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Stock Status of Chena River Arctic Grayling during 1990

by

Robert A. Clark

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ABSTRACT

Arctic grayling *Thymallus arcticus* were captured by pulsed direct-current electrofishing in two sections of the lower 152 kilometers of the Chena River in 1990. Stock status of Arctic grayling in the Chena River was described by population abundance, age composition, size composition, recruitment, and survival rate estimates. Estimated abundance of Arctic grayling in the lower 152 kilometers of the Chena River was 31,815 fish greater than 149 millimeter fork length. Age three Arctic grayling were strongly represented in the Chena River, representing 53 percent of fish greater than 149 millimeter fork length. Stock size Arctic grayling (less than 270 millimeter fork length) represented 75 percent of fish greater than 149 millimeter fork length. Annual recruitment between 1989 and 1990 was 16,881 Arctic grayling and annual survival during this period was 75.4 percent. Although annual recruitment and annual survival rate appear to be increasing, increases in recreational fishing effort and harvest have caused a decline in the abundance of mature (age five and older) Arctic grayling. Annual harvests of mature Arctic grayling must be reduced to prevent further declines in abundance.

KEY WORDS: Arctic grayling, *Thymallus arcticus*, electrofishing, population abundance, age composition, size composition, Relative Stock Density, recruitment, survival rate, management, Chena River.

INTRODUCTION

Background

The Chena River supports the largest Arctic grayling fishery in North America. For the eleven-year period from 1979 to 1989, the Chena River produced an average annual sport harvest of 16,895 Arctic grayling in 26,702 angler-days of effort (Table 1). As recently as 1984, annual harvests had exceeded 20,000 fish and 30,000 angler-days of effort and harvests of Arctic grayling from the Chena River comprised a substantial portion of total Arctic grayling harvests in the Tanana River drainage (Figure 1). However, the status of this fishery has changed since 1984. Recreational harvest of Arctic grayling has declined to historic low levels. Harvest decreased 76% from 1984 to 1985, although angling effort had decreased only 39% (Table 1). Angling effort returned to an average level in 1986, but harvest remained below 10,000 fish. Concomitant with the declining recreational fishery was the decline in Arctic grayling population abundance. Stock assessment projects during 1986 (Clark and Ridder 1987b) and 1987 (Clark and Ridder 1988) documented a decline in population abundance of 49% between these two years. Poor recruitment was the probable cause for a decline in abundance (Holmes 1984; Holmes et al. 1986; Clark *In Press*).

During winter of 1986, fishery managers were scheduled to present stock status data (Clark 1986) on the Chena River fishery to the Alaska Board of Fisheries. The Board of Fisheries meeting adjourned before the data could be presented. In spring of 1987, increased concern for the health of the Chena River stock prompted fishery managers to process emergency regulations to reduce harvest. These emergency regulations were:

1) closure of the fishery until the first Saturday in June;

2) a 12 inch (305 mm) minimum length limit; and,

3) restriction of terminal gear to unbaited artificial lures.

These emergency regulations were made permanent regulations in the summer of 1987. During the winter of 1987, fishery managers presented stock status and regulatory concerns to the Alaska Board of Fisheries (Clark 1987). The emergency regulations imposed in spring of 1987 were adopted and amended. The new permanent regulations were:

1) catch-and-release fishing from 1 April to the first Saturday in June;

2) a 12 inch (305 mm) minimum length limit from the first Saturday in June until 31 March;

3) restriction of terminal gear to unbaited artificial lures only throughout the Chena River, and bait fishing allowed downstream of the Moose Creek Dam with hooks having a gap larger than 0.75 inch (19 mm);

Table 1. Summary of total angling effort and Arctic grayling harvest on the Chena River, 1977-1989[a].

	Lower Chena River[b]		Upper Chena River[c]		Entire Chena River	
Year	Angler-days	Harvest	Angler-days	Harvest	Angler-days	Harvest
1977[d]	---	---	---	---	30,003	21,723
1978[d]	---	---	---	---	38,341	33,330
1979	9,430	11,290	8,016	11,664	17,446	22,954
1980	13,850	18,520	10,734	16,588	24,584	35,108
1981	11,763	10,814	10,740	13,735	22,503	24,549
1982	18,818	11,117	15,166	12,907	33,984	24,024
1983	17,568	7,894	16,725	10,835	34,293	18,729
1984	20,556	13,850	11,741	12,630	32,297	26,480
1985	11,169	2,923	8,568	3,317	19,737	6,240
1986	18,669	4,167	10,688	3,695	29,357	7,862
1987[e]	12,605	1,230	10,667	1,451	23,272	2,681
1988[e,f]	16,244	2,686	9,677	1,896	25,921	4,582
1989[e,f]	20,317	7,194	10,014	5,441	30,331	12,635
Averages[g]	15,544	8,335	11,158	8,560	26,702	16,895

[a] Taken from Mills (1979-1990).

[b] Lower Chena River is from the mouth upstream to 40 km Chena Hot Springs Road (Mills 1988).

[c] Upper Chena River is the Chena River and tributaries accessed from the Chena Hot Springs Road beyond 40 km on the road (Mills 1988).

[d] Angler-days and harvest are computed for the Chena River and Badger Slough.

[e] Special regulations were in effect during 1987 and 1988. These regulations were: catch-and-release fishing from 1 April until the first Saturday in June; a 305 mm (12 inch) minimum length limit; and, a restriction of terminal gear to unbaited artificial lures.

[f] In addition to the special regulations, a catch-and-release area was created on the Upper Chena River (river km 140.8 to 123.2).

[g] Averages are for 1979 through 1989 only.

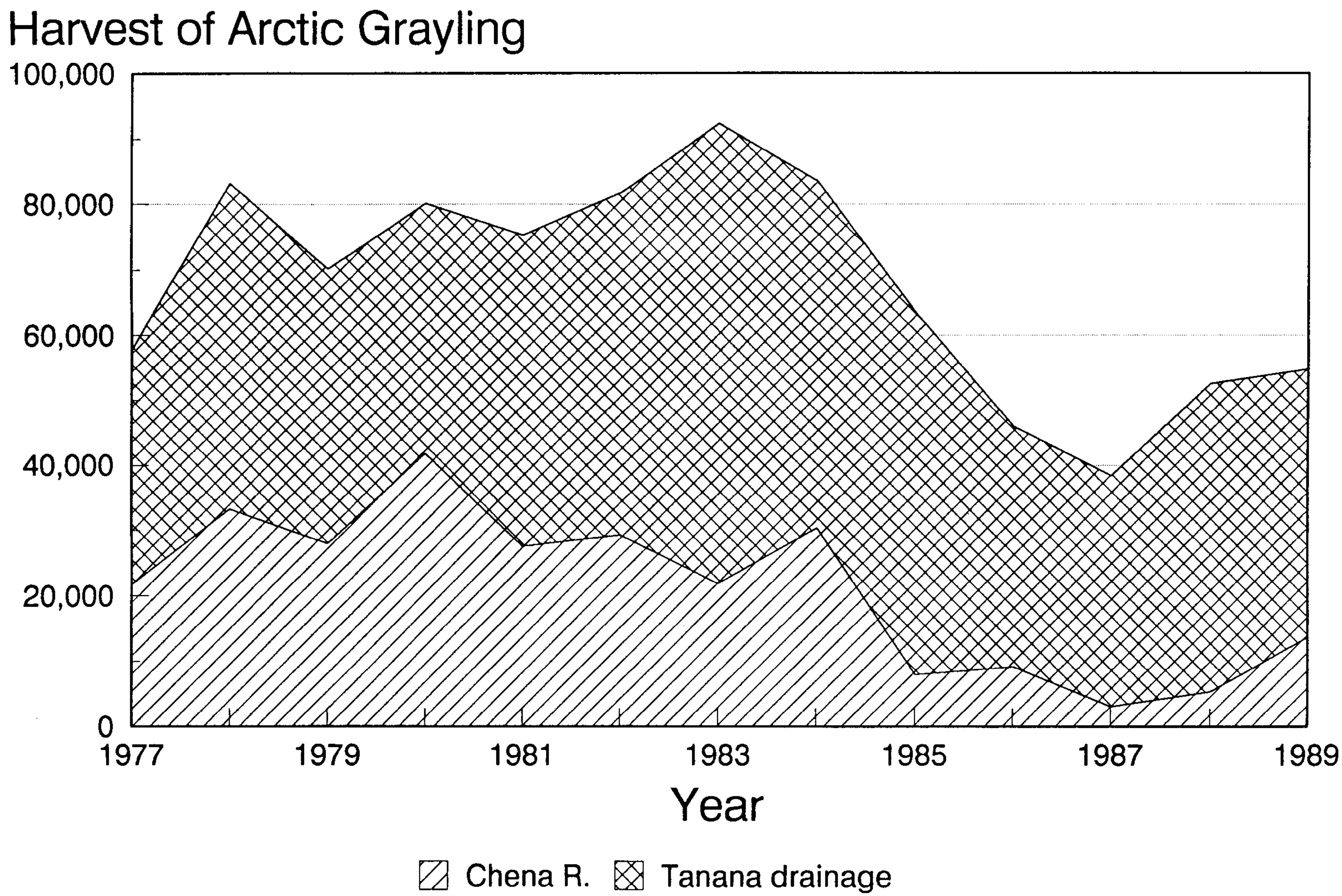

Figure 1. Annual harvests of Arctic grayling in the Chena River and in the entire Tanana drainage excluding the Chena River, 1977-1989 (taken from Mills 1979-1990).

4) catch-and-release fishing year around from river kilometer 140.8 downstream to river kilometer 123.2; and,

5) reduce the possession limit from 10 to 5 fish (Tanana drainage-wide regulation).

The regulations adopted by the Board of Fisheries in winter of 1987 were the first changes in Arctic grayling management since 1975, when the daily bag limit was decreased from 10 to 5 fish. Evaluation of the effects of new regulations on the Arctic grayling stock and recreational anglers was begun in 1987.

In 1990, continued concern for the Arctic grayling stock in the Chena River prompted the Board of Fisheries to implement a daily bag limit of two fish, riverwide, and single hook regulations upstream of the Moose Creek Dam.

<u>Objectives for Stock Assessment</u>

In order to accurately and precisely describe the stock status of Arctic grayling in the Chena River, the following objectives were sought in 1990:

1) to estimate the abundance of Arctic grayling greater than 149 mm fork length (FL) in the lower 152 km of the Chena River;

2) to estimate the age composition of Arctic grayling in the lower 152 km of the Chena River; and,

3) to estimate Relative Stock Density (RSD) of Arctic grayling in the lower 152 km of the Chena River.

In addition to these primary objectives, recruitment of new fish to the stock and the annual survival rate of the stock were estimated.

METHODS

<u>Sampling Gear and Techniques</u>

All sampling was performed with a pulsed-DC (direct current) electrofishing system mounted on a 6.1 m long river boat as previously described by Lorenz (1984). Input voltage (240 VAC) was provided by a 3,500 W single-phase gas powered generator (Homelite Model HG3500). A variable voltage pulsator (Coffelt Manufacturing Model VVP-15) was used to generate output current. Anodes were constructed of 12.7 mm diameter and 1.5 m long twisted steel cable. Four anodes were attached to the front of a 3 m long "T-boom" attached to a platform at the bow of the river boat. The aluminum hull of the river boat was used as the cathode. Output voltages during sampling varied from 200 to 300 VDC. Amperage varied from 2.0 to 3.5 A. Duty cycle and pulse rate were held constant at 50% and 60 Hz, respectively. These operating characteristics were presumed to minimally affect Arctic grayling survival during mark-recapture experiments. Water conductivity ranged from 85 μS to 125 μS (at 25°C) during electrofishing.

Sampling was conducted along the banks of the Chena River. The electrofishing boat was directed downstream along each bank, collecting all Arctic grayling seen, when possible. Captured Arctic grayling were held in an aerated holding tub to reduce capture related stress. The selected areas of the Chena River were sampled no more than once per day to prevent changes in capture probabilities of marked fish (Cross and Stott 1975). Each Arctic grayling was measured to the nearest 1 millimeter FL. A sample of scales was taken from the preferred zone[1] of each newly captured Arctic grayling. Arctic grayling greater than 149 mm FL were marked with individually numbered Floy FD-68 internal anchor tags inserted at the base of the dorsal fin. The tip of the left pectoral fin was removed to identify marked fish in case the numbered tag was shed. If any captured Arctic grayling exhibited signs of injury or imminent mortality, they were immediately sacrificed.

Estimation of Abundance

The abundance of Arctic grayling greater than 149 mm FL was estimated by mark-recapture techniques in the lower 152 km of the mainstem Chena River (Figure 2). Two sections of the Chena River were delineated for separate estimation experiments. Delineation of the Chena River was necessary because Tack (1980) and Clark and Ridder (1988) found increasing density of Arctic grayling with increasing distance upstream. Based on differences in population density from downstream to upstream areas of the Chena River, the lower 152 km of the Chena River is divided into Lower and Upper sections for estimating abundance and age composition. Downstream from the Moose Creek Dam complex to the mouth of the Chena River was designated the Lower Chena River (72 km long; Figure 3). Upstream from the dam to the second bridge on the Chena Hot Springs Road (kilometer 63.2) was designated the Upper Chena River (80 km long; Figure 3). Population abundance estimates pertain only to these two sections of the Chena River, excluding Badger Slough, the Little Chena River, and the South Fork of the Chena River.

Lower Chena River:

Population abundance in the Lower Chena River was estimated by expansion of abundance estimates in four 3.2 km-long sample areas (Clark and Ridder 1987b, 1988), utilizing a stratified design (Cochran 1977). Expansion of these estimates was accomplished by first subdividing the Lower Chena River into two subsections. Each subsection was chosen on the basis of river morphology and hydrologic characteristics that might influence Arctic grayling density.

The first subsection (Lower Chena A) encompassed the lower 40 km of river (Figure 4). Lower Chena subsection A is characterized by straight, low gradient stretches of river interspersed with slow, deep pools. Gravel bars occur in the center of the channel and the river bank has been stabilized by man-made structures (bridge abutments, riprap, and wooden pilings). The upper subsection of the Lower Chena (B) is 32 km long, extending from the crossing

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[1] The preferred zone for Arctic grayling is an area approximately six scale rows above the lateral line just posterior to the insertion of the dorsal fin.

