window whose boundaries are determined by the timing of spawning the previous season, incubation temperature, and the level of discharge. The pink fry collected during 1984 averaged approximately 35 mm which is similar to their mean length at emergence. A few pink fry which ranged in length from 40 to 50 mm were collected, indicating that a small percentage of fry may be feeding for a short period of time in freshwater before outmigrating to the ocean.

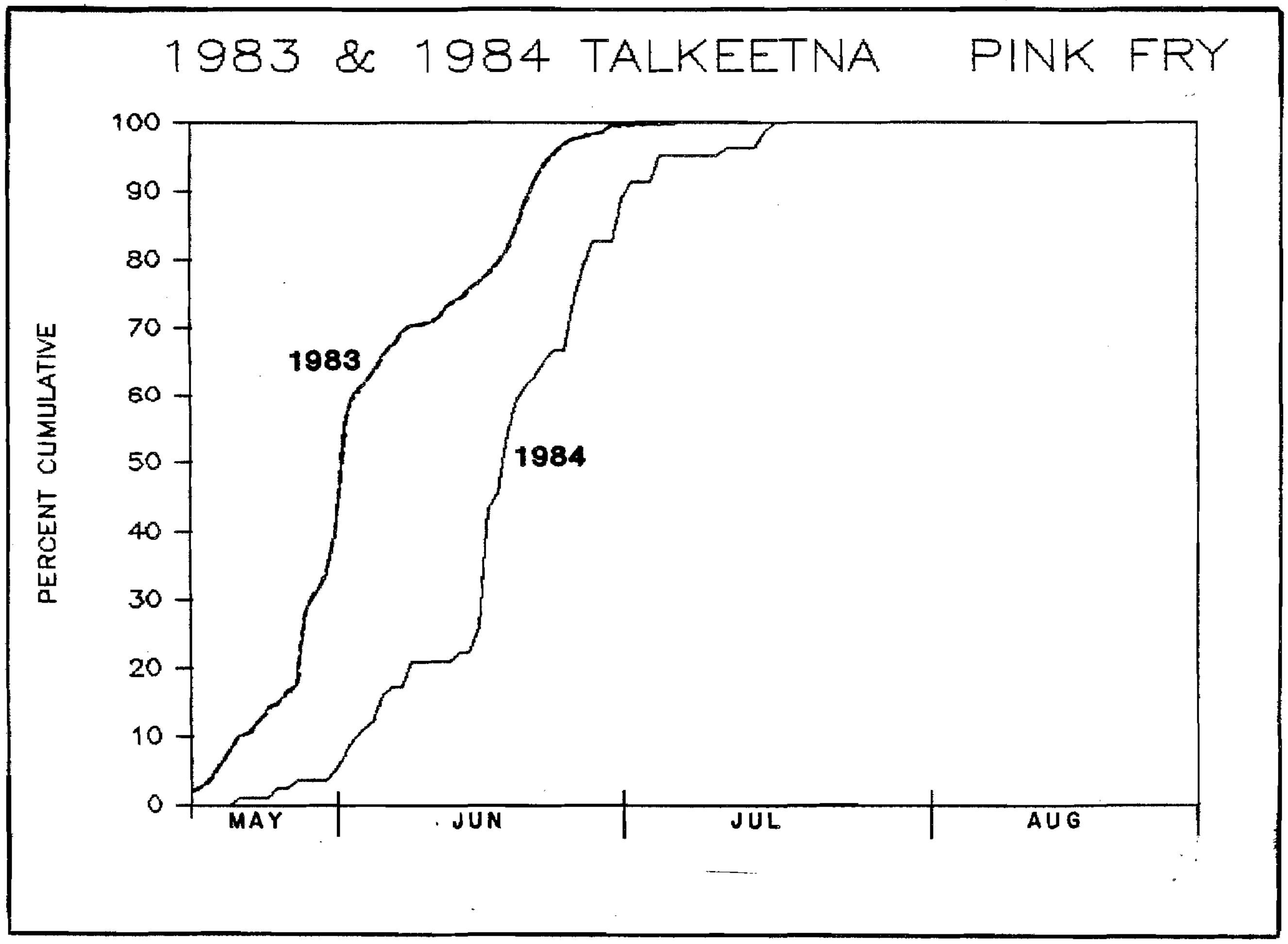


Figure 61. Pink salmon fry adjusted cumulative catch recorded at the Talkeetna stationary outmigrant traps, 1983 and 1984.

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APPENDIX A

JUVENILE SALMON CATCH AND LENGTH DATA, 1984

Appendix Table A-1. Weir catches of juvenile chinook and coho salmon on the Deshka River, May 10 through September 19, 1984.

Date	Tributary River Mile	Hours Fished	Chinook Daily Catch	Chinook Catch Per Hour	Coho Daily Catch	Coho Catch Per Hour
May 10	2.0	21.5	2	0.1	0	0.0
12	2.0	15.0	9	0.6	1	0.1
13	2.0	21.0	3	0.1	0	0.0
27	5.0	12.0	50	4.2	1	0.1
28	5.0	12.5	7	0.6	0	0.0
29	4.5	12.5	3	0.2	0	0.0
31	5.0	12.0	4	0.3	0	0.0
June 1	5.0	12.5	21	1.7	0	0.0
21	5.0	11.5	1	0.1	0	0.0
22	5.0	21.5	3	0.1	0	0.0
July 11	2.5	14.5	209	14.4	5	0.3
12	2.5	24.0	144	6.0	2	0.1
13	2.5	24.0	268	11.2	3	0.1
14	2.5	23.5	186	7.9	4	0.2
15	2.5	24.0	27	1.1	0	0.0
16	2.5	24.0	130	5.4	1	0.0
25	2.5	15.0	318	21.2	21	1.4
26	2.5	24.0	149	6.2	8	0.3
31	2.5	20.0	168	8.4	4	0.2
August 13	2.5	14.0	45	3.2	15	1.1
14	2.5	23.0	4	0.2	2	0.1
15	2.5	23.0	5	0.2	5	0.2
16	2.5	23.0	27	1.2	12	0.5
31	2.0	21.5	5	0.2	22	1.0
September 11	1.5	13.5	1	0.1	0	0.0
12	1.5	23.0	6	0.3	0	0.0
13	1.5	23.0	8	0.3	1	0.0
14	1.5	23.0	2	0.1	0	0.0
15	2.5	18.0	1	0.1	2	0.1
16	2.5	24.0	0	0.0	6	0.3
17	2.5	24.0	1	0.0	0	0.0
18	2.5	23.0	1	0.0	2	0.1
Season Totals		621.0	1,808	2.9	117	0.2

Appendix Table A-2. Results of incidental minnow trapping in the Deshka River, 1984.

Date	Tributary River Mile	Hours Fished	Number of Traps	Chinook Daily Catch	Chinook Catch Per Trap	Coho Daily Catch	Coho Catch Per Trap
June 21	5.5	16	6	56	9.3	14	2.3
August 28	2.5	9	6	15	2.5	48	8.0
29	2.7	7	7	23	3.3	50	7.1
September 17	5.5	24	4	20	5.0	4	1.0
October 10	2.2	24	2	1	0.5	2	1.0
10	6.0	24	4	30	7.5	4	1.0
11	5.0	27	7	23	3.3	21	3.0
13	2.0 to 6.0	54	5	2	0.4	10	2.0
14	2.0 to 6.0	28	5	1	0.2	4	0.8
15	4.0	24	5	41	8.2	9	1.8
Season Totals			51	212	4.2	166	3.3

Appendix Table A-3. Mean length and range of lengths for age 0+ chinook salmon by sampling period in the lower reach of the Susitna River, 1984.

Sampling Period	Flathorn Station			Deshka River			Lower Susitna JAHS Sites[a]		
	n	Mean Length	Range of Lengths	n	Mean Length	Range of Lengths	n	Mean Length	Range of Lengths
May	0	-	-	77	42.7	36-49	b	-	-
June 1-15	24	56.6	40-67	21	42.4	40-46	74	48.5	34-63
June 16-30	374	58.5	39-74	56	55.7	46-69	63	52.0	36-70
July 1-15	357	62.0	40-84	236	66.8	52-83	84	54.5	39-74
July 16-31	436	64.3	43-88	201	69.7	52-93	171	58.1	39-80
August 1-15	189	66.6	47-89	53	74.4	60-91	330	58.9	40-82
August 16-31	193	72.7	46-94	65	71.7	55-89	238	61.5	42-94
September 1-15	8	77.3	68-84	15	77.9	69-88	52	66.8	52-95
September 16 - October 15	10	78.7	68-95	102	76.0	68-85	53	73.2	51-92

[a] Includes all mainstem, slough and side channel sites sampled during the JAHS study in the Susitna River between Cook Inlet and the Chulitna River confluence.

[b] Not sampled.

Appendix Table A-4. Mean length and range of lengths for age 0+ chinook salmon by sampling period in the Talkeetna River and the middle reach of the Susitna River, 1984.

Sampling Period	Talkeetna River			Talkeetna Station			Middle Susitna Marking Sites[a]			Indian River		
	n	Mean Length	Range of Lengths	n	Mean Length	Range of Lenghts	n	Mean Length	Range of Lengths	n	Mean Length	Range of Lengths
May	b	-	-	2	55.5	53-58	60	40.8	35-45	b	-	-
June 1-15	0	-	-	54	48.6	36-66	b	-	-	b	-	-
June 16-30	26	52.2	43-64	475	53.0	37-70	b	-	-	b	-	-
July 1-15	159	56.0	44-70	538	56.2	38-75	100	47.8	38-67	50	48.9	42-64
July 16-31	155	56.1	40-74	1131	55.5	37-80	50	52.2	42-69	50	54.9	47-67
August 1-15	257	60.7	44-84	748	57.9	40-90	50	52.4	40-77	100	58.8	47-90
August 16-31	114	65.2	51-84	612	59.5	39-95	100	56.1	43-72	100	61.1	49-80
September 1-15	0	-	-	119	62.7	45-91	100	57.6	47-88	100	63.8	47-90
September 16 - October 15	b	-	-	13	60.8	51-90	200	61.0	45-90	300	65.5	50-89

[a] Includes all mainstem, slough, and side channel sites sampled during the coded wire tagging and cold branding studies in the Susitna River between the Chulitna River confluence and Devil Canyon.

[b] Not sampled.

Appendix Table A-5. Mean length and range of lengths for age 1+ chinook salmon by sampling period in the Susitna River, 1984.

Sampling Period	Flathorn Station			Talkeetna Stations			Flathorn & Talkeetna Stations Combined		
	n	Mean Length	Range of Lengths	n	Mean Length	Range of Lengths	n	Mean Length	Range of Lengths
May	11	79.7	67-105	209	77.9	61-101	220	78.0	61-105
Early June	104	89.1	70-122	126	89.6	71-112	230	89.7	70-122
Late June	101	85.2	75-122	335	88.4	71-107	436	87.7	71-122
Early July	17	94.1	86-113	218	85.7	76-117	235	86.3	76-117
Late July	4	97.5	95-102	96	87.7	81-115	100	88.1	81-115
Early August	8	98.6	90-113	1	91.0	91	9	97.8	90-113
Late August	2	96.0	95-97	0	-	-	2	96.0	95-97

Appendix Table A-6. Mean length and range of lengths for age 0+ coho salmon by sampling period in the lower reach of the Susitna River, 1984.

Sampling Period	Flathorn Station			Deshka River			Lower Susitna JAHS Sites[a]		
	n	Mean Length	Range of Lengths	n	Mean Length	Range of Lengths	n	Mean Length	Range of Lengths
May	0	-	-	0	-	-	b	-	-
June 1-15	10	42.7	32-60	0	-	-	18	40.9	33-50
June 16-30	19	48.7	32-64	0	-	-	9	46.2	34-61
July 1-15	11	49.3	36-65	0	-	-	26	50.7	35-65
July 16-31	38	58.6	44-73	21	57.3	47-65	33	50.2	37-65
August 1-15	30	62.1	49-79	19	63.6	53-72	45	49.6	41-68
August 16-31	181	66.8	40-89	59	71.2	51-89	71	59.1	40-85
September 1-15	84	75.0	55-94	2	68.0	67-69	59	62.2	49-86
September 16 - October 15	67	75.1	57-94	29	77.0	60-95	105	66.7	49-95

[a] Includes all mainstem, slough and side channel sites sampled during the JAHS study in the Susitna River between Cook Inlet and the Chulitna River confluence.

[b] Not sampled.

Appendix Table A-7. Mean lengths, and range of lengths for age 0+ coho salmon by sampling period in the middle reach of the Susitna River, 1984.

Sampling Period	Talkeetna Station			Middle Susitna Marking Sites[a]			Indian River		
	n	Mean Length	Range of Lengths	n	Mean Length	Range of Lengths	n	Mean Length	Range of Lengths
May	35	39.7	35-46	b	-	-	b	-	-
June 1-15	40	39.6	30-51	b	-	-	b	-	-
June 16-30	156	43.9	31-58	b	-	-	b	-	-
July 1-15	242	47.8	32-63	0	-	-	62	38.0	34-51
July 16-31	439	51.8	33-69	0	-	-	10	44.1	42-49
August 1-15	221	54.1	41-74	0	-	-	80	48.0	39-58
August 16-31	198	61.5	42-80	38	50.8	39-62	46	49.0	42-61
September 1-15	212	60.5	42-85	41	56.8	40-70	90	50.9	44-64
September 16 - October 15	39	69.1	51-90	5	59.4	48-76	166	55.1	44-73

[a] Includes all mainstem, slough, and side channel sites sampled during the coded wire tagging and cold branding studies in the Susitna River between the Chulitna River confluence and Devil Canyon.

[b] Not sampled.

Appendix Table A-8. Mean length and range of lengths for age 1+ coho salmon by sampling period in the lower reach of the Susitna River, 1984.

Sampling Period	Flathorn Station			Deshka River			Lower Susitna JAHS Sites[a]		
	n	Mean Length	Range of Lengths	n	Mean Length	Range of Lengths	n	Mean Length	Range of Lengths
May	0	-	-	5	69.8	58-89	b	-	-
June 1-15	7	87.4	62-110	0	-	-	1	70	70
June 16-30	15	78.1	65-96	14	78.6	58-108	11	97.4	62-111
July 1-15	12	84.9	70-111	13	79.0	62-95	6	81.3	72-101
July 16-31	39	89.8	75-120	6	101.7	65-118	4	85.3	73-92
August 1-15	16	92.8	80-112	2	97.5	83-112	4	102.0	98-109
August 16-31	68	103.4	91-122	68	98.2	90-123	11	105.2	90-123
September 1-15	68	109.4	95-129	1	118.0	118	3	105.3	104-108
September 16 - October 15	53	112.9	95-133	31	111.8	92-134	4	112.0	99-110

a Includes all mainstem, slough and side channel sites sampled during the JAHS study in the Susitna River between Cook Inlet and the Chulitna River confluence.

b Not sampled.

Appendix Table A-9. Mean lengths, and range of lengths for age 1+ coho salmon by sampling period in the middle reach of the Susitna River, 1984.

Sampling Period	Talkeetna Station			Middle Susitna Marking Sites[a]			Indian River		
	n	Mean Length	Range of Lengths	n	Mean Length	Range of Lengths	n	Mean Length	Range of Lengths
May	139	69.4	51-105	18	63.0	52-85	b	-	-
June 1-15	332	71.8	52-102	b	-	-	b	-	-
June 16-30	340	76.1	59-115	b	-	-	b	-	-
July 1-15	192	77.8	64-118	0	-	-	2	67.0	64-70
July 16-31	252	82.2	70-125	0	-	-	7	85.7	79-90
August 1-15	28	93.5	79-120	0	-	-	17	86.1	74-99
August 16-31	96	101.9	81-131	2	103.5	102-105	0	-	-
September 1-15	14	99.6	86-127	10	93.2	83-101	0	-	-
September 16 - October 15	21	114.4	93-135	4	93.5	90-99	0	-	-

[a] Includes all mainstem, slough, and side channel sites sampled during the coded wire tagging and cold branding studies in the Susitna River between the Chulitna River confluence and Devil Canyon.

[b] Not sampled.

Appendix Table A-10. Mean length and range of lengths for age 2+ coho salmon by sampling period on the Susitna River between Cook Inlet and Devil Canyon, 1984.

Sampling Period	n	Mean Length	Range of Lengths
May	5	133.2	120 - 160
E. June	7	135.6	114 - 157
L. June	1	136.0	136
E. July	2	130.0	130
L. July	0	-	-
E. August	1	126.0	126
L. August	13	138.0	125 - 176
E. September	2	134.0	134
L. September - E. October	13	141.0	135 - 150
All Season	44	137.1	114 - 176

Appendix Table A-11. Daily catches of outmigrant chum and sockeye salmon fry in a fyke net located at the mouth of Slough 21, May 23 to June 12, 1984.

Check Date	Sockeye	Chum	Check Date	Sockeye	Chum
May 23	1,005	74	June 3	155	8
24	694	83	4	140	8
25	810	60	5	164	10
26	2,150	355	6	419	12
27	1,479	399	7	1,024	82
28	400	83	8	570	85
29	1,777	198	9	761	59
30	253	89	10	31	34
June 1	156	44	11	23	8
2	344	33	12	29	8
			13[a]	2	1

[a] Slough breached allowing fish passage around net. Net pulled.

Appendix Table A-12. Mean length and range of lengths for age 0+ sockeye salmon by sampling period on the Susitna River between Cook Inlet and Devil Canyon, 1984.

Sampling Period	Flathorn Station			Lower Susitna[a] JAHS Sites			Talkeetna Station			Middle Susitna[b] Marking Sites		
	n	Mean Length	Range of Lengths	n	Mean Length	Range of Lengths	n	Mean Length	Range of Lengths	n	Mean Length	Range of Lengths
May	134	32.8	27-45	c	-	-	213	32.0	26-41	100	30.5	25-37
June 1-15	284	40.4	29-60	15	36.0	26-52	305	36.5	28-60	100	35.2	29-49
June 16-30	343	42.7	25-70	80	40.1	26-66	509	41.9	25-71	50	34.2	28-44
July 1-15	313	49.2	25-80	20	43.6	30-65	570	48.8	30-75	0	-	-
July 16-31	337	52.2	30-85	54	43.5	28-76	748	53.4	35-87	8	53.1	47-68
August 1-15	239	53.0	29-85	38	47.9	30-76	547	51.8	33-88	49	51.4	43-62
August 16-31	185	52.8	30-93	106	53.0	28-86	90	58.6	42-79	50	56.2	36-69
September 1-15	41	55.6	42-75	20	61.2	45-71	95	59.8	40-91	0	-	-
September 16 - October 15	37	57.2	38-81	62	60.3	35-79	15	60.4	48-90	0	-	-

[a] Includes all mainstem, slough, and side channel sites sampled during the JAHS study in the Susitna River between Cook Inlet and the Chulitna River confluence.

[b] Includes all mainstem, slough, and side channel sites sampled during the coded wire tagging and cold branding studies in the Susitna River between the Chulitna River confluence and Devil Canyon.

c Not sampled.

Appendix Table A-13. Mean length and range of lengths for age 1+ sockeye salmon by sampling period on the Susitna River between Cook Inlet and Devil Canyon, 1984.

Sampling Period	n	Mean Length	Range of Lengths
May	32	71.3	56 - 99
June 1-15	40	71.3	61 - 100
June 16-30	15	77.8	71 - 91
July	3	91.7	81 - 102
Season	90	73.1	56 - 102

Appendix Table A-14. Mean length and range of lengths for chum salmon fry by sampling period on the Susitna River between Cook Inlet and Devil Canyon, 1984.

Sampling Period	Flathorn Station			Lower Susitna[a] JAHS Sites			Talkeetna Station			Middle Susitna[b] Marking Sites		
	n	Mean Length	Range of Lengths	n	Mean Length	Range of Lengths	n	Mean Length	Range of Lengths	n	Mean Length	Range of Lengths
May	35	42.7	36-62	c	-	-	367	40.1	32-52	150	39.9	33-47
June 1-15	198	41.9	30-55	298	43.2	31-58	357	45.6	35-68	300	44.5	36-60
June 16-30	209	42.7	32-63	109	39.4	31-50	427	42.9	36-62	50	40.2	36-48
July 1-15	17	42.5	30-59	37	42.3	33-57	337	44.0	35-65	50	48.2	39-54
July 16-31	3	43.3	31-52	21	40.4	36-47	172	44.6	36-59	10	46.5	40-51

[a] Includes all mainstem, slough, and side channel sites sampled during the JAHS studies in the Susitna River between Cook Inlet and the Chulitna River confluence.

