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Stock Assessment of Arctic Grayling in Fielding Lake

by

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Alaska Department of Fish and Game

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ABSTRACT

During 1986 through 1990, boat electrofishing, fyke nets, seines, and gill nets were used to capture and mark 4,273 Arctic grayling *Thymallus arcticus* in Fielding Lake. Abundance in 1990 was estimated with the modified Petersen estimator, while the Jolly-Seber capture-recapture estimator was used to estimate abundance, survival rate, and recruitment for 1986 through 1990. Abundance estimates (fish greater than 199 millimeter fork length) ranged from 4,512 fish in 1987 to 8,837 fish in 1988. Annual survival rate ranged from 0.42 to 0.84 during the period, while annual recruitment ranged from 895 fish to 5,043 fish during the period. Age 3 through age 5 Arctic grayling were not fully recruited to the defined population (fish greater than 199 millimeter fork length), while age 6 through age 10 fish were fully recruited. Onset of sexual maturity of Fielding Lake Arctic grayling was at 4 years (fifth summer) and 265 millimeter fork length. Estimated sex composition of mature fish was stable during the five year period, consisting of 48 percent males and 52 percent females. Instantaneous rates of fishing and natural mortality averaged 0.23 and 0.48, respectively during the five year period. Available data suggest a relatively stable Arctic grayling stock in Fielding Lake, although causative mechanisms of variability in recruitment are unknown at the present.

KEY WORDS: Arctic grayling, *Thymallus arcticus*, abundance, survival rate, recruitment, age composition, size composition, Relative Stock Density, maturity, sex composition, instantaneous mortality rates, Fielding Lake.

INTRODUCTION

Fielding Lake (63°10′ N, 145°58′ W; Figure 1) supports a recreational fishery that targets on Arctic grayling, lake trout *Salvelinus namaycush*, burbot *Lota lota*, and round whitefish *Prosopium cylindraceum*. Harvests of Arctic grayling are numerically most abundant of the four species utilized in the fishery. Over the past nine years, anglers have taken an annual average of 1,551 Arctic grayling and expended an annual average of 1,541 days of fishing effort (Table 1). Recreational fishing for Arctic grayling begins with ice-out each year (Clark and Ridder 1987a). The heaviest fishing pressure usually occurs during a two week period in early July (Clark and Ridder 1987a). Although not currently a major Arctic grayling fishery in interior Alaska, road access and the availability of quality Arctic grayling fishing makes Fielding Lake potentially susceptible to increased fishing effort in the future.

Prior to 1986, investigations of Arctic grayling in Fielding Lake were confined to spawning habits (Warner 1955b) and sport angling pressure and success rate (Warner 1959; Peckham 1977, 1983, 1984, 1985; Holmes, et al. 1986; Clark and Ridder 1987a; and Baker 1988). Quantitative research on Arctic grayling in Fielding Lake was initiated in 1986 (Clark and Ridder 1987b). Estimates of Arctic grayling abundance, survival, and recruitment have been calculated for 1986 to the present. These estimates and age, size, and sex composition data, are used to describe the status of the Fielding Lake Arctic grayling stock.

Stock Assessment Goals and Objectives

The long-term goals of stock assessment at Fielding Lake are to:

1) accurately and precisely describe the stock status of Fielding Lake Arctic grayling on an annual basis;

2) use stock status data in models that predict the consequences of regulatory actions or changes in recreational fishing pressure; and,

3) provide fishery managers with stock status data and model results, so that informed management decisions can be made on Fielding Lake.

As part of attaining the first stock assessment goal, the objectives of 1990 research efforts were to estimate:

1) abundance of Arctic grayling greater than 199 mm fork length (FL) in Fielding Lake;

2) age composition of the Arctic grayling population in Fielding Lake; and,

3) size composition of the Arctic grayling population in Fielding Lake.

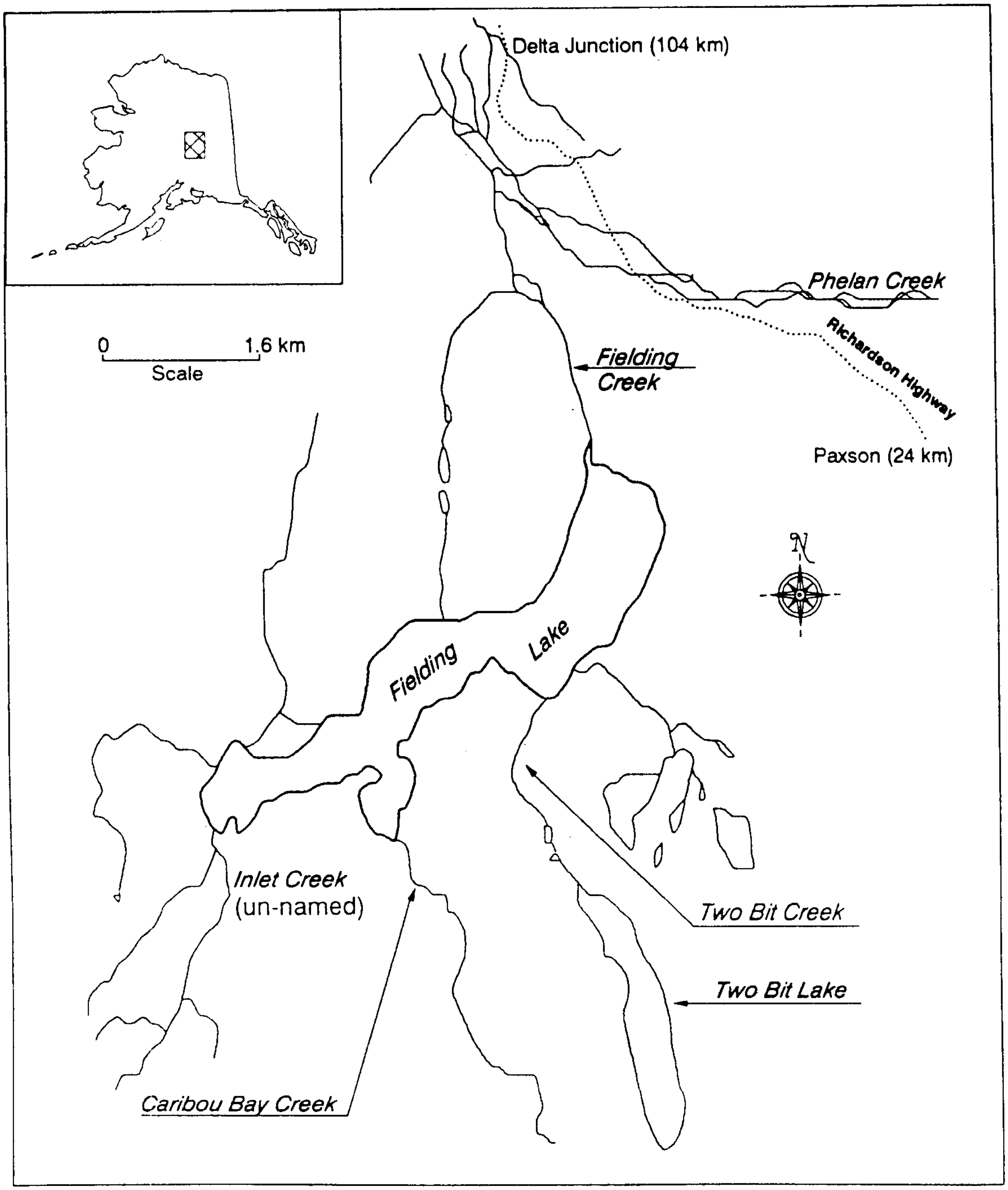

Figure 1. Fielding Lake and its tributary streams.

Table 1. Summary of total angling effort and Arctic grayling harvest at Fielding Lake, 1981-1989[a].

Year	Total Angler-days	Arctic Grayling Harvest (number of fish)
1981	1,369	1,913
1982	2,764	3,044
1983	1,737	2,035
1984	871	935
1985	1,023	1,023
1986	1,682	1,329
1987	1,032	910
1988	1,728	1,492
1989	1,664	1,283
Averages	1,541	1,551

[a] Source is Mills (1982-1990).

In addition, survival rate, recruitment, sex ratio, maturity at age, maturity at length, tag shedding rate, and instantaneous mortality rates were estimated from data collected during 1986 through 1990.

METHODS

Sampling Gear and Techniques

Fyke nets, seines, gill nets, and electrofishing gear were used to capture Arctic grayling in Fielding Lake from 1986 through 1990. The fyke nets used in Fielding Lake were the New Hampshire style with 10 mm meshes. Fyke nets were used in two ways. One method was to place the net out from shore with a lead stretching from the throat of the trap to the shore. Fish moving along the shore of the lake would be guided into the trap. A second method of deployment was to block off inlet creeks at their mouths. Wings were attached to the fyke nets and they were anchored along the banks of the lake inlets with the throat facing upstream. Arctic grayling migrating downstream after spawning were caught with these "fyke weirs."

Seines were used to capture Arctic grayling in the outlet of Fielding Lake and one of the inlets (Caribou Bay Creek; see Figure 2) during 1986 through 1988. These seines were 15 m × 2 m with 10 mm mesh and a 1 m deep bag. Arctic grayling were captured by hauling the seine downstream with the current, and then sweeping the seine towards shore. The area sampled averaged 30 m in length. In 1987, a large seine (30 m × 3 m with 25 mm mesh) was used to capture Arctic grayling in Fielding Lake. One end of the seine was anchored on shore and the body of the seine was pulled into the lake with a gas-powered boat. The free end of the seine was retrieved by hand. Seining was not performed in 1989 or 1990.

Gill nets were used to capture lake trout in Fielding Lake in 1989. Arctic grayling were incidentally captured along with round whitefish. These nets were 30 m × 3 m with 25 mm mesh and were deployed perpendicular to the shoreline approximately 10 to 15 m from shore. Nets were checked once every hour.

Pulsed direct-current (DC) and alternating-current (AC) electrofishing boats were used to capture Arctic grayling during 1986 through 1988. Pulsed-DC electrofishing was used exclusively in 1989 and 1990. Both types of electrofishing current were used from 6.1 m river boats fitted with a 3 m long "T-boom" attached to a platform at the bow of the boat. Anodes were constructed of 9.5 mm diameter and 1.5 m long twisted steel cable, or 12.5 mm diameter and 1.5 m long flexible conduit filled with lead shot. On the DC system, the aluminum hull of the boat was used as the cathode. Input voltage (120 VAC) was provided by a 3,500 or 4,000 W single-phase gas powered generator. A variable voltage pulsator was used to generate output current. Output voltages during sampling varied from 200 to 300 VDC and 150 to 185 VAC. Amperage varied from 2.0 to 4.0 amp using DC and 1.0 to 2.0 amp using AC. Duty cycle was held constant at 40%. Pulse rate was held at 80 Hz from 1986 through 1988 and held at 60 Hz in 1989 and 1990.

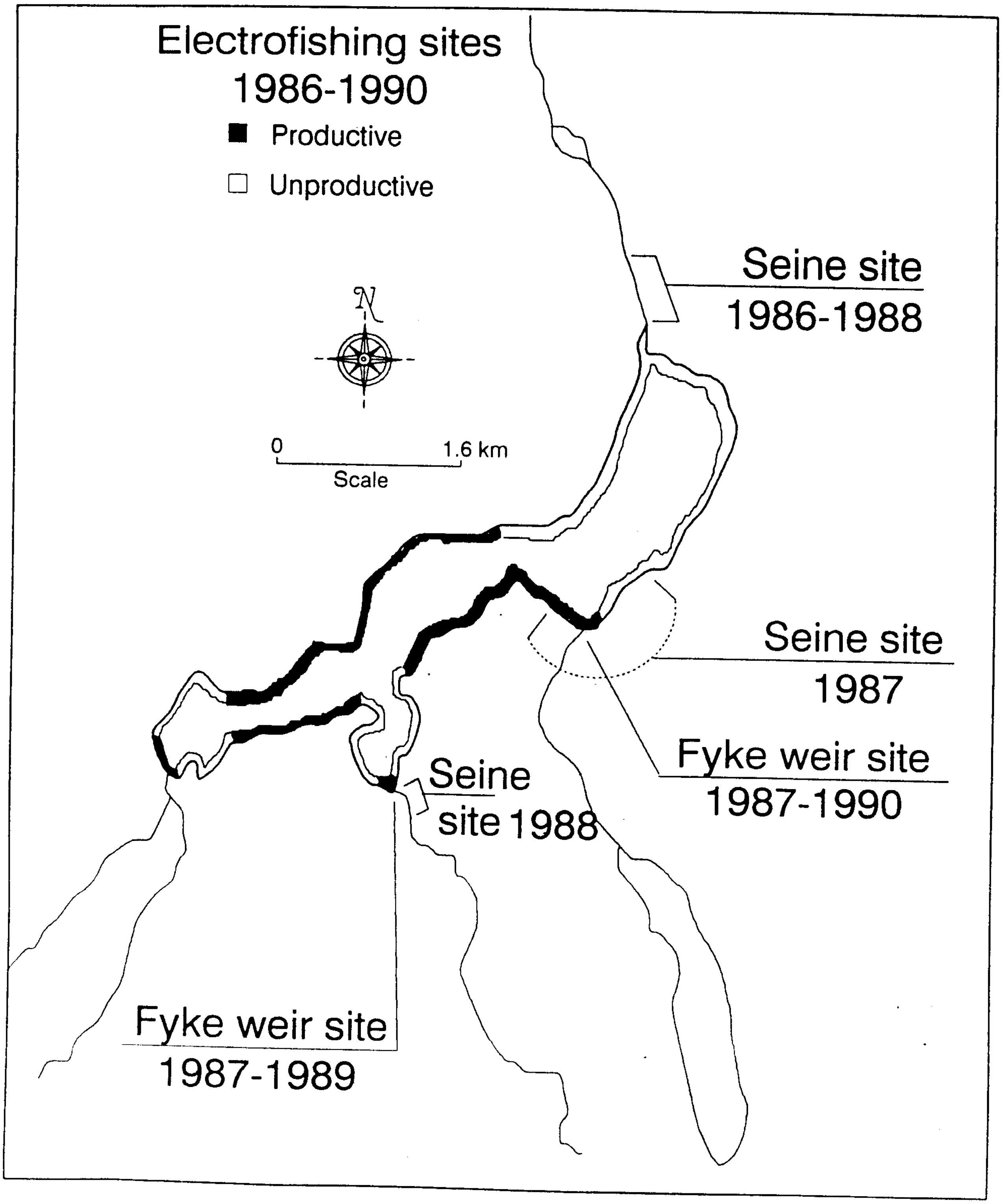

Figure 2. Sampling sites at Fielding Lake during 1986 through 1990.