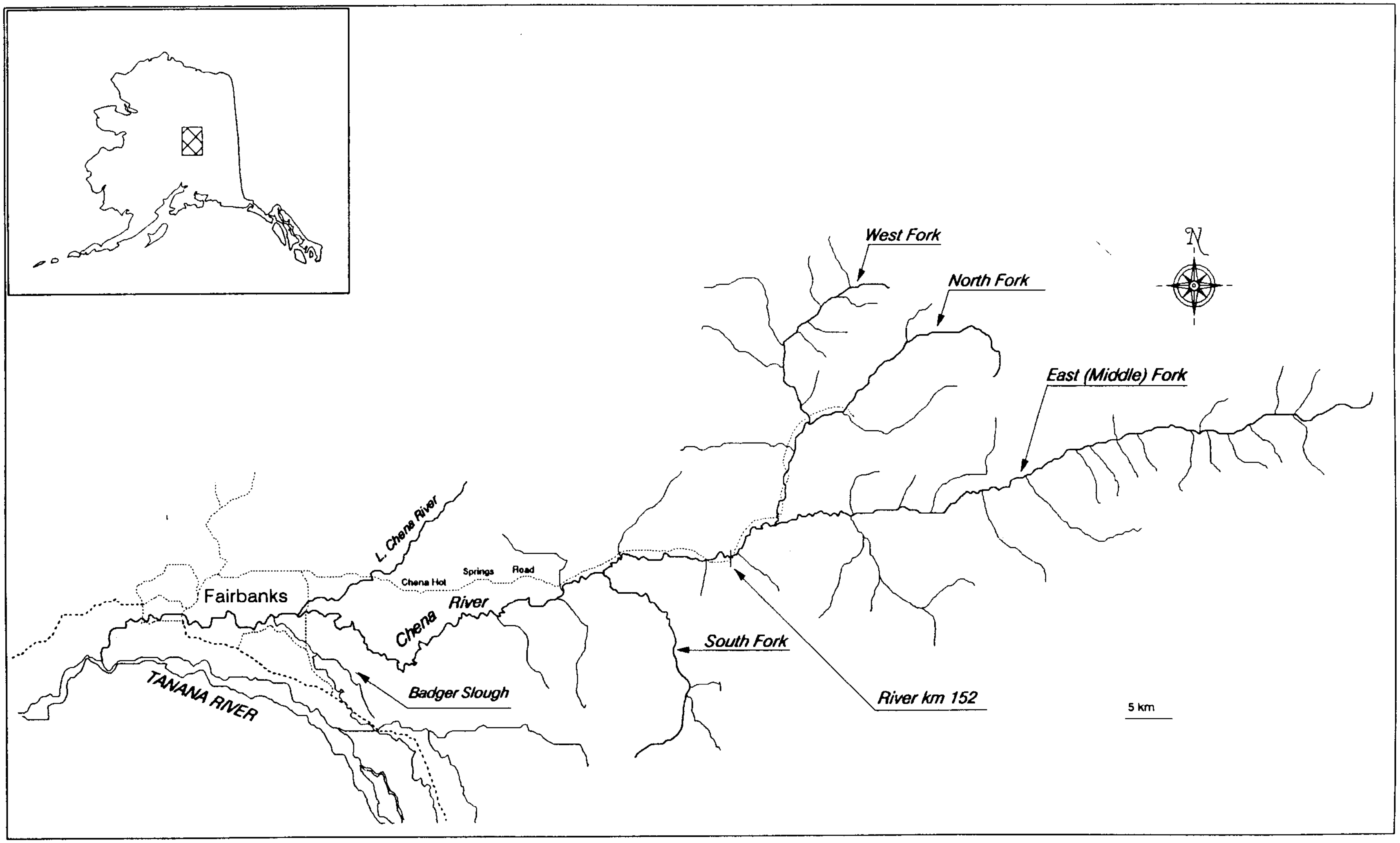

Figure 2. The Chena River drainage.

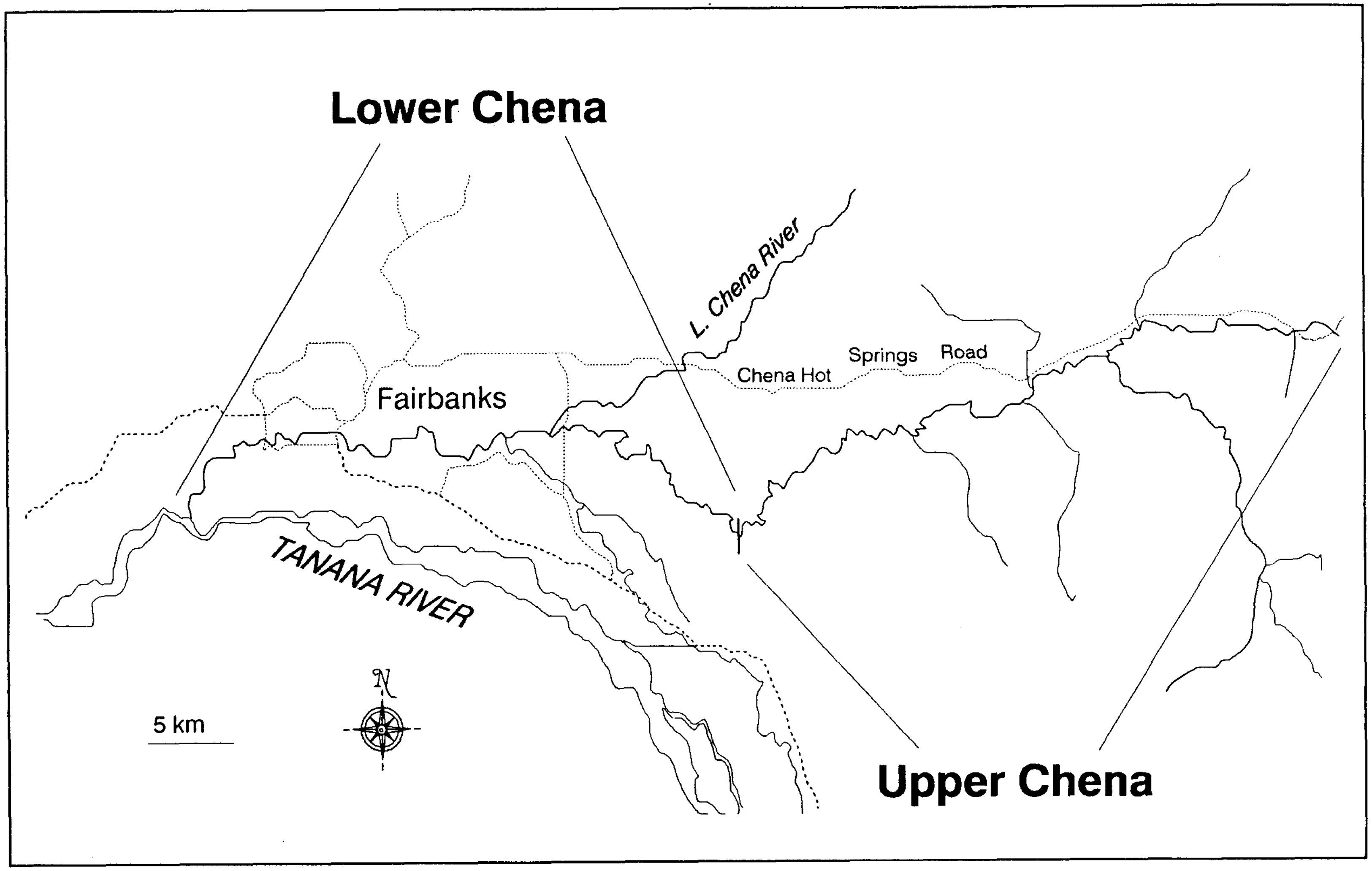

Figure 3. The lower 152 km of the Chena River drainage.

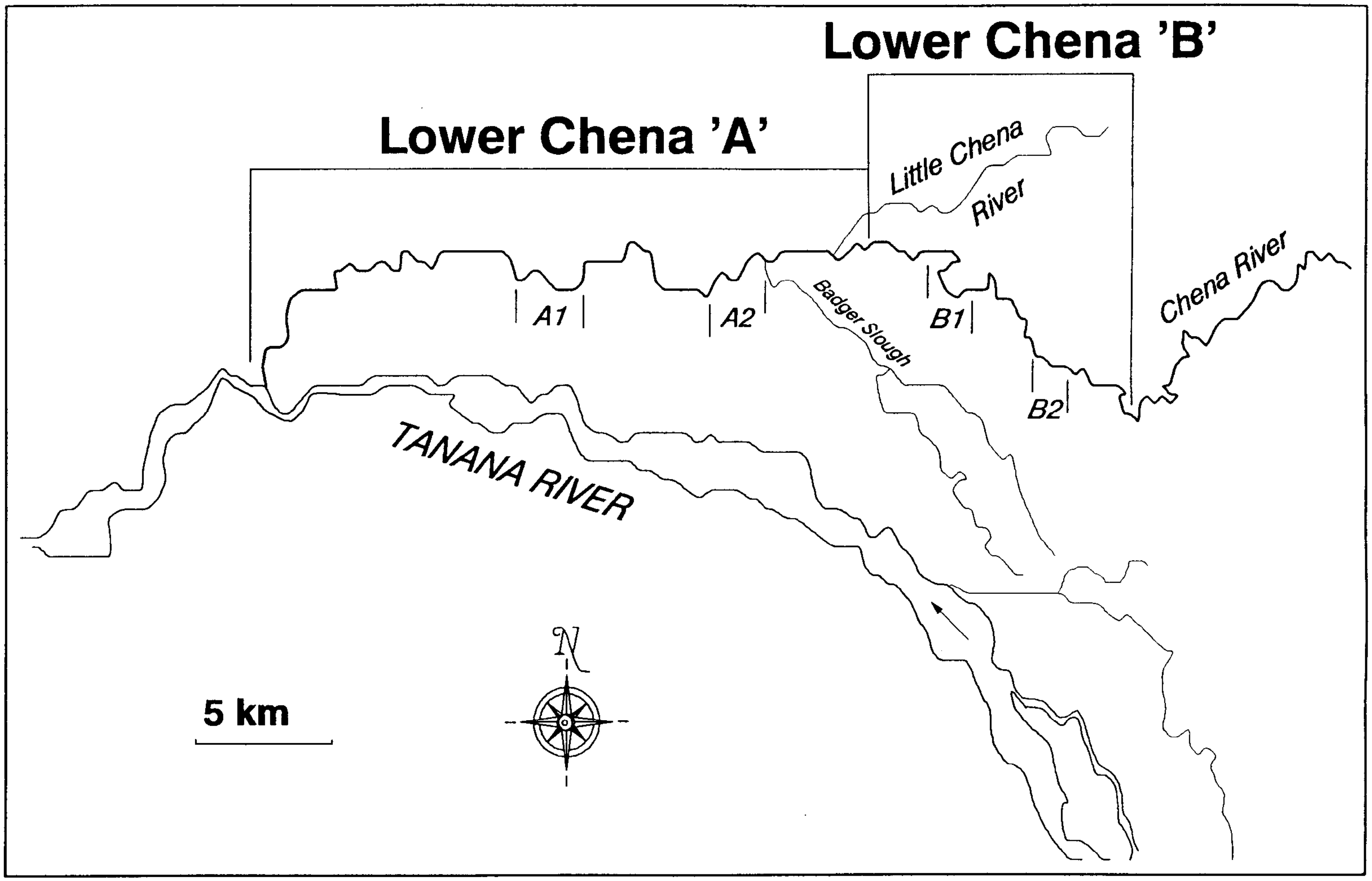

Figure 4. The lower 72 km of the Chena River drainage.

at Nordale Road to the Moose Creek Dam complex (Figure 4). Lower Chena subsection B is characterized by slow, meandering stretches interspersed with riffles.

Two of the four 3.2-km sample areas were randomly chosen in each of the subsections (2 strata, 2 samples per stratum; Figure 4). Multiple-sample population estimates were performed in each of the 3.2-km sample areas. Two of the areas were sampled once each day during a five day time span. Sampling took place between 2 and 21 July. Capture histories from each sample area were used as input to program CAPTURE (White et al. 1982). Program CAPTURE was used to perform a rigorous examination of assumptions necessary to multiple-sample abundance estimators. The assumptions necessary for accurate estimation of abundance in a closed population are (from Seber 1982):

1) the population is closed (no change in the number of Arctic grayling in the population during the estimation experiment);

2) all Arctic grayling have the same probability of capture in the first sample <u>or</u> in the second sample, <u>or</u> marked and unmarked Arctic grayling mix randomly between the first and second samples;

3) marking of Arctic grayling does not affect their probability of capture in the second sample;

4) Arctic grayling do not lose their mark between sampling events; and,

5) all marked Arctic grayling are reported when recovered in the second sample.

Assumption 1 could not be tested directly, but was implicitly assumed because of the short duration of the experiment (five days). Assumption 2 was tested with statistical procedures within program CAPTURE and with a Kolmogorov-Smirnov (Conover 1980) statistical test. Assumption 3 was tested for validity by program CAPTURE. Assumption 4 was assured of validity by double marking of Arctic grayling. Assumption 5 was assumed to be valid by rigorous examination of all Arctic grayling captured and by double marking.

Population abundance in the Lower Chena River was estimated by expanding the sample area estimates in each of the two subsections:

$$\hat{N}_i = R_i \hat{\bar{N}}_i \tag{1}$$

where: $\hat{N}_i$ = the estimated abundance in stratum (subsection) i;
R_i = the possible number of sample areas in stratum i;

$$\hat{\bar{N}}_i = \frac{\sum_{j=1}^{r_i} \hat{N}_{ij}}{r_i} = \text{average abundance in } r_i \text{ 3.2-km sample areas;} \tag{1a}$$

r_i = the number of 3.2-km sample areas in stratum i that were actually sampled;

$\hat{N}_{ij}$ = the abundance of Arctic grayling in sample area j of stratum i;

i = 1, 2 strata (Lower Chena A and Lower Chena B); and,

j = 1, 2 sample areas (A1 and A2, B1 and B2).