[b] Includes all mainstem, slough, and side channel sites sampled during the coded wire tagging and cold branding studies in the Susitna River between the Chulitna River confluence and Devil Canyon.

[c] Not sampled.

APPENDIX B

THE SCHAEFER ESTIMATE OF POPULATION SIZE

The Schaefer method of estimating population size is useful with migrating fish which can be sampled and marked at one point and recovered later at a different point on the migratory route (Ricker 1975). The Schaefer estimate of population size (N) is given by Ricker as:

$$N = \sum N_{ij} = \sum \left(R_{ij} \cdot \frac{M_i}{R_i} \cdot \frac{C_j}{R_j} \right)$$

where: R_{ij} = number of fish which were marked during a tagging period (i) and subsequently recaptured during a recovery period (j).

M_i = number of fish marked during a single tagging period.

R_i = total recaptures of fish tagged in the ith period

C_j = number of fish captured and examined for marks during a recovery period.

R_j = number of marked fish which were recaptured during a recovery period.

N_{ij} = estimate of the number of fish available for marking during a period (i) and the number available for recovery in a period (j).

Tagging and recovery periods for the Susitna River study were grouped by eight-day intervals. The data collected for the estimate of the population of sockeye salmon outmigrants are tabulated by the Schaefer method in Appendix Table B-1. The computation of the population estimate is presented in Appendix Table B-2.

Because only age 0+ sockeye fry were tagged and because some of these remained in the middle river to overwinter (therefore, there was no chance of recapturing them as age 0+ fry at Talkeetna Station), we had to assume that the marked/unmarked ratio was the same for the fry that outmigrated as it was for the fry that remained to overwinter. The purpose of sampling at Talkeetna Station was to estimate this ratio. Data collected so far indicate that the number of overwintering sockeye fry in this reach is low in comparison to the number that outmigrate, so the consequences of violating this assumption are not severe.

The mark-recovery data for chum salmon are presented in Appendix Table B-3, and the computations and final population estimate are provided in Appendix Table B-4.

Appendix Table B-1. Data collected on the coded wire tag, mark-recapture experiment for sockeye salmon fry to provide a Schaefer population estimate. Tagging and recovery periods are by eight day intervals, May 22 through September 18, 1984.

Period of Recovery (j)	Period of Tagging (i)				Tagged Fish Recovered (Rj)	Total Fish Recovered (Cj)	Cj/Rj
	1	2	3	4			
1	27	-	-	-	27	339	12.6
2	4	-	-	-	4	71	17.8
3	7	-	-	-	7	414	59.1
4	26	-	6	5	37	1,293	34.9
5	21	-	5	24	50	931	18.6
6	70	-	16	15	101	1,627	16.1
7	32	-	9	7	48	976	20.3
8	16	-	1	3	20	428	21.4
9	29	-	5	10	44	693	15.8
10	6	-	2	4	12	360	30.0
11	6	-	-	-	7	173	24.7
12	-	-	1	-	1	20	20.0
13	1	-	-	-	1	46	46.0
14	2	-	-	-	2	60	30.0
15	1	-	-	-	1	31	31.0
Total Tagged Fish Recovered (Ri)	248	0	45	69	362	7,462	
Total Fish Tagged (Mi)	8,795	0	2,052	3,685	14,532		
Mi/Ri	35.5	-	45.6	53.4			

Appendix Table B-2. Computation of the sockeye salmon for outmigrant population from the data presented in Appendix Table B-1.

Period of Recovery (j)	Period of Tagging (i)				Total
	1	2	3	4	
1	12,077	-	-	-	12,077
2	2,528	-	-	-	2,528
3	14,686	-	-	-	14,686
4	32,213	-	9,549	9,318	51,080
5	13,866	-	4,241	23,838	41,945
6	40,009	-	11,747	12,896	64,652
7	23,061	-	8,331	7,588	38,980
8	12,155	-	976	3,428	16,559
9	16,266	-	3,602	8,437	28,305
10	6,390	-	2,736	6,408	15,534
11	5,261	-	-	1,319	6,580
12	-	-	912	-	912
13	1,633	-	-	-	1,633
14	2,130	-	-	-	2,130
15	1,101	-	-	-	1,101
TOTAL	183,376	-	42,094	73,232	298,702

Appendix Table B-3. Data collected on the coded wire tag, mark-recapture experiment for chum salmon fry to provide a Schaefer population estimate. Tagging and recovery periods are by eight day intervals, May 22 through July 24, 1984.

Period of Recovery (j)	Period of Tagging (i)				Tagged Fish Recovered (Rj)	Total Fish Recovered (Cj)	Cj/Rj
	1	2	3	4			
1	11	-	-	-	11	932	84.7
2	-	1	-	-	1	104	104.0
3	3	4	2	-	9	860	95.6
4	-	3	3	6	12	526	43.8
5	1	3	-	8	12	361	30.1
6	-	-	-	1	1	334	334.9
7	-	-	-	4	4	154	38.5
8	-	-	-	1	1	132	132.0
Total Tagged Fish Recovered (Ri)	15	11	5	20	51		
Total Fish Tagged (Mi)	4,806	12,276	5,295	9,019	31,396		
Mi/Ri	320.4	1,116.0	1,059.0	451.0			

Appendix Table B-4. Computation of the chum salmon for outmigrant population from the data presented in Appendix Table B-3.

Period of Recovery (j)	Period of Tagging (i)				
	1	2	3	4	Total
1	298,517	-	-	-	298,517
2	-	116,064	-	-	116,064
3	91,891	426,758	202,481	-	721,130
4	-	146,642	139,153	118,523	404,318
5	9,644	100,775	-	108,601	219,020
6	-	-	-	150,634	150,634
7	-	-	-	69,454	69,454
8	-	-	-	59,532	59,532
TOTAL	400,052	790,239	341,634	506,744	2,038,669

APPENDIX C

Time Series Analysis of Discharge, Turbidity, and Juvenile Salmon Outmigration in the Susitna River, Alaska

TIME SERIES ANALYSIS OF DISCHARGE, TURBIDITY, AND JUVENILE SALMON OUTMIGRATION IN THE SUSITNA RIVER, ALASKA

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ABSTRACT

During the three years of study of juvenile salmon outmigration from the middle reach of the Susitna River, a correspondence has been noted between the peaks of river discharge and the peaks of outmigration. Further investigation of the relationship of outmigration to discharge was required because two large hydroelectric dams have been proposed for a region above the salmon rearing areas. These dams will markedly change the downstream discharge and turbidity regimes, factors which influence not only salmon outmigration, but almost all fish species and life stages including juvenile salmon rearing. Box-Jenkins models were developed for the 1983 and 1984 time series of river discharge, turbidity, and chinook and sockeye salmon fry outmigration rates in order to better understand the forces that shape the series and to statistically describe the natural conditions as a baseline against which future changes can be measured. The time series examined were described by relatively simple models, using mostly first-order autoregressive terms. About 85% of the variance in turbidity for one day was explained by the value for turbidity of the previous day. This figure was 44% for chinook salmon outmigration and 43% for sockeye salmon outmigration, the lower numbers indicating the effect of behavioral decisions on biological time series. Although the form of the time series plots of discharge and chinook salmon outmigration was different between the two years, the underlying stochastic processes which generated these series were the same. Bivariate transfer function models were constructed for turbidity and salmon outmigration rates which explain present values of these variables in terms of their own past values as well as past values of discharge.

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1.0 INTRODUCTION

While examining the plots of daily catch rate of outmigrating juvenile salmon at the Talkeetna Station outmigrant traps, an apparent correspondence was noted between the peaks of the time series of mean daily discharge and the time series of salmon outmigration (Hale 1983; Roth et al. 1984). Correlation analysis showed that there was a relatively strong relationship between discharge and the outmigration rates of various species/age classes of salmon during certain periods of time. The term outmigration rate is used here to mean the number of outmigrating fry captured at the traps per hour, not the distance travelled per hour. This relationship is not simply a matter of a greater volume of water being fished at higher discharges. The correlations of catch rate of age 0+ salmon with water velocity at the mouths of the traps were not significantly different from zero (Roth et al. 1984, Appendix A). There was in fact a greater number of fry per unit volume of water at high levels of discharge than at low levels.

A correspondence between discharge rate and salmonid outmigration has also been reported by other investigators (Cederholm and Scarlett 1982 - coho salmon; Congleton et al. 1982 - chum and chinook salmon; Godin 1982; Grau 1982; Solomon 1982b). The selective advantages of this behavior, according to Solomon (1982b), include easier passage over long distances or shallow areas and protection from predators provided by increased turbidity and by the large numbers resulting from a coordinated mass migration in response to an environmental cue.

There are probably two mechanisms which account for this relationship in the Susitna River. One is that the fish, which have gradually become physiologically ready for outmigration by growth and in response to photoperiod and temperature, are stimulated by a rise in mainstem discharge to begin that outmigration (Grau 1982). The second mechanism is that high flows physically displace the fish downstream. This latter mechanism may frequently occur for fry rearing in side sloughs, particularly for chum salmon (Oncorhynchus keta) and sockeye salmon (O. nerka). The natal sloughs for many chum and sockeye salmon have berms at the heads which prevent water from entering the site at low levels of discharge. When high flows occur, the slough heads are overtopped and the fry which had been rearing in low velocity water are subjected to a strong current.

Because two large hydroelectric dams have been proposed for the Susitna River in an area upstream of the rearing areas of the juvenile salmon (Fig. 1), and because these dams would markedly alter the natural discharge and turbidity regimes, it is necessary to quantify the relationship between the discharge and turbidity regimes and the outmigration patterns of the juvenile salmon. After the dams begin operation, the annual patterns of river discharge and turbidity level would be smoothed - both would be lower than normal in the summer and higher than normal in the winter. Also, the high frequency (daily) oscillations of these two time series would be dampened; there would be less day to day variation.

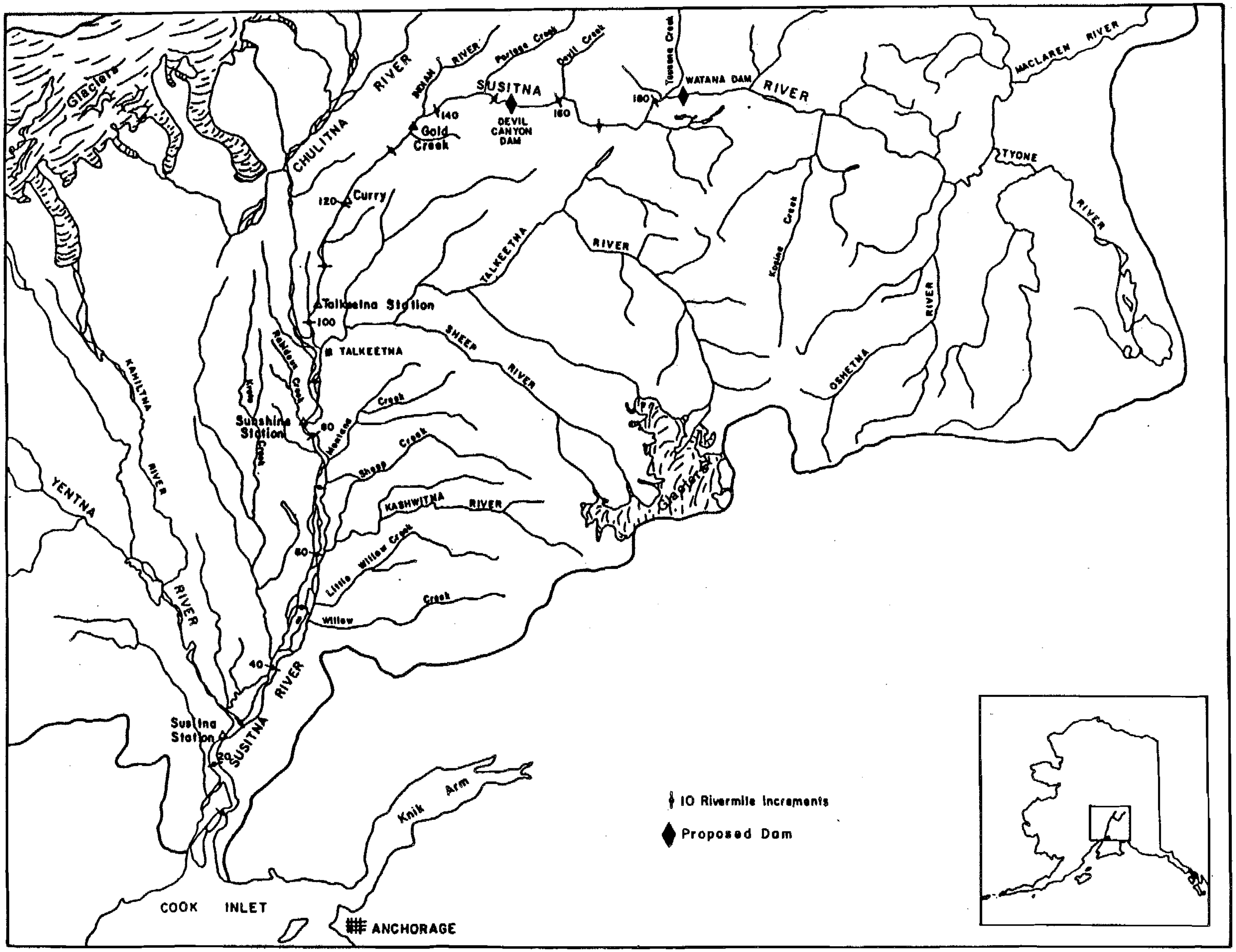


Figure 1. Map of the Susitna basin study region. (Source: Arctic Environmental Information Data Center).

There are many factors other than discharge and turbidity which affect the outmigration timing of juvenile salmon including time of year, size of fish, photoperiod, light intensity, and temperature (Brannon and Salo 1982); however, discharge and turbidity bear further investigation because of the changes in these two variables which would be caused by the proposed dams. Changes in river flow can affect the survival rate of young salmon (Stevens and Miller 1983). Potential negative effects of an altered flow regime include accelerated or delayed timing of outmigrations. Changes in outmigration timing may place the fish in their rearing areas at an unfavorable time from the standpoint of food supply, which could cause reduced survival (Hartman et al. 1967). Lower discharge levels can result in a shorter distance covered per day (Raymond 1968). Decreasing mainstem flows can lead to stranding of fish in pools which have been isolated from the mainstem (Solomon 1982a). Lower flows and clearer water than normal may also result in increased predation (Stevens and Miller 1983).

Turbidity level in the Susitna River probably does not have much direct effect on the daily number of fry which outmigrate or on the initiation of outmigration. In clear water streams, however, an increase in turbidity level can directly increase the number of outmigrating salmon by providing cover from predators (Solomon 1982b). Turbidity level in the Susitna River does change outmigration timing because fry in turbid water outmigrate during the day as well as during the night (Godin 1982; Roth et al. 1984). Clearing of the water could force the fry to shift to a nocturnal outmigration to avoid predators. However, this would be of marginal benefit for fry during the continuous daylight in June and July at 63° N latitude.

To avoid or alleviate the above problems, it is necessary to understand the mechanisms producing the present discharge, turbidity, and outmigration regimes. Knowledge of the discharge-outmigration relationships will be useful in trying to establish a post-project flow regime which will not interfere with the natural outmigration timing.

Also, because discharge and turbidity level are important variables affecting salmon life stages other than the outmigration phase as well as other species, it is necessary to statistically describe the natural discharge and turbidity regimes as a baseline against which future changes in these variables can be measured. Turbidity provides cover for salmon fry (Suchanek et al. 1984; Part 2 of this report) but also decreases primary production and affects the feeding, movement, and distribution of many of the fish species present in the river. Turbidity level after the dams begin operation will not only be influenced by a changed discharge regime, but will also be directly changed by the dams because settling of suspended sediment in the reservoir will create a turbidity regime substantially different from the present regime. Turbidity was included as a variable of interest in this paper more because of its effect on other life stages and species than because of its effect on salmon outmigration.

Further, discharge is the major variable in the extensive instream flow habitat modeling effort which has been conducted in the Susitna River; turbidity is also an important factor (Hale et al. 1984; Suchanek et al.

1984; Part 2 of this report). The current discharge and turbidity regimes that are driving these habitat models must be accurately described so that the models can be put into a proper perspective.

1.1 Time Series Analysis

The statistical methods collectively known as time series analysis are a logical choice for analyzing the natural discharge, turbidity, and outmigration regimes. A time series is a collection of observations ordered in time such as daily water temperature measurements. Time series analysis includes frequency domain (spectral analysis) and time domain problems. Spectral analysis is concerned with transforming a time series with a Fourier transform to a sum of sines and cosines (see Priestley 1981) and is appropriate with periodic series such as the classical example of the Canada lynx/snowshoe hare ten year cycle (Bulmer 1978). Methods for time domain problems (or Box-Jenkins models) are referred to as ARIMA (autoregressive, integrated, moving average) models (Box and Jenkins 1976). ARIMA models have been used extensively in economic forecasting (Nelson 1973; Granger and Newbold 1977).

Time series are shaped by both deterministic and stochastic (random) events. The series has a "memory" of the random events (or "shocks") operating on the series, that is, the effect of these disturbances may be apparent for several time units after the event occurred. One aspect of time series analysis consists of removing deterministic trends from a time series so that the values fluctuate around a mean level. A transformation may be necessary to ensure a constant variance. The random processes that generated the observed series can then be mathematically defined. The residuals left over after this model is fitted should be "white noise" (completely random) if the model is adequate.

Time series can be passed through a mathematical filter which changes the form of the input series. A "low pass filter" dampens high frequency perturbations and allows low frequency perturbations to pass unchanged. This is useful in smoothing noisy time series so that the basic pattern may be more readily observed. High pass filters are used when it is desirable to remove obvious (low frequency) trends in order to focus on the high frequency events.

Box-Jenkins models can be constructed using only the information contained in the time series itself. For example, although the discharge time series results from several independent variables including rainfall, air temperature, and solar insolation on the glaciers, it is not necessary to quantify these inputs in order to model the output (discharge). Information on the effects of all the inputs is already contained in the past history of the discharge record. However, information on the input series can be used in a transfer function model to obtain an equation with more predictive power. This is a model where an output series is a function of one or more independent input series as well as its own past history.

An observed series is one realization of all possible time series which could have been generated from a random process. Time series analysis examines the nature of the probablistic process that generated the observed series. The model should have similar properties to the generating mechanisms of the stochastic process (Granger and Newbold 1977). Then, one can form summary statistics about the series and make inferences about the nature of the stochastic process. After a model has been developed, it can be used to test some hypothesis about the generating mechanism of the time series, to forecast future values of the series, or to make decisions on how to control future values of the series (Granger and Newbold 1977).

1.2 Applications of Time Series Analysis

Time series analysis has been extensively used in examining physical data, particularly in oceanography. Salas and Smith (1981) demonstrated that ARIMA models can be used to model the time series of annual flows in streams. Srikanthan et al. (1983) analyzed the time series of annual flows in 156 streams in Australia. Time series models have also been used to examine the effect of the Aswan dam on the discharge of the Nile River and the effect of a hydroelectric dam on the discharge regime of the Saskatchewan River (Hipel et al. 1978).

Time series analysis methods have been also been used in examining time series of abundance and catch in marine fisheries (Van Winkle et al. 1979; Botsford et al. 1982; Peterman and Wong 1984; and Taylor and Prochaska 1984). These methods have been used by Saila et al. 1980, Mendelssohn 1981, Stocker and Hilborn (1981), Kirkley et al. (1982), and Jensen (1985) for forecasting future abundance or catch of marine fish stocks. Mendelssohn (1981) used transfer function models in addition to univariate Box-Jenkins models to forecast fish catch. Botsford et al. (1982) focused on searching for causal mechanisms of observed cycles in salmon fisheries in California rather than on defining models for the fisheries.