Sampling with electrofishing boats was conducted along the shoreline of Fielding Lake during hours of darkness. Although most of the shoreline of Fielding Lake was sampled with electrofishing gear during all five years, greatest catches of Arctic grayling occurred on the windward side of the lake and over cobble and boulder substrate (Figure 2). To reduce capture-related stress, Arctic grayling were held in an aerated holding tub and subsequently transferred to a 2.4 m × 1.2 m holding pen anchored near the lake shore. Fish were sampled for age, sex, maturity, and length within 24 hours of capture.

Regardless of sampling gear, each captured Arctic grayling was measured to the nearest 1 millimeter FL. Sex was determined by external morphology (Clark and Ridder 1987b), or by the presence of sex products. A sample of at least two scales was taken from the preferred zone[1] of each newly captured Arctic grayling. Scales were processed by immersion in a solution of hot water (~90°C) and laundry soap, cleaned with a tooth brush, and mounted on gum cards. The gum cards were used to make triacetate impressions of the scales (30 seconds at 137,895 kPa, at a temperature of 97°C). These impressions were read once, with the aid of a microfiche reader, to determine the age of each sampled fish. Arctic grayling greater than 199 mm FL were marked with individually numbered Floy FD-68 or FD-67 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. Arctic grayling exhibiting signs of injury or imminent mortality were killed.

Population Abundance, Survival, and Recruitment

A Jolly-Seber multiple capture-recapture study was initiated at Fielding Lake in 1988 to alleviate problems inherent with single-sample abundance estimators (Clark 1990a). Capture-recapture data collected in 1986 (Clark and Ridder 1987b) and 1987 (Clark and Ridder 1988) during single-sample experiments were also used to estimate abundance in 1987 and 1988 (Clark 1989). As of 1989, Clark (1990a) had used the Jolly-Seber estimator for abundance, survival, and recruitment estimates in 1987, 1988, and 1989. However, in 1990 there were two capture-recapture samples taken. Sample size during the first event (12 through 15 June) was insufficient for precise estimation of the Jolly-Seber parameters. Therefore, sampling was resumed on 19 June and continued until 21 June, when the number of captures for the 1990 sampling plans had been met. As a result, two estimates of abundance for the 1990 population of Arctic grayling could be calculated. First, a single-sample estimate of abundance was calculated from marked fish collected during 12 through 15 June and recaptured on 19 through 21 June. Second, the captures from each of these two samples could be used separately along with captures from 1986 through 1989 in the Jolly-Seber estimates of abundance, survival, and recruitment. This sampling design resembles that of Pollock's (1982) "robust capture-recapture" experiment, as described in Pollock, et al. (1990) and used by Parker, et al. (1989) on burbot in interior Alaska. The similarity of these experimental designs to that used at Fielding Lake in 1990 is due to an unexpected circumstance (low number of captures) rather than explicit use of the design.

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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.

Petersen Estimate in 1990:

Using methodologies previously described for Arctic grayling in rivers by Clark (1990b), fish (≥ 200 mm FL) were marked during 12 though 15 June (first event) and sampled for marks during 19 through 21 June (second event). Although Arctic grayling were captured throughout the lake, two areas were used to release the fish. These two areas are: at the mouth of Two Bit Creek; and, near the mouth of Caribou Bay (Figure 1). The area of recovery was not recorded. The modified Petersen estimator of Chapman (1951) was used to estimate abundance. Variance was estimated with an equation from Seber (1982, page 60) that assumes the hypergeometric model.

The assumptions necessary for reliable estimation of abundance (from Seber 1982, page 59) are:

1) the population is closed (no change in the number of Arctic grayling (≥ 200 mm FL) in the population during the estimation experiment);

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

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

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 (nine days) and short hiatus between events (three days). Assumptions 2 and 3 were tested with two two-sample Anderson-Darling tests (Scholz and Stevens 1987). The first test compared the length frequency distribution of recaptured Arctic grayling with those marked during the first event. The second test compared the length frequency distribution of Arctic grayling captured in the first event with those captured in the second event. These two tests only evaluate assumptions 2 and 3 in light of sampling bias that would affect the capture probabilities by size (or age) of fish captured. Additionally, recapture rates of Arctic grayling by area of release were tested for differences with a chi-squared contingency table (recaptured versus not-recaptured fish by area). Recovery locations were not recorded; thus, a test of mixing between area of release and area of recovery was not possible. Assumptions 4 and 5 were assumed to be valid because of double marking of released Arctic grayling and rigorous examination of all captured Arctic grayling. Consequences of violations of these assumptions are discussed in Appendix A1.

Given that the assumptions of the estimator are valid, abundance is calculated from numbers of Arctic grayling marked, examined for marks, and recovered (Seber 1982, page 60):

$$\hat{N}_{90} = \frac{(n_1 + 1)\ (n_2 + 1)}{(m_2 + 1)} - 1 \qquad (1)$$

where: n_1 = the number of Arctic grayling marked and released alive during the first event;

n_2 = the number of Arctic grayling examined for marks during the second event;

m_2 = the number of marked Arctic grayling recaptured in the second event; and,

$\hat{N}_{90}$ = the estimated abundance of Arctic grayling.

An approximately unbiased estimate of variance of N_{90} can be calculated with the equation (from Seber 1982, page 60):

$$\hat{V}[\hat{N}_{90}] = \frac{(n_1 + 1)(n_2 + 1)(n_1 - m_2)(n_2 - m_2)}{(m_2 + 1)^2(m_2 + 2)} \qquad (2)$$

Jolly-Seber Estimates for 1986 through 1990:

Following the methodology of Clark (1990a) for estimation of abundance, survival, and recruitment of Arctic grayling in Fielding Lake, the Jolly-Seber model for a demographically open population (Seber 1982, chapter 5.1) was used to obtain estimates of these parameters for 1986 through 1990. Updates of parameter estimates for 1986 through 1988 (see Clark 1990a) were obtained. Moreover, by partitioning the marks released and recovered in 1990 into two events, parameter estimates were obtained for 1989 and 1990. Partitioning of the 1990 sample into two events provides six time periods (samples) for use in estimation.

The assumptions necessary for reliable estimation of the parameters are (from Seber 1982, page 196):

1) all Arctic grayling ($\geq$ 200 mm FL) in the population have the same probability of being caught in the *i*th sample;

2) all Arctic grayling in the population have the same probability of surviving from the *i*th to the $(i+1)$th sample;

3) all Arctic grayling caught in the ith sample have the same probability of being released alive into the population;

4) all marked Arctic grayling do not lose their marks and all marks are reported on recovery; and,

5) all samples are instantaneous and each release is made immediately after the sample.

Assumptions 1 and 2 are central to reliable parameter estimation. However, changes in survival rate cannot be separated from changes in capture probability. These assumptions were tested for marked fish with a goodness-of-fit test devised by Pollock, et al. (1985) and implemented in a modified form in program JOLLY (Pollock, et al. 1990, page 22). The test is composed of two sets of chi-square contingency tables, the first "component" compares the rate of recapture of fish first captured before the *i*th sample with those first captured in the *i*th sample. The second component compares the rate of recapture of fish first captured before the (*i*-1)th sample with those first captured in the (*i*-1)th sample. For six samples there would be four contingency tables from the first component and three contingency tables from the second component. A nonsignificant test statistic would imply that the recapture rates were consistent among samples. If unmarked fish behave as do marked fish then the data would fit the Jolly-Seber model. Assumption 3 was assumed to be valid because none of the sampling gears exhibited size selective mortality and numbers of dead or live unmarked fish were small. Assumption 4 was met by double marking of Arctic grayling with Floy tags and fin clips by sampling event (adipose fin in 1986; partial upper caudal fin in 1987; partial right ventral fin in 1988; partial lower caudal fin in 1989; and, partial left pectoral in 1990). Assumption 5 was met by restricting each sampling event to 10 days or less during the open water season.

Abundance and survival rate were estimated for 1986 through 1990 by first estimating the number of Arctic grayling marked in *i*th sample that survived to the (*i*+1)th sample:

$$\hat{M}_i = \frac{R_i \; z_i}{r_i} + m_i, \; (i = 2, 3, \ldots, s\text{-}1) \qquad (3)$$

where: R_i = the number of marked Arctic grayling released after the *i*th sample;

z_i = the number of different Arctic grayling caught before the *i*th sample, not seen during the *i*th sample, but subsequently recaptured;

r_i = the number of Arctic grayling subsequently recaptured that were released in the *i*th sample (recaptures from R_i);

m_i = the number of marked Arctic grayling caught during the *i*th sample (recaptures); and,

s = the number of capture events.

With estimates of M_i, survival rate can be calculated from the relation of those surviving to those initially marked and released:

$$\hat{\phi}_i = \frac{\hat{M}_{i+1}}{M_i - m_i + R_i}, \; (i = 2, 3, \ldots, s\text{-}2) \qquad (4)$$

Abundance is then calculated by substituting estimated marks alive for marks released in a standard Petersen estimate:

$$\hat{N}_i = \frac{\hat{M}_i \, n_i}{m_i}, \quad (i = 2, 3, \ldots, s\text{-}1) \qquad (5)$$

where: n_i = the number of Arctic grayling caught during the ith sample.

If assumption 2 does actually apply to unmarked fish, then the estimated number of recruits added to the population between the ith sample and $(i+1)$th sample and surviving to the $(i+1)$th sample (B_i) becomes:

$$\hat{B}_i = \hat{N}_{i+1} - \hat{\phi}_i(\hat{N}_i - n_i + R_i), \quad (i = 2, 3, \ldots, s\text{-}2) \qquad (6)$$

Point estimates were calculated by two similar methods. The first method used program RECAP (Buckland 1980) to estimate the parameters. This method also calculates bootstrap estimates of variance for the parameters. The second method bootstrapped the point estimation procedure of program RECAP and gave bootstrap estimates of the parameters and variances. Bootstrapping was used to resample the capture histories of all Arctic grayling captured during 1986 through 1990 1,000 times. The following protocol was used:

1) generate a pseudorandom number (between 0 and 1) from a uniform distribution;

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

3) repeat 1 and 2, with replacement, until a sample of "total number of capture histories" is taken;

4) use program RECAP to generate parameter estimates for this iteration;

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

6) calculate the bootstrap mean (standard arithmetic mean) and variance of the 1,000 estimates of each parameter.

Since abundance is not estimated for the first sample (1986) in this form of the Jolly-Seber model (see Seber 1982, page 201), but had been estimated in 1986 by Clark and Ridder (1987b), recruitment was estimated for 1986 to 1987 by:

$$\hat{B}_{86} = \hat{N}_{87} - \hat{\phi}_{86} \hat{N}_{86} \qquad (7)$$

Variance of B_{86} was estimated by replacing N_{87} and ϕ_{86} with their bootstrap estimates for each of the 1,000 iterations and calculating a mean and variance as discussed above. Abundance in 1986 (N_{86}) was held constant at 6,578 fish (Clark and Ridder 1987b) for all 1,000 iterations, so that the variance of B_{86} was considered a minimum estimate.

Tag Shedding Rates

Although tag shedding can cause bias in estimation of survival rate (Pollock et al. 1990), double marking was employed at Fielding Lake to alleviate bias due to tag shedding. However, estimates of tag shedding rate are desirable for planning future capture-recapture experiments. Using double marks, tag shedding was estimated by the fraction of recaptured fish that had shed their tag or regenerated their fin clip. Since no complete regeneration of fin clips was evident throughout the five year experiment, tag shedding rate was restricted to the loss of Floy tags alone:

$$\hat{L}_i = \frac{t_k}{r_i} \tag{8}$$

where: $\hat{L}_i$ = the proportion of Floy tags shed from marked fish released during the *i*th sample;

t_k = the number of recaptured fish in the *k*th (after *i*) sample that had shed their tag; and,

r_i = the number of recaptured fish that were released in the *i*th sample.

From equation 8, estimates of tag shedding were calculated for year of release (*i*th sample) and for each year of recovery ($k = i + 1, 2, 3, 4$ samples). Estimates were summed by year of recovery and number of years at large. Variance of equation 8 was calculated by:

$$\hat{V}[\hat{L}_i] = \frac{\hat{L}_i\ (1 - \hat{L}_i)}{r_i - 1}. \tag{9}$$

Age and Size Composition

Collection of Arctic grayling for age-length samples was conducted in conjunction with capture-recapture sampling. Because estimates of abundance were germane to the time just before the *i*th sample, estimates of age and size composition used to apportion the abundance estimate by age or size group were taken from *i*th sample. For example, the abundance estimate for 1987 was first calculated in 1988, but age composition from samples in 1987 were used to apportion abundance into age and size groups.

Unadjusted age and size data were used to estimate age and size compositions for all samples. It was assumed that bias in age and size data was minimal if assumptions 1 and 2 of the Jolly-Seber estimator were being met. Also, if bias in length data was not detected in the 1990 Petersen estimate, it could be reasonably assumed that bias did not occur in samples from previous years.

The proportion of Arctic grayling in the sample that are age j was estimated by:

$$\hat{p}_j = \frac{y_j}{n} \qquad (10)$$

where: y_j = the number of age j Arctic grayling sampled; and,
n = the total number of Arctic grayling sampled.

The unbiased variance of this proportion was estimated by:

$$\hat{V}[\hat{p}_j] = \frac{\hat{p}_j (1 - \hat{p}_j)}{n - 1} \qquad (11)$$

Size composition of Arctic grayling in Fielding Lake was described with the incremental Relative Stock Density (RSD) indices of Gabelhouse (1984). Equations 10 and 11 were used to estimate the proportion of fish and variance in each RSD category. In addition, cumulative distribution functions of fork length (≥ 200 mm FL) by year were plotted for comparative purposes.