Lower Chena A had 12.5 possible 3.2-km sample areas (R_1 = 12.5) and Lower Chena B had 10 possible 3.2-km sample areas (R_2 = 10). The variance of each subsection abundance estimate was (Cochran 1977):

$$\hat{V}[\hat{N}_i] = (1 - r_i/R_i)\, R_i^2\, \hat{S}_i^2 + (r_i/R_i)(R_i^2/r_i^2) \sum_{j=1}^{r_i} \hat{V}[\hat{N}_{ij}] \qquad (2)$$

where: $\hat{V}[\hat{N}_i]$ = variance of estimated abundance in stratum i;

$$\hat{S}_i^2 = \frac{\sum_{j=1}^{r_i} (\hat{N}_{ij} - \hat{\bar{N}}_i)^2}{r_i(r_i - 1)}; \qquad (2a)$$

$\hat{V}[\hat{N}_{ij}]$ = variance of estimated abundance in sample area j of stratum i (from program CAPTURE); and,

r_i = the number of 3.2-km sample areas sampled in stratum i.

Equations 1 and 2 were used to estimate abundance and variance in subsections Lower Chena A and Lower Chena B. Estimated abundance and variance of the Lower Chena section was calculated by summing the subsection (stratum) abundance estimates and summing the variances:

$$\hat{N}_L = \sum_{i=1}^{2} \hat{N}_i \text{ ; and,} \qquad (3)$$

$$\hat{V}[\hat{N}_L] = \sum_{i=1}^{2} \hat{V}[\hat{N}_i] \text{ .} \qquad (4)$$

where: $\hat{N}_L$ = estimate of Arctic grayling abundance in the Lower Chena River; and,

$\hat{V}[\hat{N}_L]$ = estimated variance of abundance of Arctic grayling in the Lower Chena River.

Upper Chena River:

Abundance of Arctic grayling greater than 149 mm FL was estimated with the modified Petersen estimator of Bailey (1951, 1952). Two electrofishing boats were used to mark Arctic grayling along both banks of the entire 80 km of the Upper Chena River (Figure 3). Marking of fish required four days, sampling four areas. After a hiatus of seven days, the two electrofishing boats were used in the same way to examine Arctic grayling for marks. The entire experiment was conducted between 24 and 27 July for the first sample and between 31 July and 3 August for the second (recapture) sample.

Assumptions necessary for accurate estimation of abundance were identical to those listed in the Lower Chena River experiments. Assumption 1 was implicitly assumed because of the large size of the sample area (80 km) and short duration of the experiment (two weeks). Assumptions 2 and 3 that relate to changes in capture probability by size of fish were tested with two Kolmogorov-Smirnov statistical tests. The first test compared the length frequency distributions of recaptured Arctic grayling with those captured during the marking run. The second test compared the length frequency distributions of Arctic grayling captured during the marking run with those captured in the recapture run. In addition, sampling was conducted with equal effort along the entire 80 km of river, so it was assumed that all Arctic grayling had equal probability of capture throughout the Upper Chena River section. The assumption of equal probability of capture along the entire 80 km of river was tested with a chisquared contingency table. The recapture to mark ratios were compared for the four areas of the Upper Chena. Assumptions 4 and 5 were assumed to be valid because of double marking of tagged Arctic grayling and rigorous examination of all captured Arctic grayling.

Estimated abundance was calculated from numbers of Arctic grayling marked, examined for marks, and recaptured (Bailey 1951; Seber 1982):

$$\hat{N}_U = \frac{M\,(C + 1)}{(R + 1)} \qquad (5)$$

where: M = the number of Arctic grayling marked and released alive during the first sample;
C = the number of Arctic grayling examined for marks during the second sample;
R = the number of Arctic grayling recaptured during the second sample; and,
$\hat{N}_U$ = estimated abundance of Arctic grayling during the first sample.

Bailey's (1951, 1952) modification was used instead of the more familiar modification by Chapman (1951) because of the sampling design used on the Upper Chena River section. Seber (1982) found that if the assumption of a random sample for the second sample was false and a systematic sample was taken (for example, a systematic sample of both banks of the Chena River), then the binomial model of Bailey (1951, 1952) is most appropriate. The binomial model will hold in this situation when:

1) there is uniform mixing of marked and unmarked fish; and,

2) all fish, whether marked or unmarked, have the same probability of capture.

The Upper Chena River section sample design does not allow for thorough mixing of fish marked at the uppermost reaches with those marked in the downstream reaches, although local mixing of marked and unmarked fish probably occurs.

Variance of the estimate ($V[\hat{N}_U]$) was calculated by bootstrapping the capture histories of all fish in both samples 1,000 times (Efron 1982). The bootstrap procedure also permitted examination of bias in the Petersen estimate by generating a bootstrap estimate in addition to a bootstrap variance. The bootstrap procedure is as follows:

1) generate a pseudorandom number (between 0 and 1);

2) sample capture history of fish number "random number" × "total number of fish" + 1;

3) repeat 1 and 2 until a sample of "total number of fish" is taken;

4) generate population estimate from randomly sampled capture histories using equation 5;

5) repeat 1 through 4 for 1,000 iterations; and,

6) calculate mean and variance of 1,000 iterations of population estimate.

Estimated abundance and variance in the entire Chena River was calculated as the sum of Lower Chena and Upper Chena River estimates:

$$\hat{N} = \hat{N}_L + \hat{N}_U \text{ ; and,} \tag{6}$$

$$V[\hat{N}] = V[\hat{N}_L] + V[\hat{N}_U]. \tag{7}$$

Estimation of Age and Size Composition

Collections of Arctic grayling for age-length samples were conducted in conjunction with abundance estimation experiments. The Lower Chena River age-length samples were analyzed independently of the Upper Chena River age-length samples.

Lower Chena River:

A stratified design was used to derive age composition estimates for the Lower Chena River. This design was similar to the estimator for population abundance except that equations 1 through 4 were further partitioned into age classes. Using the estimates of abundance for age k (k = 1, 2, 3, ..., o age classes) and the abundance estimates (N_i's), age composition of the Lower Chena River was estimated. First the proportions for each age class were estimated in each of the two sample areas for each of the two subsections of the Lower Chena:

$$\hat{p}_{ijk} = \frac{y_{ijk}}{n_{ij}} \qquad (8)$$

where: y_{ijk} = the number of age k Arctic grayling sampled in sample area j of subsection (stratum) i; and,

n_{ij} = the number of Arctic grayling sampled in sample area j of subsection i.

Variance of these proportions was estimated by:

$$V[\hat{p}_{ijk}] = \frac{\hat{p}_{ijk}\,(1 - \hat{p}_{ijk})}{n_{ij} - 1} \qquad (9)$$

The sample area abundance estimates were then apportioned by each of the unweighted proportions from the respective sample area:

$$\hat{N}_{ijk} = \hat{N}_{ij}\,\hat{p}_{ijk} \qquad (10)$$

where: $\hat{N}_{ijk}$ = the estimated abundance of age k Arctic grayling in sample area j of stratum i.

Variance of this product was approximated by the exact formula of Goodman (1960):

$$V[\hat{N}_{ijk}] = \hat{p}_{ijk}^2\,V[\hat{N}_{ij}] + \hat{N}_{ij}^2 V[\hat{p}_{ijk}] - V[\hat{p}_{ijk}]\,V[\hat{N}_{ij}] \qquad (11)$$

The abundance by age was then scaled by the average abundance per 3.2 km sample area to produce a weighted proportion:

$$\hat{q}_{ijk} = \frac{\hat{N}_{ijk}}{\overline{N}_i} \qquad (12)$$

where: $\hat{q}_{ijk}$ = the weighted proportion of age k Arctic grayling in sample area j of stratum i; and,

$\hat{\overline{N}}_i$ = the <u>average</u> abundance of Arctic grayling in a 3.2 km sample area of stratum i (from equation 1).

Variance of the weighted proportions were estimated by the delta method (see Seber 1982):

$$V[\hat{q}_{ijk}] \approx (\hat{N}_{ijk}/\hat{\overline{N}}_i)^2\,(V[\hat{N}_{ijk}]/\hat{N}_{ijk}^2 + V[\hat{\overline{N}}_i]/\hat{\overline{N}}_i^2) \qquad (13)$$

Next, the average weighted proportion of age k Arctic grayling in stratum i was calculated:

$$\hat{\bar{q}}_{ik} = \frac{\sum_{j=1}^{2} \hat{q}_{ijk}}{2} \tag{14}$$

The variance of this average of weighted proportions is (Cochran 1977):

$$\hat{V}[\hat{\bar{q}}_{ik}] = (1 - 2/R) \frac{\sum_{j=1}^{2} (\hat{q}_{ijk} - \hat{\bar{q}}_{ik})^2}{2(2 - 1)} + 2/R \sum_{j=1}^{2} (1 - n_{ij}/N_{ij}) \frac{\hat{V}[\hat{q}_{ijk}]}{2^2} \tag{15}$$

Then the average weighted proportions for each stratum i were combined by weighting with the strata abundance estimates and the estimate of abundance for the Lower Chena:

$$\hat{\bar{q}}_{k} = \sum_{i=1}^{2} \frac{\hat{N}_i}{\hat{N}_L} \hat{\bar{q}}_{ik} \tag{16}$$

Variance of the proportions were approximated with the delta method (see Seber 1982):

$$\hat{V}[\hat{\bar{q}}_{k}] \approx \sum_{i=1}^{2} (\hat{\bar{q}}_{ik} - \hat{\bar{q}}_{k})^2 \frac{\hat{V}[N_i]}{\hat{N}_i^2} + \sum_{i=1}^{2} (\hat{N}_i/\hat{N}_L)^2 \hat{V}[\hat{\bar{q}}_{ik}] \tag{17}$$

These average weighted proportions and variances by age were used as estimates of age composition in the Lower Chena.

Upper Chena River:

Age composition of Upper Chena River Arctic grayling could have been calculated directly from age-length samples taken during the first sample of the mark-recapture estimate. However, a statistical difference in the capture probabilities by lengths of fish was detected (from tests of assumptions 2 and 3). Using the estimates of capture probability by size class, adjustment factors were estimated and used to correct for the bias. First, the capture probabilities were estimated from the recapture to mark ratios in each of two size classes:

$$\hat{\rho}_1 = \frac{RECAP_1}{MARK_1} \tag{18}$$

where: $\hat{\rho}_l$ = the capture probability of Arctic grayling in size class l, regardless of age k;
$RECAP_l$ = the number of recaptures of Arctic grayling in size class l; and,
$MARK_l$ = the number of marked Arctic grayling in size class l.

The two size classes were 150 through 235 mm FL and greater than 235 mm FL. These categories were chosen by performing a series of chisquared contingency table tests to determine the largest possible significant chisquared test statistic among all possible sets of stratification. These tests were restricted to the case of only two size classes, because further stratification would reduce precision with no appreciable increase in accuracy.

From the ratio of the largest capture probability to the capture probability in size class l, an adjustment to the number sampled at age k that are also of size class l was estimated (ignoring the hat symbols of ρ):

$$\hat{A}_l = \frac{\rho_L}{\rho_l} \tag{19}$$

where: $\hat{A}_l$ = the adjustment factor for all Arctic grayling of size class l, regardless of age class k; and,
$\rho_L = \max(\rho_l)$, l = 1, 2 size classes (represented by m).

The adjustment factor was multiplied by the number of Arctic grayling sampled at age k that were also in size class l:

$$\hat{x}_{kl} = \hat{A}_l \, n_{kl} \tag{20}$$

where: $\hat{x}_{kl}$ = the adjusted number of Arctic grayling of age k that were also in size class l; and,
n_{kl} = the actual number of Arctic grayling sampled that were age k and also in size class l.

The proportion of Arctic grayling that were age k then reevaluates to:

$$\hat{p}_k = \frac{\sum_{l=1}^{m} \hat{x}_{kl}}{\sum_{k=1}^{o} \sum_{l=1}^{m} \hat{x}_{kl}} = \frac{\hat{x}_{k.}}{\hat{x}_{..}} \tag{21}$$

where: k = 1, 2, ..., o age classes; and,
l = 1, 2 size classes (represented by m).

The variances of these adjusted proportions were estimated by bootstrap techniques (Efron 1982). The adjustment factors (recapture to mark ratios) from bootstrapping of capture histories were used to estimate variance of the proportions. Using equations 10 and 11 to apportion the abundance estimate by age class, the resulting abundance estimates at age k (N_{Uk}'s) and variances ($V[N_{Uk}]$'s) were then combined with the corresponding N_{Lk} and $V[N_{Lk}]$ to estimate abundance at age in the entire Chena River. Combination of Upper and Lower Chena age compositions was performed with equations 12 through 17.

Size composition of Arctic grayling in the Upper Chena River was described by the RSD categories as described above. The same adjustment factors (equation 19) were used to adjust biased RSD estimates, replacing the number sampled at age k that were also in size class l (n_{kl}) with the number sampled in RSD category k (k = 1, 2, 3, 4, and 5 RSD categories) that were also in size class l. The adjusted RSD estimates, expanded to abundance by RSD category, were then combined with abundance by RSD category from the Lower Chena River. RSD proportions and variances for the entire Chena River were then estimated with equations 12 through 17.

Estimation of Survival and Recruitment

As of 1990, five years of population abundance and age composition estimates had been completed for the lower 152 km of the Chena River. Using data from 1986 through 1989, Clark (1990) reported on survival rates and recruitment for 1986 through 1988. Survival rate and recruitment for 1989 were calculated in the same manner.

Annual recruitment was defined as the number of age 3 Arctic grayling added to the population between year t and year $t+1$, and alive in year $t+1$. Estimates of recruitment were calculated with population abundance estimates and estimates of the proportion of age 3 Arctic grayling in 1989 and 1990:

$$\hat{B}_{t,t+1} = \hat{N}_{t+1}\,\hat{p}_{3,t+1} \qquad (22)$$

where: $\hat{B}_{t,t+1}$ = recruits entering the population between year t and year $t+1$, and alive in year $t+1$;

$\hat{N}_{t+1}$ = number of fish age 3 and older in the population in year $t+1$; and,

$\hat{p}_{3,t+1}$ = the proportion of age 3 Arctic grayling in the population in year $t+1$.

Variance of annual recruitment was estimated with equation 11, the variance of a product. With recruitment and population abundance estimates in years t and $t+1$, the estimate of survival rate between year t and year $t+1$ becomes:

$$\hat{S}_{t,t+1} = \frac{\hat{N}_{t+1} - \hat{B}_{t,t+1}}{N_t} \qquad (23)$$

The variance of annual survival was approximated as the variance of a quotient of two independent variables with the delta method (Seber 1982; ignoring hat symbols):

$$V[S] \approx \left[\frac{N'_{t+1}}{N_t} \right]^2 \left[\frac{V[N'_{t+1}]}{N'^{2}_{t+1}} + \frac{V[N_t]}{N_t^2} \right] \qquad (24)$$

where: $N'_{t+1} = N_{t+1} - B_{t,t+1}$;

$V[N'_{t+1}] = \sum_{k=4}^{11} V[N_{t+1,k}]$; and,.