Applications to freshwater fish ecology problems are much more limited. Saila et al. (1972) used time series methods to cross correlate upstream migration activity of the alewife to solar radiation and water temperature. O'Heeron and Ellis (1975) considered a time series model for judging the effects of reservoir management on fish. Applications of spectral analysis to ecological problems have been reviewed by Platt and Denman (1975) and time series analysis in ecology was the subject of a symposium proceedings edited by Shugart (1978).

1.3 Objectives

The objective of this paper was to develop mathematical models for the times series of mean daily Susitna River discharge at the Gold Creek gaging station (river mile 136.7), daily turbidity level, and daily outmigration rates of chinook salmon (*Oncorhynchus tshawytscha*) and sockeye salmon (*O. nerka*) at the Talkeetna Station outmigrant traps (river mile 103.0) during the open water seasons of 1983 and 1984. Because time series analysis can provide an efficient summarization of a data set by a few parameters (Hipel et al. 1978), these models will be useful to statistically describe the present conditions as a baseline against which future changes can be measured. The discharge and turbidity information will be useful for examining their relationship with salmon fry outmigration as well as with other species and life history stages. In addition, discharge was used as an input in transfer function models of discharge-turbidity, discharge-chinook outmigration and discharge-sockeye outmigration in order to describe the relationship between these variable and to be used as a possible technique to forecast future values or to examine the probable effects of the proposed dams.

Turbidity was chosen as a variable of interest because of its relationship with discharge and because of its importance in determining the distribution of rearing juvenile salmon (Suchanek et al. 1984; Part 2 of this report) and other species. It was selected more for this reason than for its effect on salmon outmigration, so it was not used as an input in a transfer function model with salmon outmigration. Chinook salmon were chosen because this species rears in sloughs and side channels affected by mainstem discharge and because chinook salmon have been selected as the evaluation species of the impact assessment study (EWT&A 1985). The sockeye salmon time series was chosen because mainstem discharge affects sloughs which are both natal and rearing areas for this species. While chinook salmon spawn mainly in tributaries in this system, sockeye salmon spawn mostly in mainstem sloughs.

2.0 METHODS

2.1. The Data

Mean daily discharge values for 1983 and 1984 (Fig. 2, Fig. 3) were obtained from the U.S. Geological Survey gaging station on the Susitna River at Gold Creek, river mile 136.7 (Still et al. 1984; U. S. Geological Survey provisional data, 1984). The time frame examined was May 18 to August 30 (105 observations). Discharge levels begin to decline in September when glacier melting decreases; hence, a longer series would not be stationary. Throughout this paper, the unit for discharge is one thousand cubic feet per second.

Daily water samples for turbidity (Fig. 2, Fig. 3) were taken at the outmigrant trap station and measured with an HF Instruments Model No. DRT-15B field turbidometer (Roth et al. 1984). Units are in nephelometric turbidity units (NTU). Only the 1984 turbidity series was examined.

Outmigration rate (Fig. 2, Fig. 3) was measured by two outmigrant traps, one on each bank, located at river mile 103.0 (Roth et al. 1984). The rate is reported as number of fish per trap hour with catch from the two traps combined. Only age 0+ fry were used in the analysis because the traps were not efficient at capturing age 1+ fry and, consequently, the numbers were low. Further, age 1+ chinook and sockeye salmon have essentially completed their outmigration from this reach of river by the end of July so the time series are shorter.

The chinook salmon time series for 1983 runs from May 18 (shortly after ice-out) to August 30 (when outmigration is winding down), a total of 105 observations. The 1983 sockeye salmon data were not examined. There were six days during the 105 day series when the outmigrant traps were not fished - a one day, a two day, and a three day period. Although values for gaps in time series can be estimated by a spline method, the gaps in the outmigration series are short enough so that a simple interpolation of values is sufficient (Sturges 1983).

In 1984, the traps were continuously operated from May 14 to October 6. However, the series were cut off at the end of August in order to be comparable to 1983 and to achieve a stationary series. About 98% of the cumulative outmigration of age 0+ chinook and sockeye fry in 1984 had occurred by the end of August.

2.2. Identification and Estimation of Time Series Models

Univariate models were developed for the four time series: discharge, turbidity, and chinook and sockeye salmon outmigration. Methods for developing Box-Jenkins ARIMA and transfer function models are described in section 7.0. Basically, there are three steps in developing an ARIMA model: model identification, parameter estimation, and diagnostic checking (Box and Jenkins 1976). The autocorrelation (AC) and partial autocorrelation (PAC) plots for each series were examined to help identify possible autoregressive (AR) and moving average (MA) components. A tentative model was developed and the parameters estimated.

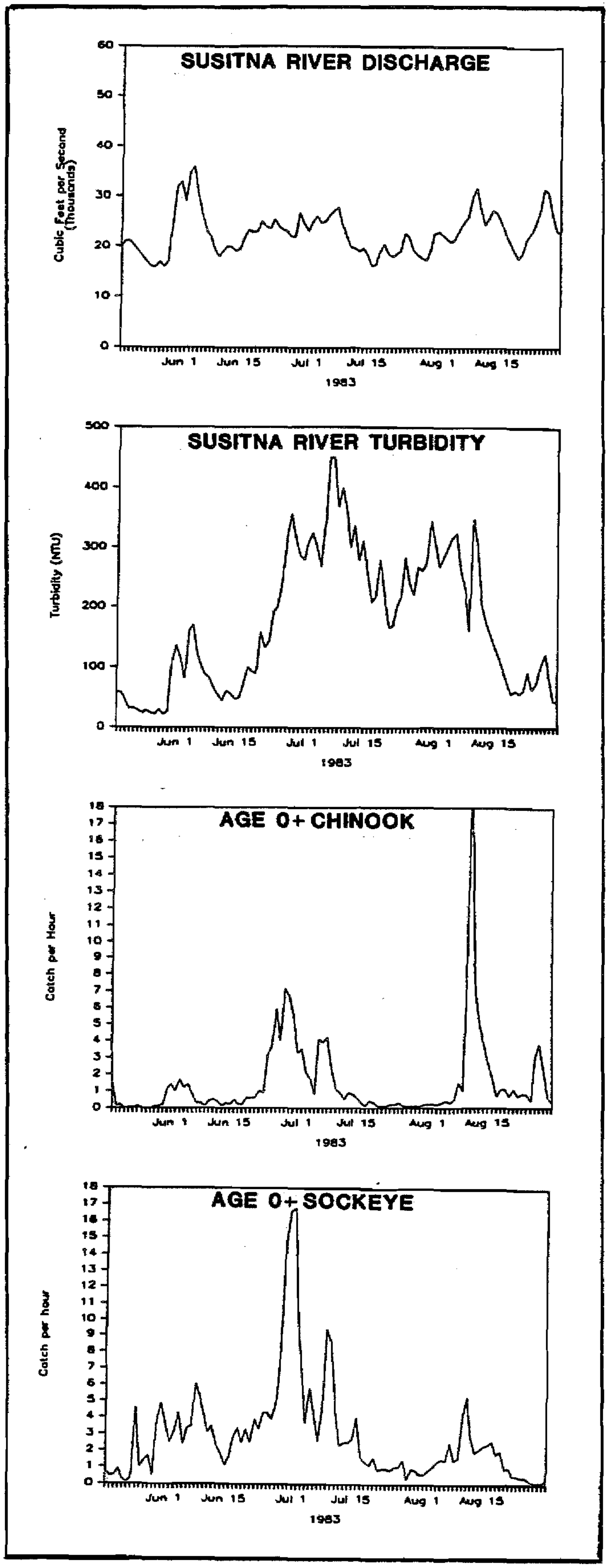


Figure 2. Discharge, turbidity, and chinook and sockeye salmon outmigration rate, 1983.

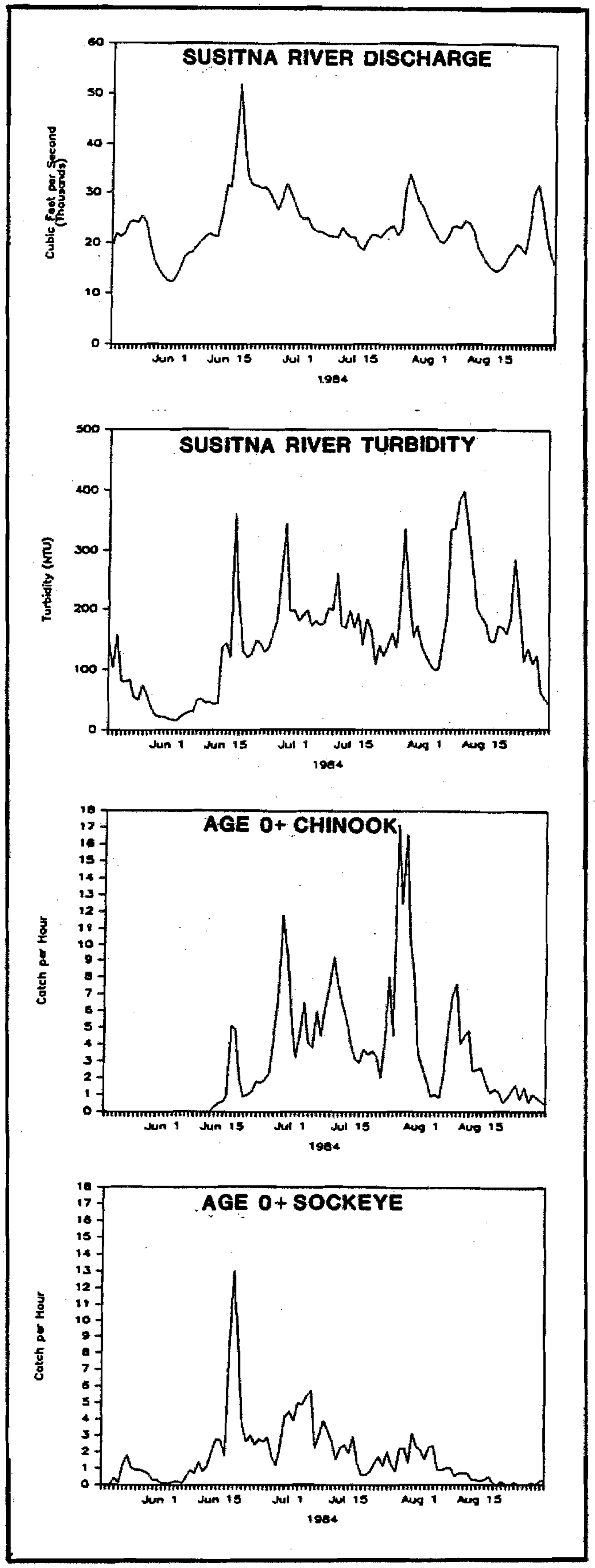


Figure 3. Discharge, turbidity, and chinook and sockeye salmon outmigration rate, 1984.

Insignificant components were removed from the model. The residuals were checked to see if there was significant departure from the assumption that they were white noise. If the residuals were white noise, the model was considered to be adequate. If not, a new model was identified and the process repeated until the residuals were reduced to a white noise process.

All of the time series work was done using the BMDP statistical package (Dixon et al. 1981). The BMDP Box-Jenkins program estimates parameters by both the conditional least squares method and the backcasting method. The estimates chosen for this paper were from whichever method gave the lowest residual mean square.

The time series of mean daily discharge from May 18 to August 30 appeared to be stationary so no differencing was done. A plot of the range of sub-groups of the series against the mean of the sub-groups (as suggested by Hoff (1983) indicated that a logarithmic transformation of the data would be helpful in stabilizing the magnitude of the fluctuations throughout the series; therefore, a model was also developed for the natural log of the raw data. As the turbidity time series was questionably stationary, models were developed for both the original series and for a differenced series.

Models were developed for the chinook and sockeye salmon outmigration rate time series on both the raw data and on data transformed by ln (x + 1). This transformation was used to avoid taking logarithms of zero; there was zero catch on some days.

2.3 Transfer Function Models

Transfer function models (see section 7.0) were developed for discharge/turbidity, discharge/chinook outmigration, and discharge/sockeye outmigration. Only one input (discharge) was used. Multiple input transfer function models (Liu and Hanssens 1980) or multivariate time series models (Mendelssohn 1982) can be developed, but are substantially more complex.

3.0 RESULTS

3.1. Univariate Model for Mean Daily Discharge

The time series of mean daily discharge during the summer of 1983 is shown in Fig. 4; the log-transformed data are in Fig. 6. Autocorrelation function (ACF) and partial autocorrelation function (PACF) plots for the raw data are given in Fig. 5 and for the log- transformed data in Fig. 7. In all the ACF and PACF plots, the "+" symbol on either side of the vertical axis indicates the 95% confidence interval. The first order autoregressive component was strong in both the raw and the transformed series. The ACF and PACF plots for the raw data indicated that a moving average component was required. Models containing various combinations of first and second order AR and MA terms were examined. Of the acceptable models identified, the model with the lowest standard errors on the parameter estimates and the least significant residuals was an ARMA(2,2). However, the ARMA(1,1) was nearly as good as the ARMA (2,2) so, in keeping with Box and Jenkins' (1976) advice that a parsimonious model (i.e., the one with the fewest possible parameters) is desirable, the ARMA(1,1) is considered the "best" model for the non-transformed data. Parameter estimates were:

$$\hat{\phi}_1 = .992 \text{ with std. error of } .0135$$

$$\hat{\theta}_1 = -.580 \text{ with std. error of } .0807$$

The model is:

$$y_t = 22.7 + .99\,(y_{t-1} - 22.7) - .58\, a_{t-1} + a_t$$

where: y_t is the discharge level at time t and

a_t is a white noise process at time t

Neither the mean nor any of the autocorrelations or partial autocorrelations of the residuals was significant; therefore, the model is considered to be adequate. This equation can be interpretted as: The discharge level for any given day is a function of (the mean level, 22.7 cfs, of discharge during the period) plus (most of the previous day's discharge level minus the mean level) minus (about half of the previous day's noise component) plus (the given day's noise component).

The plots of both the ACF and PACF on the residuals from this model showed a slightly significant spike at a lag of 15 or 16 days. This could indicate that the discharge time series has a periodicity of about 15 days, or slightly more than two weeks. This possibility was further examined by spectral analysis. The spectrum of discharge (Fig. 8) did in

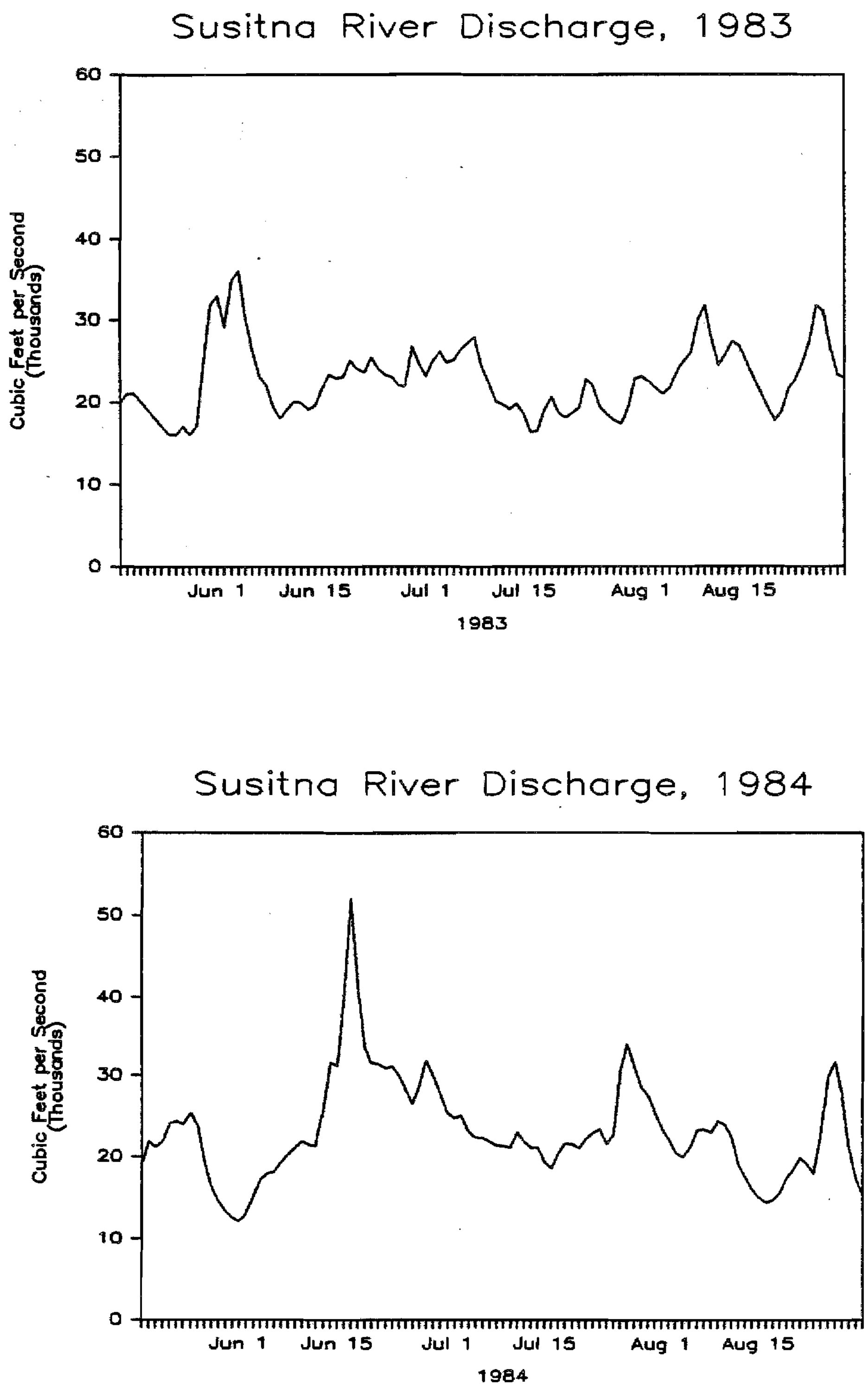
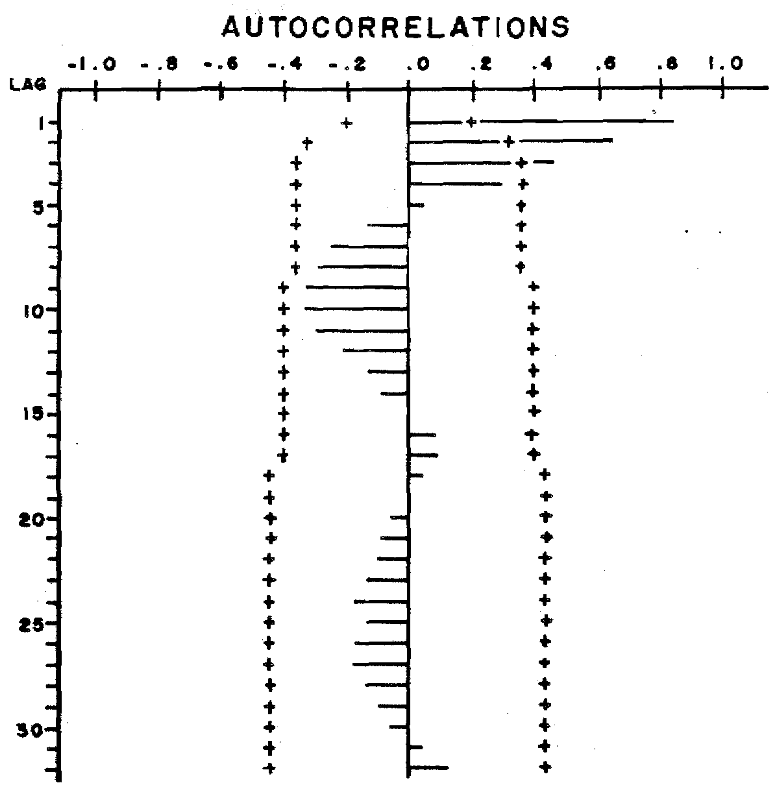


Figure 4. Susitna River discharge time series at the Gold Creek gaging station, 1983 and 1984.