Partitioning of the Population:

In order to assess stock status of Arctic grayling in Fielding Lake, it was necessary to partition the abundance, survival, and recruitment estimates into groups of ages that were deemed partially recruited or fully recruited into the defined population (those fish ≥ 200 mm FL). Two methods were used to assess the extent of recruitment by age. The first method involved calculation of age-specific survival rates by year of sampling (see Clark 1990a, Appendix B1). This method resulted in survival rate estimates that were greater than unity (> 1.0) from age 3 through age 5 and less than unity for ages 6 through 9. Thus, recruitment by growth was indicated in ages 3 through 5. The second method involved a graphical procedure, plotting normal curves for each mean length at age from data collected in 1986 through 1988 (Clark 1989). Normal curves were constructed with the mean and standard deviation of fork length at age for ages 2 through 9 using the formula for a normal distribution (Abramowitz and Stegun 1964). From this method, age 5 fish appear to be the youngest fully recruited age-class (Appendix B2). However, the Jolly-Seber method for estimation of recruitment defines recruitment as those fish added to the population between the ith sample and the $(i + 1)$th sample and surviving to the $(i + 1)$th sample (Seber 1982). Using this definition, it is evident that age 5 fish are not fully recruited between samples because not all age 4 fish are long enough to mark during the ith sample (some are less than 200 mm FL; Figure 3) and some of these insufficiently long age 4 fish recruit to the population as age 5 in the $(i+1)$th sample.

Based on these two methods, partially recruited fish are age 3 though age 5 and fully recruited fish are age 6 through 10. Age 2 fish were removed from consideration in these partitions, since age 2 fish only appear in the

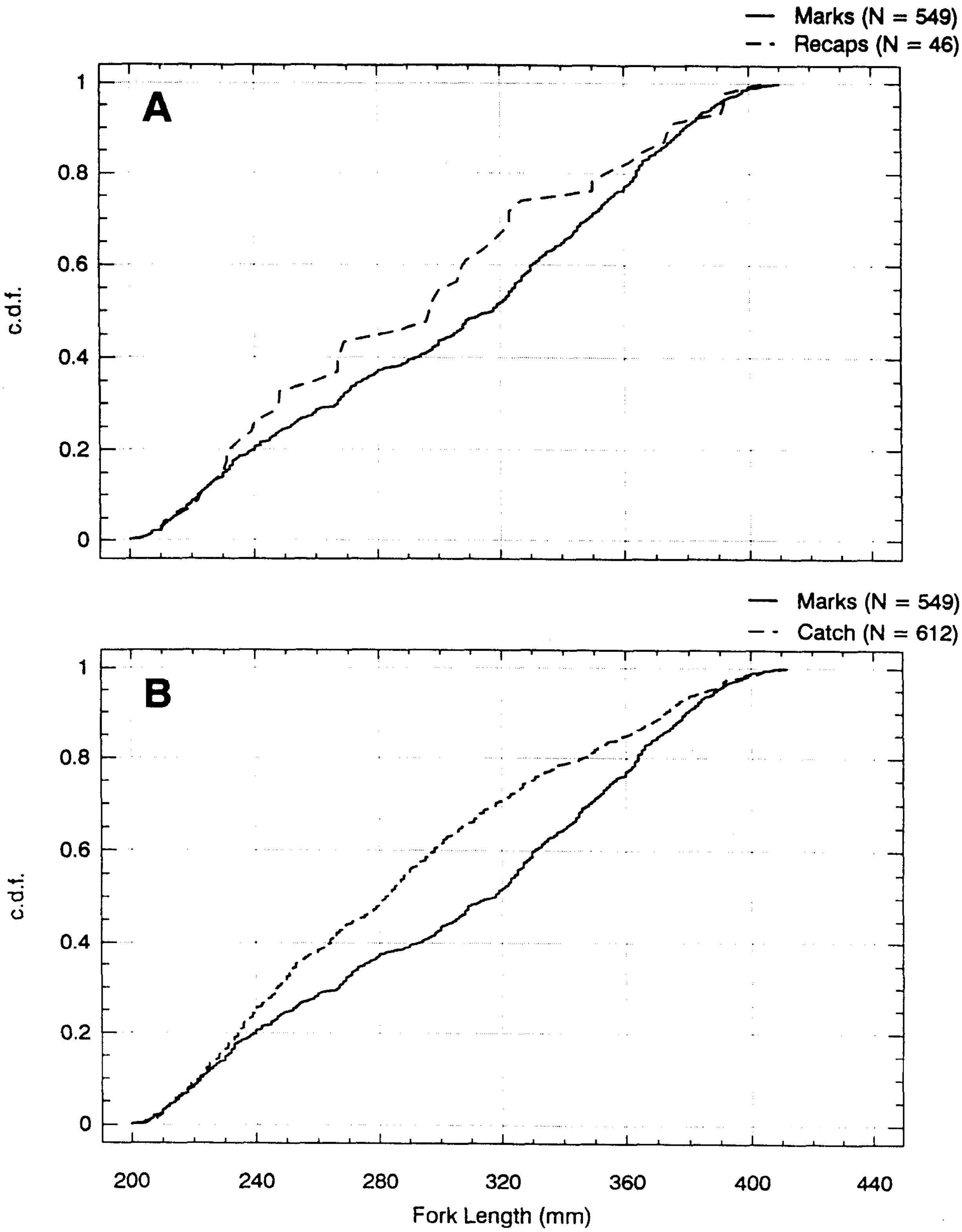

Figure 3. Cumulative distribution functions of the lengths (mm FL) of Arctic grayling marked versus the lengths of Arctic grayling recaptured in 1990 (A). Cumulative distribution functions of the lengths of Arctic grayling marked versus the lengths of Arctic grayling examined for marks in 1990 (B).

population in 1986 (Clark and Ridder 1987b) and in 1990. Abundance of fully recruited fish was estimated from abundance and age composition:

$$\hat{N}_{Fi} = \sum_{j=6}^{10} \hat{N}_{ji} \qquad (12)$$

where:

$\hat{N}_{Fi}$ = the abundance of fully recruited Arctic grayling in year i;

$\hat{N}_{ji}$ = $\hat{p}_{ji} \cdot \hat{N}_i$;

$\hat{p}_{ji}$ = the proportion of Arctic grayling at age j in year i; and,

j = age 6, 7, ..., 10.

Variance of abundance of fully recruited fish was calculated by summing the estimated variances of age-class abundances:

$$\hat{V}[\hat{N}_{Fi}] = \sum_{j=6}^{10} \hat{V}[\hat{N}_{ji}] \qquad (13)$$

where (from Goodman 1960):

$$\hat{V}[\hat{N}_{ji}] = \hat{p}_{ji} \hat{V}[\hat{N}_i] + \hat{N}_i \hat{V}[\hat{p}_{ji}] - \hat{V}[\hat{N}_i] \hat{V}[\hat{p}_{ji}] \qquad (14)$$

Abundance of partially recruited Arctic grayling (age 3 through age 5) was estimated by summing age-class abundances for ages 3 through 5:

$$\hat{N}_{Pi} = \sum_{j=3}^{5} \hat{N}_{ji} \qquad (15)$$

where:

$\hat{N}_{Pi}$ = the abundance of partially recruited Arctic grayling in year i; and,

j = age 3, 4, 5.

Variance of this abundance estimate was calculated with equations 13 and 14, substituting j with j = age 3, age 4, and age 5.

Recruitment of fully recruited Arctic grayling was by definition the estimated abundance of age 6 fish in year i+1:

$$\hat{B}_{Fi} = \hat{N}_{6i+1} \qquad (16)$$

where:

$\hat{B}_{Fi}$ = the number of fully recruited Arctic grayling that were added to the population between year i and i+1 and were alive in year i+1; and,

$\hat{N}_{6i+1}$ = the number of age 6 Arctic grayling in the population in year i+1.

Variance of recruitment was simply the variance of estimated abundance of age 6 fish in year i+1:

$$\hat{V}[\hat{B}_{Fi}] = \hat{V}[\hat{N}_{6i+1}] \quad (17)$$

Recruitment of partially recruited Arctic grayling was calculated by subtracting the estimate of recruitment for fully recruited fish from the Jolly-Seber estimate of recruitment for the entire stock (≥ 200 mm FL). If age 2 fish were present in the abundance estimate, recruitment for the stock was adjusted by subtracting the abundance of age 2 fish from the Jolly-Seber recruitment estimate. The equation for this estimate was:

$$\hat{B}_{Pi} = \hat{B}_i - \hat{B}_{Fi} \quad (18)$$

where:

$\hat{B}_{Pi}$ = the number of partially recruited Arctic grayling that were added to the population between year i and year i+1 and were alive in year i+1; and,

$\hat{B}_i$ = the number of Arctic grayling (≥ 200 mm FL) that were added to the population between year i and year i+1 and were alive in year i+1.

If age 2 fish were present in the abundance estimate, equation 18 reevaluated to:

$$\hat{B}_{Pi} = \hat{B}_i - \hat{B}_{Fi} - \hat{N}_{2i+1} \quad (19)$$

Variances were calculated by summing the estimates of recruitment from the Jolly-Seber estimate and from equation 17:

$$\hat{V}[\hat{B}_{Pi}] = \hat{V}[\hat{B}_i] + \hat{V}[\hat{B}_{Fi}] \quad \text{or} \quad \hat{V}[\hat{B}_{Pi}] = \hat{V}[\hat{B}_i] + \hat{V}[\hat{B}_{Fi}] + \hat{V}[\hat{N}_{2i+1}] \quad (20)$$

Survival rate for fully recruited Arctic grayling was calculated by subtracting recruitment from abundance in year i+1 and dividing the result by abundance of fully recruited fish in year i:

$$\hat{\phi}_{Fi} = \frac{\hat{N}_{Fi+1} - \hat{B}_{Fi}}{\hat{N}_{Fi}} \quad (21)$$

where:

$\hat{\phi}_{Fi}$ = the survival rate of fully recruited Arctic grayling between year i and i+1.

Variance of survival rate of fully recruited fish was approximated with the delta method (Seber 1982):

$$\hat{V}[\hat{\phi}_{Fi}] \approx \frac{(\hat{N}_{Fi+1} - \hat{B}_{Fi})^2}{\hat{N}_{Fi}^2} \left[\frac{\hat{V}[\hat{N}_{Fi+1}] + \hat{V}[\hat{B}_{Fi}]}{(\hat{N}_{Fi+1} - \hat{B}_{Fi})^2} + \frac{\hat{V}[\hat{N}_{Fi}]}{\hat{N}_{Fi}^2} \right] \quad (22)$$

Survival rate for partially recruited Arctic grayling was calculated in a similar way:

$$\hat{\phi}_{Pi} = \frac{\hat{N}_{Pi+1} - \hat{B}_{Pi}}{\hat{N}_{Pi}}. \quad (23)$$

Maturity and Sex Composition

Age and length at sexual maturity were estimated from data collected during June 1988, June 1989, and June 1990. All Arctic grayling greater than 199 mm FL were examined for maturity by the presence of sex products or by external methods (Clark and Ridder 1987b). The data were stratified by assigned age or 10 mm length groups. The proportion of mature fish at age j or within 10 mm length group j was estimated as:

$$\hat{q}_j = \frac{y_j}{n_j} \quad (24)$$

where:

- y_j = the number of mature Arctic grayling at age or length group j; and,
- n_j = the number of Arctic grayling examined for maturity at age or length group j.

The estimated proportions were used to estimate the percent mature at age or arithmetic mean length within a 10 mm group for the population with probit analysis (Finney 1971). Estimated proportions mature at age and length were graphically compared to estimated proportions from samples taken at Mineral Lake outlet, Goodpaster River, Caribou Creek of Shaw Creek, and Tangle Lakes (Ridder 1990).

Sex composition was estimated directly from samples taken during 1987 through 1990. Fish examined and found to be mature were also assigned a sex, based on the presence of sex products or by external methods (Clark and Ridder 1987b). The proportion of mature Arctic grayling that were either male or female was estimated by dividing the number sampled of one sex by the total number of mature fish sampled. Variance was estimated by the binomial relation shown in equation 11. Because sex composition data were not collected in 1986, it was assumed that the average sex composition during the years 1987 through 1990 could be used to approximate the sex composition in 1986. To approximate the variance of sex composition in 1986, it was assumed that variance of sex composition in 1986 was similar to that of 1987, since total sample sizes in these two years were similar.

Partitioning of the Population:

Estimates of abundance of fully recruited Arctic grayling can be useful for determining population trends over time. However, estimates of mature Arctic grayling in Fielding Lake could be used to estimate return-per-spawner or estimate egg deposition if fecundity estimates were available. Thus, abundance of mature Arctic grayling in Fielding Lake from 1986 through 1990 was estimated from abundances at age, maturity at age, and sex composition data. The basic relation can be written as:

$$\hat{S}_i = \sum_{j=3}^{10} \hat{N}_{ji} \hat{q}_j \hat{s}_i \qquad (25)$$

where:

- $\hat{S}_i$ = the abundance of either mature male or mature female Arctic grayling in year i;
- $\hat{N}_{ji}$ = the abundance of age j Arctic grayling in year i;
- $\hat{q}_j$ = the proportion of age j Arctic grayling that are mature; and,
- $\hat{s}_i$ = the proportion of either mature male or mature female Arctic grayling in year i.

Variance of abundance by sex for mature fish was estimated with the variance of a product (Goodman 1960).

<u>Mortality Rates</u>

In addition to estimation of survival rates, instantaneous rates of mortality were estimated for the four intervening 1 year periods between 1986 and 1990. Estimates of instantaneous fishing mortality could be used to assess the level of exploitation of Arctic grayling in Fielding Lake. Estimates of natural mortality could be used to assess the balance between growth and natural mortality rate. Both of these parameter estimates could be used to model the Arctic grayling population in Fielding Lake. Since survival rate estimates were calculated from bootstrapping, it seemed prudent to derive instantaneous rates from these bootstrap samples. Instantaneous rates of mortality could have been estimated from the partitioned population, although information on catch-at-age is lacking for 1988 through 1990.

Initially, instantaneous total mortality was calculated from the bootstrap estimate of survival (Ricker 1975):

$$\hat{Z}_i = -\ln(\hat{\phi}_i) \qquad (26)$$

where:

$\hat{Z}_i$ = the instantaneous rate of total mortality for Arctic grayling (≥ 200 mm FL) in year i; and,
$\hat{\phi}_i$ = the bootstrap estimate of survival rate in year i.