$k =$ the age classes 4 through 11.

Historic Data Summary

Data collected from the Chena River (1955 to 1989) were summarized in Appendix A. Creel survey estimates, population abundance estimates, length at age estimates, age composition estimates, size composition estimates, and a model of Arctic grayling growth were summarized from Federal Aid in Sport Fish Restoration reports and State of Alaska Fishery Data Series reports written from 1959 to the present (Appendix A). When possible, estimates of precision were reported with point estimates. Precision was reported as either standard error or 95% confidence interval. Sample sizes were reported if neither of these estimates of precision were available. Length frequency was generally reported in the literature as numbers sampled per 10 mm length increment. The length frequency distributions were converted into the RSD categories of Gabelhouse (1984) for comparison with data collected from 1986 to 1990. In addition to the aforementioned reports in Appendix A, Arctic grayling migration studies were summarized in a report by Tack (1980). Reports concerning Arctic grayling research from 1952-1980 were compiled by Armstrong (1982). Armstrong, et al. (1986) have compiled a bibliography for the genus *Thymallus* to 1985.

RESULTS

Estimated abundance of Arctic grayling (≥ 150 mm FL) in the lower 152 km of the Chena River was 31,815 fish. Age 3 Arctic grayling dominated the age composition in the Chena River (53.1% of the stock). Stock size Arctic grayling dominated the size compostion of the Chena River (74.9% of the stock). Details of these estimates follow below.

Lower Chena

A total of 1,248 Arctic grayling (≥ 150 mm FL) was captured during mark-recapture experiments in the Lower Chena River. Twenty-six immediate mortalities or serious injuries were recorded for an overall injury rate of 2.1%.

A significant change in capture probabilities by size of fish occurred in sample area A1 during population estimation (Kolmogorov-Smirnov test statistic and tail probability is: $DN^2 = 0.34$, $P = 0.04$; Figure 5). As a result, the mark-recapture data were stratified into small (150 through 249 mm FL) and large (greater than 249 mm FL) fish and separate CAPTURE analyses performed for each stratum. Conversely, no significant changes in capture probability were detected in the other three sample areas (Kolmogorov-Smirnov test statistics and tail probabilities are: A2($DN = 0.16$, $P = 0.15$); B1($DN = 0.20$, $P = 0.13$); B2($DN = 0.12$, $P = 0.40$; Figure 5). In addition, program CAPTURE detected significant changes in capture probability of marked Arctic grayling as the experiments progressed (Table 2).

Using the stratified mark-recapture data from sample area A1, program CAPTURE failed to detect a change in capture probability of small Arctic grayling, and detected a significant temporal change in capture probability of large fish. Program CAPTURE selected model M_o for small fish, with an estimated abundance of 1,169 Arctic grayling (SE = 365 fish, CV = 31.2%). Model M_t was chosen as most likely to fit the mark-recapture data for large fish, with an estimated abundance of 73 Arctic grayling (SE = 17 fish, CV = 23.3%). The summed abundance estimate for Arctic grayling in sample area A1 was 1,242 fish (SE = 366 fish, CV = 29.5%; Table 2)

In sample areas A2, B1, and B2 program CAPTURE estimated population abundance without stratification by length. A significant behavioral component caused a change in capture probability in sample areas A2 and B2. Model M_b (Otis et al. 1978) was chosen as most appropriate for abundance estimation in sample areas A2 and B2. Estimated abundance in sample area A2 was 429 Arctic grayling (SE = 24 Arctic grayling, CV = 5.7%; Table 2). Estimated abundance in sample area B2 was 204 Arctic grayling (SE = 8 Arctic grayling, CV = 4.1%; Table 2). Model M_h (heterogeneity) was chosen as most likely to fit the mark-recapture data from sample area B1, with an estimated abundance of 258 Arctic grayling (SE = 19 Arctic grayling, CV = 7.3%; Table 2).

Expansion of estimated abundance in sample areas A1 and A2 resulted in an estimated population size of 10,444 Arctic grayling in subsection A of the Lower Chena River (Table 3). Expansion of estimates in sample areas B1 and B2 to all of subsection B resulted in an estimate of 2,310 Arctic grayling (Table 3). Estimated abundance of Arctic grayling in the Lower Chena River was 12,754 fish (SE = 4,753 fish, CV = 37.3%).

Age composition of samples taken from sample areas A1 and A2 of subsection A of the Lower Chena River were significantly different ($\chi^2 = 25.3$, $df = 4$, $P < 0.01$; Figure 6; Table 4). Similarly, a significant difference was found in samples taken from sample areas B1 and B2 of subsection B ($\chi^2 = 11.28$, $df = 5$, $P < 0.05$; Figure 6; Table 4). Therefore, age composition data were weighted by sample area to adjust for differences in age composition within subsections A and B. Age 3 Arctic grayling dominated the estimated age composition of the Lower Chena River in 1990. Of the estimated 12,754 Arctic grayling in the Lower Chena River, 6,629 fish (SE = 3,876 fish, CV = 58.5%), or 52.0% were age 3 (Table 4). The abundance estimate for age 2 fish was most

[2] DN = test statistic for the Kolmogorov-Smirnov test.

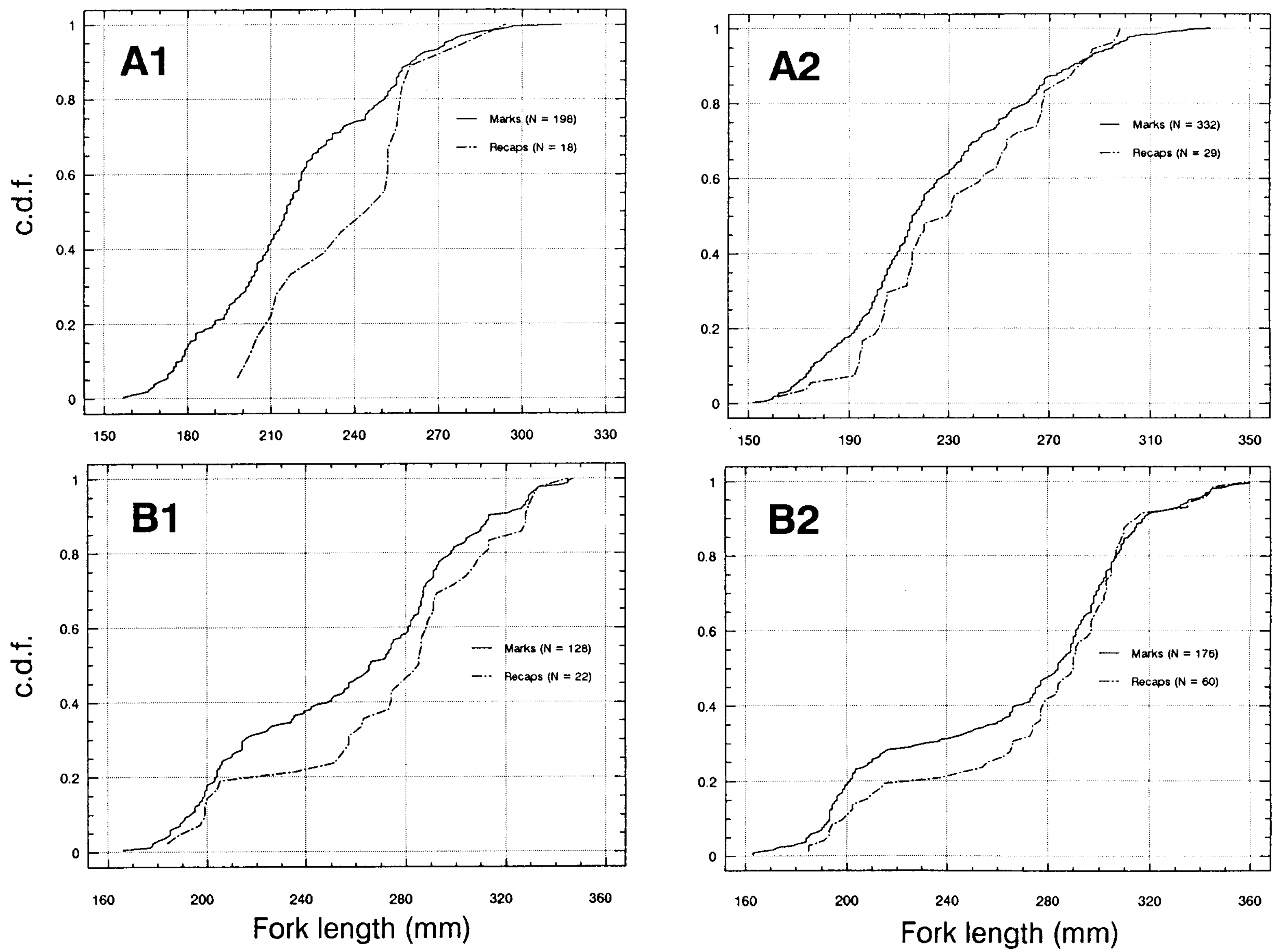

Figure 5. Cumulative distribution functions (c.d.f) of lengths of Arctic grayling marked versus lengths of Arctic grayling recaptured for four 3.2-km sample areas of the Lower Chena section of the Chena River, 2 through 21 July, 1990.

Table 2. Summary of sample area abundance estimates of Arctic grayling (≥ 150 mm FL) in the Lower Chena section of the Chena River, 2 through 21 July, 1990.

Subsection	River KM	CAPTURE Model[a]	Abundance Estimate	Standard Error	Fish/km
A1	24.0 to 27.2	M_o, M_t[b]	1,242	366	388
A2	33.6 to 36.8	M_b	429	24	134
B1	49.6 to 52.8	M_h	258	19	81
B2	59.2 to 62.4	M_b	204	8	64

[a] Models selected by program CAPTURE as most appropriate:
M_o: constant probability of capture;
M_t: temporal changes in probability of capture;
M_b: behavioral changes in probability of capture; and,
M_h: heterogeneous capture probabilities among fish.
These models and their estimators are described in White at al. (1982) and Otis et al. (1978).

[b] Model M_o was chosen for fish greater than 149 mm FL and less than 250 mm FL. Model M_t was chosen for fish greater than 249 mm FL.

Table 3. Estimated abundance of Arctic grayling (≥ 150 mm FL) in the lower 72 km of the Chena River (Lower Chena section), 2 through 21 July, 1990.

Subsection[a]	Subsection Length (km)	Estimated Abundance	Standard Error
A1	3.2	1,242	366
A2	3.2	429	24
Average	3.2	836	446
Total	40.0	10,444	4,746
B1	3.2	258	19
B2	3.2	204	8
Average	3.2	231	29
Total	32.0	2,310	246
Lower Chena	72.0	12,754	4,753

[a] Subsection A1 = river km 24.0 to 27.2; A2 = river km 33.6 to 36.8; B1 = river km 49.6 to 52.8; and, B2 = river km 59.2 to 62.4.

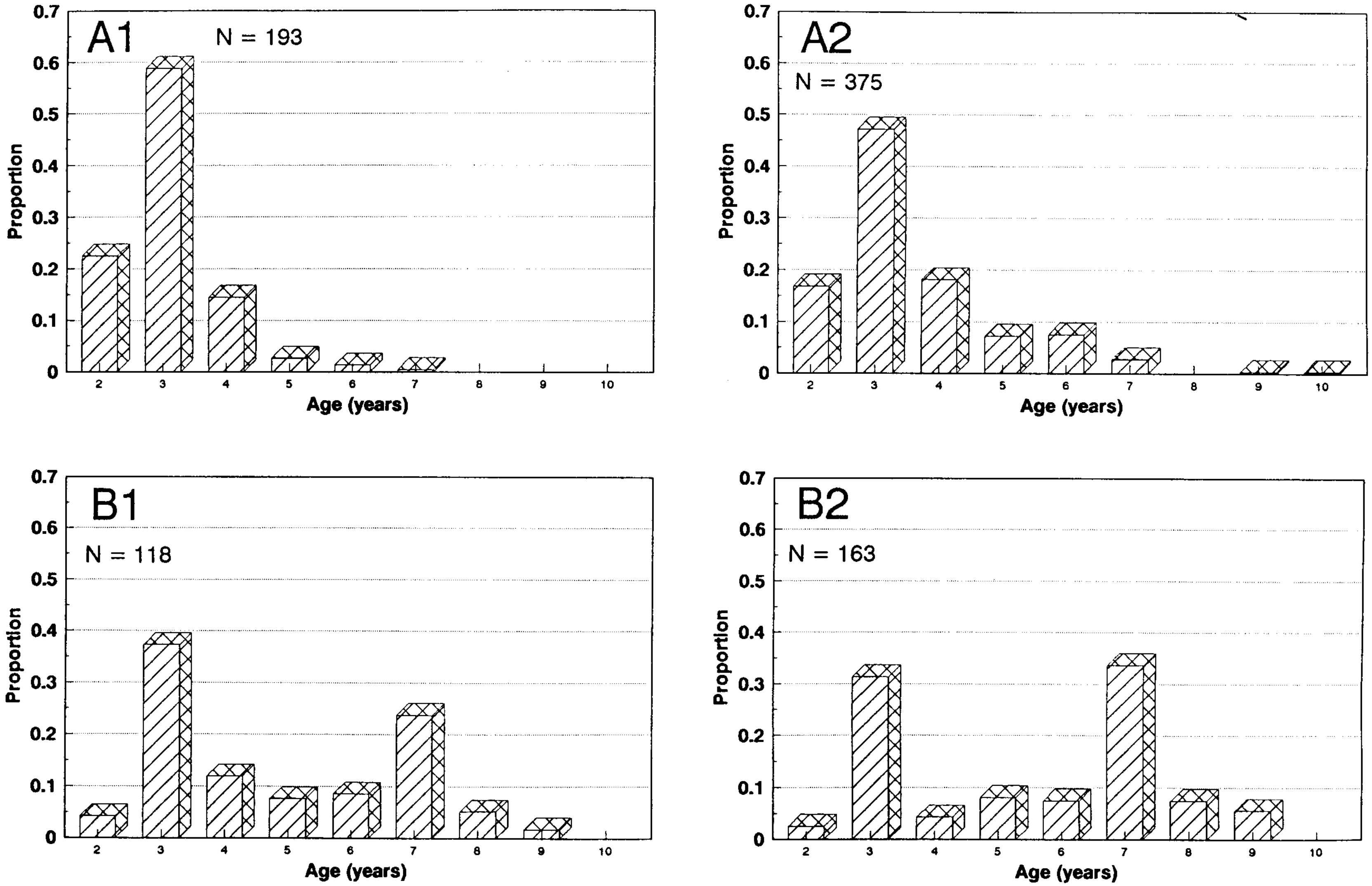

Figure 6. Age compositions of Arctic grayling sampled from each of four 3.2-km sample areas of the Lower Chena section of the Chena River, 2 through 21 July, 1990 (N = sample size).