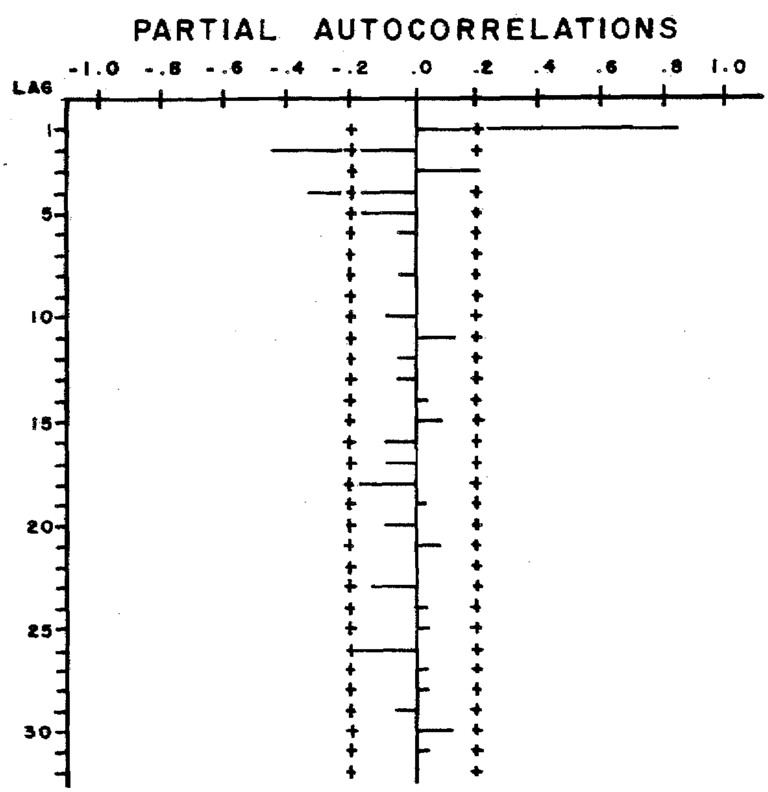


Figure 5. Plots of autocorrelations and partial autocorrelations for 1983 discharge time series.

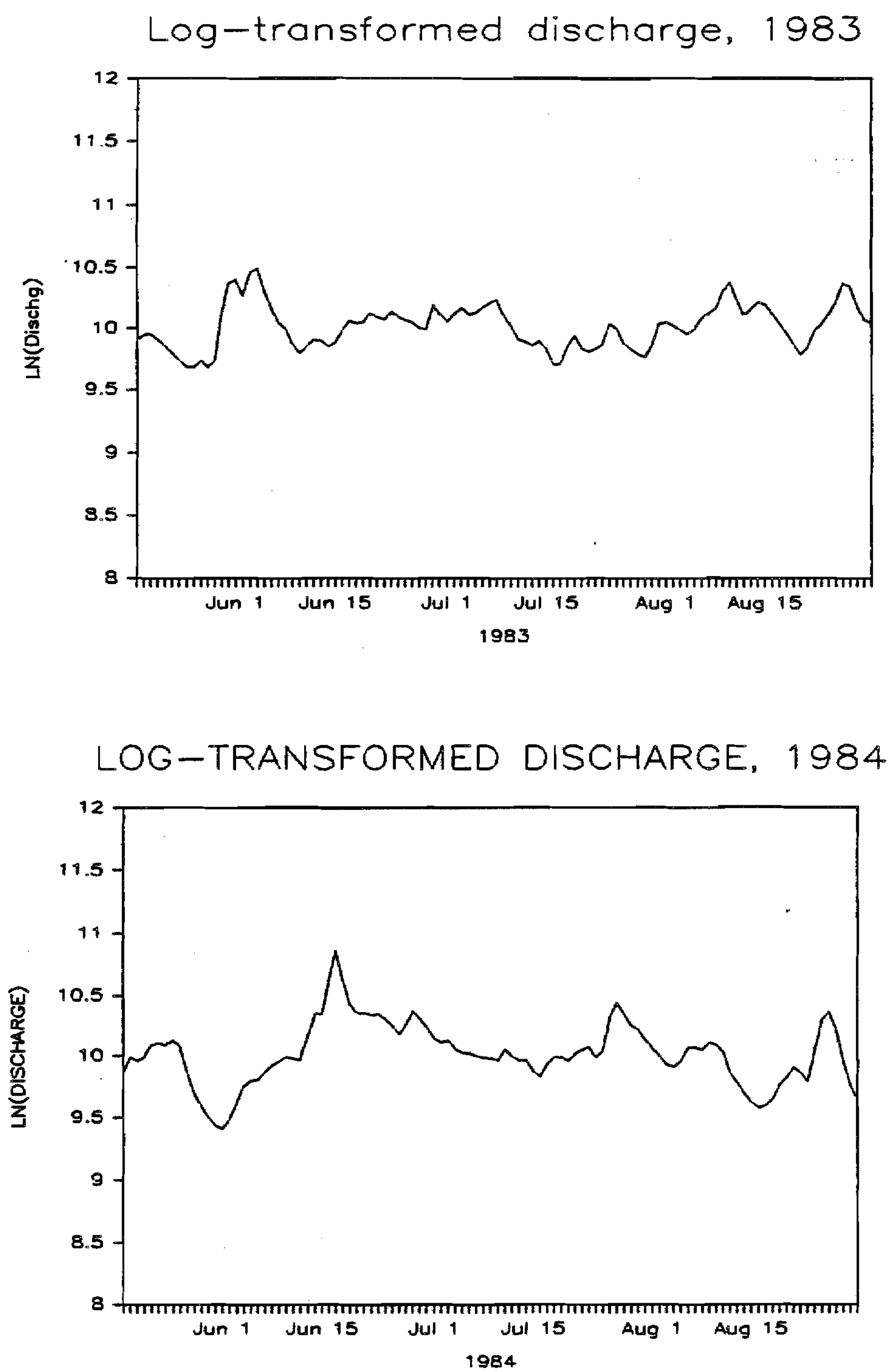


Figure 6. Log-transformed discharge time series, 1983 and 1984.

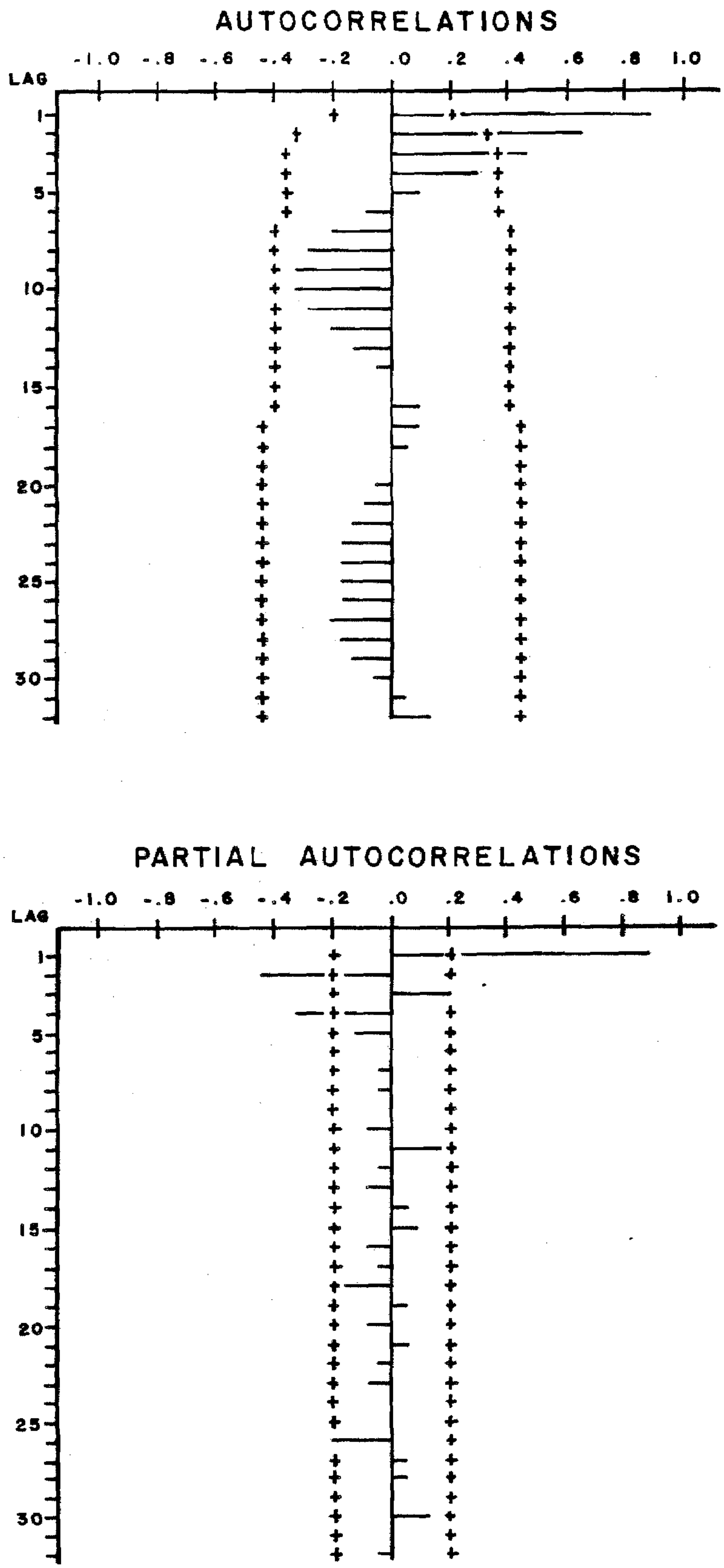


Figure 7. Plots of autocorrelations and partial autocorrelations for 1983 log-transformed discharge time series.

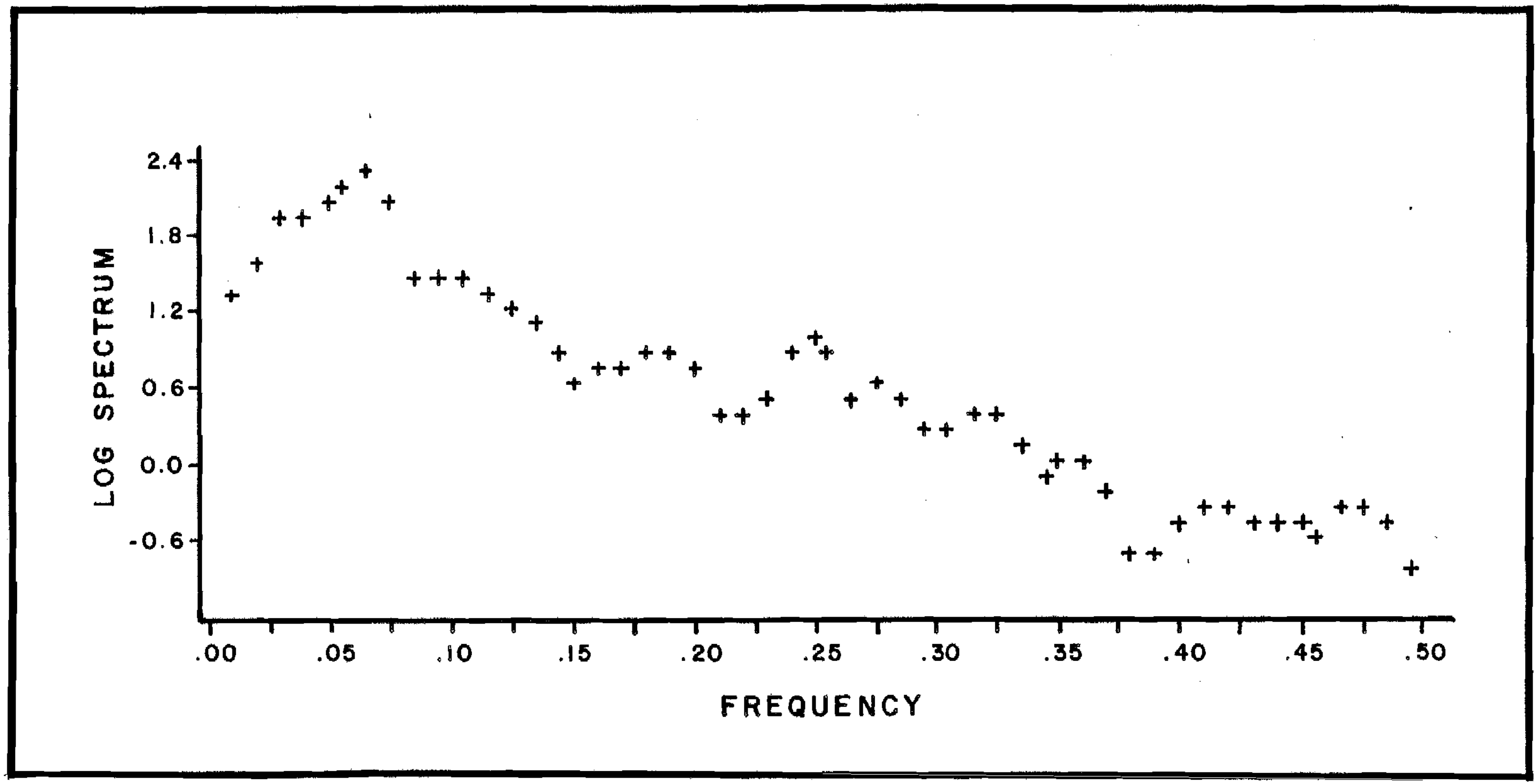


Figure 8. Spectrum of 1983 discharge time series.

fact indicate a peak at a frequency of .065 (a period of 15 days). It is not known at this time if this periodicity is "real". It may be related to weather patterns in the basin which control solar insolation (cloud cover) and rainfall. A much longer time series of discharge would have to be examined to answer this question. A periodic term could be added to the ARMA(1,1) model (Box and Jenkins 1976) but, given the low significance level of the periodicity, it does not seem appropriate at this stage of model development.

Carrying the idea of parsimony a step further, it can be seen that an ARMA(1,0) model using the log-transformed data is adequate and has the lowest number of parameters. The parameter estimates for this model were:

$$\hat{\phi}_1 = .994 \text{ with std. error of } < .00005$$

giving

$$\ln y_t = 10.0 + .99\,(\ln y_{t-1} - 10.0) + a_t$$

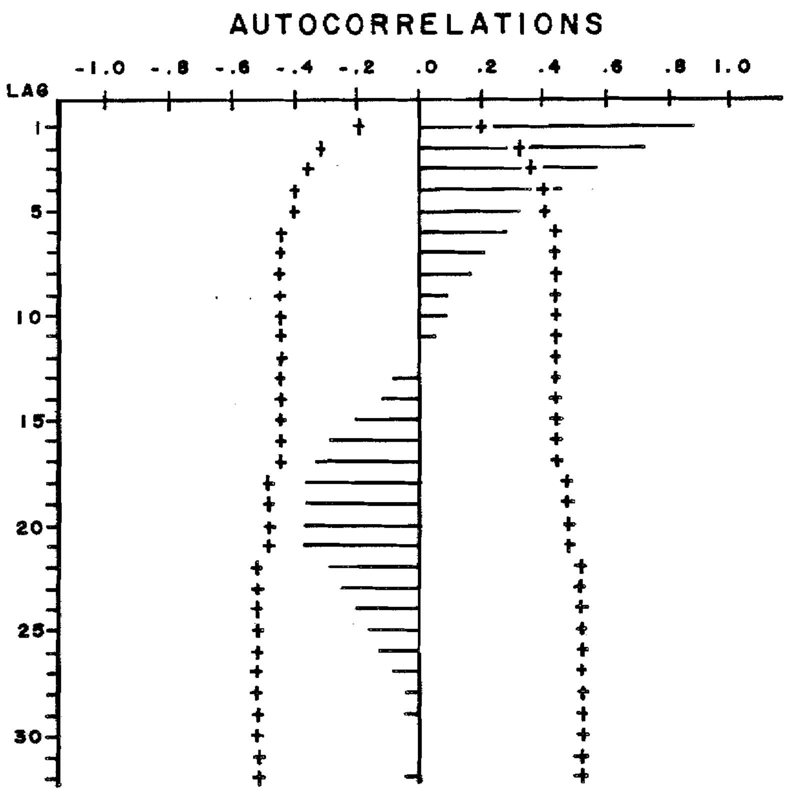
The parameter $\hat{\phi}_1$ was very close to unity. If $\hat{\phi}_1$ were equal to 1.000, the model would be reduced to a random walk model (Chatfield 1984). That is, the log of the discharge for today is the same as the log of the discharge for yesterday plus a random error term. When $\hat{\phi}_1$ approaches 1.000 in a model with only one AR term, the series could be non-stationary (Hoff 1983). To test this, the series was differenced. The residuals from an ARIMA(1,1,0) model showed significant spikes, so the differencing did not help; the ARIMA(1,0,0) model is better.

The AC's on the residuals of the ARMA(1,0) model were a little better than those of the ARMA(1,1) on the non-transformed data. However, the mean of the residuals was slightly significant, so the ARMA(1,1) model on the raw data is probably superior to this one.

The 1984 discharge time series is shown in Fig. 4 and Fig. 6. The ACF and PACF plots (Fig. 9) were similar to those of 1983. An ARMA(1,1) model on the 1984 raw data was adequate, as it was in 1983. Parameter estimates were: $\bar{y}$ = 23.2; $\hat{\phi}_1$ = .808 (std. error = .0638); and $\hat{\theta}_1$ = -.692 (std. error = .0750). An AR(1) model on the log-transformed data was also adequate but, again, had a slightly significant mean residual. The ACF and PACF plots, using log-transformed data (Fig. 10), were similar to those of 1983, but perhaps showed less indication of a moving average process. The estimate for $\hat{\phi}_1$ was .994 (exactly the same as the 1983 data), with a standard error of 0.0001, and the estimate for $\bar{y}$ was 10.0.

3.2. Univariate Model for Turbidity

The time series for turbidity in 1983 (Fig. 11) was more complex than that of discharge. The ACF and PACF plots (Fig. 12) indicated a strong AR(1) component. However, AR(1), AR(2), and ARMA(1,1) models were not adequate to explain the series.



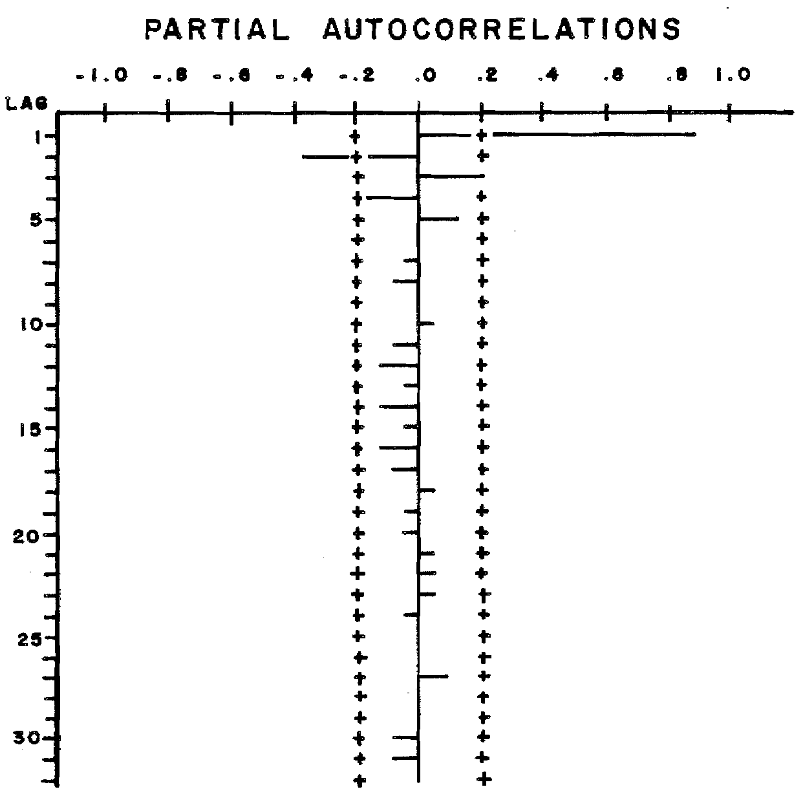


Figure 9. Plots of autocorrelations and partial autocorrelations for 1984 discharge time series.