Next, the harvest of Arctic grayling in year i was taken from Mills (1987-1990) and used to estimate instantaneous fishing mortality. Harvest of Arctic grayling at Fielding Lake begins just after ice-out on the lake (Clark and Ridder 1987a), so that the abundance estimate for year i was assumed to be the starting abundance for that fishing year. The Baranov catch equation (Ricker 1975) with recruitment during fishing (Parker, et al. 1989) was solved for fishing mortality by iteration until the estimated harvest (C_i) equalled the harvest obtained from Mills (1987-1990):

$$C_i = \frac{F_i\ (1 - e^{-Z_i})\ N_i}{Z_i} + \frac{F_i}{Z_i^2} B_i(e^{-Z_i} + Z_i - 1) \qquad (27)$$

where:

C_i = the harvest of Arctic grayling in year i; and,
F_i = the instantaneous rate of fishing mortality in year i.

Natural mortality rate was calculated by subtraction (natural mortality = total mortality - fishing mortality). Variances of total mortality were estimated by taking the standard variance of 1,000 bootstrap iterations of these calculations. Variance of fishing and natural mortality could not be estimated without bias because no estimates of variance were provided for estimates of harvest from Mills (1987-1990).

Historic Data Summary

Data collected from Fielding Lake (1953 to 1990) were summarized (Appendix C). Creel census estimates, catch distributions, population abundance estimates, length at age estimates, age composition estimates, and a growth model were summarized from Federal Aid in Sport Fish Restoration reports and State of Alaska Fishery Data Series reports written from 1955 to the present. When possible, estimates of precision were reported with point estimates. Precision was reported as either a standard error or the 95% confidence interval. Sample sizes were reported if neither of these estimates of precision were available. Research on spawning habits of Fielding Lake Arctic grayling was reported by Warner (1955b). In addition to the aforementioned state and federal reports, reports concerning Arctic grayling research in Alaska from 1952-1980 were compiled by Armstrong (1982); and, Armstrong, et al. (1986) have compiled a bibliography for the genus *Thymallus* to 1985.

RESULTS

Petersen Estimate in 1990

Relative to the Petersen estimate for 1990, 549 fish were released during the first event and 612 fish examined for marks during the second event (Table 2). Forty-six fish were recaptured in the second event of 1990. No statistical

Table 2. Summary of captures, fish released with marks, and recaptures of Arctic grayling (≥ 200 mm FL) in Fielding Lake, 1986 through 1990.

Time of last capture	Time of recapture					
	1986	1987	1988	1989	1990[a]	1990[b]
1986	0	32	22	17	5	2
1987	0	0	40	32	4	4
1988	0	0	0	78	15	6
1989	0	0	0	0	44	53
1990 (1st event)	0	0	0	0	0	46
1990 (2nd event)	0	0	0	0	0	0
Marked	0	32	62	127	68	111
Unmarked	551	437	812	1,198	485	501
Caught	551	469	874	1,325	553	612
Released	551	468	864	1,276	549	611

[a] First sampling event of 1990: 12 through 15 June.
[b] Second sampling event of 1990: 19 through 21 June.

difference was found in the cumulative distribution functions (cdf) of lengths of Arctic grayling marked versus those recaptured (T_{kN} = 0.16, $P > 0.25$, n_1 = 549, n_2 = 46 [2]). However, there appeared to be a functional difference between these two distributions (Figure 3A). A statistical difference was found in the cdf of Arctic grayling marked versus the cdf of fish examined for marks in 1990 (T_{kN} = 18.37, $P < 0.01$, n_1 = 549, n_2 = 612). These tests infer that the second sample was unbiased with respect to gear selectivity, but the first sample was biased (Figure 3B). Thus, the abundance estimate was germane to the population at Fielding Lake during the second event (19 through 21 June; see Appendix A1). Abundance during the second event of 1990 was estimated at 7,172 fish (SE = 951 fish).

Parameter Estimates

A total of 4,273 Arctic grayling was marked and released between 1986 and 1990 (Table 3). From these releases, a total of 400 recoveries of marked fish were made (Table 2). No significant departure was evident when these capture-recapture data were fitted to the Jolly-Seber model (Table 4). However, the test statistic for component 2 of the goodness-of-fit test for the 1990 sample (i = 5) did have a significant test statistic (Table 4). Chi-square cell values of this test indicate that the failure of fit was due equally to all the individual cell statistics (Appendix D1).

Bootstrap estimates of survival rate varied from 0.42 in 1988 to 0.84 in 1987 (Table 5). None of the 95% confidence intervals included a survival rate of 0.00 or less, but the estimate for 1987 had an upper 95% confidence bound of 1.00. Bootstrap estimates were similar to those calculated from a single run of program RECAP, differing by less than 1.5% for all four estimates of survival (Table 6). Abundance estimated by bootstrapping varied from a low of 4,512 in 1987 to a high of 8,837 in 1988 (Table 5). Abundance in 1989 was 6,286 fish (SE = 655 fish) and abundance in 1990 (first event) was 7,298 fish (SE = 1,173 fish). Abundance estimates generated from a single run of program RECAP were generally biased low, but biased less than 2.5% for all estimates (Table 6). The Petersen estimate of 7,172 fish during second event of 1990 was comparable to the Jolly-Seber estimate of 7,298 fish during the first event of 1990 (difference = -126 fish, SE = 1,510 fish; Seber 1982, page 121). Estimated recruitment into the population between samples varied from 2,565 fish in 1988 to 5,043 fish in 1987. However, if the Petersen estimate for 1986 is used (6,578 fish, SE = 1,150 fish), the lowest estimated recruitment was 895 fish (SE = 849 fish) in 1986. Bias in estimation of recruitment with a single run of program RECAP was less than 3.3% for all samples (Table 6).

Although tag shedding was accounted for by double marking and rigorous examination of all captured fish, shedding rates for one year at large ranged from 3% (SE = 3% for 1987 and SE = 2% for 1989) to 13% (SE = 6%). When summed over all years of tagging, shedding rate for one year at large was 7% (SE = 2%; Table 7). Shedding rate increased to 23% (SE = 5%) at two years at large, and 39% (SE = 9%) at three years, then leveled off to 33% (SE = 17%) at four years.

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[2] The Anderson-Darling test statistic is T_{kN}, P is the probability of a greater test statistic, n_x is the sample size for sample x.

Table 3. Summary of captures[a] of Arctic grayling with fyke, seine, and gill nets, and electrofishing gear in Fielding Lake during spring sampling, 1986 through 1990.

Year	Dates	Fyke Net[b]	Seine[c]	Gill Net[d]	Electro-fishing[e]	Total Marks
1986	24 June to 3 July	46	208	NU[f]	297	551
1987	16 to 21 June	221	25	NU	222	468
1988	13 to 20 June	50	30	NU	784	864
1989	22 to 26 June	33	NU	137	1,106	1,276
1990	12 to 15 June	78	NU	NU	471	549
1990	19 to 21 June	NU	NU	NU	565	565
Total		428	263	137	3,445	4,273

[a] Captures are those Arctic grayling ≥200 mm FL, released alive, and bearing a Floy internal anchor tag.

[b] Fyke nets were deployed along the shoreline of Fielding Lake in 1986. In 1987, 1988, and 1989 fyke nets were deployed as weirs across Two Bit and Caribou Bay Creeks. During the first event in 1990 a fyke net was deployed across Two Bit Creek only. All fyke nets were similar to the New Hampshire style and had 10 mm mesh.

[c] Seining was done with 15 m × 2 m beach seines (10 mm mesh) primarily in Fielding Lake outlet. Some beach seining in Fielding Lake proper was done in 1987 with a 60 m × 3 m seine (25 mm mesh) near Two Bit Creek.

[d] Gill nets (33 m × 3 m; 25 mm mesh) were used to capture lake trout in 1989. Arctic grayling were incidentally caught in these gill nets.

[e] Electrofishing was performed with AC and pulsed-DC boat electrofishing units mounted on a 6.1 m riverboat (1986 through 1988). Pulsed-DC was used exclusively in 1989 and 1990.

[f] NU = gear type not utilized to capture Arctic grayling.

Table 4. Goodness-of-fit tests of mark-recapture data from Arctic grayling (≥ 200 mm FL) in Fielding Lake to the Jolly-Seber model with death and immigration, 1986 through 1990.

	Component 1[a]			Component 2[b]		
Year of sampling (*i*)	χ^2	*df*	*P*	χ^2	*df*	*P*
1987	0.052	1	0.819	---	---	---
1988	0.616	1	0.433	0.269	2	0.874
1989	0.032	1	0.858	0.508	1[c]	0.476
1990[d]	0.479	1	0.489	8.942	2	0.011
Totals	1.179	4	0.882	9.719	5	0.084
Overall	10.897	9	0.283	(Components 1 and 2)		

[a] Component 1 compares the frequency of first captures <u>before</u> the year of sampling (<*i*) with first captures <u>from</u> the year of sampling (*i*), stratified by whether these fish were subsequently recaptured versus not recaptured after the year of sampling (Pollock, et al. 1985, 1990).

[b] Component 2 compares the frequency of first captures <u>before</u> the year *i-1* (<*i-1*) that were not subsequently captured in year *i-1*, with those subsequently captured in year *i-1*; and, with those first captured in year *i-1*, stratified by whether these fish were captured in year *i* or they were not captured in year *i*, but captured after year *i* (Pollock, et al. 1985, 1990).

[c] Degrees of freedom reduced to 1 through pooling of those fish first captured before year *i-1*.

[d] First event of 1990: 12 through 15 June.

Table 5. Summary of bootstrap[a] parameter estimates from the Jolly-Seber model applied to capture-recapture data from Fielding Lake, 1986 through 1990.

Parameter[b]	Estimate	Standard Error	Lower 95% C.I.[c]	Upper 95% C.I.	CV[d]
ϕ_{86}	0.55	0.08	0.43	0.67	14.3
M_{86}	303	45	231	365	15.0
N_{87}	4,512	1,115	3,179	6,006	24.7
B_{87}	5,043	727	3,897	6,271	14.4
ϕ_{87}	0.84	0.08	0.72	1.00	9.2
M_{87}	623	69	505	749	11.1
N_{88}	8,837	745	7,568	10,141	8.4
B_{88}	2,565	352	2,031	3,149	13.7
ϕ_{88}	0.42	0.04	0.36	0.48	10.4
M_{88}	600	60	523	690	10.0
N_{89}	6,286	655	5,445	7,289	10.4
B_{89}	4,178	917	2,795	5,781	22.0
ϕ_{89}	0.50	0.06	0.43	0.59	11.7
M_{90}	878	105	751	1,031	12.0
N_{90}	7,298	1,173	5,690	9,306	16.1

[a] Bootstrapping was accomplished by replicating the output of point estimates produced by program RECAP (Buckland 1980) 1,000 times (Efron 1982).

[b] Parameter definitions are:

- ϕ_i = the proportion of marked Arctic grayling that survived from marking in year *i* to recapture in year *i+1*;
- M_i = the number of Arctic grayling marked up until year *i* that were alive just before sampling in year *i+1*;
- N_i = population size of Arctic grayling ≥ 200 mm FL prior to sampling in year *i*; and,
- B_i = the number of new Arctic grayling ≥ 200 mm FL that recruited to the population between year *i* and year *i+1* and were alive in year *i+1*.

[c] 95% C.I. = the 95% bootstrap confidence intervals (Efron 1981).

[d] CV = the coefficient of variation of the estimate, expressed as a percentage. Calculated as standard error/estimate x 100%.

Table 6. Comparison of Jolly-Seber and bootstrap estimates of Arctic grayling (≥ 200 mm FL) survival, marked fish at large, abundance, and recruitment in Fielding Lake, 1986 through 1990.

Parameter	Jolly-Seber[a] Estimate	Bootstrap[b] Estimate	Bias (%)[c]
ϕ_{86}	0.55	0.55	0.6
M_{86}	301	303	0.7
N_{87}	4,413	4,512	2.2
B_{87}	5,033	5,043	0.2
ϕ_{87}	0.84	0.84	0.2
M_{87}	621	623	0.3
N_{88}	8,748	8,837	1.0
B_{88}	2,577	2,565	0.5
ϕ_{88}	0.42	0.42	0.0
M_{88}	601	600	0.2
N_{89}	6,266	6,286	0.3
B_{89}	4,039	4,178	3.3
ϕ_{89}	0.50	0.50	1.2
M_{89}	868	878	1.1
N_{90}	7,125	7,298	2.4

[a] Jolly-Seber estimates were calculated with a single run of program RECAP of Buckland (1980).

[b] Bootstrap estimates were calculated by replicating the output of point estimates produced by program RECAP (Buckland 1980) 1,000 times (Efron 1982).

[c] Bias is the difference between the Jolly-Seber point estimate and the bootstrap mean from 1,000 replications of the capture history data expressed as a percentage: |Jolly-Seber - Bootstrap|/Bootstrap x 100%.

Table 7. Summary of tag shedding estimates calculated by duration at large and year of release for Arctic grayling (≥ 200 mm FL) at Fielding Lake, 1986 through 1990.

Year of release	Total recovered				Tags shed by year				By years at large[a]			
	87	88	89	90	87	88	89	90	1	2	3	4
1986	30	23	16	9	1	4	10	3	1	4	10	3
p[b]					0.03	0.17	0.62	0.33				
SE[c]					0.03	0.08	0.12	0.17				
1987		38	28	12		5	8	1	5	8	1	---
p						0.13	0.29	0.08				
SE						0.06	0.09	0.08				
1988			67	24			7	5	7	5	---	---
p							0.10	0.21				
SE							0.04	0.08				
1989				88				3	3	---	---	---
p								0.03				
SE								0.02				
Totals	30	61	111	133	1	9	25	12	16	17	11	3
p[d]									0.07	0.23	0.39	0.33
SE									0.02	0.05	0.09	0.17

[a] By years at large is the number of tags shed by the time in years between capture events. Total recoveries by years at large are: 223 for 1 year; 75 for 2 years; 28 for 3 years; and, 9 for 4 years at large.

[b] p is the proportion of tags shed, tags shed/total recovery.

[c] SE is the standard error of p.

[d] p in this case is the proportion of tags shed for a certain number of years at large, tags shed after *x* years/total recoveries after *x* years; where x = the number of years at large.