Table 4. Estimates of age composition and abundance by age with standard errors from Arctic grayling (≥ 150 mm FL) captured by pulsed-DC electrofishing in the Lower Chena section of the Chena River, 2 to 21 July, 1990.

	Subsection A1[a]					Subsection A2[b]					Subsection B1[c]					Subsection B2[d]					Lower Chena[e]			
Age	n[f]	p[g]	SE[h]	N[i]	SE[j]	n	p	SE	N	SE	n	p	SE	N	SE	n	p	SE	N	SE	p	SE	N	SE
2	38	0.22	0.04	279	91	63	0.17	0.02	72	9	5	0.04	0.02	11	5	4	0.02	0.01	5	2	0.18	0.10	2,276	1,451
3	100	0.59	0.05	730	220	177	0.47	0.03	202	16	44	0.37	0.04	96	13	51	0.31	0.04	64	8	0.52	0.25	6,629	3,876
4	33	0.14	0.04	180	62	68	0.18	0.02	78	10	14	0.12	0.03	31	8	7	0.04	0.02	9	3	0.14	0.05	1,809	912
5	15	0.03	0.03	32	16	27	0.17	0.01	31	6	9	0.08	0.02	20	6	13	0.08	0.02	16	4	0.04	0.01	574	226
6	5	0.01	0.03	16	10	28	0.07	0.01	32	6	10	0.08	0.03	22	7	12	0.07	0.02	15	4	0.04	0.01	484	212
7	2	<0.01	0.02	4	3	10	0.03	0.01	11	4	28	0.24	0.04	61	11	55	0.34	0.04	69	8	0.06	0.02	749	363
8	0	0.00	0.00	0	0	0	0.00	0.00	0	0	6	0.05	0.02	13	5	12	0.07	0.02	15	4	0.01	<0.01	141	74
9	0	0.00	0.00	0	0	1	<0.01	<0.00	1	1	2	0.02	0.01	4	3	9	0.05	0.02	11	4	0.01	<0.01	85	52
10	0	0.00	0.00	0	0	1	<0.01	<0.01	1	1	0	0.00	0.00	0	0	0	0.00	0.00	0	0	<0.01	<0.01	7	7
Total	193	1.00	---	1,242	366	375	1.00	---	429	24	118	1.00	---	258	19	163	1.00	---	204	8	1.00	---	12,754	4,753

[a] Subsection A1 - River kilometer 24.0 to 27.2; 2 July to 6 July. p does not correspond to sample size because p was adjusted for selectivity of the electrofishing boat.
[b] Subsection A2 - River kilometer 33.6 to 36.8; 2 July to 6 July.
[c] Subsection B1 - River kilometer 49.6 to 52.8; 16 July to 21 July.
[d] Subsection B2 - River kilometer 59.2 to 62.4; 16 July to 21 July.
[e] Expansion to the entire Lower Chena section - River kilometer 0 to 72.0.
[f] n = number of Arctic grayling sampled at age.
[g] p = estimated proportion of Arctic grayling at age in the subsection.
[h] SE = estimated standard error of p (normal approximation to binomial).
[i] N = estimated subsection abundance of Arctic grayling at age.
[j] SE = estimated standard error of N.

likely biased because of the imposed lower length limit for mark-recapture experiments (150 mm FL). However, age 2 Arctic grayling made up 17.8% of the estimated abundance in the Lower Chena. Age 4 Arctic grayling were next most abundant, representing 14.2% of the stock, or 1,809 fish (SE = 902 fish, CV = 50.4%). Very few Arctic grayling older than age 7 were found in the Lower Chena River (Table 4).

Size composition samples taken from subsection A were significantly different (χ^2 = 17.1, *df* = 1, *P* < 0.01; Figure 7; Table 5). Size composition estimates in the two sample areas in subsection B were also significantly different (χ^2 = 7.0, *df* = 1, *P* < 0.01; Figure 7; Table 5). Therefore, size composition data were weighted by sample area to adjust for differences in size composition within the subsections. Eighty-seven percent of Arctic grayling greater than 149 mm FL were also less than 270 mm FL (Table 5). Of the 1,503 Arctic grayling (SE = 669 fish, CV = 44.5%) greater than 270 mm FL, only 77 fish (SE = 42 fish, CV = 54.5%) were of preferred size (≥ 340 mm FL). No memorable or trophy size Arctic grayling were sampled from the Lower Chena River.

Upper Chena

A total of 3,052 Arctic grayling (≥ 150 mm FL) was captured during the mark-recapture experiment on the Upper Chena River. Seventeen immediate mortalities or serious injuries were recorded for an overall injury rate of 0.5%.

During 24 through 27 July, 1,539 Arctic grayling (≥ 150 mm FL) were marked and released along 80 km of the Upper Chena River. During 31 July through 3 August, 1,513 Arctic grayling were examined for marks along the same 80 km section of river. A total of 139 Arctic grayling was recaptured during the second sample. There was no significant difference in capture probabilities among the four areas of the Upper Chena (χ^2 = 5.9, *df* = 3, 0.10 < *P* < 0.25). A significant difference was found between the CDF of lengths of marked Arctic grayling and the CDF of lengths of recaptured Arctic grayling (*DN* = 0.14, *P* = 0.01). The CDF of recaptures was most different than the CDF of marks for fish smaller than 235 mm FL (Figure 8A). Therefore, the mark-recapture data were stratified into small (150 to 234 mm FL) and large (≥ 235 mm FL) segments for separate estimation. The bootstrap estimate of Arctic grayling abundance for small fish was 11,402 fish (SE = 949 fish, CV = 8.3%; Table 6). The estimate for large fish was 7,659 fish (SE = 573 fish, CV = 7.5%; Table 6). The combined estimate of Arctic grayling abundance in the Upper Chena was 19,061 fish (SE = 1,108 fish, CV = 5.8%). If the mark-recapture data were not stratified by size, the resulting estimate of abundance would have been 16,643 fish (SE = 1,335 fish; see Seber (1982), page 61) with a bias of 12.7% (see also Appendix B1).

The CDF of lengths of marked Arctic grayling was significantly different than the CDF of lengths of Arctic grayling examined for marks (*DN* = 0.06, *P* = 0.01), although no functional difference was evident (Figure 8B). It was therefore judged that age-length samples taken during the marking and recapture events could be used to estimate age and size compositions of Arctic grayling in the Upper Chena River. The difference in capture probabilities of

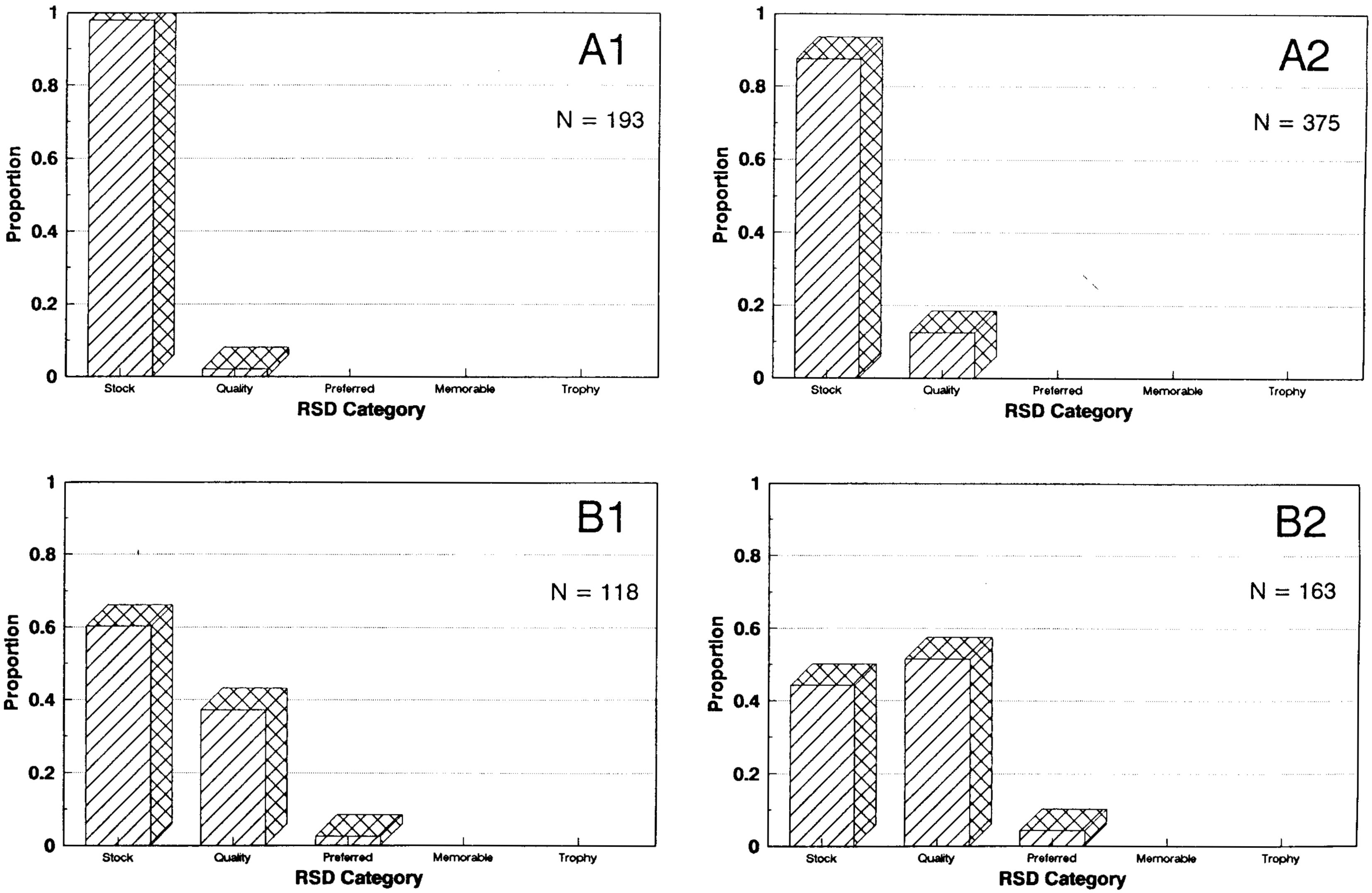

Figure 7. Size compositions of Arctic grayling sampled from each of four 3.2-km sample areas of the Lower Chena section of the Chena River, 2 through 21 July 1990 (N - sample size; S - stock (150 to 269 mm FL), Q - quality (270 to 339 mm FL), P - preferred (340 to 449 mm FL), M - memorable (450 to 559 mm FL), and T - trophy (greater than 559 mm FL).

Table 5. Summary of Relative Stock Density (RSD) indices of Arctic grayling (≥ 150 mm FL) captured in the Lower Chena section of the Chena River, 2 through 21 July, 1990.

	RSD Category[a]				
	Stock	Quality	Preferred	Memorable	Trophy
Subsection A1[b]					
Number sampled	181	12	0	0	0
RSD[c]	0.98	0.02	0.00	0.00	0.00
Standard Error	0.01	0.01	0.00	0.00	0.00
Abundance[d]	1,216	26	0	0	0
Standard Error	358	13	0	0	0
Subsection A2					
Number sampled	328	47	0	0	0
RSD	0.87	0.13	0.00	0.00	0.00
Standard Error	0.02	0.02	0.00	0.00	0.00
Abundance	375	54	0	0	0
Standard Error	23	8	0	0	0
Subsection B1					
Number sampled	71	44	3	0	0
RSD	0.60	0.37	0.03	0.00	0.00
Standard Error	0.04	0.04	0.01	0.00	0.00
Abundance	155	96	7	0	0
Standard Error	16	13	4	0	0
Subsection B2					
Number sampled	72	84	7	0	0
RSD	0.44	0.52	0.04	0.00	0.00
Standard Error	0.04	0.04	0.02	0.00	0.00
Abundance	90	105	9	0	0
Standard Error	9	9	3	0	0
Lower Chena					
RSD	0.87	0.12	0.01	0.00	0.00
Standard Error	0.40	0.03	<0.01	0.00	0.00
Abundance	11,174	1,503	77	0	0
Standard Error	6,351	669	42	0	0

[a] Minimum lengths for RSD categories are (Gabelhouse 1984): Stock - 150 mm FL; Quality - 270 mm FL; Preferred - 340 mm FL; Memorable - 450 mm FL; and, Trophy - 560 mm FL.

[b] Subsections are: A1 - River kilometer 24.0 to 27.2; A2 - River kilometer 33.6 to 36.8; B1 - River kilometer 49.6 to 52.8; and, B2 - River kilometer 59.2 to 62.4.

[c] RSD in subsection A1 was adjusted for size selectivity of the electrofishing boat.

[d] Abundance is the estimated abundance in a 3.2 km subsection.