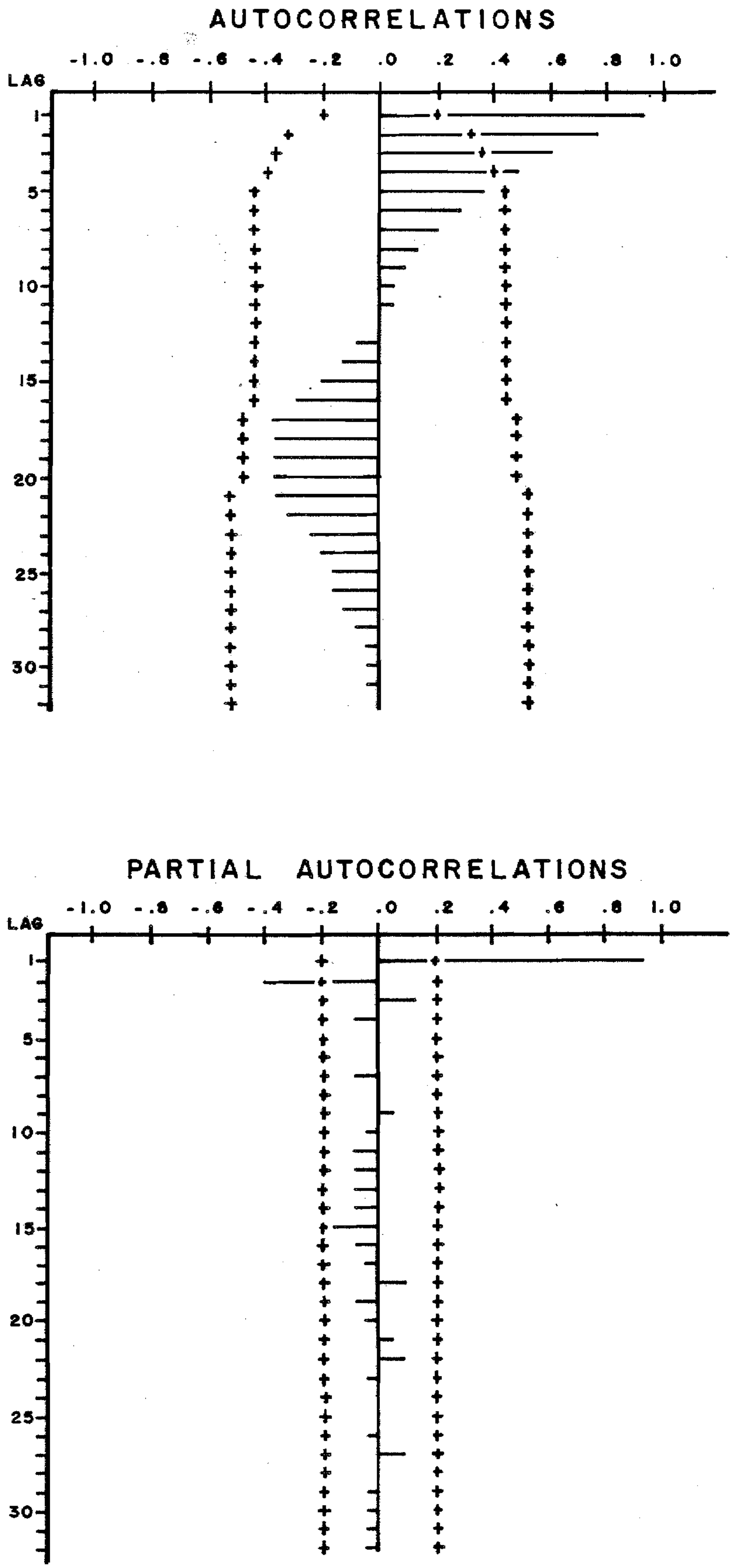


Figure 10. Plots of autocorrelations and partial autocorrelations for 1984 log-transformed discharge time series.

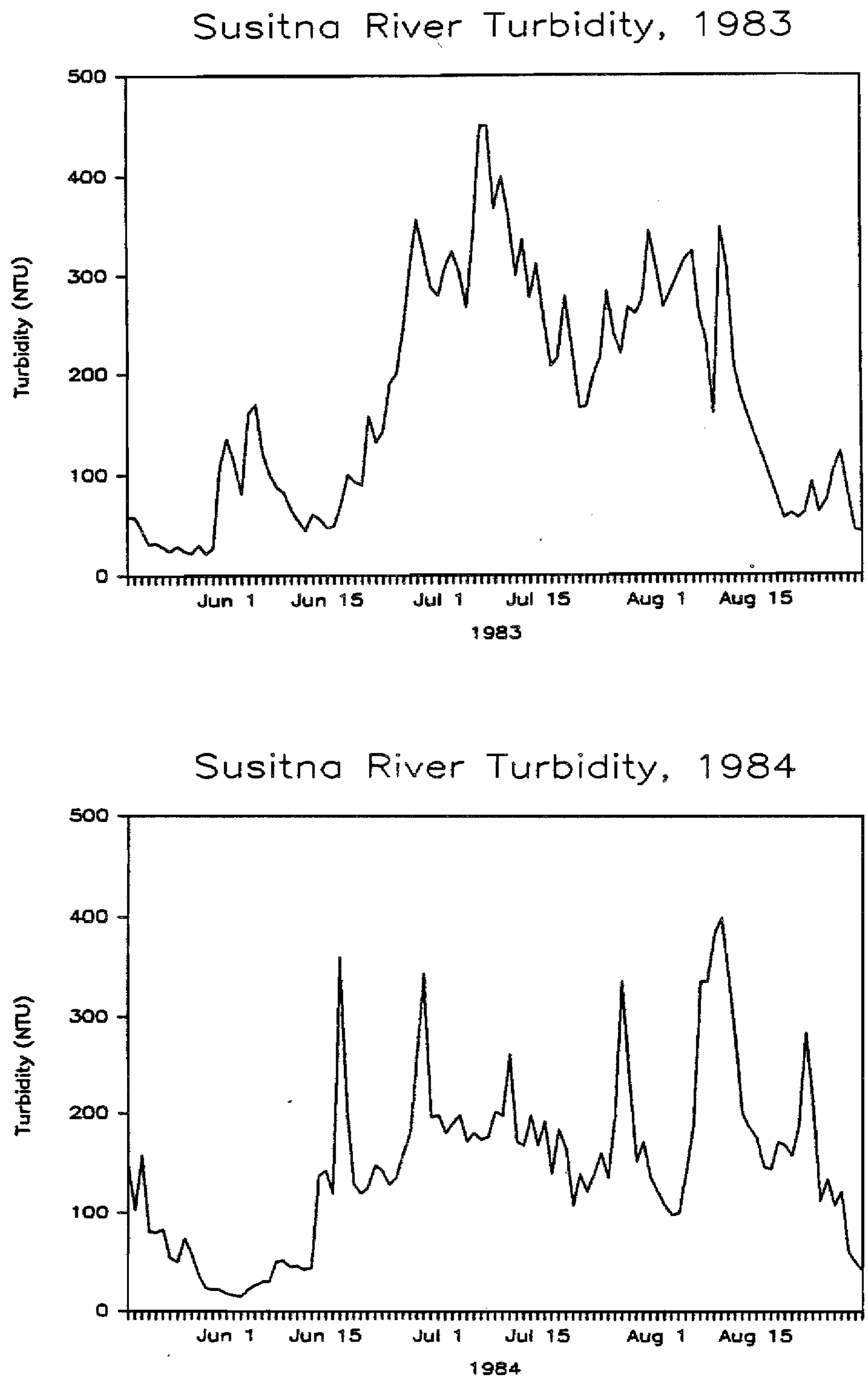
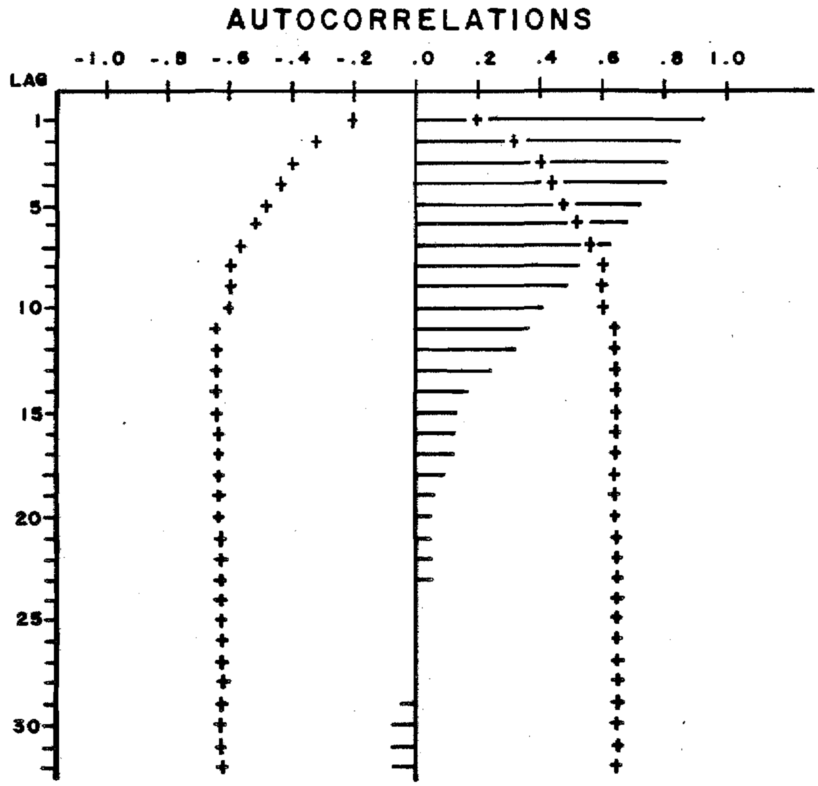


Figure 11. Turbidity time series at Talkeetna Station, 1983 and 1984.



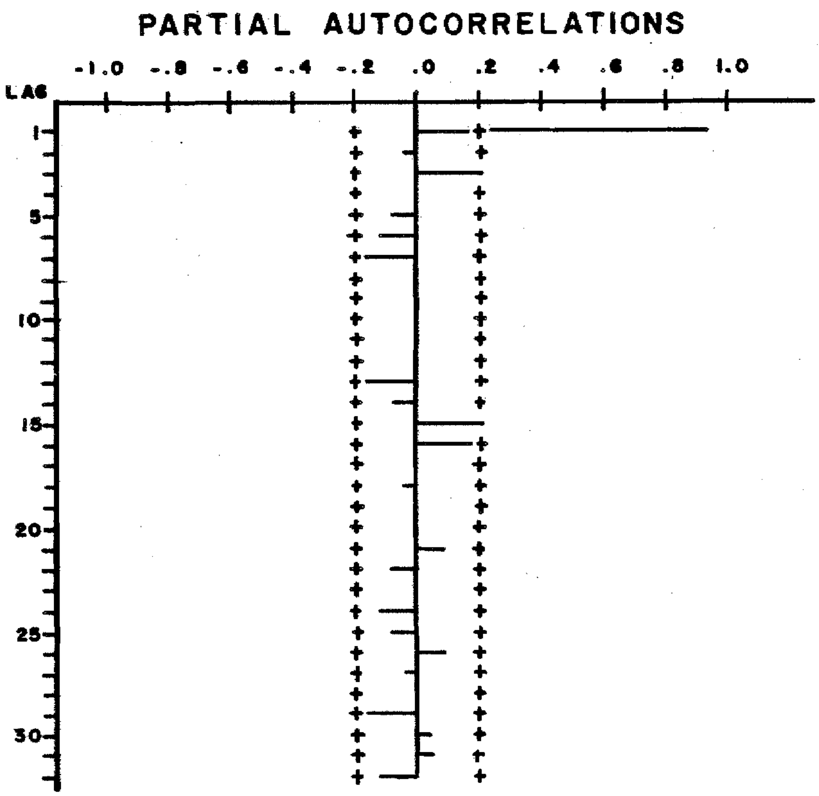


Figure 12. Plots of autocorrelations and partial autocorrelations for 1983 turbidity time series.

The series appears to border on being non-stationary because it increases in the spring as glacier melt increases and then declines in the fall. (This series would certainly be non-stationary over a longer time frame because the turbidity level is very low in the winter). The slow decay of the autocorrelations in the ACF (Fig. 12) also indicated non-stationarity.

Further investigation using the raw data showed that the series had a significant second order MA term, while the first order MA term was not significant. Both first and second order AR terms were significant. This gives the model:

$$y_t = 176.1 + .94(y_{t-1} - 176.1) + .06(y_{t-2} - 176.1) + .23\,a_{t-2} + a_t$$

with std. errors: on $\hat{\phi}_1$ = .0122

on $\hat{\phi}_2$ = .0234

on $\hat{\theta}_2$ = .0988

Note that even though the same notation is used, the white noise process (a_t) here is different from that in section 3.1.

While this ARMA model is adequate for the time frame examined, in general, an integrated model (i.e., one with a differencing operation) is probably more appropriate because of the suspected non-stationarity of the raw data. The differenced series (Fig. 13), which represents consecutive changes in the original series values, is clearly stationary with a mean close to zero. The ACF and PACF plots for the differenced series (Fig. 14) showed that the differenced series could be adequately modeled with just the second order MA term; the first order autoregression term was not significant in the differenced series. The equation is:

$$Z_t = .23\,a_{t-2} + a_t$$

where: $Z_t = y_t - y_{t-1}$

with std. error on $\hat{\theta}_2$ = .0972 and the mean of the residuals insignificant.

3.3. Univariate Model for Age 0+ Chinook Salmon Outmigration

The time frame chosen for Age 0+ chinook salmon was the same as that of discharge (Fig. 15). The plots of the ACF and the PACF for 1983 (Fig. 16) showed a strong first order autoregresssive component. In fact, an ARMA(1,0) model, abbreviated as AR(1), adequately represents the data. Although the plot of the range of sub-groups against the mean of the

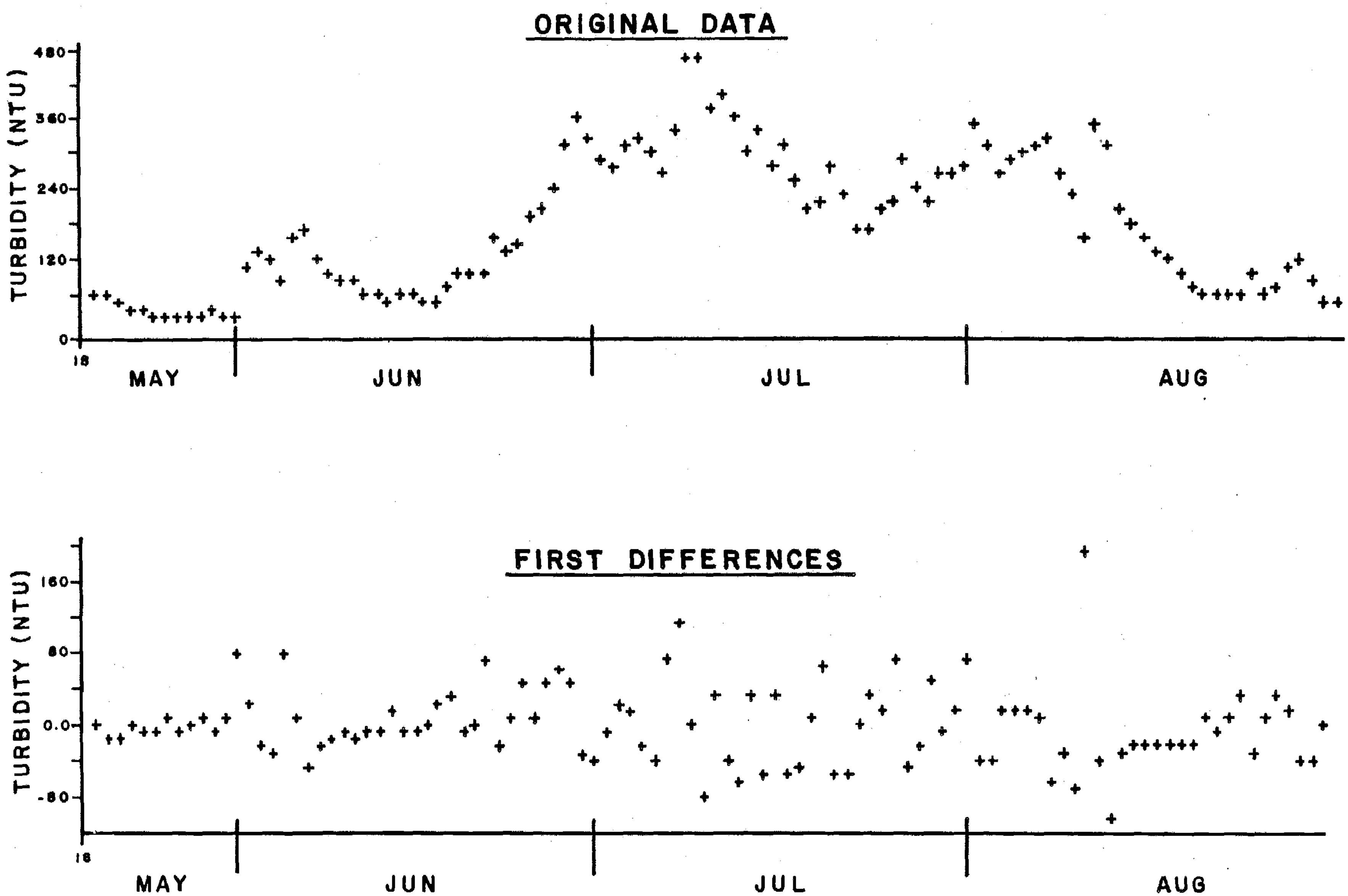
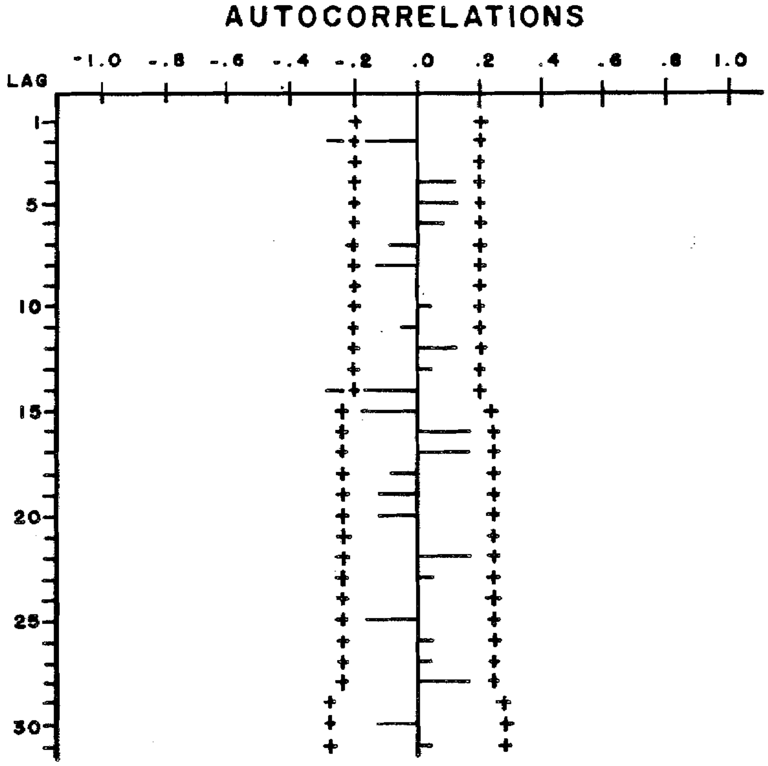


Figure 13. Differenced turbidity time series, 1983.