Partitioning Of The Population, 1986-1990

When partitioned by age-class, maximum abundance at age varied from age 7 in 1986 and 1987, to age 5 in 1988 and 1989, and to age 3 in 1990 (Table 8). Shifts in age composition during the five year estimation experiment was accompanied by shifts in size composition as well (Table 9). Stock size fish were most abundant in 1986, 1988 and 1990, while quality size fish were dominant in the 1989 sample. Preferred size fish were most abundant in the 1987 sample.

When the estimated parameters were partitioned into partially and fully recruited age groupings, estimated survival rate tended to be higher for partially recruited Arctic grayling (Table 10). However, survival rate of partially recruited fish in 1989 was less than that of fully recruited fish in the same year. Estimated recruitment into the partially recruited segment of the population was more variable than recruitment for fully recruited fish (Table 10). Recruitment of fully recruited Arctic grayling in 1986 was higher than the Jolly-Seber estimate of recruitment for the entire population that year. This was due to a negative value (-7 fish, SE = 319 fish) for recruitment of partially recruited fish in the same year.

Observed maturity increased with increasing length, with less than 1% maturity at 245 mm FL, 56% maturity at 305 mm FL, and 97% maturity at 385 mm FL (Table 11). Moreover, maturity at age increased from less than 1% at age 4 to 65% at age 5, and to 98% at age 8 (Table 11). These values corresponded closely with estimates of maturity at length (Figure 4A) and maturity at age (Figure 4B) when fitted to the probit model (Table 11). When compared with other stocks of Arctic grayling in the Tanana drainage, Fielding Lake was one of the last stocks to reach maturity and had the highest fork length when 50% maturity was attained (Figure 5). After maturity was attained, the observed sex composition varied across the four years of sampling (Table 12). On average 48% of mature fish were males and 52% were females. Because of the relatively similar proportions of each sex in the population, abundance of each sex varied principally with changes in age composition (Table 13). Abundance of males was lowest in 1989 and highest in 1986, while abundance of females was lowest in 1987 and highest in 1988.

Instantaneous rates of mortality were calculated for the four intervening periods between 1986 and 1990 (Table 14). Total mortality rate varied from 0.17 (SE = 0.09) in 1987 to 0.87 (SE = 0.09) in 1988. Fishing mortality rate did not vary considerably during the sampled years, ranging from 0.22 in 1987 and 1988 to 0.26 in 1986. Because total mortality rate was low in 1987, a nonsensical value of -0.05 was calculated for natural mortality rate in 1987 (Table 14).

Table 8. Summary of age composition estimates, abundance, and standard errors for Arctic grayling (≥ 200 mm FL) in Fielding Lake, 1986 through 1990

	1986[a]					1987[b]					1988[c]				
Age	n[f]	p[g]	SE[h]	N[i]	SE[j]	n	p	SE	N	SE	n	p	SE	N	SE
2	3	0.01	<0.01	38	23	0	---	---	0	---	0	---	---	0	---
3	127	0.25	0.02	1,622	301	16	0.04	0.01	180	92	30	0.04	0.01	325	64
4	50	0.10	0.01	639	137	114	0.25	0.02	1,128	292	201	0.25	0.02	2,177	226
5	31	0.06	0.01	396	96	52	0.11	0.02	496	151	229	0.28	0.02	2,480	251
6	111	0.22	0.02	1,418	268	90	0.20	0.02	902	240	160	0.20	0.01	1,733	191
7	142	0.28	0.02	1,814	333	143	0.31	0.02	1,400	357	116	0.14	0.01	1,256	151
8	51	0.10	0.01	651	140	35	0.08	0.01	361	99	65	0.08	0.01	704	102
9	0	---	---	0	---	6	0.01	0.01	45	45	14	0.02	0.00	152	42
10	0	---	---	0	---	0	---	---	0	---	1	<0.01	<0.01	11	11
Total	515	1.00	---	6,578	1,150	456	1.00	---	4,512	1,115	816	1.00	---	8,837	745

- Continued -

Table 8. (Page 2 of 2).

	1989[d]					1990[e]				
Age	n	p	SE	N	SE	n	p	SE	N	SE
2	0	---	---	0	---	36	0.04	0.01	265	60
3	68	0.07	0.01	440	69	266	0.27	0.01	1,955	330
4	131	0.14	0.01	847	112	182	0.18	0.01	1,338	232
5	327	0.34	0.02	2,115	240	104	0.10	0.01	764	141
6	235	0.24	0.02	1,520	180	150	0.15	0.01	1,102	195
7	114	0.12	0.01	737	100	177	0.18	0.01	1,301	227
8	71	0.07	0.01	459	71	66	0.07	0.01	485	97
9	26	0.03	0.01	168	37	11	0.01	<0.01	81	27
10	0	---	---	0	---	1	<0.01	<0.01	7	7
Total	972	1.00	---	6,286	655	993	1.00	---	7,298	1,173

[a] Samples taken in 1986 were from seining (37.7%), fyke net (8.3%), and electrofishing (54.0%). Age composition was adjusted for gear selectivity (Clark and Ridder 1987b). Sampling dates were 24 June - 3 July.

[b] Samples taken in 1987 were from seining (5.3%), fyke weir (47.2%), and electrofishing (47.4%). Age composition did not need adjustment for length selectivity (Clark and Ridder 1988). Sampling dates were 16 June - 21 June.

[c] Samples taken in 1988 were from seining (3.5%), fyke weir (5.8%), and electrofishing (90.7%), but were not adjusted for length selectivity (Clark 1989). Sampling dates were 13 June - 20 June.

[d] Samples taken in 1989 were from fyke weir (2.6%),electrofishing (86.7%), and gill net (10.7%) and were not adjusted for length selectivity (Clark 1990a). Sampling dates were 22 - 26 June.

[e] Samples taken in 1990 were from fyke weir (7.0%) and electrofishing (93.0%) and were not adjusted for length selectivity. Sampling dates were 12-15 June and 19-21 June.

[f] n = sample size.

[g] p = estimated proportion of sample at age.

[h] SE = estimated standard error of p.

[i] N = estimated population size at age.

[j] SE = estimated standard error of N.

Table 9. Summary of Relative Stock Density (RSD) indices of Arctic grayling (≥ 200 mm FL) captured in Fielding Lake, 1986 through 1990[a].

	RSD Category[b]				
	Stock[c]	Quality	Preferred	Memorable	Trophy
1986 (24 June through 3 July)					
Number sampled	218	144	189	0	0
RSD	0.40	0.26	0.34	0.00	0.00
Standard Error	0.02	0.02	0.02	0.00	0.00
1987 (16 through 21 June)					
Number sampled	134	120	217	0	0
RSD	0.29	0.26	0.46	0.00	0.00
Standard Error	0.02	0.02	0.02	0.00	0.00
1988 (13 through 20 June)					
Number sampled	344	225	295	0	0
RSD	0.40	0.26	0.34	0.00	0.00
Standard Error	0.02	0.02	0.02	0.00	0.00
1989 (22 through 26 June)					
Number sampled	379	604	301	0	0
RSD	0.30	0.47	0.23	0.00	0.00
Standard Error	0.01	0.01	0.01	0.00	0.00
1990 (12 through 15 June and 19 through 21 June)					
Number sampled	448	387	328	0	0
RSD	0.39	0.33	0.28	0.00	0.00
Standard Error	0.01	0.01	0.01	0.00	0.00

[a] Sampling dates are in parentheses.
[b] 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.
[c] The stock category only represents Arctic grayling size from 200 to 269 mm FL, whereas the stock category determined by Gablehouse (1984) has a minimum length of 150 mm FL.

Table 10. Estimates of abundance, survival, and recruitment of partially and fully recruited Arctic grayling (≥ 200 mm FL) in Fielding Lake, 1986 through 1990.

Parameter	Partially recruited[a]	SE	Fully recruited[b]	SE
N_{86}	2,657	344	3,883	450
ϕ_{86}	0.68	0.20	0.46	0.11
B_{86}	(7)	319	902	240
N_{87}	1,804	341	2,708	444
ϕ_{87}	0.93	0.49	0.78	0.15
B_{87}	3,310	751	1,733	191
N_{88}	4,982	344	3,856	268
ϕ_{88}	0.47	0.10	0.35	0.04
B_{88}	1,045	396	1,520	180
N_{89}	3,402	274	2,884	221
ϕ_{89}	0.37	0.30	0.65	0.10
B_{89}	2,811	940	1,102	195
N_{90}	4,057	427	2,976	316

[a] Partially recruited Arctic grayling are defined as age 3 through age 5 fish that are greater than 199 mm FL.
[b] Fully recruited Arctic grayling are defined as age 6 and older fish that are greater than 199 mm FL.

Table 11. Estimates of age (years) and fork length (mm) at maturity for Arctic grayling (≥ 200 mm FL) collected from Fielding Lake in June 1988, June 1989, and June 1990.

Age	Number Examined	Number Mature	Length Group	Number Examined	Number Mature
Raw data:					
2	36	0	200-209	66	0
			210-219	132	0
3	362	0	220-229	166	0
			230-239	182	0
4	508	1	240-249	191	1
			250-259	194	1
5	651	73	260-269	221	0
			270-279	186	4
6	537	348	280-289	218	13
			290-299	180	34
7	401	368	300-309	175	42
			310-319	151	85
8	199	196	320-329	145	102
			330-339	143	119
9	51	50	340-349	149	145
			350-359	152	145
10	2	2	360-369	181	175
			370-379	173	170
			380-389	113	110
			390-399	96	93
			400-409	38	38
			410-429	9	9

Summary statistics[a]:

	Mean	Range		Mean	Range
AM_{01}[b]	4.3 yrs	3.8 to 4.6 yrs	LM_{01}[c]	265 mm	254 to 273 mm
AM_{50}	5.8 yrs	5.6 to 6.0 yrs	LM_{50}	315 mm	310 to 320 mm
AM_{99}	7.8 yrs	7.3 to 8.8 yrs	LM_{99}	373 mm	362 to 389 mm

[a] Summary statistics were calculated from probit analysis (Finney 1971).
[b] AM_x = xth percentile for age at maturity rounded to the nearest 0.1 year (ranges are the 95% fiducial limits).
[c] LM_x = xth percentile for fork length at maturity (ranges are the 95% fiducial limits).

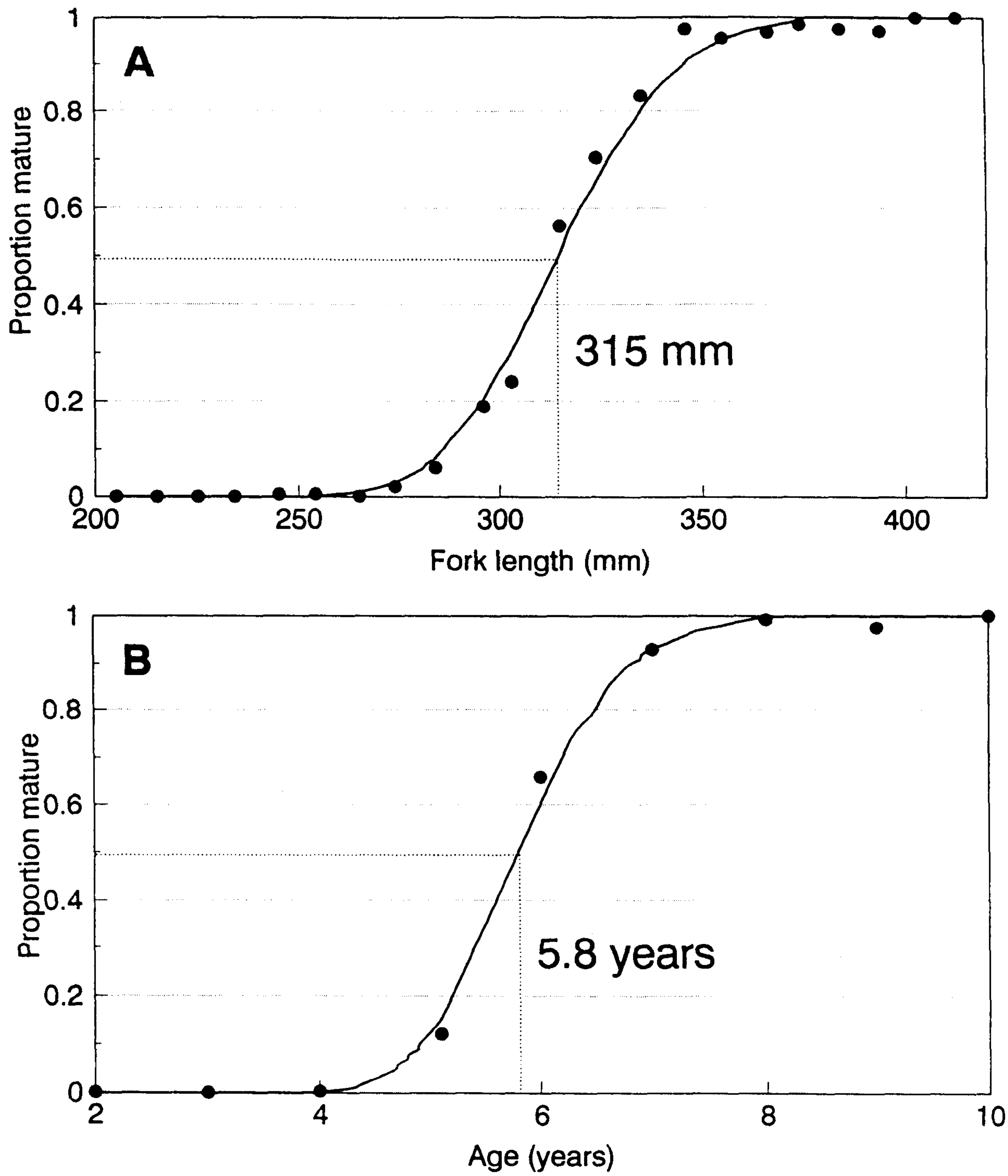

Figure 4. Actual and predicted proportions of mature Arctic grayling at fork length (mm) in Fielding Lake, 1988 through 1990 (A). Actual and predicted proportions of mature Arctic grayling at age (years) in Fielding Lake, 1988 through 1990 (B). Predicted proportions were estimated with a probit model (Finney 1971).