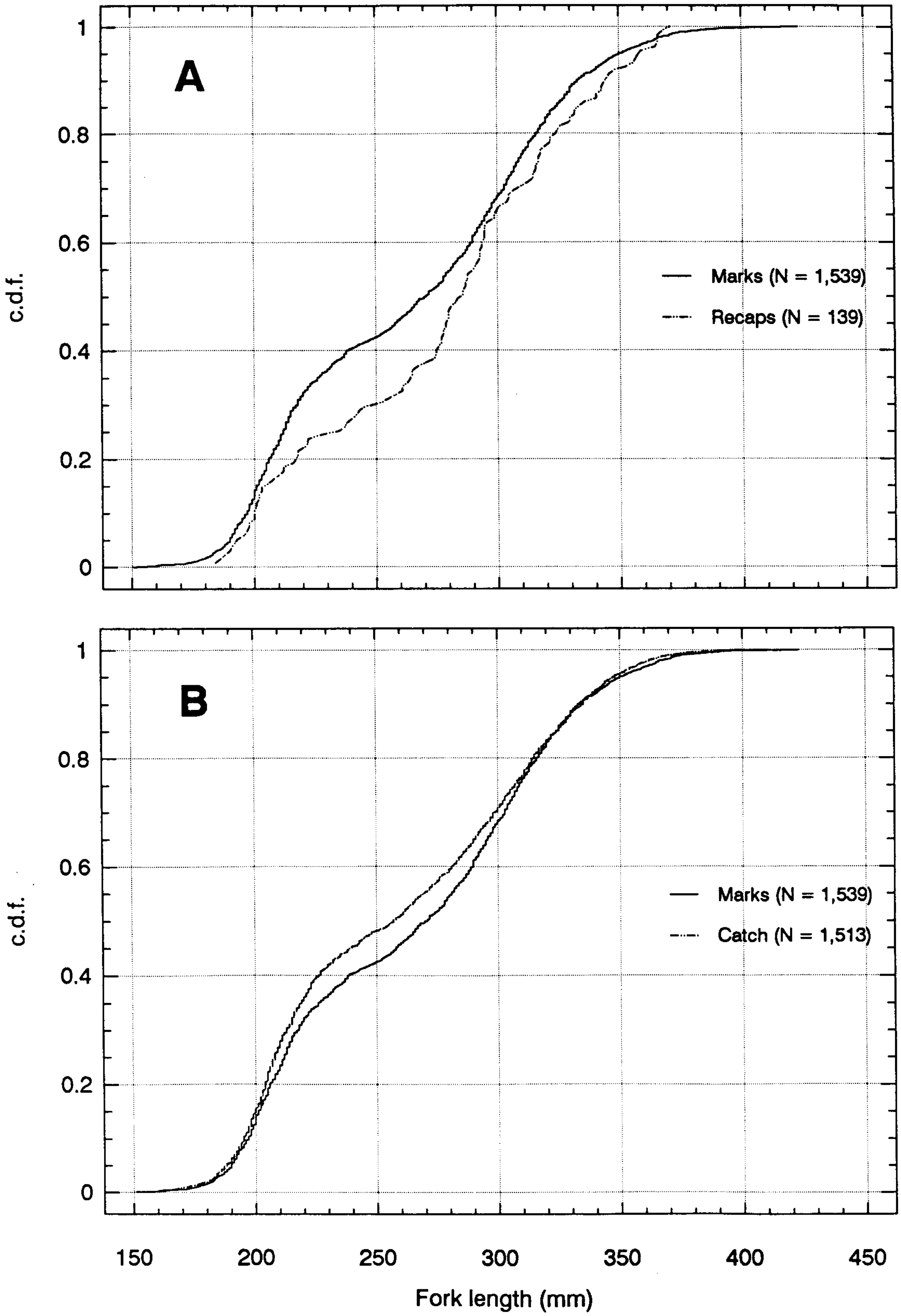

Figure 8. Cumulative distribution functions (c.d.f.) of lengths of Arctic grayling marked versus lengths of Arctic grayling recaptured (A) and versus lengths of Arctic grayling examined for marks (B) for the Upper Chena section of the Chena River, 24 July through 3 August, 1990.

Table 6. Capture probabilities and estimated abundance in two size categories used for population estimation of Arctic grayling (≥ 150 mm FL) in the Upper Chena section of the Chena River, 24 July through 3 August, 1990.

Length Category	Mark n_1	Catch n_2	Recap m	ρ[a]	SE[ρ][b]	N[c]	SE[N][d]
150 to 234 mm	594	662	34	0.06	0.01	11,402	949
≥ 235 mm	945	851	105	0.11	0.01	7,659	573
Total	1,539	1,513	139	---	---	19,061	1,108

[a] ρ is the probability of capture determined from bootstrap methods.
[b] SE[ρ] is the standard error of ρ determined from bootstrap methods.
[c] N is the estimated abundance in a length category, determined from bootstrap methods.
[d] SE[N] is the bootstrap standard error of N.

Arctic grayling by size noted above prompted the use of adjustment factors to remove bias from the age-length samples. After adjustment, age 3 and age 7 Arctic grayling were dominant in the Upper Chena River, representing 53.8% and 11.3% of the abundance, respectively (Table 7). Age 5 and age 6 fish were next most abundant, accounting for 9.7% and 10.0% of the abundance, respectively.

Size composition in the Upper Chena consisted of 66.3% stock size Arctic grayling (Table 8). Quality size Arctic grayling accounted for 28.1% of Upper Chena Arctic grayling. Least abundant were preferred size Arctic grayling, representing 5.6% of fish greater than 149 mm FL. No memorable or trophy size Arctic grayling were sampled on the Upper Chena River.

Chena River

The summed estimate of Arctic grayling abundance in the lower 152 km of the Chena River was 31,815 fish (SE = 4,880 fish, CV = 15.3%). Of these fish, 53.1% were age 3, representing an abundance of 16,881 fish (Table 9). The next most abundant age class was age 4, totalling 3,215 fish or 10.1%. Although not fully recruited to the mark-recapture estimates, age 2 Arctic grayling represented 8.4% of the estimated abundance or 2,685 fish (SE = 1,447 fish, CV = 53.9%). Of the 31,815 Arctic grayling greater than 149 mm FL, 74.9% or 23,821 fish (SE = 6,377, CV = 26.8%) were less than 270 mm FL (Table 9). Of the remaining 7,995 fish that were greater than 269 mm FL, 1,142 fish (SE = 258 fish, CV = 22.6%) were also greater than 339 mm FL. No memorable or trophy size Arctic grayling were captured in the lower 152 km of the Chena River.

Population size (age 3 and older) in summer of 1989 was 16,236 fish (SE = 1,618 fish, CV = 9.9%; Clark 1990). Annual recruitment from summer 1989 to summer 1990 was 16,881 fish (SE = 4,172 fish, CV = 24.7%; Table 10). Population size in summer of 1990 was 29,130 fish (SE = 4,373 fish, CV = 15.0%). Annual survival was estimated as 75.4% (SE = 11.0%, CV = 14.6%) between 1989 and 1990 (Table 10).

DISCUSSION

Sampling Design

The estimate of abundance for Arctic grayling in the lower 152 km of the Chena River was not as precise as estimates performed in 1988 (Clark 1989) or 1989 (Clark 1990). Lower precision in abundance estimation resulted in lower precision in the secondary statistics, such as recruitment and survival. The cause of imprecision is the stratified sampling design used to estimate abundance in the Lower Chena section. This year, sample area abundance estimates were estimated with sufficient precision, but the differences among sample areas, within subsections, caused increased variation when these abundances were expanded. Coefficients of variation for sample area abundance estimates ranged from 4.1% to 29.5%, but coefficient of variation of the expanded abundance estimate was 37.3%. More specifically, the average abundance in a 3.2 km sample area of subsection A was 836 fish (SE = 446 fish, CV = 53.4%), but the CV of individual estimates in this subsection were 5.7%

Table 7. Estimates of adjusted age composition and abundance by age class with standard errors for Arctic grayling (≥ 150 mm FL) captured by pulsed-DC electrofishing from the Upper Chena section of the Chena River, 24 through 27 July, 1990.

	Age Composition				Abundance		
Age	n[a]	p[b]	SE[c]	CV[d]	N[e]	SE[f]	CV[g]
2	20	0.02	0.01	36.2	409	150	36.6
3	507	0.54	0.04	7.7	10,253	985	9.6
4	122	0.07	0.01	9.0	1,405	151	10.7
5	170	0.10	0.01	13.6	1,855	274	14.8
6	184	0.10	0.01	11.7	1,912	249	13.0
7	203	0.11	0.02	14.8	2,156	343	15.9
8	51	0.03	<0.01	11.7	519	68	13.0
9	33	0.02	<0.01	14.1	380	58	15.3
10	16	0.01	<0.01	23.6	155	38	24.3
11	2	<0.01	<0.01	39.0	19	7	39.4
Total	1,308	1.000	---	---	19,061	1,108	5.8

[a] n = number of Arctic grayling sampled at age.
[b] p = estimated adjusted proportion of Arctic grayling at age in the population. Calculated with bootstrap methods (Efron 1982).
[c] SE = estimated standard error of p. Calculated with bootstrap methods (Efron 1982).
[d] CV = coefficient of variation of p, expressed as a percentage of p.
[e] N = estimated population abundance of Arctic grayling at age.
[f] SE = estimated standard error of N (Seber 1982).
[g] CV = coefficient of variation of N, expressed as a percentage of N.

Table 8. Summary of Relative Stock Density (RSD) indices of Arctic grayling (≥ 150 mm FL) captured in the Lower and Upper Chena sections, and the Chena River, 1990.

	RSD Category[a]				
	Stock	Quality	Preferred	Memorable	Trophy
Lower Chena					
RSD	0.87	0.12	0.01	0.00	0.00
Standard Error	0.40	0.03	<0.01	0.00	0.00
Abundance	11,174	1,503	77	0	0
Standard Error	6,351	669	42	0	0
Upper Chena					
Number sampled	1,587	1,202	245	0	0
RSD	0.52	0.40	0.08	0.00	0.00
Adjusted RSD[b]	0.66	0.28	0.06	0.00	0.00
Standard Error	0.04	0.03	<0.01	0.00	0.00
Abundance	12,647	5,349	1,065	0	0
Standard Error	999	686	104	0	0
Chena River					
RSD	0.75	0.21	0.04	0.00	0.00
Standard Error	0.17	0.03	0.01	0.00	0.00
Abundance	23,821	6,853	1,142	0	0
Standard Error	6,377	1,461	258	0	0

[a] Minimum lengths for RSD categories are (Gabelhouse 1984):
Stock - 150 mm FL; Quality - 270 mm FL; Preferred - 340 mm FL;
Memorable - 450 mm FL; and, Trophy - 560 mm FL.

[b] Adjusted RSD is the RSD corrected for differential vulnerability by length from electrofishing. The adjustment is made with bootstrapping methods (Efron 1982). Standard error of RSD is for the adjusted estimate.

Table 9. Estimates of age composition and abundance by age with standard errors for Arctic grayling captured by pulsed-DC electrofishing from the Lower and Upper Chena sections and the Chena River, 1990.

	Lower Chena[a]				Upper Chena[b]				Chena River[c]			
Age	p[d]	SE[e]	N[f]	SE[g]	p	SE	N	SE	p	SE	N	SE
2	0.17	0.10	2,276	1,451	0.02	0.01	409	150	0.08	0.02	2,685	1,447
3	0.52	0.25	6,629	3,876	0.54	0.04	10,253	985	0.53	0.03	16,881	4,172
4	0.14	0.05	1,809	912	0.07	0.01	1,405	151	0.10	0.02	3,215	865
5	0.04	0.01	574	226	0.10	0.01	1,855	274	0.08	0.02	2,429	489
6	0.04	0.01	484	212	0.10	0.01	1,912	249	0.07	0.03	2,396	495
7	0.06	0.02	749	363	0.11	0.02	2,156	343	0.09	0.01	2,905	671
8	0.01	<0.01	141	74	0.03	<0.01	519	68	0.02	0.01	660	154
9	0.01	<0.01	85	52	0.02	<0.01	380	58	0.01	0.01	465	115
10	<0.01	<0.01	7	7	0.01	<0.01	155	38	<0.01	<0.01	162	49
11	0.00	0.00	0	0	<0.01	<0.01	19	7	<0.01	<0.01	19	8
Totals	1.000	---	12,754	4,753	1.00	---	19,061	1,108	1.00	---	31,815	4,880

[a] Lower Chena section - River kilometer 0 to 72.0.
[b] Upper Chena section - River kilometer 72.0 to 152.0.
[c] Chena River - River kilometer 0 to 152.0.
[d] p = estimated proportion of Arctic grayling at age in the section.
[e] SE = estimated standard error of p.
[f] N = estimated population abundance of Arctic grayling at age in the section.
[g] SE = estimated standard error of N.

Table 10. Summary of population abundance, annual survival (%), annual recruitment, and standard error estimates during 1986-1989, and forecasts of recruitment during 1991 and 1992 for Arctic grayling (≥ age 3) in the lower 152 km of the Chena River.

Year	Abundance	SE	Survival	SE	Recruitment	SE
1986[a]	61,581	26,987				
			43.9	20.1	2,526	358
1987[a]	29,580	3,525				
			57.1	8.1	3,373	529
1988[a]	20,268	1,214				
			58.7	9.0	4,332	491
1989[a]	16,236	1,618				
			75.4	11.0	16,881	4,172
1990	29,130	4,373				
					~6,500	---
1991[b]						
					~9,500	---
1992[b]						

[a] Source document for parameter estimates in these years is Clark (1990).
[b] Recruitment estimates for 1990-1991 and 1991-1992 are forecast with an environment-dependent model developed for the Chena River (Clark unpublished).

for sample area A2 and 29.5% for sample area A1. Therefore the problem stems from an inefficient sampling design, and not from insufficient sample sizes for mark-recapture experiments. To remedy this problem, abundance of Arctic grayling in the Lower Chena section of the Chena River will be estimated in 1991 with the same design used for the Upper Chena section in 1990. Precision in estimation of abundance in the Upper Chena exceeded that of all previous years (CV = 5.8%).

Stock Status

During the past five years (1986 through 1990) population abundance, age and compositions, annual recruitment, and annual survival have been estimated for Arctic grayling in the lower 152 km of the Chena River (Clark and Ridder 1987b, 1988; Clark 1989, 1990). Estimates of recruitment and survival during this period indicate low, but increasing recruitment and increasing survival over time (Table 10). Prior to 1990, the last three years of recruitment estimates were well below (average = 3,487 fish, SE = 597 fish, CV = 17.1%) the long-term average of approximately 13,425 recruits annually (range: 2,755 to 24,510 fish; Clark *In Press*). However, recruitment in 1990 exceeded the long-term average for recruitment. Increases in survival rate of the stock have come mainly from increases in survival rate of young (ages 3 through 5) Arctic grayling (see Clark and Ridder 1988, Clark 1989, 1990), indicating that some benefits of the minimum size limit are accruing over time.