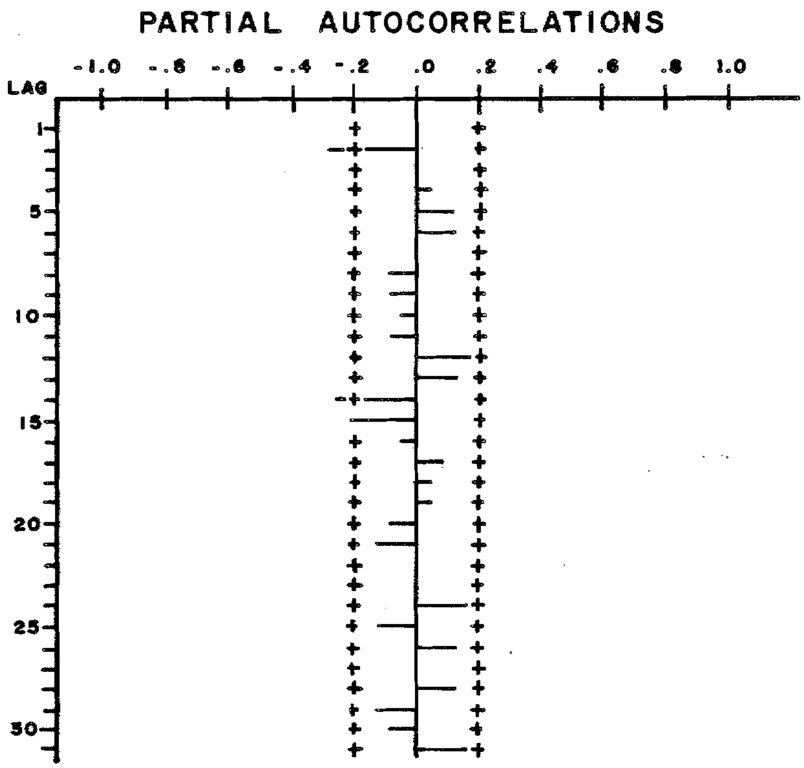


Figure 14. Plots of autocorrelations and partial autocorrelations for differenced 1983 turbidity time series.

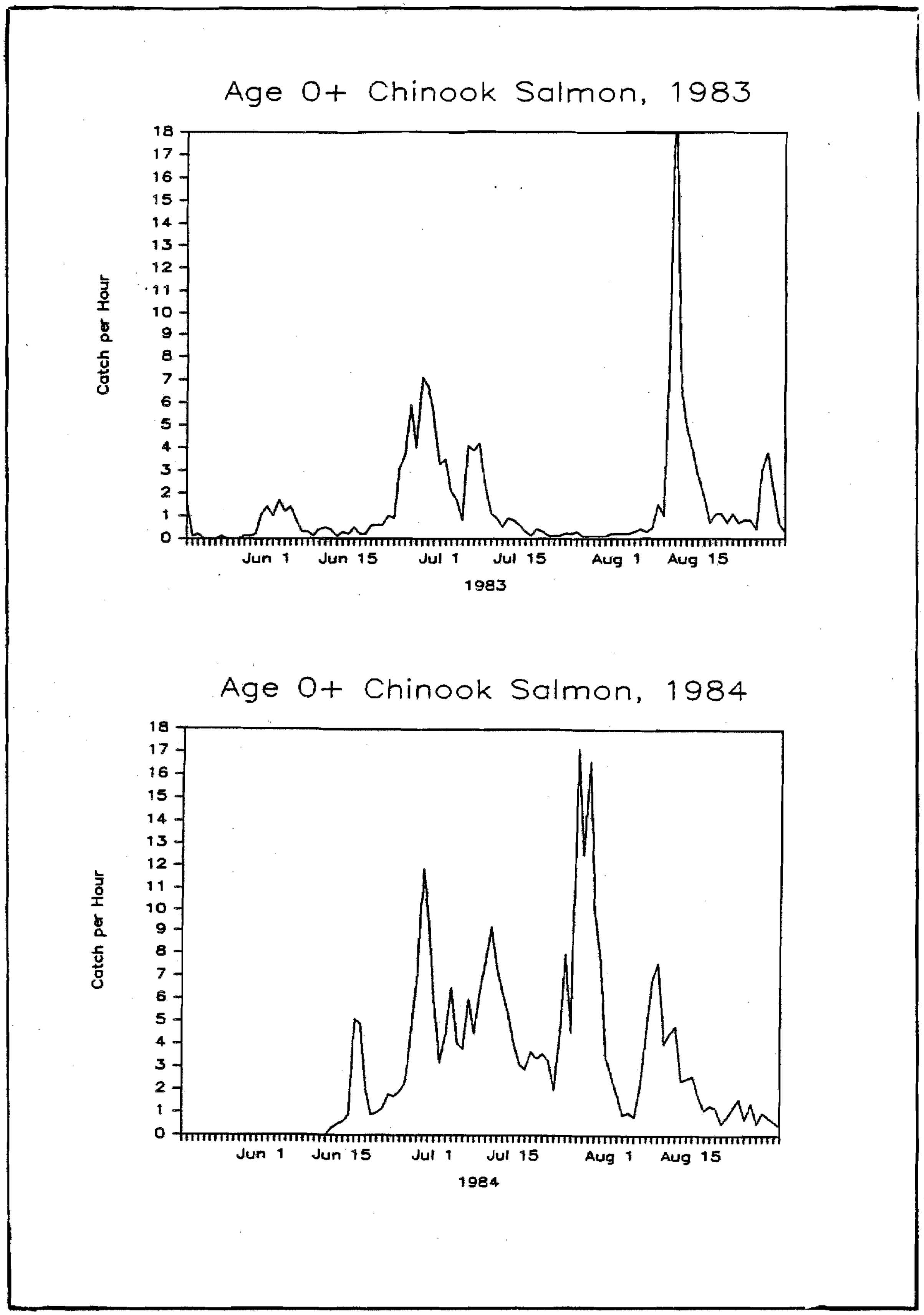


Figure 15. Age 0+ chinook salmon outmigration rate time series, 1983 and 1984.

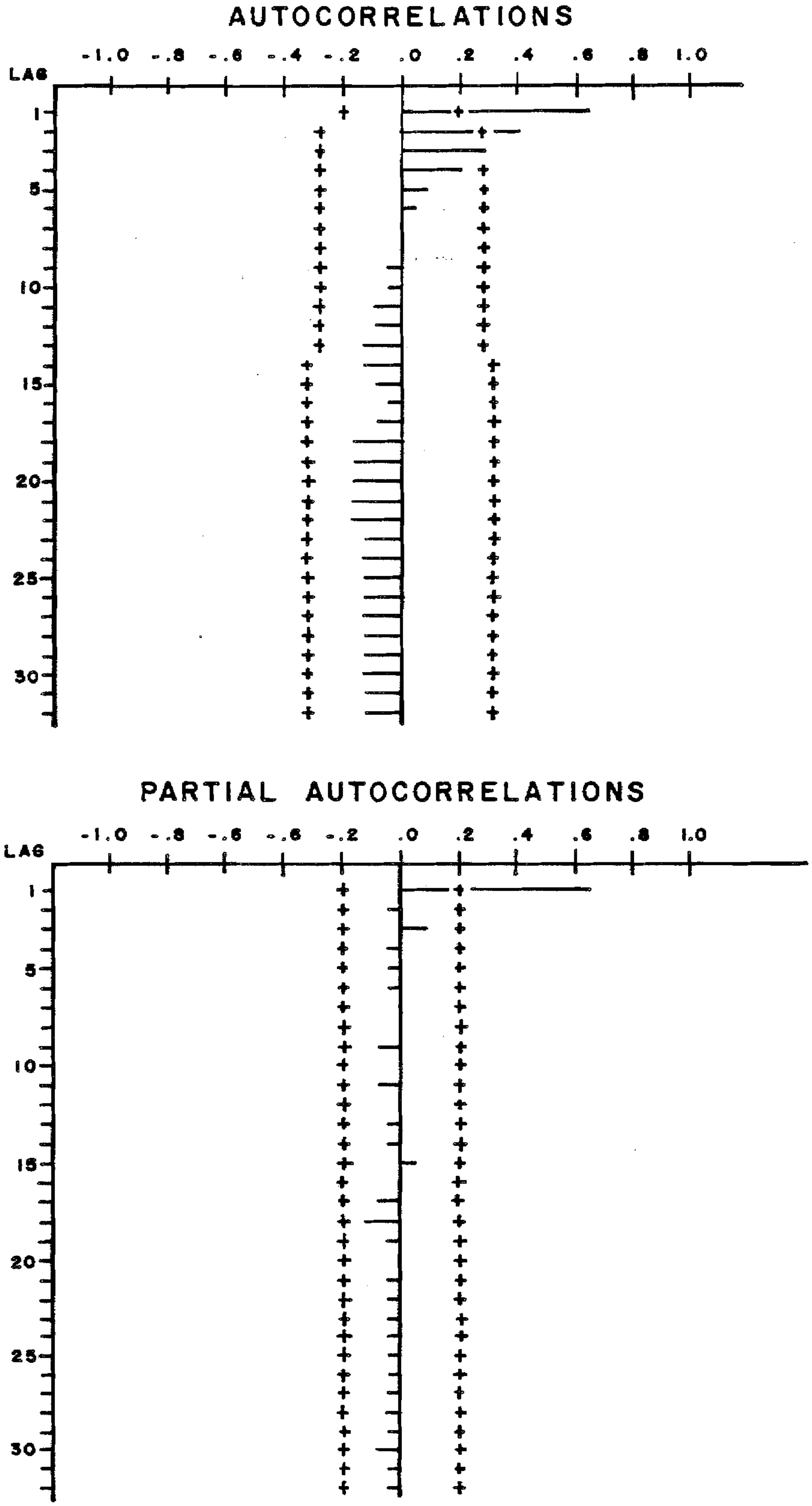


Figure 16. Plots of autocorrelations and partial autocorrelations for 1983 chinook salmon outmigration time series.

sub-groups indicated the need for a logarithmic transformation, the residual AC's of an AR(1) model on the log- transformed data (Fig. 17) were slightly larger (but still insignificant) than those of the AR(1) model on the raw data. The standard error on $\hat{\phi}_1$, however, was lower with the log-transformed data. ACF and PACF plots for the log-transformed data are shown in Fig. 18. The AR(1) model for the raw data is:

$$y_t = 1.52 + .66\,(y_{t-1} - 1.52) + a_t$$

with standard error on $\hat{\phi}_1$ = .0743.

The AR(1) model for the log-transformed data is:

$$\ln(y_t + 1) = .67 + .92\,(\ln(y_{t-1} + 1) - .67) + a_t$$

with standard error on $\hat{\phi}_1$ = .0363.

The mean of the residuals was not significant.

The time series plot for age 0+ chinook salmon outmigration in 1984 (Fig. 15) shows a different pattern from that of 1983. The fry did not begin to migrate in 1984 until about June 12. The low level of outmigration early in the season causes a time series which is non-stationary. To avoid this problem, the time frame selected for 1984 ran from June 12 to August 31 (79 cases). Analysis of this shorter series is not as strong as that of the longer series in 1983 but the series is long enough from a statistical point of view; Hoff (1983) suggests that about 40 or 50 observations is the minimum necessary for attempting an ARIMA model. Although logarithmic transformation did not appear to be strictly necessary for the 1983 data, it was required (to produce an AR(1) model) with the 1984 data, perhaps because of the shorter time series in 1984.

The ACF plot for 1984 on the log-transformed data (Fig. 19) was similar to that of 1983, although it did decay a little more quickly. The 1984 PACF plot (Fig. 19) was very similar to that of 1983 in indicating a strong AR(1) component. The estimated value of ϕ_1 in 1984 was 0.973 (very close to that of 1983), with a standard error of 0.0265. The 1984 model is:

$$\ln(y_t + 1) = 1.39 + .97\,(\ln(y_{t-1} + 1) - 1.39) + a_t$$

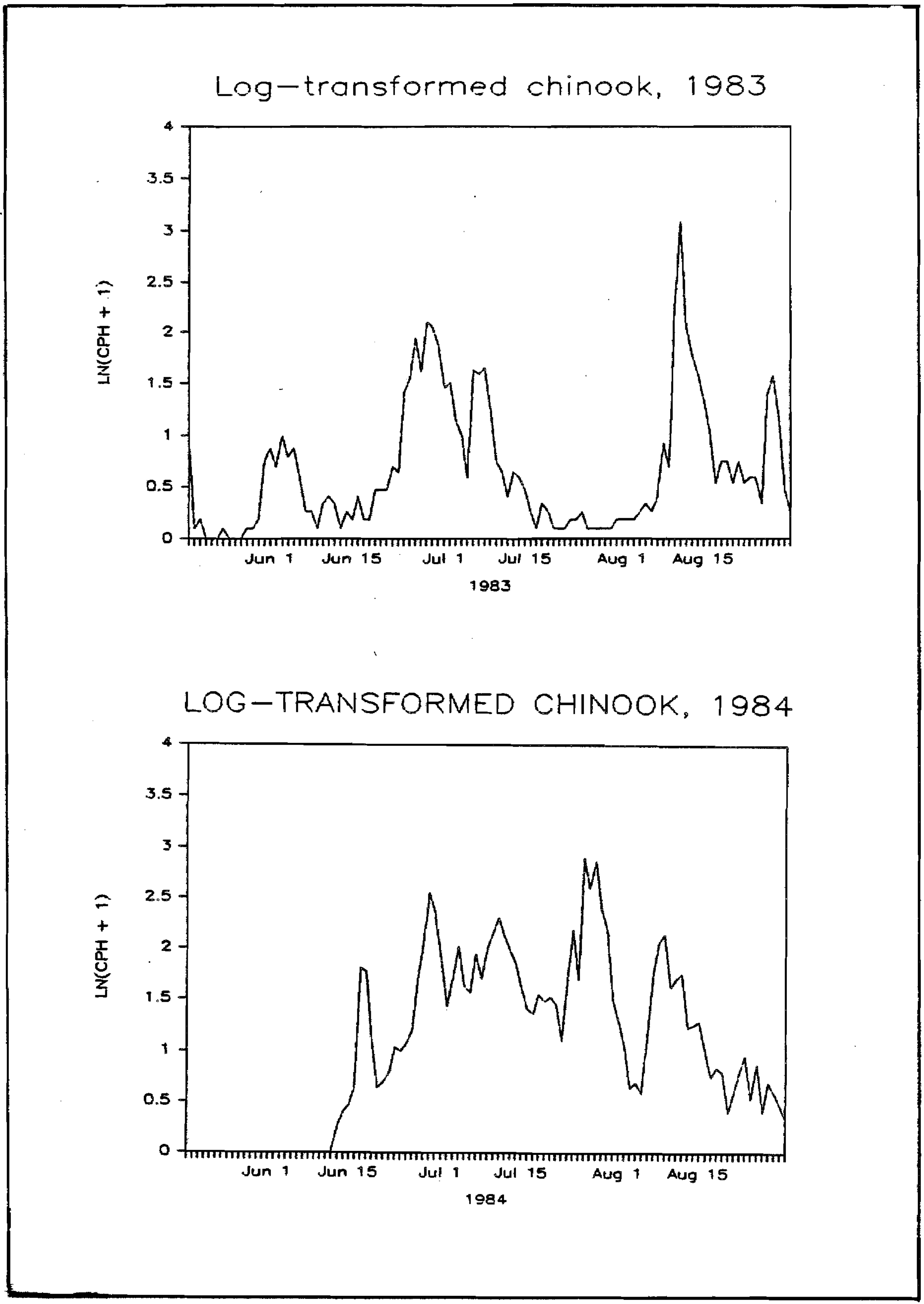


Figure 17. Log-transformed age 0+ chinook salmon outmigration rate, 1983 and 1984.

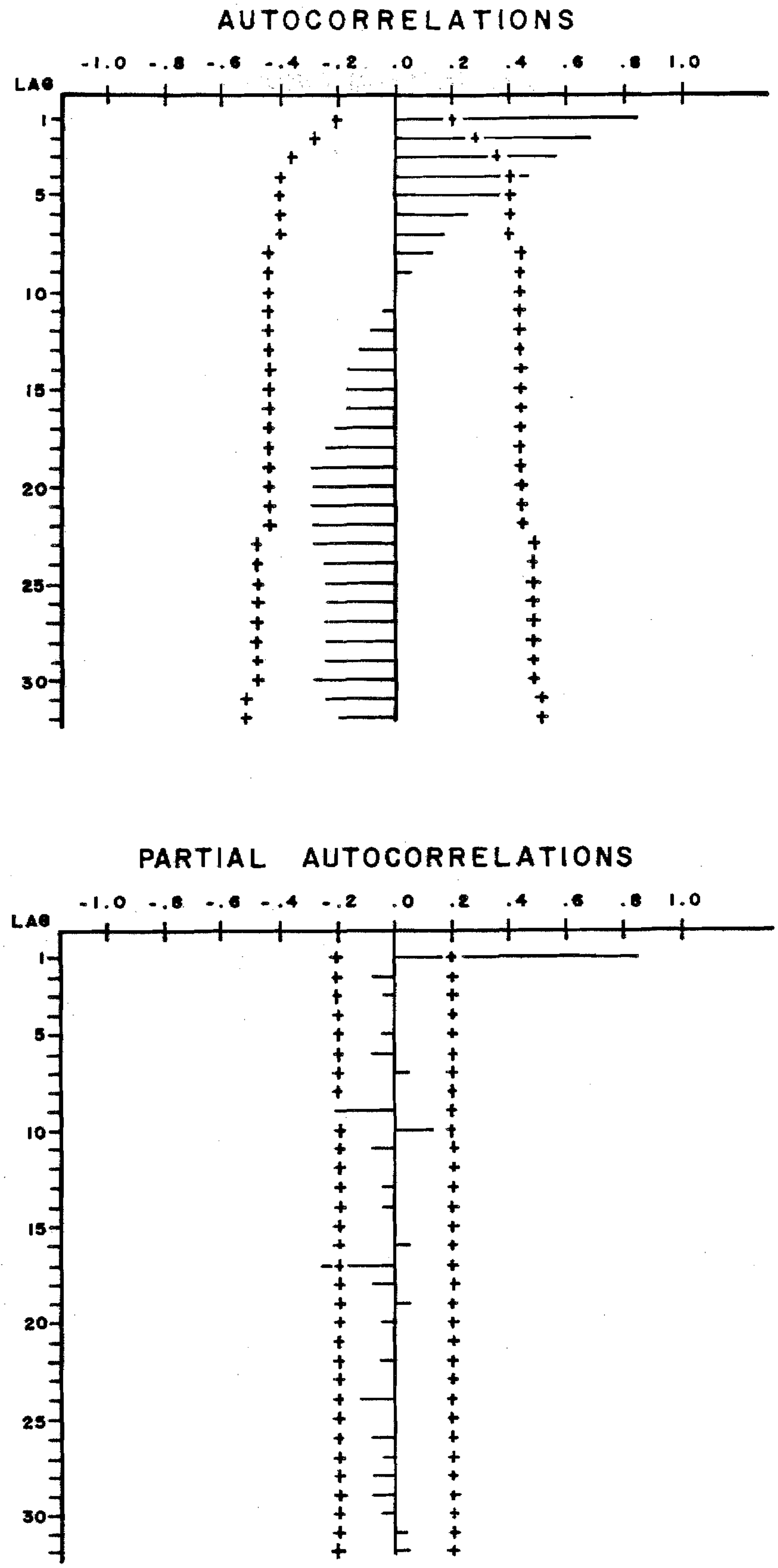


Figure 18. Plots of autocorrelations and partial autocorrelations for log-transformed 1983 chinook salmon outmigration time series.