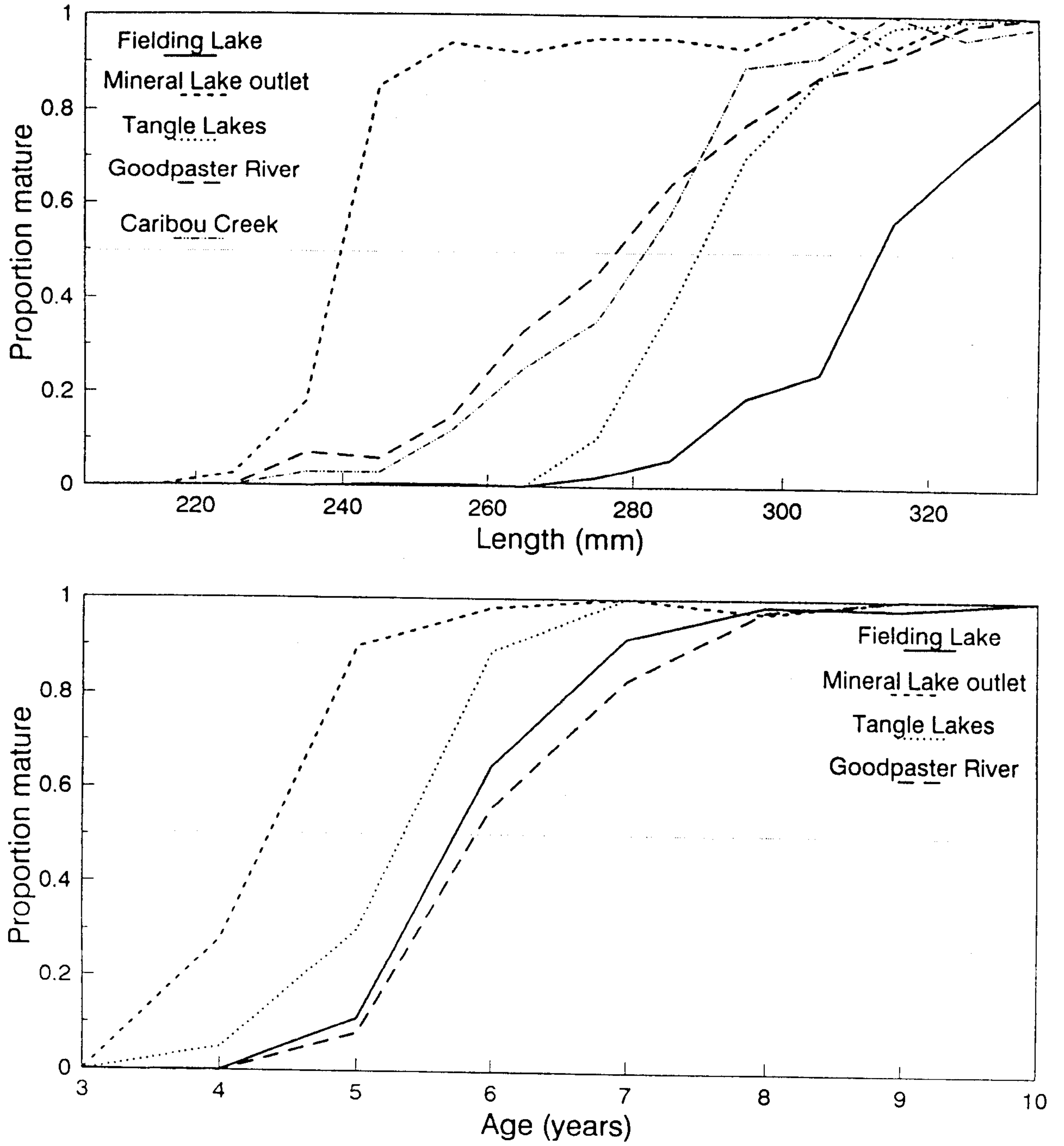

Figure 5. Comparisons of maturity at fork length (mm) and age (years) for Arctic grayling from Fielding Lake, Mineral Lake outlet, Tangle Lakes, Goodpaster River, and Caribou Creek of the Shaw Creek drainage.

Table 12. Estimates of sex composition by year for mature Arctic grayling in Fielding Lake, 1987 through 1990.

Year	Males	p	SE	Females	p	SE
1987	175	0.58	0.03	128	0.42	0.03
1988	148	0.43	0.03	198	0.57	0.03
1989	191	0.37	0.02	320	0.63	0.02
1990	251	0.58	0.02	178	0.42	0.02
Total	765	0.48	0.01	824	0.52	0.01

Table 13. Estimates of abundance of mature Arctic grayling by sex in Fielding Lake, 1986[a] through 1990.

Year	Males	SE	Females	SE	Total	SE
1986	1,575	182	1,696	197	3,270	268
1987	1,344	219	983	160	2,327	271
1988	1,459	95	1,952	128	3,411	159
1989	941	65	1,576	110	2,517	128
1990	1,498	155	1,062	110	2,560	190

[a] Sex ratio for 1986 was not estimated, but was assumed to be the average sex ratio for 1987 through 1990 combined. Variance of the sex ratio for 1986 was assumed to be equal to that for 1987 since sample sizes were similar.

Table 14. Bootstrap estimates of instantaneous mortality rates and standard error of total mortality rate of Arctic grayling (≥ 200 mm FL) in Fielding Lake, 1986 through 1989.

	Primary statistics[a]				Instantaneous mortality rates[b]			
Year	*N*	ϕ	*B*	*C*	*Z*	SE	*F*	*M*
1986	6,578	0.55	895	1,329	0.61	0.15	0.26	0.35
1987	4,512	0.84	5,043	910	0.17	0.09	0.22	-0.05
1988	8,837	0.42	2,565	1,492	0.87	0.09	0.22	0.64
1989	6,286	0.50	4,178	1,283	0.69	0.17	0.24	0.45

[a] Primary statistics: *N* = abundance estimate; ϕ = survival rate; *R* = recruitment; and, *C* = harvest. *N*, ϕ, and *B* are from this report and *C* is from Mills (1987-1990).

[b] Instantaneous mortality rates: *Z* = total mortality; *F* = fishing mortality; *M* = natural mortality; and, SE = bootstrap standard error of *Z*. *Z* is estimated by $Z = -\ln(\phi)$, *F* is estimated with the Baranov catch equation (Ricker 1975) with recruitment during fishing, and *M* is estimated by $M = Z - F$.

DISCUSSION

Bias in Parameter Estimates

The Petersen estimate in 1990 and the estimates of parameters of the Jolly-Seber model appear to be unbiased and relatively precise, given the sample sizes and constraints of each estimation model. The estimates appear unbiased because statistical tests of assumptions failed to reveal any significant biases. However, the Petersen estimate may be biased in at least two ways that were not detected in the statistical tests. The first way is that size-selectivity may have occurred, but was not statistically detected. Stratification of the capture-recapture data may have alleviated this bias, and any bias due to size-selectivity is probably small. The second source of potential bias stems from the failure to record recapture locations during the second event. Capture probabilities in the release locations were similar, but inadequate mixing between recapture locations could bias the estimate of abundance. If recapture locations had been recorded and unequal mixing had occurred, the modified Petersen estimator of Darroch (1961) could have been used to compensate for incomplete mixing among recapture locations. Fortunately, the fact that the Petersen estimate was comparable to the Jolly-Seber estimate for a time period four days earlier adds support to the assertion of an accurate Petersen estimate for 1990.

Bias may have entered into the estimation process through differential capture probability or survival rate by length (or age) of fish in the Jolly-Seber model. Although the capture-recapture data appears to fit the Jolly-Seber estimation model, differences in survival rate between partially and fully recruited fish were evident in all years and most evident in 1989 (Table 10). The goodness-of-fit test may have detected the difference in survival among age groupings in 1989, but its influence on the overall chi-square was not significant (Table 4). The significance of this bias should be investigated after sampling in 1991, when the two samples from 1990 will be added together. The resultant doubling of sample size for 1990 should increase sensitivity of the goodness-of-fit test. Moreover, a doubling of sample size will increase precision of parameter estimates for 1989 and 1990.

Another curious result from the Jolly-Seber estimates was the existence of an unusually high survival rate between 1987 and 1988. After partitioning of the population, the estimated survival rate of partially recruited fish is unbelievably high. Clark (1990a) commented on this phenomenon after estimation in 1988 and offered some insights into why survival rate might be high. However, these insights are insufficient evidence for bias in the 1987 estimate of survival rate. Using equations 3 and 4, survival rate is calculated from the ratio of marked fish alive and in the population in 1987 to those that were alive and in the population from marking in 1986. For survival to be biased high, either M_{86} is too high or M_{87} is too small. From Table 5, it seems plausible that 303 fish remained in 1987 from an initial mark of 551 fish in 1986. However, when the release (R_{87}) in 1987 of 468 fish is added to these 303 fish for a total of 739 fish (771 fish minus 32 recaptures), an estimated 623 fish survive to just before sampling in 1988 (Table 5). Thus, either some of the fish sampled in 1988 were mistaken for recaptures (fin clips noted for fish not actually tagged) or survival rate made an unexpected increase between 1987 and 1988. The first supposition is plausible, because tag shedding was estimated at 13% for fish marked in 1987 and recovered in 1988, the highest observed shedding rate for a single year at large (Table 7). If the estimated shedding rate were actually 3% (the observed shedding rate for releases in 1986 and 1989), then only one tag would have been shed instead of five tags (Table 7). This change in recoveries appears to be a small one, yet the recalculated estimate of marks alive in 1988 would be 468 fish at a minimum instead of 623 fish. Survival rate for 1987 would then reevaluate to a minimum of 0.65, and the minimum abundance estimate would be 7,052 fish. Although this scenario seems plausible, it is impossible to ascertain the rate at which fin clips are detected when in fact the fin had not been clipped. Obviously, a more permanent and easily identifiable method of double marking would ensure reliable reporting of recoveries.

Stock Status

Albeit five years of Arctic grayling population data have been collected from Fielding Lake, it is difficult to ascertain the long-term health of this stock. For example, point estimates of recruitment are available and show a three- to four-fold change during the five year study (Table 10), but the processes that produced this variation have not been determined. Spawner abundance varies by a factor of two during the study (Table 13), but these fish are not the spawners that produced the observed recruitments. Moreover, fecundity surely varies with length (and age) of fish so that egg deposition may be more variable than spawner abundance.

Critical changes in the population that signal ill health are absent in the estimated parameters from Fielding Lake. Abundance of spawners, and therefore large, high quality fish seems to be fairly stable and shows no downward trend over time (Table 13). Moreover, recruitment into the fully recruited age-classes appears to have no downward trend over time. Clark and Ridder (1987a) also found that sport harvest began after Arctic grayling spawning had concluded, providing a high level of protection for mature fish awaiting spawning in spring. Recreational harvest and effort are also fairly stable (Table 1), resulting in stable fishing mortality rates (Table 14). Natural mortality rates varied considerably during the study, if the 1987 datum is included. Without the 1987 datum, natural mortality rate averages 0.48 over three years. This rate is roughly twice that of fishing mortality, indicating that less than maximal harvests have been taken from the lake (Gulland 1988). Regardless of these general observations, the quantitative effect of a potential increase in the harvest of Arctic grayling at Fielding Lake on size composition and abundance is a matter of conjecture at this time. Investigation of this topic will involve simulation of the Arctic grayling stock in Fielding Lake. The parameter estimates from this report will provide a good starting point for modelling of the stock.

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LITERATURE CITED

Abramowitz, M., and I. A. Stegun. 1964. Handbook of mathematical functions. National Bureau of Standards, Applied Mathematics Series No. 55, U. S. Government Printing Office, Washington, D.C. 1,046 pp.

Armstrong, R. H. 1982. Arctic grayling studies in Alaska. Alaska Cooperative Fisheries Research Unit and the Alaska Department of Fish and Game, Fairbanks, Alaska. 1,593 pp.

Armstrong, R. H., H. Hop, and J. H. Triplehorn. 1986. Indexed bibliography of the holarctic genus *Thymallus* (grayling) to 1985. Biological Papers of the University of Alaska No. 23, Fairbanks, Alaska.

Baker, T. T. 1988. Creel censuses in interior Alaska in 1987. Alaska Department of Fish and Game, Fishery Data Series No. 64, Juneau, Alaska. 138 pp.

Buckland, S. T. 1980. A modified analysis of the Jolly-Seber capture-recapture model. Biometrics 36: 419-435.

Chapman, D. G. 1951. Some properties of the hypergeometric distribution with applications to zoological censuses. University of California Publications in Statistics 1: 131-160.

Clark, R. A. 1989. Stock assessment of Arctic grayling in Fielding Lake. Alaska Department of Fish and Game, Fishery Data Series No. 78, Anchorage, Alaska. 26 pp.

______. 1990a. Stock assessment of Arctic grayling in Fielding Lake. Alaska Department of Fish and Game, Fishery Data Series No. 90-1, Anchorage, Alaska. 29 pp.

______. 1990b. Stock status of Chena River Arctic grayling. Alaska Department of Fish and Game, Fishery Data Series No. 90-4, Anchorage, Alaska. 52 pp.

Clark, R. A., and W. P. Ridder. 1987a. Tanana drainage creel census and harvest surveys, 1986. Alaska Department of Fish and Game, Fishery Data Series No. 12, Juneau, Alaska. 91 pp.

______. 1987b. Abundance and length composition of selected grayling stocks in the Tanana drainage during 1986. Alaska Department of Fish and Game, Fishery Data Series No. 26, Juneau, Alaska. 55 pp.

______. 1988. Stock assessment of Arctic grayling in the Tanana River drainage. Alaska Department of Fish and Game, Fishery Data Series No. 54, Juneau, Alaska. 79 pp.

Darroch, J. N. 1961. The two-sample capture-recapture census when tagging and sampling are stratified. Biometrika 48: 241-260.

Efron, B. 1981. Nonparametric standard errors and confidence intervals. Canadian Journal of Statistics 9: 139-172.

______. 1982. The jackknife, the bootstrap, and other resampling plans. Society for Industrial and Applied Mathematics, Monograph 38, CBMS-NSF, Philadelphia.

Finney, D. J. 1971. Statistical methods in biological analysis, second edition. Charles Griffin & Company, Ltd. London. 668 pp.