Alternatively, annual fishing effort (Table 1) has increased from 23,272 angler-days in 1987 to 30,331 angler-days in 1989. Much of this increase has come from angling days expended in the lower Chena River[3], where annual fishing effort has increased from 12,605 angler-days in 1987 to 20,317 angler-days in 1989 (Table 1). By regulation, this increase in fishing effort is targeted on Arctic grayling that are 305 mm total length or longer (a fork length of approximately 265 mm or an age of 5 years). An increase in harvest has accompanied increases in fishing effort. Annual harvest increased from 2,681 fish in 1987 to 12,635 fish in 1989 (Table 1). Moreover, poor recruitment documented in 1987 (Clark and Ridder 1988) and 1988 (Clark 1989) also caused abundance of mature[4] Arctic grayling to decrease markedly in 1989 (Clark 1990) and 1990 (9,034 fish, SE = 986 fish; see Table 9). Although the abundance of mature Arctic grayling varies annually, average abundance of these age classes since 1976 has been 16,561 fish (range: 5,795 to 37,145 fish; Clark *In Press*). In contrast, the average abundance of mature Arctic grayling from 1987 through 1990 was 10,240 fish (SE = 1,516 fish, CV = 14.8%).

With substantial evidence of poor recruitment to the population in 1987 through 1989 and increases in fishing effort and harvest since 1987, it seems prudent that additional regulatory actions are needed to ensure adequate protection of mature Arctic grayling in the Chena River. If regulatory action is taken, it must ensure a substantial reduction in fishing mortality.

[3] The lower Chena River in this context is that portion of the Chena River accessable from km 40 of the Chena Hot Spring Road downstream to the mouth of the Chena River (approximately the lower 108.8 km of the Chena River).

[4] Arctic grayling in the Chena River were found to be sexually mature at age 5 and older (Van Hulle 1968).

Because forecasts of annual recruitment in 1991 and 1992 (Table 10) are below the long-term average for recruitment, the likely abundance of mature Arctic grayling in 1993 and 1994 will be insufficient to sustain the same annual harvest seen in 1989 (approximately 12,000 fish).

Future Research

Although the stock assessment program for Arctic grayling in the Chena River provides estimates of many of the parameters needed to describe stock status on an annual basis, other kinds of data are needed to aid in the development of a management plan for this stock. Although Tack (1973) surmised that flooding of the Chena River could affect year-class strength, potential factors influencing recruitment were not rigorously investigated until 1990 (Clark *In Press*). Age and size at maturity data were last collected in 1967 by Van Hulle (1968). To update these data, age and size at maturity will be investigated in 1991 and 1992. Assessment of annual intrastream movements of Arctic grayling was last performed in 1979 (Tack 1980). Recaptures of Arctic grayling tagged during 1987 through 1990 will be used to determine the extent of annual intrastream migration in the lower 152 km of the Chena River. A comprehensive assessment of growth of Arctic grayling in the Chena River was last performed in 1988 (Appendix A8; Clark 1989). Validation of the growth model, using recaptures of marked fish, should be performed in the near future. Lastly, annual changes in stock status have never been fully investigated. An analysis and comparison of Arctic grayling stock status during 1979 through 1990 should be completed in late 1991.

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APPENDIX A
Historic Data Summary

Appendix A1. Source citations for Federal Aid and Fishery Data Reports used for data summaries, 1955-1958 and 1967-1990.

Year	Type of Data[a]	Source Document
1955	CC	Warner (1959)
1956	CC	Warner (1959)
1957	CC	Warner (1959)
1958	CC	Warner (1959)
1967	AL, CC, POP	Van Hulle (1968)
1968	AL, CC, POP	Roguski and Winslow (1969)
1969	AL, CC, POP	Roguski and Tack (1970)
1970	CC, POP	Tack (1971)
1971	POP	Tack (1972)
1972	CC, POP	Tack (1973)
1973	AL, POP	Tack (1974)
1974	AL, CC, POP	Tack (1975)
1975	AL, CC, POP	Tack (1976)
1976	AL, CC, POP	Hallberg (1977)
1977	AL, CC, POP	Hallberg (1978)
1978	AL, CC, POP	Hallberg (1979)
1979	AL, CC, POP	Hallberg (1980)
1980	AL, CC, POP	Hallberg (1981)
1981	AL, CC, POP	Hallberg (1982)
1982	AL, CC, POP	Holmes (1983)
1983	AL, CC, POP	Holmes (1984)
1984	AL, CC, POP	Holmes (1985)
1985	AL, CC, POP	Holmes et al. (1986)
1986	CC	Clark and Ridder (1987a)
	AL, POP	Clark and Ridder (1987b)
1987	CC	Baker (1988)
1987	AL, POP	Clark and Ridder (1988)
1988	CC	Baker (1989)
	AL, POP	Clark (1989)
1989	CC	Merritt et al. (1990)
	AL, POP	Clark (1990)
1990	AL, POP	Clark (this report)

[a] CC = Creel census estimates;
AL = age and size composition estimates; and,
POP = population abundance estimates.

Appendix A2. Chena River study sections used from 1968 to 1985[a].

Section Number	Section Name	River Kilometers	Length in Kilometers
1	River mouth to University Ave.	0-9.6	9.6
2A	University Ave. to Peger Road	9.6-12.8	3.2
2B	Peger Road to Wendell Street	12.8-17.6	4.8
3	Wendell St. to Wainwright Bridge	17.6-23.2	5.6
4	Wainwright Bridge to Badger Slough	23.2-34.4	11.2
5	Badger Slough		26.4
6	Badger Slough to Little Chena R.	34.4-39.2	4.8
7	Little Chena River		98.4
8	Little Chena to Nordale Slough	39.2-49.6	10.4
DS	Nordale Slough to Bluffs	49.6-88.8	39.2
9B	Bluffs to Bailey Bridge	88.8-100.8	12.0
10	Bailey Bridge to Hodgins Slough	100.8-126.4	25.6
11	Hodgins Slough to 90 Mi. Slough	126.4-144.0	17.6
12	90 Mi. Slough to First Bridge	144.0-147.2	3.2
13	First Bridge to Second Bridge	147.2-151.2	4.0
14	Second Bridge to North Fork	151.2-163.2	12.0
15	North Fork of Chena River		56.0
16	East Fork of Chena River		99.2
17	West Fork of Chena River		56.0

[a] Taken from Hallberg 1980.

Appendix A3. Summary of population abundance estimates of Arctic grayling (≥ 150 mm FL) in the Chena River, 1968-1990.

Year	Dates	Area[a]	Estimator[b]	Estimate	Confidence[c]
1968	Summer?	2	SN	411/km	393-1,209
	Summer?	6	SN	283/km	228-381
1969	June?	2	SN	596/km	474-850
	June?	6	SN	571/km	439-816
1970	7/02-7/10	2	SN	919/km	690-1,519
	5/26-5/30	6	SN	373/km	346-408
	6/08-7/08	9B	SN	1,005/km	803-1,411
	6/07-7/07	10	SN	1,171/km	876-1,957
1971	8/30-9/03	2A	SN	300/km	192-1,157
	6/02-6/07	2B	SN	1,302/km	958-2,305
	8/30-9/03	2B	SN	2,338/km	1,753-3,897
	6/21-6/24	6	SN	189/km	161-233
1972	6/22-6/26	2A	SN	309/km	236-489
	6/22-6/26	2B	SN	608/km	493-828
	6/19-6/20	6	SN	159/km	124-235
	6/27-6/29	DS	SN	812/km	604-1,393
1973	7/10-7/13	2A	SN	293/km	218-502
	7/03-7/14	2B	SN	424/km	354-545
	7/16-7/17	6	SN	243/km	203-312
	7/18-7/19	DS	SN	500/km	379-806
1974	6/26-6/28	2A	SE	65/km	36-372
	6/25-6/28	2B	SE	488/km	207-1,378
	8/13-8/15	6	SE	100/km	71-164
	7/09-7/11	DS	SE	263/km	221-326
1975	7/10-7/14	6	SE	191/km	114-589
1976	7/19-7/21	2A	SE	258/km	223-307
	7/22-7/24	2B	SE	409/km	323-556
	7/28-7/30	6	SE	163/km	153-175
	8/04-8/06	DS	SE	306/km	285-329
1977	7/05-7/08	2A	SE	318/km	298-343
	7/11-7/14	2B	SE	318/km	280-370
	7/18-7/21	6	SE	173/km	170-177
	7/26-7/30	DS	SE	315/km	283-359
1978	7/14-7/17	2A	SE	69/km	44-156
	7/25-7/28	2B	SE	162/km	148-179
	7/10-7/13	6	SE	226/km	210-243
	8/08-8/11	DS	SE	345/km	333-359

-continued-

Appendix A3. (Page 2 of 2).

Year	Dates	Area[a]	Estimator[b]	Estimate	Confidence[c]
1979	7/01-7/03	2A	SE	57/km	45-76
	6/26-6/30	2B	SE	201/km	188-216
	8/20-8/23	8A	SE	177/km	161-197
	7/17-7/20	DS	SE	193/km	144-288
1980	7/01-7/04	2B	SE	308/km	229-471
	7/14-7/17	8A	SE	190/km	154-248
	7/29-8/01	DS	SE	236/km	200-287
	8/12-8/15	10B	SE	842/km	640-1,234
1981	8/07-8/10	2B	SN	262/km	223-392
	8/03-8/06	8A	SN	224/km	164-309
	8/11-8/14	DS	SN	302/km	174-440
	7/21-7/24	10B	SN	869/km	466-1,778
1982	7/16-7/20	2B	SN	116/km	79-177
	7/13-7/15	8A	SN	87/km	60-132
	7/23-7/27	DS	SN	232/km	113-579
	7/28-7/30	10B	SN	875/km	529-1563
1983	7/13-7/15	2B	SN	216/km	168-265
	7/05-7/07	8A	SN	119/km	81-545
	7/8,7/11-7/12	DS	SN	209/km	149-303
	7/26-7/28	10B	SN	911/km	647-1,338
	7/19-7/21	12	SN	208/km	138-332
1984	7/16-7/18	2B	SN	211/km	167-268
	7/3,7/05-7/06	8A	SN	139/km	95-215
	7/09-7/11	DS	SN	179/km	124-273
	7/19-7/20	10B	P	493/km	275-1,003
	7/31,8/02-8/03	12	SN	1,318/km	449-6,592
1985	7/10-7/17	2B	SN	189/km	92-287
	6/26-7/02	8A	SN	271/km	189-360
	7/03-7/08	DS	SN	333/km	234-432
	7/22-7/31	10B	SN	1,156/km	304-3,035
	6/12-6/24	12	SN	1,092/km	552-1,643
1986	7/07-8/06	WC	EXP	61,581	SE = 26,987
1987	6/27-7/30	WC	EXP+P	31,502	SE = 3,500
1988	6/26-8/04	WC	EXP+P	22,204	SE = 2,092
1989	7/10-8/03	WC	EXP+P	19,028	SE = 1,578
1990	7/2-8/03	WC	EXP+P	31,815	SE = 4,880

[a] Areas are taken from Hallberg (1980); WC = Whole Chena River (lower 152 km).

[b] Estimators are: SN = Schnabel; SE = Schumacher-Eschmeyer; P = Petersen (Ricker 1975); EXP = Expanded estimates (Clark and Ridder 1987b); EXP+P = expanded estimates and a Petersen estimate (Clark and Ridder 1988).

[c] Confidence is either the 95% confidence interval or the Standard Error (SE) of the estimate.

Appendix A4. Summary of Arctic grayling creel census on the Chena River, 1955-1958, 1967-1970, 1972, and 1974-1989.

Year	Dates	Area	Angler Hours	Harvest	CPUE	Mean Length
1955	ND	Lower Chena	---	---	0.89	226
1956	ND	Lower Chena	---	---	0.95	251
1957	ND	Lower Chena	---	---	0.62	246
1958	ND	Lower Chena	---	---	0.88	226
1967	4/10 to 8/11	Entire Chena	12,885	---	0.32	245
1968	5/01 to 9/02	Entire Chena	10,269	5,643	0.55	251
1969	7/01 to 9/30	Entire Chena	7,998	7,686	0.96	263
1970	5/01 to 5/30 and 7/01 to 8/31	Entire Chena	12,518	6,770	0.54	---
1972	5/25 to 8/27	Lower Chena	13,116	10,099	0.77	---
1974	7/01 to 8/31	Upper Chena	11,680	18,049	1.72	---
1975	6/01 to 8/31	Upper Chena	22,657	14,067	0.62	252
1976	6/01 to 8/31	Upper Chena	10,762	4,161	0.39	230
1977	6/01 to 8/31	Upper Chena	13,563	9,406	0.71	208
1978	5/29 to 8/31	Upper Chena	10,508	6,898	0.65	222
1979	6/01 to 8/31	Upper Chena	12,564	8,544	0.69	240
1980	5/08 to 9/30	Upper Chena	20,827	16,390	0.78	256
1981	5/01 to 8/31	Upper Chena	15,896	13,549	0.80	---
1982	5/01 to 9/15	Upper Chena	20,379	12,603	0.62	248
1983	5/01 to 9/15	Upper Chena	19,018	10,821	0.58	260
1984	5/06 to 9/15	Upper Chena	17,090	9,623	0.59	278
1985	5/08 to 9/05	Upper Chena	10,613	2,367	0.22	273
1986	5/10 to 9/15	Upper Chena	10,716	3,326	0.31	271
1987	5/18 to 9/15	Upper Chena	9,090	1,260	0.14	290
1988	5/14 to 9/13	Upper Chena	11,763	1,583	0.13	287
1989	5/19 to 9/13	Upper Chena	11,349	3,325	0.21	295

Appendix A5. Summary of age composition estimates of Arctic grayling in the Chena River, 1967-1969 and 1973-1990.