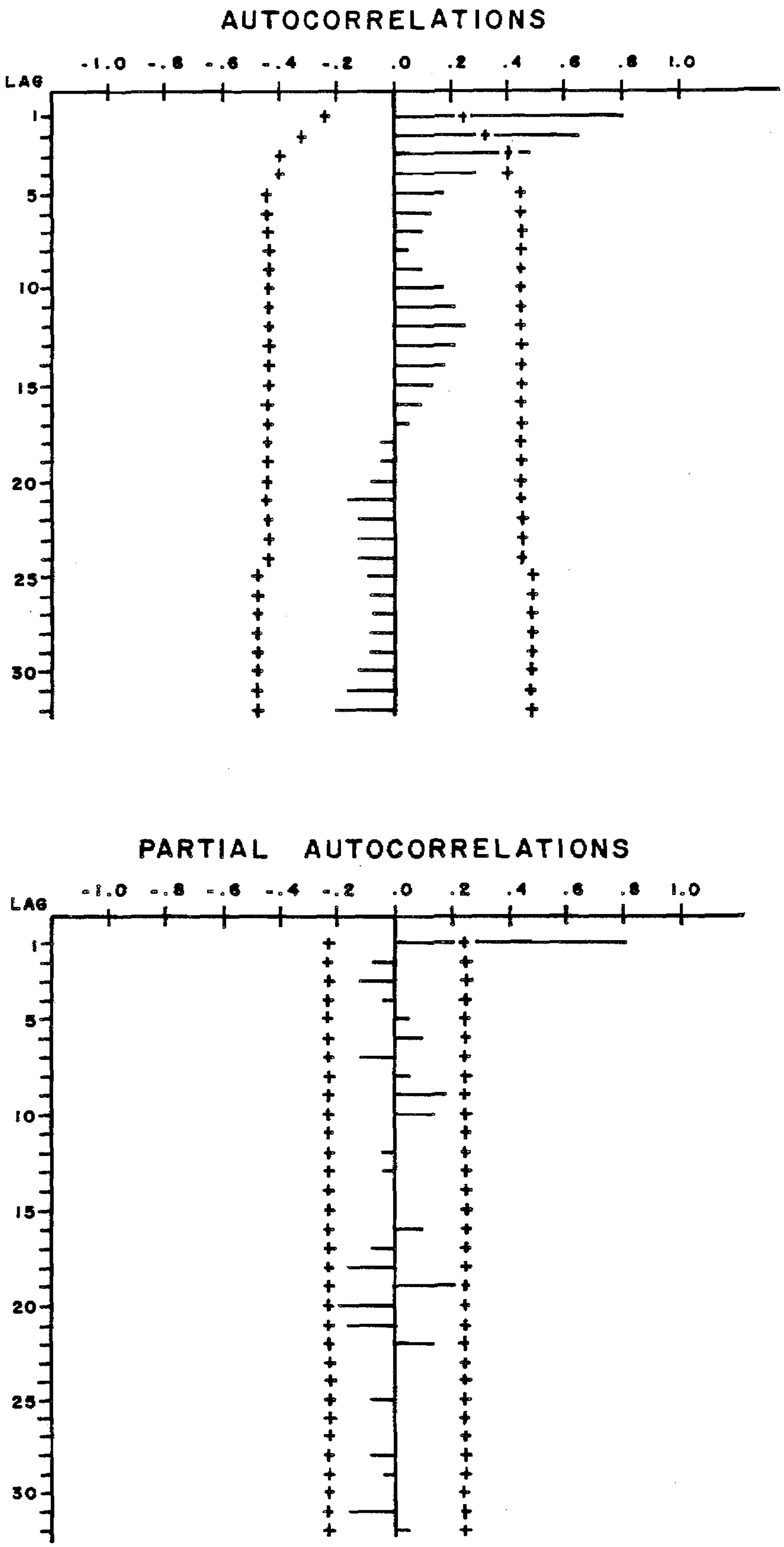


Figure 19. Plots of autocorrelations and partial autocorrelations for log-transformed 1984 chinook salmon outmigration time series.

The mean of the residuals was insignificant. This model does not differ from that of 1983, except that the mean level was higher. This was a result of a higher escapement of adult chinook salmon in 1983 than in 1982.

All three of the ACF plots for chinook fry outmigration (Figs. 16, 18, and 19) had AC's after lag 18 which did not appear to decay further. This may indicate the presence of a weak non-stationary or periodic element which should be explored with subsequent data sets.

3.4. Univariate Model for Age 0+ Sockeye Salmon Outmigration

Age 0+ sockeye salmon outmigration was examined from May 23 through August 31, 1984 (Fig. 20). This time series showed a strong AR(1) component (Fig. 21), similar to that of the chinook salmon time series. However, neither an AR(1) model on the raw data or on the log-transformed data was adequate. A MA(1) component was also significant in the raw data, leading to the model:

$$y_t = 1.76 + .78\,(y_{t-1} - 1.76) - .57\,a_{t-1} + a_t$$

The standard error on $\hat{\phi}_1$ (.775) was .0681 and on $\hat{\theta}_1$ (-.567) was .0883. Although the mean of the residuals was slightly significant, none of the autocorrelations or partial autocorrelations were, so the model is reasonable.

3.5. Discharge-Turbidity Transfer Function Model

The cross correlations for the residuals from the 1983 discharge series and the 1983 turbidity series, both filtered by the ARMA(1,1) model for discharge, had a significant spike at lag = 1 day (Fig. 22). This suggested a candidate model (Box and Jenkins 1976; McCleary and Hay 1980):

$$y_t = \frac{\omega_0 B}{1 - \delta_1 B}\, x_t + N_t$$

where: y_t is the output series (turbidity)

ω_0 and δ_1 are transfer function parameters

B is the backward shift operator

x_t is the input series (discharge)

N_t is the noise component, an ARIMA model

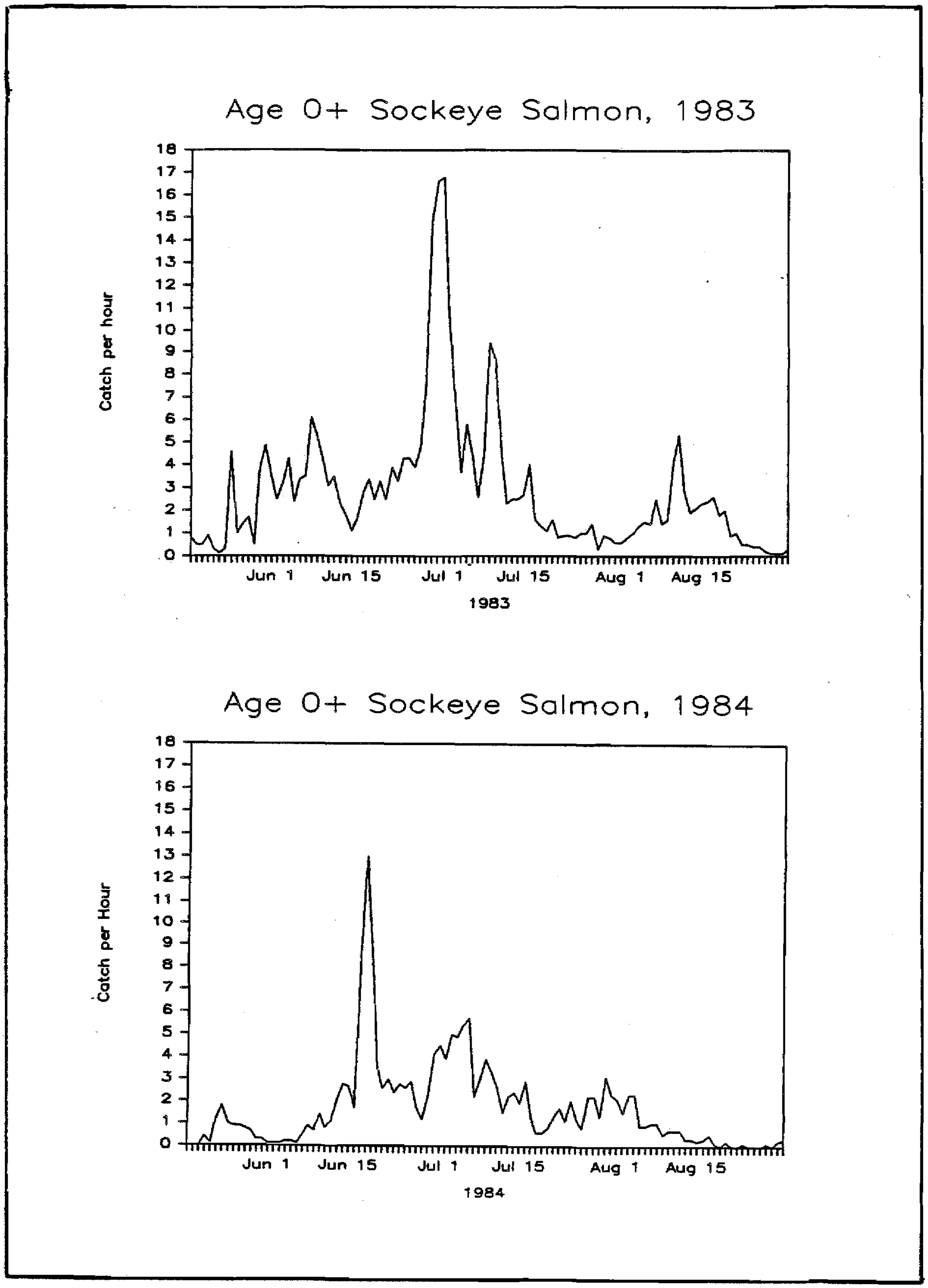


Figure 20. Age 0+ sockeye salmon outmigration rate time series, 1983 and 1984.

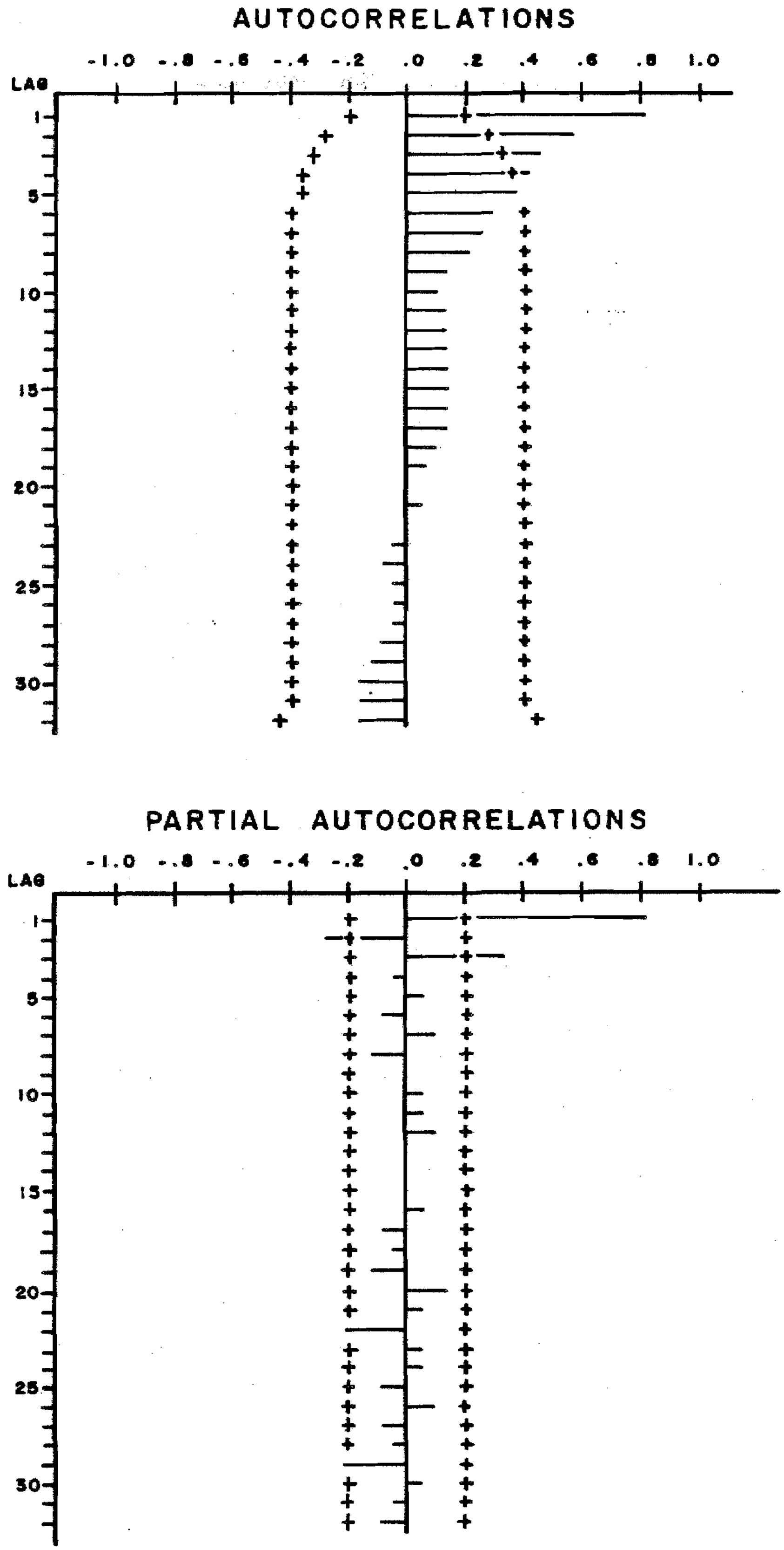


Figure 21. Plots of autocorrelations and partial autocorrelations for 1984 sockeye salmon outmigration time series.

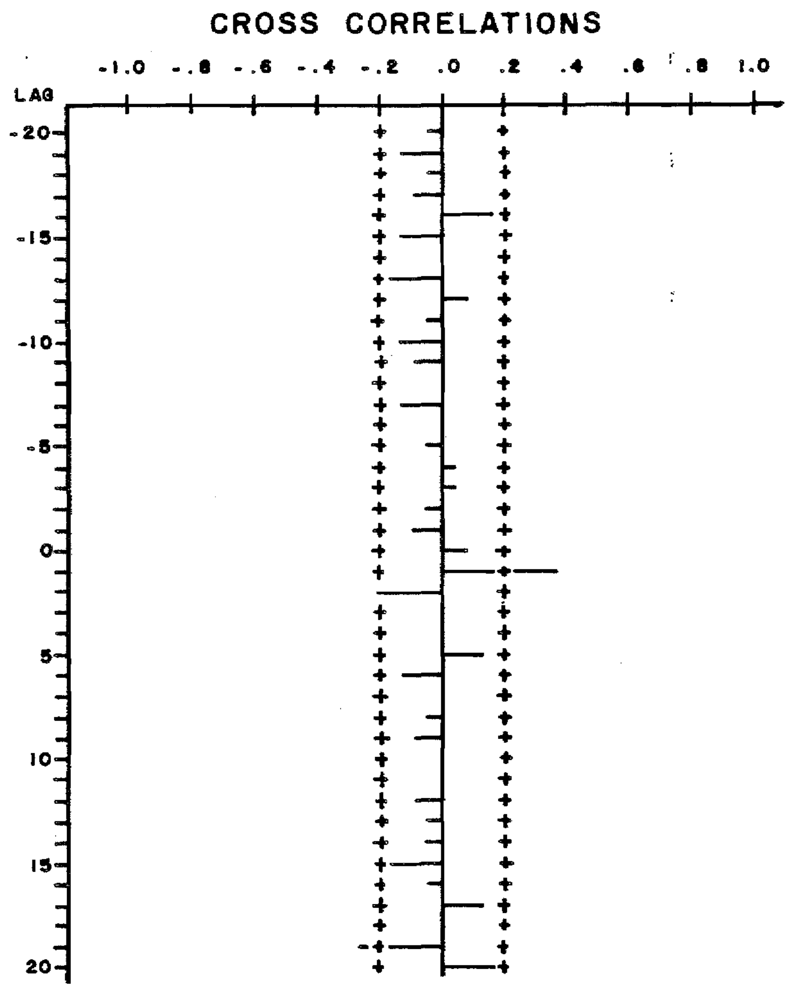


Figure 22. Plot of cross correlations between the residuals of the ARMA (1,1) discharge model and the prewhitened turbidity time series, 1983 data.

The assumption that the ARIMA component of the model was white noise led to significant AC's in the residuals series and was therefore rejected. The ACF and PACF plots on the residuals from this model suggested an AR(1) model for the N_t component, leading to the full model:

$$y_t = \frac{\omega_0 B}{1 - \delta_1 B} x_t + \frac{a_t}{1 - \phi_1 B}$$

Parameter estimates were:

$\hat{\omega}_0$ = 8.349 with std. error of 1.7044

$\hat{\delta}_1$ = -0.559 with std. error of 0.1718

$\hat{\phi}_1$ = 0.993 with std. error of 0.0009

The t statistic for each of these estimates was significant, leading to the conclusion that discharge and turbidity are related by the equation:

$$y_t = \frac{8.35\, B}{1 + .56\, B} x_t + \frac{a_t}{1 - .99\, B}$$

The ACF and PACF plots on the residuals from this model showed no significant spikes; therefore, the model is adequate.

3.6. Discharge-Chinook Transfer Function Model

After both the input series (discharge) and the output series (chinook salmon outmigration rate) from 1983 were filtered by the ARMA(1,1) model for the discharge series and the residuals from both series were cross correlated, there was a significant correlation at lag = 1 day (Fig. 23). This suggested the transfer function model, as given by McCleary and Hay (1980):

$$y_t = \omega_0 x_{t-1} + N_t$$

or, using the backward shift notation of Box and Jenkins (1976):

$$y_t = \omega_0 B x_t + N_t$$

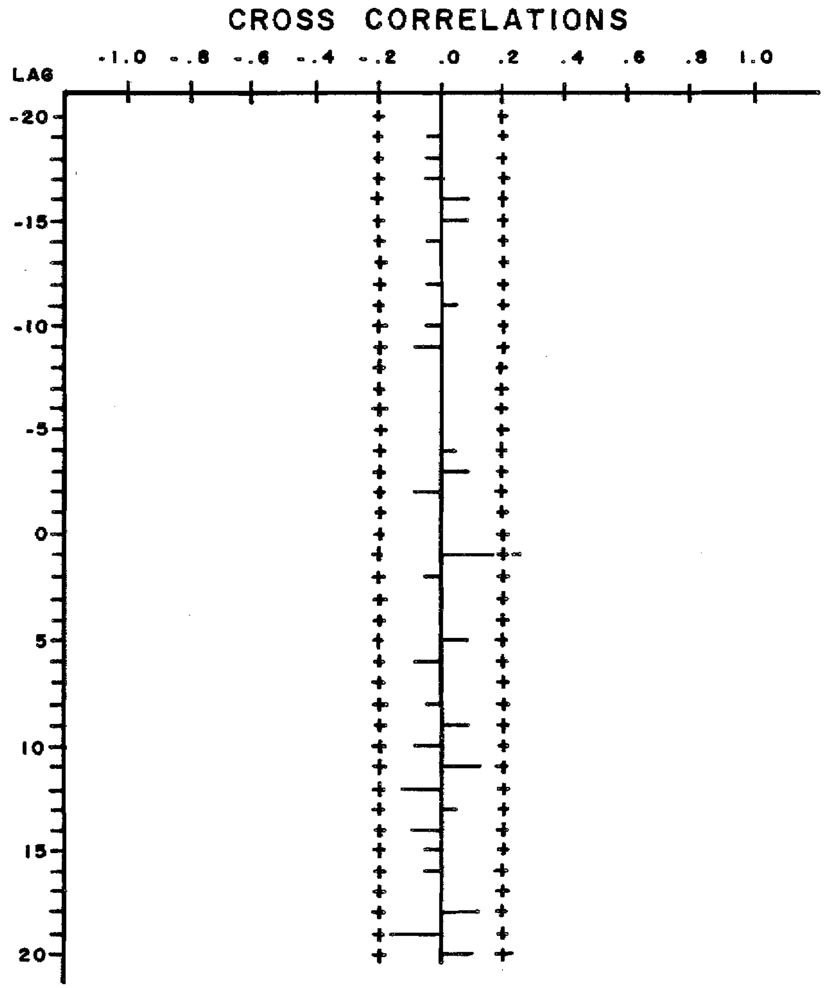


Figure 23. Plot of cross correlations between the residuals of the ARMA (1,1) discharge model and the prewhitened chinook salmon outmigration time series, 1983 data.

This model implies that the current day's discharge rate has an effect on the next day's outmigration rate. The estimate of ω_0 was 0.02. The residual ACF using this model suggested that the assumption of white noise for the N_t component was not valid; it appeared that an ARMA(1,0) model would be appropriate. The full model is:

$$y_t = \omega_0 B x_t + \frac{a_t}{1 - \phi_1 B}$$

The parameters for this model were estimated as:

$\hat{\omega}_0$ = .025 with std. error of .0249

$\hat{\phi}_1$ = .667 with std. error of .0751

The t statistic on the estimate for ω_0 was not significant. However, because the practice of prewhitening the output series with the model for the input series tends to underestimate the significance of the results (Botsford et al. 1982) and because there was a significant cross correlation between discharge and outmigration rate at a lag of one day, it seemed best to leave this term in the model. This would have to be verified with more years of data. The model is:

$$y_t = .025 B (x_t) + \frac{a_t}{1 - .67 B}$$

The ACF and PACF for the residuals from this model showed no significant spikes so we may conclude that the model is adequate.