Gabelhouse, D. W. 1984. A length-categorization system to assess fish stocks. North American Journal of Fisheries Management 4:273-285.

Goodman, L. A. 1960. On the exact variance of products. Journal of the American Statistical Association 55: 708-713.

Gulland, J. A. 1988. Fish population dynamics, second edition. John Wiley & Sons, New York, New York. 422 pp.

Holmes, R. A., W. P. Ridder, and R. A. Clark. 1986. Population structure and dynamics of Arctic grayling in the Tanana River drainage. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1985-1986, Project F-10-1, 27(G-8-1). 68 pp.

Jolly, G. M. 1965. Explicit estimates from capture-recapture data with both death and immigration-stochastic model. Biometrika 52: 225-247.

Marquardt, D. W. 1963. An algorithm for least-squares estimation of nonlinear parameters. Journal for the Society of Industrial and Applied Mathematics 11:431-441.

Mills, M. J. 1982. Alaska statewide sport fish harvest studies (1981). Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Performance Report, 1981-1982, Project F-9-14, 23(SW-I-A). 115 pp.

_____. 1983. Alaska statewide sport fish harvest studies (1982). Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Performance Report, 1982-1983, Project F-9-15, 24(SW-I-A). 118 pp.

_____. 1984. Alaska statewide sport fish harvest studies (1983). Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Performance Report, 1983-1984, Project F-9-16, 25(SW-I-A). 123 pp.

_____. 1985. Alaska statewide sport fish harvest studies (1984). Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Performance Report, 1984-1985, Project F-9-17, 26(SW-I-A). 137 pp.

_____. 1986. Alaska statewide sport fish harvest studies (1985). Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Performance Report, 1985-1986, Project F-10-1, 27(RT-2). 137 pp.

_____. 1987. Alaska statewide sport fisheries harvest report (1986). Alaska Department of Fish and Game, Fishery Data Series No. 2, Juneau, Alaska. 140 pp.

_____. 1988. Alaska statewide sport fisheries harvest report (1987). Alaska Department of Fish and Game, Fishery Data Series No. 52, Juneau, Alaska. 142 pp.

_____. 1989. Alaska statewide sport fisheries harvest report (1988). Alaska Department of Fish and Game, Fishery Data Series No. 122, Juneau, Alaska. 142 pp.

_____. 1990. Harvest and participation in Alaska sport fisheries during 1989. Alaska Department of Fish and Game. Fishery Data Series No. 90-44, Anchorage, Alaska. 152 pp.

Parker, J. F., R. Lafferty, W. D. Potterville, and D. R. Bernard. 1989. Stock assessment and biological characteristics of burbot in lakes of interior Alaska during 1988. Alaska Department of Fish and Game, Fishery Data Series No. 98, Juneau, Alaska. 86 pp.

Peckham, R. 1977. Evaluation of interior Alaska waters and sport fish with emphasis on managed waters, Delta District. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1976-1977, Project F-9-9, 18(G-III-I): 88-105.

______. 1983. Evaluation of interior Alaska waters and sport fish with emphasis on managed waters, Delta District. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1982-1983, Project F-9-15, 24(G-III-I): 1-38.

______. 1984. Evaluation of interior Alaska waters and sport fish with emphasis on managed waters, Delta District. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1983-1984, Project F-9-16, 25(G-III-I): 1-25.

______. 1985. Evaluation of interior Alaska waters and sport fish with emphasis on managed waters, Delta District. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1984-1985, Project F-9-17, 26(G-III-I): 27-66.

Pollock, K. H. 1982. A capture-recapture design robust to unequal probability of capture. Journal of Wildlife Management 46: 757-760.

Pollock, K. H., J. E. Hines, and J. D. Nichols. 1985. Goodness-of-fit tests for open capture-recapture models. Biometrics 41: 399-410.

Pollock, K. H., J. D. Nichols, C. Brownie, and J. E. Hines. 1990. Statistical inference for capture-recapture experiments. Wildlife Monographs 107: 1-97.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada, No. 191. 382 pp.

Ridder, W. P. 1990. Stock assessment of Arctic grayling in the Tangle Lakes and river system. Alaska Department of Fish and Game, Fishery Data Series No. 90-15, Anchorage, Alaska. 55 pp.

Scholz, F. W., and M. A. Stevens. 1987. K-sample Anderson-Darling tests. Journal of the American Statistical Association 82: 918-924.

Seber, G. A. F. 1965. A note on the multiple recapture census. Biometrika 52: 249-259.

______. 1982. The estimation of animal abundance and related parameters, second edition. Charles Griffin and Co., Ltd. London, U.K. 654 pp.

Warner, G. 1955a. Dynamics of fish populations in waters of interior Alaska. U.S. Fish and Wildlife Service, Federal Aid in Fish Restoration, Quarterly Progress Report. Project F-1-R-5, Work Plan C, Job No. 3: 15-20.

_______. 1955b. Spawning habits of grayling in interior Alaska. U.S. Fish and Wildlife Service, Federal Aid in Fish Restoration, Quarterly Progress Report. Project F-1-R-5, Work Plan E, Job No. 1. 10 pp.

_______. 1959. Catch distribution, age and size composition sport fish in Fairbanks area. U.S. Fish and Wildlife Service, Federal Aid in Fish Restoration, Quarterly Progress Report. Project F-1-R-8, Work Plan A, Job 3c, 8(3). 7 pp.

APPENDIX A
Detection of Bias

Appendix A1. Methodologies for alleviating bias due to gear selectivity by means of statistical inference.

Result of first A-D test[a]	Result of second A-D test[b]
Case I[c]	
Fail to reject H_0	Fail to reject H_0
Inferred cause: There is no size-selectivity during either sampling event.	
Case II[d]	
Fail to reject H_0	Reject H_0
Inferred cause: There is no size-selectivity during the second sampling event, but there is during the first sampling event	
Case III[e]	
Reject H_0	Fail to reject H_0
Inferred cause: There is size-selectivity during both sampling events.	
Case IV[f]	
Reject H_0	Reject H_0
Inferred cause: There is size-selectivity during the second sampling event; the status of size-selectivity during the first event is unknown.	

[a] The first A-D (Anderson-Darling) test is on the lengths of fish marked during the first event versus the lengths of fish recaptured during the second event. H_0 for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish recaptured during the second event.

[b] The second A-D test is on the lengths of fish marked during the first event versus the lengths of fish captured during the second event. H_0 for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish sampled during the second event.

[c] Case I: Calculate one unstratified abundance estimate, and pool lengths and ages from both sampling event for size and age composition estimates.

[d] Case II: Calculate one unstratified abundance estimate, and only use lengths and ages from the second sampling event to estimate size and age composition.

[e] Case III: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Pool lengths and ages from both sampling events and adjust composition estimates for differential capture probabilities.

[f] Case IV: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Also calculate a single abundance estimate without stratification. If stratified and unstratified estimates are dissimilar, discard unstratified estimate and use lengths and ages from second event and adjust these estimates for differential capture probabilities. If stratified and unstratified estimates are similar, discard estimate with largest variance. Use lengths and ages from first sampling event to directly estimate size and age compositions.

APPENDIX B
Age at Full Recruitment

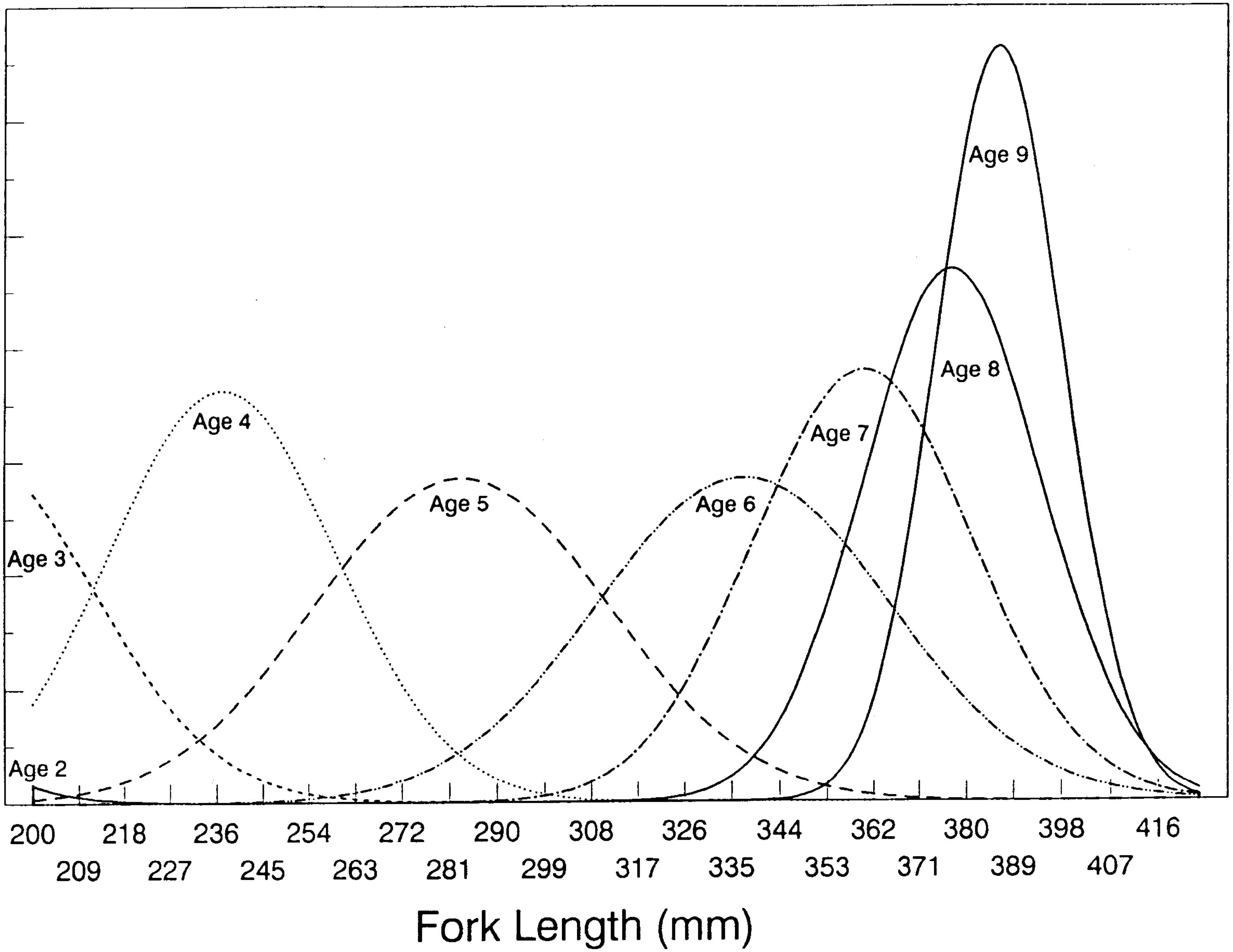
Appendix B1. Summary of age-specific survival rate calculations used to determine age at recruitment into the Arctic grayling population (≥ 200 mm FL) at Fielding Lake, 1986 through 1990.

	1986			1987			1988			1989			1990	
Age	N[a]	SE[b]	ϕ_{86}[c]	N	SE	ϕ_{87}	N	SE	ϕ_{88}	N	SE	ϕ_{89}	N	SE
2	38	23		0	---		0	---		0	---		265	60
			4.73			---			---			---		
3	1,622	301		180	92		325	64		440	69		1,955	330
			0.69			12.09			2.61			3.04		
4	639	137		1,128	292		2,177	226		847	112		1,338	232
			0.78			2.20			0.97			0.90		
5	396	96		496	151		2,480	251		2,115	240		764	141
			2.28			3.49			0.61			0.52		
6	1,418	268		902	240		1,733	191		1,520	180		1,102	195
			0.99			1.39			0.42			0.86		
7	1,814	333		1,400	357		1,256	151		737	100		1,301	227
			0.20			0.50			0.36			0.66		
8	651	140		361	99		704	102		459	71		485	97
			0.07			0.42			0.24			0.18		
9	0	---		45	45		152	42		168	37		81	27
			---			0.24			0.00			0.04		
10	0	---		0	---		11	11		0	---		7	7
Total	6,578	1,150		4,512	1,115		8,837	745		6,286	655		7,298	1,173

[a] N = age-specific abundance by year.

[b] SE = standard error of age-specific abundance by year.

[c] ϕ_i = age-specific survival rate for the year i through year (i + 1). A survival rate greater than 1.00 is biologically impossible.



Appendix B2. Normal curves of Arctic grayling mean fork length at age (mm) for ages 2 through 9, calculated from data collected at Fielding Lake from 1986 through 1988

APPENDIX C
Historic Data Summary

Appendix C1. Summary of Arctic grayling creel surveys at Fielding Lake, 1953 through 1958, 1976, and 1982 through 1987[a].

Year	Dates	Angler Interviews	Angler Hours	Harvest Rate Grayling/hr	Mean Length (mm)
1953	ND[b]	200	1,077	0.50	---
1954	ND	250	1,493	0.49	---
1955[c]	ND	72	277	0.62	348
1956[c]	ND	158	1,073	0.49	348
1957[c]	ND	96	388	0.69	257
1958[c]	ND	75	579	0.34	249
1976	6/15 - 9/4	143	508	0.38	---
1982	7/4 - 9/5	95	288	0.43	336
1983	ND	ND	ND	0.55	325
1984	6/10 - 8/11	43	136	0.46	318
1985	6/30 - 8/25	181	ND	0.34	318
1986	6/24 - 8/31	173	2,374	0.34	304
1987	6/15 - 8/31	162	1,609	0.49	300

[a] Sources are: 1953-1958 from Warner (1959); 1976 from Peckham (1977); 1982 from Peckham (1983); 1983 from Peckham (1984); 1984 from Peckham (1985); 1985 from Holmes, et al. (1986); 1986 from Clark and Ridder (1987a); and, 1987 from Baker (1988).

[b] ND – data not available from source document.

[c] A spring closure (closed until 1 July) of the fishery was in effect during these years.

Appendix C2. Distributions of Arctic grayling harvest among interviewed anglers at Fielding Lake, 1986 and 1987[a].