Year	Age 0		Age 1		Age 2		Age 3		Age 4		Age 5		Age 6		Age 7		Age 8		Age 9		Age 10		Age 11	
	p[a]	SE[b]	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE
1967	0.10	0.02	0.13	0.02	0.13	0.02	0.06	0.01	0.17	0.02	0.25	0.02	0.11	0.02	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1968	0.09	0.03	0.21	0.04	0.24	0.04	0.25	0.04	0.13	0.03	0.03	0.01	0.05	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1969	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.06	0.38	0.07	0.12	0.05	0.16	0.05	0.06	0.03	0.06	0.03	0.00	0.00	0.00	0.00	0.00	0.00
1973	0.00	0.00	0.06	0.02	0.13	0.02	0.61	0.03	0.18	0.03	0.03	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.04	0.01	0.11	0.02	0.12	0.02	0.44	0.03	0.25	0.02	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.13	0.04	0.25	0.05	0.13	0.04	0.26	0.05	0.19	0.04	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.10	0.02	0.24	0.03	0.29	0.03	0.15	0.02	0.09	0.02	0.11	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.06	0.02	0.34	0.03	0.45	0.03	0.08	0.02	0.06	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.15	0.02	0.38	0.03	0.22	0.03	0.21	0.02	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1979	0.00	0.00	0.11	0.02	0.20	0.03	0.45	0.03	0.17	0.03	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.02	0.01	0.12	0.02	0.39	0.03	0.28	0.03	0.13	0.02	0.05	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.16	0.02	0.13	0.02	0.40	0.02	0.12	0.02	0.12	0.02	0.06	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.06	0.01	0.30	0.03	0.11	0.02	0.35	0.03	0.09	0.02	0.04	0.01	0.02	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1983	0.01	0.01	0.07	0.01	0.11	0.01	0.45	0.02	0.08	0.01	0.17	0.02	0.06	0.01	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.19	0.02	0.07	0.01	0.12	0.02	0.41	0.02	0.08	0.01	0.09	0.01	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.00	0.02	0.00	0.16	0.01	0.11	0.01	0.14	0.01	0.32	0.01	0.10	0.01	0.10	0.01	0.04	0.00	0.02	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.01	0.07	0.01	0.09	0.01	0.13	0.01	0.04	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.05	0.01	0.08	0.01	0.60	0.03	0.07	0.01	0.05	0.01	0.10	0.02	0.02	0.01	0.02	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.09	0.02	0.15	0.02	0.12	0.02	0.42	0.04	0.07	0.01	0.06	0.01	0.07	0.01	0.02	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.15	0.02	0.23	0.03	0.14	0.02	0.14	0.02	0.22	0.03	0.06	0.01	0.04	0.01	0.03	0.01	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.08	0.04	0.53	0.08	0.10	0.03	0.08	0.02	0.07	0.02	0.09	0.02	0.02	0.01	0.01	0.00	<0.01	0.00	<0.01	0.00

[a] p = the proportion of the sample at age.
[b] SE = the standard error of p.

Appendix A6. Summary of mean length at age estimates of Arctic grayling from the Chena River, 1967-1969 and 1973-1990.

Year	Age 0 n[a]	Age 0 FL[b]	Age 1 n	Age 1 FL	Age 2 n	Age 2 FL	Age 3 n	Age 3 FL	Age 4 n	Age 4 FL	Age 5 n	Age 5 FL	Age 6 n	Age 6 FL	Age 7 n	Age 7 FL	Age 8 n	Age 8 FL	Age 9 n	Age 9 FL	Age 10 n	Age 10 FL	Age 11 n	Age 11 FL
1967	30	25	41	135	41	186	17	243	51	272	77	293	32	321	15	335	0	---	0	---	0	---	0	---
1968	10	73	24	103	28	150	29	214	15	255	3	289	6	304	2	372	0	---	0	---	0	---	0	---
1969	0	---	0	---	0	---	11	191	19	236	6	273	8	304	3	317	3	356	0	---	0	---	0	---
1973	0	---	11	111	25	167	121	194	36	215	6	279	0	---	1	310	0	---	0	---	0	---	0	---
1974	0	---	12	130	32	169	37	199	133	217	76	236	12	259	1	315	0	---	0	---	0	---	0	---
1975	0	---	0	---	12	171	22	200	12	229	23	238	17	258	2	275	1	320	0	---	0	---	0	---
1976	0	---	26	144	61	175	74	194	39	221	24	249	28	270	4	308	0	---	0	---	0	---	0	---
1977	0	---	14	112	77	176	102	208	19	245	13	263	4	299	0	---	0	---	0	---	0	---	0	---
1978	0	---	39	128	102	167	59	206	56	230	9	256	2	290	1	325	0	---	0	---	0	---	0	---
1979	0	---	25	107	44	165	99	197	38	236	11	266	1	310	0	---	0	---	0	---	0	---	0	---
1980	0	---	4	114	31	154	97	198	71	231	33	259	12	292	3	327	0	---	0	---	0	---	0	---
1981	0	---	61	112	48	162	152	187	46	215	47	240	22	268	5	287	3	310	0	---	0	---	0	---
1982	0	---	19	105	88	137	34	190	105	215	26	251	11	279	7	305	6	337	0	---	0	---	0	---
1983	6	62	33	114	53	151	215	177	38	216	83	239	29	273	13	307	7	338	0	---	0	---	0	---
1984	0	---	82	97	32	153	54	182	179	213	36	226	40	257	7	275	6	321	0	---	0	---	0	---
1985	0	---	42	108	300	141	203	188	267	215	609	233	182	285	188	285	80	308	30	377	2	377	0	---
1986	0	---	40	109	104	164	755	184	79	220	110	251	153	270	42	301	22	318	5	330	1	346	0	---
1987	0	---	0	---	54	160	92	204	691	228	115	274	76	292	184	309	30	324	31	338	2	353	0	---
1988	0	---	7	108	135	172	238	216	181	239	707	260	118	288	95	313	110	325	35	347	7	337	2	374
1989	0	---	17	123	285	156	295	215	205	254	245	272	423	285	112	314	73	329	54	347	5	372		
1990	0	---	13	129	134	174	840	207	232	251	223	280	221	298	284	308	63	332	43	340	17	362	2	359
Average		40		114		159		198		230		255		285		305		323		348		358		366

[a] n = sample size.
[b] FL = the arithmetic mean fork length in millimeters.

Appendix A7. Summary of Relative Stock Density (RSD) indices of Arctic grayling (≥ 150 mm FL) captured by electrofishing from the Chena River, 1972-1990.

	RSD Category[a]				
	Stock	Quality	Preferred	Memorable	Trophy
1972 (2A, 2B, 6, DS) - 6/19-6/22[b]					
Sample size	1,392	42	3	0	0
RSD	0.97	0.03	<0.01	0.00	0.00
Standard Error	0.01	<0.01	<0.01	0.00	0.00
1973 (2A, 2B, 6, DS) - 7/3-7/19					
Sample size	176	7	0	0	0
RSD	0.96	0.04	0.00	0.00	0.00
Standard Error	0.01	0.01	0.00	0.00	0.00
1974 (2A, 2B, 6, DS) - 6/25-8/15					
Sample size	889	58	0	0	0
RSD	0.94	0.06	0.00	0.00	0.00
Standard Error	0.01	0.01	0.00	0.00	0.00
1975 (6) - 7/10-7/14					
Sample size	76	13	0	0	0
RSD	0.85	0.15	0.00	0.00	0.00
Standard Error	0.04	0.04	0.00	0.00	0.00
1976 (2A, 2B, 6, DS) - 7/19-8/6					
Sample size	613	59	1	0	0
RSD	0.91	0.09	<0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
1977 (2A, 2B, 6, DS) - 7/5-7/30					
Sample size	916	30	0	0	0
RSD	0.967	0.03	0.00	0.00	0.00
Standard Error	0.01	0.01	0.00	0.00	0.00
1978 (2A, 2B, 6, DS) - 7/10-8/11					
Sample size	841	20	0	0	0
RSD	0.98	0.02	0.00	0.00	0.00
Standard Error	0.01	0.01	0.00	0.00	0.00

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Appendix A7. (Page 2 of 3).

	RSD Category[a]				
	Stock	Quality	Preferred	Memorable	Trophy
1979 (2A, 2B, 8A, DS) - 6/26-8/23					
Sample size	802	13	0	0	0
RSD	0.98	0.02	0.00	0.00	0.00
Standard Error	<0.01	<0.01	0.00	0.00	0.00
1980 (2B, 8A, DS, 10B) - 7/1-8/15					
Sample size	1,260	53	2	0	0
RSD	0.96	0.04	<0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
1981 (2B, 8A, DS, 10B) - 7/21-8/14					
Sample size	1,247	42	1	0	0
RSD	0.97	0.03	<0.01	0.00	0.00
Standard Error	<0.01	<0.01	<0.01	0.00	0.00
1982 (2B, 8A, DS, 10B) - 7/13-7/30					
Sample size	919	76	5	0	0
RSD	0.92	0.08	0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
1983 (2B, 8A, DS, 10B, 12) - 7/5-7/28					
Sample size	1,560	152	10	0	0
RSD	0.91	0.09	0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
1984 (2B, 8A, DS, 10B, 12) - 7/3-8/3					
Sample size	1,349	74	4	0	0
RSD	0.95	0.05	<0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
1985 (2B, 8A, DS, 10B, 12) - 6/12-7/31					
Sample size[c]	ND	ND	ND	ND	ND
RSD	---	---	---	---	---
Standard Error	---	---	---	---	---

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Appendix A7. (Page 3 of 3).

	RSD Category[a]				
	Stock	Quality	Preferred	Memorable	Trophy
<u>1986 (lower 152 km) - 7/7-8/6</u>					
Sample size	1,268	160	29	0	0
RSD	0.87	0.11	0.02	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
<u>1987 (lower 152 km) - 6/27-7/30</u>					
Sample size	1,678	693	154	0	0
RSD	0.67	0.27	0.06	0.00	0.00
Adjusted RSD[d]	0.78	0.19	0.03	0.00	0.00
Standard Error[e]	0.04	0.04	0.01	0.00	0.00
<u>1988 (lower 152 km) - 6/26-8/4</u>					
Sample size[f]	1,855	1,242	217	0	0
RSD	0.63	0.32	0.05	0.00	0.00
Standard Error	0.04	0.03	0.01	0.00	0.00
<u>1989 (lower 152 km) - 7/10-8/3</u>					
Sample size[f]	1,363	1,340	184	0	0
RSD	0.47	0.46	0.06	0.00	0.00
Adjusted RSD[d]	0.57	0.38	0.05	0.00	0.00
Standard Error[e]	0.04	0.04	0.01	0.00	0.00
<u>1990 (lower 152 km) - 7/2-8/3</u>					
Sample size[f]	2,239	1,389	255	0	0
RSD	0.58	0.36	0.06	0.00	0.00
Adjusted RSD[d]	0.75	0.21	0.04	0.00	0.00
Standard Error[e]	0.17	0.03	0.01	0.00	0.00

[a] Minimum lengths for RSD categories are (Gabelhouse 1984):
Stock - 150 mm FL; Quality - 270 mm FL; Preferred - 340 mm FL;
Memorable - 450 mm FL; and, Trophy - 560 mm FL.

[b] Year (sections sampled (taken from Hallberg 1980)) - sampling dates.

[c] Lengths were taken in 1985, but not reported in Holmes et al. (1986).

[d] RSD was adjusted to correct for bias due to the electrofishing boat (Clark and Ridder 1988).

[e] Standard error is for adjusted RSD only.

[f] Sample sizes do not correspond to RSD proportions because RSD proportions are weighted by abundance estimates in a stratified design (Clark 1989) and RSD is adjusted to correct for bias due to the electrofishing boat (Clark and Ridder 1988).

Appendix A8. Parameter estimates and standard errors of the von Bertalanffy growth model[a] for Arctic grayling from the Chena River, 1986-1988.

Parameter	Estimate	Standard Error
L_∞[b]	538	21
K[c]	0.10	0.01
t_0[d]	-1.72	0.11
$Corr(L_\infty, K)$[e]	-0.99	---
$Corr(L_\infty, t_0)$	-0.91	---
$Corr(K, t_0)$	0.95	---
Sample size	4,301	

[a] The form of the von Bertalanffy growth model (Ricker 1975) is as follows: $l_t = L_\infty (1 - exp(-K (t - t_0)))$. The parameters of this model were estimated with data collected during 1986 through 1988. This model was fitted to the data by nonlinear regression (SAS 1985) utilizing the Marquardt compromise (Marquardt 1963). The range of ages used to model growth was age 1 through age 11.

[b] L_∞ is the length a fish would achieve if it continued to live and grow indefinitely (Ricker 1975).

[c] K is a constant that determines the rate of increase of growth increments (Ricker 1975).

[d] t_0 represents the hypothetical age at which a fish would have zero length (Ricker 1975).

[e] $Corr(x,y)$ is the correlation of parameter estimates x and y.

APPENDIX B
Potential Bias in Abundance Estimation

Appendix B1. Estimates of potential bias in abundance estimates of Arctic grayling (≥ 150 mm FL) due to sampling selectivity in the Upper Chena section of the Chena River, 1987-1990.

Year	Without stratification[a]	With stratification[b]	Potential bias[c] (%)
1987	20,746	24,446	15.1
1988	14,444	NA[d]	0
1989	14,082	14,863	5.2
1990	16,643	19,061	12.7

[a] Without stratification is the estimated abundance of Arctic grayling (≥ 150 mm FL) if stratification by size had not been used to reduce bias due to size selectivity.

[b] With stratification is the estimated abundance of Arctic grayling (≥ 150 mm FL) if stratification by size had been used to reduce bias due to size selectivity.

[c] Potential bias is the difference between estimates without stratification and with stratification if stratification was needed, expressed as a percentage.

[d] NA means that a stratified estimate of abundance was not performed because changes in capture probability by size of fish were not detected.

APPENDIX C
Data File Listing

Appendix C1. Data files[a] used to estimate parameters of the Arctic grayling population in the Chena River in 1990.

Data file	Description
U002ALA0.DTA	Population and marking data for Arctic grayling captured in sample area A2 of the Lower Chena section of the Chena River (river km 33.6 to 36.8), 2 through 6 July 1990.
U002BLA0.DTA	Population and marking data for Arctic grayling captured in sample area A1 of the Lower Chena section of the Chena River (river km 24.0 to 27.2) 2 through 6 July 1990.
U002CLA0.DTA	Population and marking data for Arctic grayling captured in sample area B2 of the Lower Chena section of the Chena River (river km 59.2 to 62.4) 16 through 21 July 1990.
U002DLA0.DTA	Population and marking data for Arctic grayling captured in sample area B1 of the Lower Chena section of the Chena River (river km 49.6 to 52.8) 16 through 21 July 1990.
U001ELA0.DTA	Population and marking data (first event) for Arctic grayling captured in the Upper Chena section of the Chena River (river km 72 to 152) 24 through 27 July 1990.
U001FLA0.DTA	Population and recapture data (second event) for Arctic grayling captured in the Upper Chena section of the Chena River (river km 72 to 152) 31 July through 3 August 1990.

[a] Data files have been archived at, and are available from the Alaska Department of Fish and Game, Sport Fish Division, Research and Technical Services, 333 Raspberry Road, Anchorage, Alaska 99518-1599.