This model does not imply that the discharge series is a strong predictor for the outmigration series. But adding discharge does result in an expression which has more predictive value than would be obtained by looking at the outmigration series by itself.

3.7. Discharge-Sockeye Transfer Function Model

As with the discharge-chinook relationship, the cross-correlations of the 1984 discharge and sockeye series, filtered by an ARMA(1,1) model for discharge, showed a significant spike when the sockeye series was lagged one day behind the discharge series (Fig. 24). This spike was stronger for sockeye than it was for chinook. A candidate model (Box and Jenkins 1976; McCleary and Hay 1980) was:

$$y_t = \frac{\omega_0 B}{1 - \delta_1 B} x_t + N_t$$

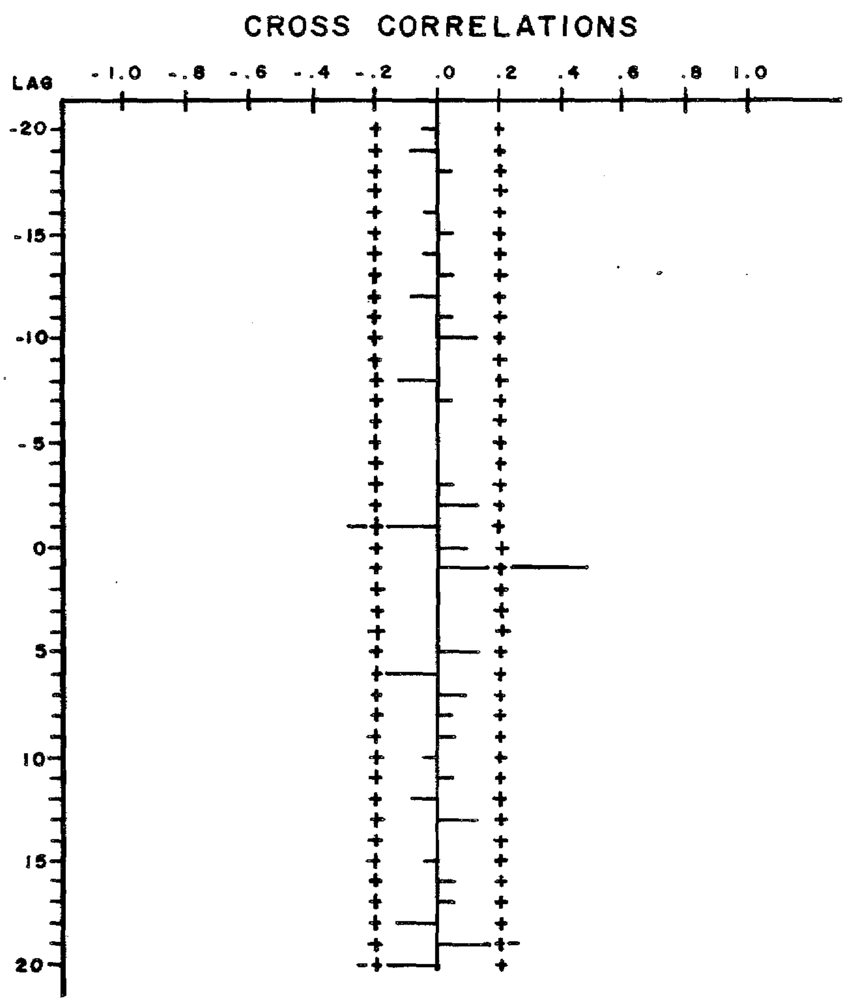


Figure 24. Plot of cross correlations between the residuals of the ARMA (1,1) discharge model and the prewhitened sockeye salmon outmigration time series, 1984 data.

The ACF and PACF plots on the residuals from this model suggested an ARMA(1,1) model for the N_t component, leading to the full model:

$$y_t = \frac{\omega_0 B}{1-\delta_1 B} x_t + \frac{(1-\theta_1 B)}{(1-\phi_1 B)} a_t$$

Parameter estimates were:

$\hat{\omega}_0$ = .206 with std. error < .00005

$\hat{\delta}_1$ = -.190 with std. error .1848

$\hat{\phi}_1$ = .952 with std. error .0483

$\hat{\theta}_1$ = -.318 with std. error .1078

The t statistic for each of these estimates except $\hat{\delta}_1$ was significant, giving:

$$y_t = .21\, B\,(x_t) + \frac{(1+.32\,B)}{(1-.95\,B)} a_t$$

where x_t = discharge X 10^{-3}

The ACF and PACF plots on the residual series from this model showed no significant spikes and the mean of the residuals was barely significant; therefore, the model is deemed adequate.

4.0 DISCUSSION

Time series analysis is a useful method for dealing with time ordered data sets, including ones that do not appear to make much sense at first glance because they are too noisy or because they drift as a result of random events. The modeling effort helps us to understand why the plots look as they do and what factors shape them. It also is useful in trying to understand what effect a change in the controlling factors might produce.

The influence of discharge level on turbidity and chinook and sockeye salmon outmigration is clearly seen upon inspection of Fig. 2 and Fig. 3. Of course, these latter three series are shaped by several factors other than discharge, so the correlation coefficient between them and discharge is not normally expected to be high, unless a relatively short section is examined. For example, the discharge peak in early June of 1983 is reflected in the other three series (Fig. 2). The bimodal discharge peak in August of 1983 is reflected in the turbidity and the chinook outmigration series, but only the first August peak is shown by the sockeye outmigration series. This was because most age 0+ sockeye salmon in the reach above the traps had left by the middle of August. Similarly, the late August discharge spike in 1984 had no effect on the sockeye series (Fig. 3). However, the high discharge peak in mid June of 1984 is strongly reflected in the sockeye series because this was a time when many age 0+ sockeye salmon were present in the reach.

Another example of a change in the relative effect of a discharge spike is shown by the 1984 chinook salmon series. The high discharge peak is mid-June had less effect on chinook outmigration than did the lower discharge peak in late July, a time when more age 0+ chinook fry were ready, because of physiological and behavioral reasons, to outmigrate.

The segments of the time series examined (discharge, turbidity, chinook and sockeye salmon outmigration) were described by relatively simple Box-Jenkins models, using mostly first-order terms. The usefulness of Box-Jenkins models is shown by the relative simplicity of the models developed for the salmon outmigration series; a visual inspection of the plots of the raw data for these series (Figs. 15 and 20) gives the impression of an erratic series of events. None of the series appeared to require differencing (although turbidity was on the borderline) to achieve stationarity nor did they appear to have a periodic component (discharge being a possible exception) which would require seasonal differencing. However, this should be re-examined when subsequent seasons of data are available. All of the series showed a strong first order autoregressive term, indicating that the value for any one day is greatly influenced by the value for the previous day. Similar results for the flow regimes of several streams in Australia was reported by Srikanthan et al. (1983), who found that most of the discharge series which were not white noise had a first order autoregressive term.

Examination of the autocorrelation coefficients of the four time series at lag = 1 day (adjacent values) gives an idea of the smoothness of the time series. Typically, the coefficient for physical/chemical variables is higher than that of biological variables and the time series for discharge (Fig. 4) and turbidity (Fig. 11) are less jagged than those for chinook salmon outmigration rate (Fig. 15) and sockeye salmon outmigration rate (Fig. 20). Saila et al. (1972) reported similar results for the autocorrelations of alewife upstream migration activity in relation to incident solar radiation and water temperature.

The square of the autocorrelation coefficient at lag = 1 gives a measure of the percentage of the variance of the value for today which is explained by what was measured yesterday (Murray and Farber 1982). In 1983, $(.86)^2 = 74\%$ of the variance of discharge for one day was explained by the value for discharge on the previous day. The percentage for turbidity was $(.92)^2 = 85\%$ while, for chinook salmon outmigration rate, it was only $(.66)^2 = 44\%$, and, for sockeye salmon, $(.65)^2 = 42\%$.

So, although fish tend to move in pulses more so than water or suspended sediments, fish outmigration is far from being a random event. That is, when an outmigration pulse occurs, the impetus has affected many fish and the phenomenon extends over a three or four day period. When we look at an outmigration time series, we are seeing the integrated results of several factors operating on sub-groups of the population in different locales. The fry in one slough may have emerged two weeks earlier than those of another slough because of a higher intragravel temperature. Or the head of one slough may have overtopped at a lower discharge level than the head of another slough, thus providing an environmental cue to the two groups at different points in time. But there is also a behavioral effect in that fry are stimulated to migrate when they see other fry migrating. This is particularly true for those species that form schools during outmigration.

The turbidity time series was the only one examined which included a second order term. The second order moving average term is likely related to the random "shock" caused by a rising discharge (which is in turn caused by rainfall) which resuspends sediment. It takes a few days after the rainfall is over for this perturbation in turbidity level to drop to the pre-rainfall level.

The discharge-turbidity transfer function model does not necessarily imply that discharge level is a strong causal factor for turbidity. These two variables are correlated largely because when glacial melting is high, both discharge and turbidity are high. This phenomenon provides the seasonal trend of the two series; the discharge of clear water tributaries such as Portage Creek and Indian River (which increases discharge but not turbidity) is a noise component. However, discharge does in fact have some direct causal effect on turbidity by resuspending sediments and other particles during a rapid rise in discharge level. Certainly turbidity is not a cause of discharge, so it makes sense to take discharge and noise as the input and turbidity as the output of a transfer function model. The value of the model is that it allows levels of turbidity for a few days ahead to be predicted from past values of both turbidity and discharge.

Turbidity level after the dams begin operation will not only be influenced by a changed discharge regime, but will also be directly changed by the dams because of settling of suspended sediments in the reservoir.

By building Box-Jenkins models for these four time series, a better understanding of the processes which control these variables was developed in that the structure of the random processes which generate an observed series has now been specified. Also, we have statistically described the natural time series as a baseline against which future changes can be assessed. This description of the discharge and turbidity regimes is important not only because of their effects on salmon outmigration, but also because of their effects on other life stages and species. It is important to explore the effect on salmon outmigration of a construction project which will change the basic rules, that is, change the underlying physical processes. Whereas the present discharge regime can be described as a mixed first order autoregressive and moving average process, the discharge regime under a post-project scenario could include entirely different terms.

An important point is that the underlying processes (the autoregressive and moving average components) were essentially the same in 1983 and in 1984 even though the actual time series, or "realizations," looked very different between the two years. This was true for both discharge and for chinook salmon outmigration; only a single year of turbidity and sockeye salmon outmigration was examined. Even though the discharge peaks do not match between the two years and the mean levels between years may have been different, the process which generated these peaks in both years was the same and can be described by an ARMA(1,1) model with similar parameter estimates for both years.

In a sense, the proposed dams would operate like a gigantic low pass filter on the discharge regime, dampening out the high frequency perturbations and letting the low frequency (annual cycle) events pass, but at a reduced amplitude. In other words, there are two effects of introducing a reservoir into this system: 1) the day-to-day changes in discharge would be smoothed and 2) the general discharge level would be higher than normal in winter and lower than normal in summer. However, this is an oversimplification because a new element would be present if the dams are built - namely, power demand. Power demand is not in phase with the natural discharge fluctuations, so dam operation to accommodate power demand will change the mechanisms which generate the current discharge regime.

The important question is, how would the salmon outmigration rates be affected if these discharge spikes were not present, as with a dam-regulated discharge regime? Further, what effects would these changes have on the population survival rate? Relatively high levels of discharge, and possibly four or five day peaks, in the late spring and early summer may be necessary to facilitate normal outmigration timing of juvenile salmon. On the other hand, very high discharge levels at this time of year, which occur naturally, may be harmful to juvenile chinook salmon if these floods displace the fry downstream from what would otherwise be their rearing areas.

Time series analysis is a statistical tool which has many potential applications to the Susitna River Aquatic Studies Program. It would be useful to build Box-Jenkins models for the 36 year record of discharge at Gold Creek gaging station. Because this information is continuous, it can be digitized as monthly, weekly, daily, or even hourly means. Turbidity, temperature, and dissolved gas time series could also be modeled in this manner. Developing time series models for the proposed post-project discharge regime to see whether the post-project discharge regime is also an ARMA(1,1) process would be informative in assessing dam-related effects. Intervention analysis, which is an extension of Box-Jenkins models concerned with a natural or human caused change to a system, would be an appropriate method to use (Box and Tiao 1975; Hipel et al. 1978; Thompson et al. 1982). One could determine if the intervention (construction of the dams) would have a significant effect on the time series processes. This method has been used to model the effects of the Aswan dam on the Nile River and of the Gardiner dam on the South Saskatchewan River in Canada (Hipel et al. 1978). Before and after mean levels can not be compared using normal analysis of variance because the observations are serially correlated.

Developing forecast models for the annual return of adult salmon or the annual total number of outmigrants would be an excellent use of time series analysis. The adult salmon return of a particular year is strongly related to the return of the previous year (that is, when catch is high one year, it tends to be high for several years) and there is probably a periodic component based on strong year classes. With such a model, one could predict the size of next year's adult salmon return, a piece of information which would be very useful to both fishery and hydroelectric dam managers. However, the time series of adult salmon return to the Susitna River is not long enough (only seven or eight years of data) to develop Box-Jenkins models. A minimum of about 40 or 50 observations is necessary (McCleary and Hay 1980; Huff 1983), although the method has been applied by Jensen (1985) to fish catch data with as few as 32 observations. The annual abundance of adult chinook and coho salmon in the California marine fishery has been successfully examined with time series analysis by Botsford et al. (1982) and Peterman and Wong (1984) have looked at sockeye salmon cycles in British Columbia and Bristol Bay. For the present, analysis of salmon time series in the Susitna River will have to be restricted to daily rates of a single year.

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7.0 BOX-JENKINS ARIMA AND TRANSFER FUNCTION MODELS

Box-Jenkins models can be summarized as follows (Box and Jenkins 1976; McCleary and Hay 1980; Chatfield 1984). Suppose there is a time series y_t, $t = 1..N$. Then y_t is a moving average process of order q (or an MA(q) process) if

$$y_t = \theta_0 a_t + \theta_1 a_{t-1} + \theta_2 a_{t-2} + \ldots + \theta_q a_{t-q}$$

where θ_i are constants and $\theta_0 = 1$. The term a_t is a white noise process. White noise consists of a series of random shocks, each distributed normally and independently about a zero mean with a constant variance. The series y_t is an autoregressive process of order p (or an AR(p) process) if

$$y_t = \phi_1 y_{t-1} + \phi_2 y_{t-2} + \ldots + \phi_p y_{t-p} + a_t$$

where ϕ_i are constants. This is similar to a multiple regression model except that y_t is regressed not on independent variables but on past values of itself. A first order autoregressive process, AR(1), has the form:

$$y_t = \phi_1 y_{t-1} + a_t$$

Box and Jenkins (1976) define a backward shift operator B as:

$$B^m(Y_t) = Y_{t-m}$$

For m = 1,

$$BY_t = Y_{t-1}$$ or, the previous value.

Using B, the AR(1) equation can be written:

$$y_t = \frac{a_t}{1 - \phi_1 B}$$

Time series resulting from a mixture of AR and MA processes are called ARMA(p,q) models and have the form:

$$y_t = \phi_1 y_{t-1} + \ldots + \phi_p y_{t-p} + a_t + \theta_1 a_{t-1} + \ldots + \theta_q a_{t-q}$$

Using the backward shift operator B, an ARMA (1,1) may be written as:

$$y_t = (1 - \phi_1 B)^{-1} (1 - \theta_1 B) a_t$$

ARMA (p,q) models are appropriate only when the time series is stationary. Stationary in an ARMA model means that there is no systematic change in the mean or the variance over time and that there are no strictly periodic variations (Chatfield 1984); in other words, the mean, variance, and autocovariance are not dependent on time. Time series which are not stationary can sometimes be handled by "differencing" the series. Taking the difference of adjacent values gives a differencing order, d, of one:

$$\nabla^d Y_t = Y_t - Y_{t-d} \quad , \quad d = 1$$

Such models are said to be "integrated" and are denoted by ARIMA(p,d,q) where p is the order of the autoregressive component, d is the order of differencing, and q is the order of the moving average component.

Time series with seasonal variations, such as would occur in a multiple year series of daily water temperature measurements, can be made stationary by seasonal differencing. For example, the value for April 15 of one year is subtracted from the value for April 15 of the following year, and so on for all days of the year.

It has been assumed above that the time series had a mean value of zero. With stationary time series which have a non-zero mean, the mean has to be subtracted from every y_i term. For example, the form of an AR(1) model would be:

$$y_t = \mu + \phi_1 (y_{t-1} - \mu) + a_t$$

The autocorrelation function plays a major role in identifying and building time series models. A regular correlation coefficient measures the correlation between N pairs of observations on two variables. The autocorrelation coefficient is somewhat similar except that it measures the correlation between all observations of the same variable at a given distance apart in time (that is, between Y_t and Y_{t-k} for all values of t, where k = time lag). Also, the covariance is estimated only over N-k pairs of observations (McCleary and Hay 1980). Autocorrelation coefficients at different lags indicate the extent to which one value of the series is related to previous values and can be used to evaluate the duration and the degree of the "memory" of the process. The autocorrelation function (ACF) is the set of autocorrelation (AC) coefficients at different lags associated with a time series; a plot of the ACF is called a correlogram (Chatfield 1984).

The ACF is defined as:

$$ACF_k = \frac{\text{covariance}(Y_t, Y_{t+k})}{\text{Variance}(Y_t)}$$

and is estimated by:

$$ACF_k = \frac{\sum_{t=1}^{N-k} (Y_t - \bar{Y})(Y_{t+k} - \bar{Y})}{\sum_{t=1}^{N} (Y_t - \bar{Y})^2} \cdot \frac{N}{N-k}$$

A partial autocorrelation (PAC) coefficient measures the excess correlation at lag k which is not accounted for by an autoregressive model of order k-1. The set of PAC's at different lags associated with a time series is called the partial autocorrelation function (PACF).

There are three steps in developing an ARIMA model: model identification, parameter estimation, and diagnostic checking (Box and Jenkins 1976). ARIMA model building is an iterative process. The first thing to do is to look at a plot of the time series. Time series that are not stationary must be made so by trend removal which can be accomplished by such methods as differencing the series or by polynomial (or other) regression. Examination of the autocorrelation function (ACF) and the partial autocorrelation function (PACF) of a stationary series helps to identify a possible ARIMA model. The next step is to estimate the parameters of the model and again examine the ACF and PACF plots, this time on the residuals from the model. This process is repeated until the residuals show no significant AC's or PAC's at any lag, which indicates that the residuals consist of only a white noise process.

When there is an independent variable which is also a time series, a transfer function model can be developed. This model consists of the transfer function component from the independent variable as well as the ARIMA component (or noise component) from the dependent variable (McCleary and Hay 1980) and can be represented as:

$$Y_t = f(X_{t-b}) + N_t$$

where: Y_t is the output time series

X_t is the input time series

$f(X_{t-b})$ is the transfer function component

N_t is the noise or ARIMA component

Transfer function models can be bivariate (when there is one independent variable) or multivariate (more than one independent variable).

The steps to take in developing a transfer function model (Box and Jenkins 1976; McCleary and Hay 1980; Dixon et al. 1981) are: (1) develop an ARIMA model for the input series, obtaining the pre-whitened input (residuals), (2) filter the output series by the model for the input series, (3) cross-correlate the residuals from the first two steps, (4) identify the form of the transfer function component from the cross correlation function, (5) assuming the errors are white noise, estimate the values for the parameters, (6) identify an ARIMA model for the residuals, (7) if the ARIMA component is not white noise, combine the ARIMA component with the transfer function component to form a new model, (8) estimate the parameter values, and (9) examine the ACF and PACF plots on the residuals from the new model to see if the model is adequate.

Part 1
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ALASKA DEPARTMENT OF FISH AND GAME

SUSITNA RIVER AQUATIC STUDIES PROGRAM

REPORT NO. 7

RESIDENT AND JUVENILE ANADROMOUS FISH INVESTIGATIONS (MAY - OCTOBER 1984)

PARTS 1 AND 2

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