	1986		1987	
Number harvested	Anglers	p	Anglers	p
0	109	0.65	49	0.55
1	23	0.14	16	0.18
2	15	0.09	10	0.11
3	7	0.04	6	0.07
4	9	0.05	5	0.06
5	4	0.02	3	0.03
Total	167	1.00	89	1.00

[a] Sources are Clark and Ridder (1987a) for 1986, and Clark and Ridder (1988) for 1987.

Appendix C3. Summary of population estimates of Arctic grayling (≥ 200 mm FL) in Fielding Lake, 1986 through 1990.

Date	Estimator[a]	Estimate	SE
3 July 1986	Petersen[b]	6,578	1,150
16 June 1987	Jolly-Seber[c]	4,512	1,115
13 June 1988	Jolly-Seber[c]	8,837	745
22 June 1989	Jolly-Seber[c]	6,286	655
12 June 1990	Jolly-Seber[c]	7,298	1,173
19 June 1990	Petersen[c]	7,172	951

[a] Petersen = the Petersen estimator as modified by Chapman (1951); and, Jolly-Seber = the estimator of Jolly (1965) and Seber (1965).

[b] Source is Clark and Ridder (1987b).

[c] Source is this report. These estimates supersede those of Clark (1990a).

Appendix C4. Estimates of age composition of Arctic grayling harvested in the sport fishery from Fielding Lake, 1953 through 1954, 1982, and 1984 through 1987[a].

	Age																			
	1		2		3		4		5		6		7		8		9		10	
Year	n[b]	p[c]	n	p	n	p	n	p	n	p	n	p	n	p	n	p	n	p	n	p
1953	0	0.00	11	0.09	23	0.19	16	0.13	22	0.18	30	0.25	13	0.11	5	0.04	0	0.00	0	0.00
1954	1	0.00	1	0.00	12	0.03	14	0.04	30	0.08	122	0.34	104	0.29	59	0.17	12	0.03	2	0.00
1982	0	0.00	0	0.00	5	0.07	8	0.11	25	0.36	22	0.31	8	0.11	2	0.03	0	0.00	0	0.00
1984	0	0.00	0	0.00	4	0.18	6	0.27	7	0.32	4	0.18	1	0.05	0	0.00	0	0.00	0	0.00
1985	0	0.00	5	0.04	11	0.09	9	0.07	34	0.27	33	0.26	26	0.20	6	0.05	3	0.02	0	0.00
1986	0	0.00	0	0.00	8	0.07	14	0.13	22	0.20	44	0.39	16	0.14	8	0.07	0	0.00	0	0.00
1987	0	0.00	1	0.01	13	0.10	49	0.39	18	0.14	14	0.11	19	0.15	7	0.06	4	0.03	0	0.00

[a] Sources are: Warner (1955a) for 1953 and 1954; Peckham (1983) for 1982; Peckham (1985) for 1984; Holmes, et al. (1986) for 1985; Clark and Ridder (1987a) for 1986; and, Baker (1988) for 1987.

[b] n = number sampled at age.

[c] p = proportion of sample at age.

Appendix C5. Mean fork length (mm) at age of Arctic grayling sampled from Fielding Lake, 1953, 1982, and 1984 through 1990[a].

	Age																			
	1		2		3		4		5		6		7		8		9		10	
Year	n[b]	FL[c]	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL
1953[d]	0	---	11	159	23	204	16	245	22	320	30	356	13	347	5	379	0	---	0	---
1982[d]	0	---	0	---	5	247	8	293	25	328	22	358	8	383	2	400	0	---	0	---
1982[e]	ND[f]	124	ND	190	ND	253	ND	312	ND	343	ND	359	0	---	0	---	0	---	0	---
1984[d]	0	---	0	---	4	243	6	275	7	353	4	373	1	385	0	---	0	---	0	---
1985[e]	89	126	75	176	35	217	12	262	9	320	4	341	0	---	2	400	0	---	0	---
1986[d]	0	---	0	---	8	210	14	273	22	301	44	335	16	362	8	381	0	---	0	---
1986[e]	0	---	229	142	409	183	115	240	58	295	99	337	102	362	36	383	0	---	0	---
1987[d]	0	---	1	200	13	237	49	259	18	300	14	347	19	370	7	388	4	396	0	---
1987[e]	21	80	37	121	147	169	129	230	52	291	90	336	143	357	35	377	6	387	0	---
1988[e]	0	---	15	150	62	198	206	236	229	278	160	338	116	360	65	375	14	385	1	370
1989[e]	0	---	50	155	102	208	132	247	327	284	235	315	114	357	71	369	26	384	0	---
1990[e]	0	---	36	161	266	221	182	257	104	283	150	324	177	351	66	371	11	385	1	407

[a] Sources are: Warner (1955a) for 1953; Peckham (1983) for 1982; Peckham (1985) for 1984; Holmes, et al. (1986) for 1985; Clark and Ridder (1987a, 1987b) for 1986; Baker (1988) and Clark and Ridder (1988) for 1987; Clark (1989) for 1988; Clark (1990a) for 1989; and, this report for 1990.

[b] n = number sampled at age.

[c] FL = mean fork length in mm.

[d] Collected from harvest sample.

[e] Collected from population sample.

[f] ND = data not available from source document.

Appendix C6. Mean fork length at age of Arctic grayling from Fielding Lake, 1986 through 1988[a].

Age	n[b]	FL[b]	SD[d]	SE[e]
1	21	80	11	2
2	130	143	23	2
3	465	186	25	1
4	446	237	22	1
5	339	283	28	2
6	349	337	28	1
7	361	360	21	1
8	136	377	17	1
9	20	386	12	3
Totals	2,267	271	79	2

[a] From Clark (1989).
[b] n is the total number of fish aged from samples taken in 1986, 1987, and 1988.
[c] FL is the arithmetic mean fork length in millimeters.
[d] SD is the estimated standard deviation of FL.
[e] SE is the estimated standard error of FL.

Appendix C7. Parameter estimates and standard errors of the von Bertalanffy growth model with t_0 omitted[a] for Arctic grayling from Fielding Lake, 1986 through 1988[b].

Parameter	Estimate	Standard Error	Coefficient Of Variation
<u>von Bertalanffy without t_0</u>			
L_∞[c]	558	42	7.5%
K[d]	0.14	0.02	11.9%
$Corr(L_\infty,K)$[e]	-0.99	---	---
Sample size	2,267		

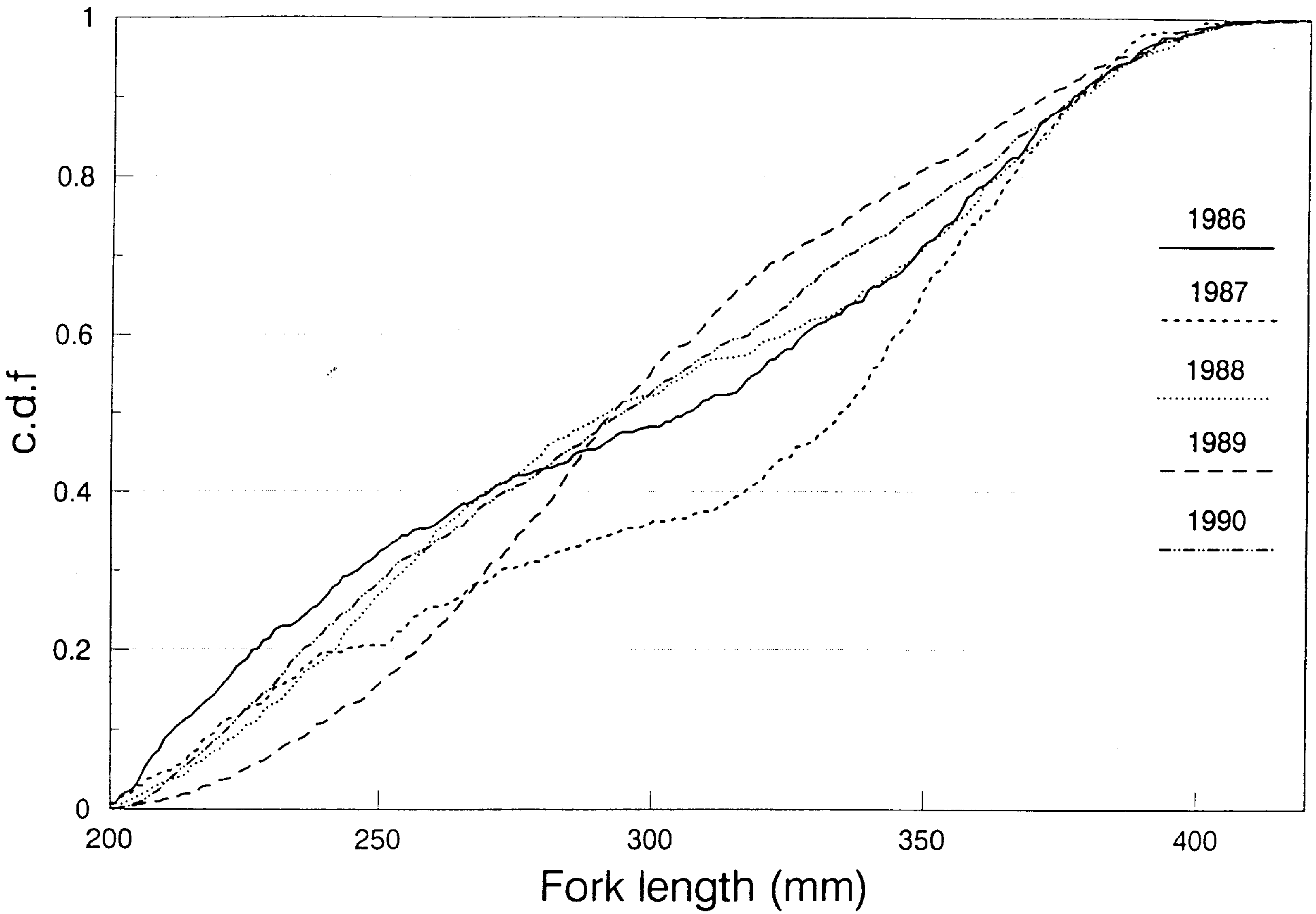
[a] The von Bertalanffy growth model (Ricker 1975) without t_0 is as follows: $l_t = L_\infty (1 - exp(-Kt))$. The applicable range of ages for this model are 1 through 9 years. This model was fitted to the data by nonlinear regression utilizing the Marquardt compromise (Marquardt 1963).

[b] From Clark (1989).

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

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

[e] $Corr(L_\infty,K)$ is the correlation of parameter estimates.



Appendix C8. Cumulative distribution functions of fork lengths (mm) of Arctic grayling (≥ 200 mm FL) sampled from Fielding Lake, 1986 through 1990.

APPENDIX D
Goodness-of-fit-tests

Appendix D1. Cell values of Jolly-Seber model goodness-of-fit tests[a] performed on capture-recapture data collected from Arctic grayling in Fielding Lake, 1986 through 1990.

Component 1			**Component 2**			
Row elements	**Column elements**		**Row elements**	**Column elements**		
<u>i = 2 (1987)</u>	First captured before i	First captured in i				
Released and recaptured	5	75				
Expected value	5.5	74.5				
Not recaptured	27	361				
Expected value	26.5	261.5				
<u>i = 3 (1988)</u>	First captured before i	First captured in i		Captured before i-1 not captured in i-1	Captured before i-1 captured in i-1	First captured in i-1
Released and recaptured	9	90	Captured in i	22	3	37
Expected value	7.1	91.9	Expected value	22.6	2.5	36.9
Not recaptured	53	712	Captured after i	24	2	38
Expected value	54.9	710.1	Expected value	23.4	2.5	38.1
<u>i = 4 (1989)</u>	First captured before i	First captured in i		Captured before i-1 not captured in i-1	Captured before i-1 captured in i-1	First captured in i-1
Released and recaptured	9	88	Captured in i	49	6	72
Expected value	9.5	87.5	Expected value	49.9	7.0	70.1
Not recaptured	116	1,063	Captured after i	15	3	18
Expected value	115.5	1,063.5	Expected value	14.3	2.0	19.9
<u>i = 5 (1990)</u>	First captured before i	First captured in i		Captured before i-1 not captured in i-1	Captured before i-1 captured in i-1	First captured in i-1
Released and recaptured	4	41	Captured in i	24	7	37
Expected value	5.5	39.5	Expected value	18.4	4.6	45.0
Not recaptured	63	445	Captured after i	12	2	51
Expected value	61.5	446.5	Expected value	17.6	4.4	43.0

[a] The goodness-of-fit test was devised by Pollock, et al. (1985).

APPENDIX E
Data File Listing

Appendix E1. Data files[a] used to estimate parameters of the Arctic grayling population in Fielding Lake, 1986 through 1990.

Data file	Description
U0013ABA.DTA	Population and marking data for Arctic grayling captured in Fielding Lake (all areas) in 1986.
U013BBA7.DTA	Population and marking data for Arctic grayling captured in Fielding Lake (in the lake itself) by electrofishing in 1987.
U013GBB7.DTA	Population and marking data for Arctic grayling captured at Caribou Bay Creek with fyke nets in 1987.
U013HBA7.DTA	Population and marking data for Arctic grayling captured at Two Bit Creek with fyke nets in 1987.
U013IBA7.DTA	Population and marking data for Arctic grayling captured at Fielding Lake outlet with seines in 1987.
U013BLA8.DTA	Population and marking data for Arctic grayling captured in Fielding Lake (in the lake itself) with electrofishing in 1988.
U013FLA8.DTA	Population and marking data for Arctic grayling captured at Two Bit Creek with fyke nets in 1988.
U013GLA8.DTA	Population and marking data for Arctic grayling captured at Caribou Bay Creek with fyke nets in 1988.
U013ILA8.DTA	Population and marking data for Arctic grayling captured at Fielding Lake outlet with seines in 1988.
U013BLA9.DTA	Population and marking data for Arctic grayling captured in Fielding Lake (in the lake itself) with electrofishing in 1989.
U013GLA9.DTA	Population and marking data for Arctic grayling captured at Two Bit Creek with fyke nets in 1989.
U013ELA0.DTA	Population and marking data for Arctic grayling captured at Fielding Lake (all areas) in 1990.
U013OLA0.DTA	Data base of releases and recoveries used for estimating parameters of the Jolly-Seber model for Arctic grayling in Fielding Lake, 1986 through 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.