Fishery Data Series No. 94-34

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[1] This investigation was partially funded by the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under Project F-10-9 Job No. R-3-2(c).

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ABSTRACT

A mark-recapture experiment was conducted on Arctic grayling *Thymallus arcticus* in Piledriver Slough, near Fairbanks, Alaska during 1993. The timing of the experiment corresponded with spring break-up and the onset of a popular spring fishery, similar to past years. Age and size composition of the Arctic grayling population were also estimated. An estimated 10,587 (SE = 1,351) Arctic grayling $\geq$ 150 millimeters fork length were present during the late-April spawning period. The stock was characterized by a high proportion of sublegal-sized Arctic grayling (less than 270 millimeter fork length) and the age composition was predominated by ages 3 and 5 year old fish. Estimates of survival and exploitation indicated the stock of Arctic grayling continues to have a low survival rate and a moderate exploitation rate. Continued declines in overall abundance and of legal-sized fish have indicated these survival and exploitation rates to be unsustainable. Restrictions to a no-harvest regulation and close monitoring of the population will occur during 1994 and 1995. Lower than expected catches of stocked rainbow trout *Oncorhynchus mykiss* precluded mark-recapture estimates of abundance and size composition.

KEY WORDS: Arctic grayling, *Thymallus arcticus*, rainbow trout, *Oncorhynchus mykiss*, Piledriver Slough, abundance estimation, age composition, size composition, spawning stock, survival rate, exploitation.

INTRODUCTION

Many freshwater fish species common to interior Alaska colonized Piledriver Slough (Timmons and Clark 1991) after its establishment as a clearwater stream, by blockage of flow from the Tanana River in 1976. It is likely that Piledriver Slough was colonized by Arctic grayling *Thymallus arcticus* straying from area streams and rivers. Limited information on the movements of tagged fish have suggested donor stocks were from the adjoining Moose and French Creek watersheds (Figure 1; Fleming 1991), as well as the more distant Chena and Salcha rivers. In the ensuing years, Arctic grayling have become well established in the slough at higher densities than other assessed populations in the Tanana River drainage. Hydrologically, the slough has attributes of both spring-fed and rapid run-off streams. Water enters the slough by upwelling from the Tanana aquifer; the height or stream-stage is influenced directly by glacial meltwater runoff in the Tanana River. Other studies have indicated that Arctic grayling utilize spring-fed systems for feeding but not spawning (Clark and Ridder 1988, Ridder 1989). Unlike spring creeks, such as the Delta Clearwater and Richardson Clearwater, Piledriver Slough is warmer and provides habitat for both spawning and feeding.

Piledriver Slough's close proximity to Fairbanks, accessibility, and the presence of both Arctic grayling and stocked rainbow trout have provided a popular sport fishery. Prior to initiation of a stocked rainbow trout program, Piledriver Slough received between 1 and 3% of the total Tanana drainage effort in angler-days (Mills 1983-1993). Effort in Piledriver Slough has increased as much as five-fold since 1987; in 1990 it received an estimated 15% of the Tanana River drainage effort. The fishery also has provided as much as 20% of the drainage total catches of Arctic grayling in 1990 (Mills 1991) and as much as 16% of the drainage harvest of rainbow trout in 1988 (Mills 1989).

Due to the large increases in angling effort, annual stock assessment began in 1990, including estimates of Arctic grayling, abundance along with length and age composition (Timmons and Clark 1991, Fleming 1991, Fleming and Schisler 1993). Estimated abundances of Arctic grayling have ranged between 14,030 and 17,323 fish greater than 149 mm fork length (FL) during early spring. Age-length data indicate lower growth potential than most Tanana River drainage Arctic grayling stocks (Fleming 1991) and the age of 50% maturity is between 4 and 5 years (Clark 1992). Tagging studies have found that nearly all fish examined during late-summer (August) were present during the previous May sampling period (Fleming 1991). Additionally, up to 50% of the stock examined in adjoining Moose Creek during July and August, had moved from Piledriver Slough sometime after tagging in May.

Concurrent investigations have sought to estimate abundance and survival of stocked rainbow trout (Timmons 1992, Fleming and Schisler 1993). In these investigations, the overwinter survival of stocked rainbow trout was very low. The estimated abundance of surviving stocked rainbow trout was 72 fish, indicating that the carryover survival from the 1991 stocking was only 0.25%.

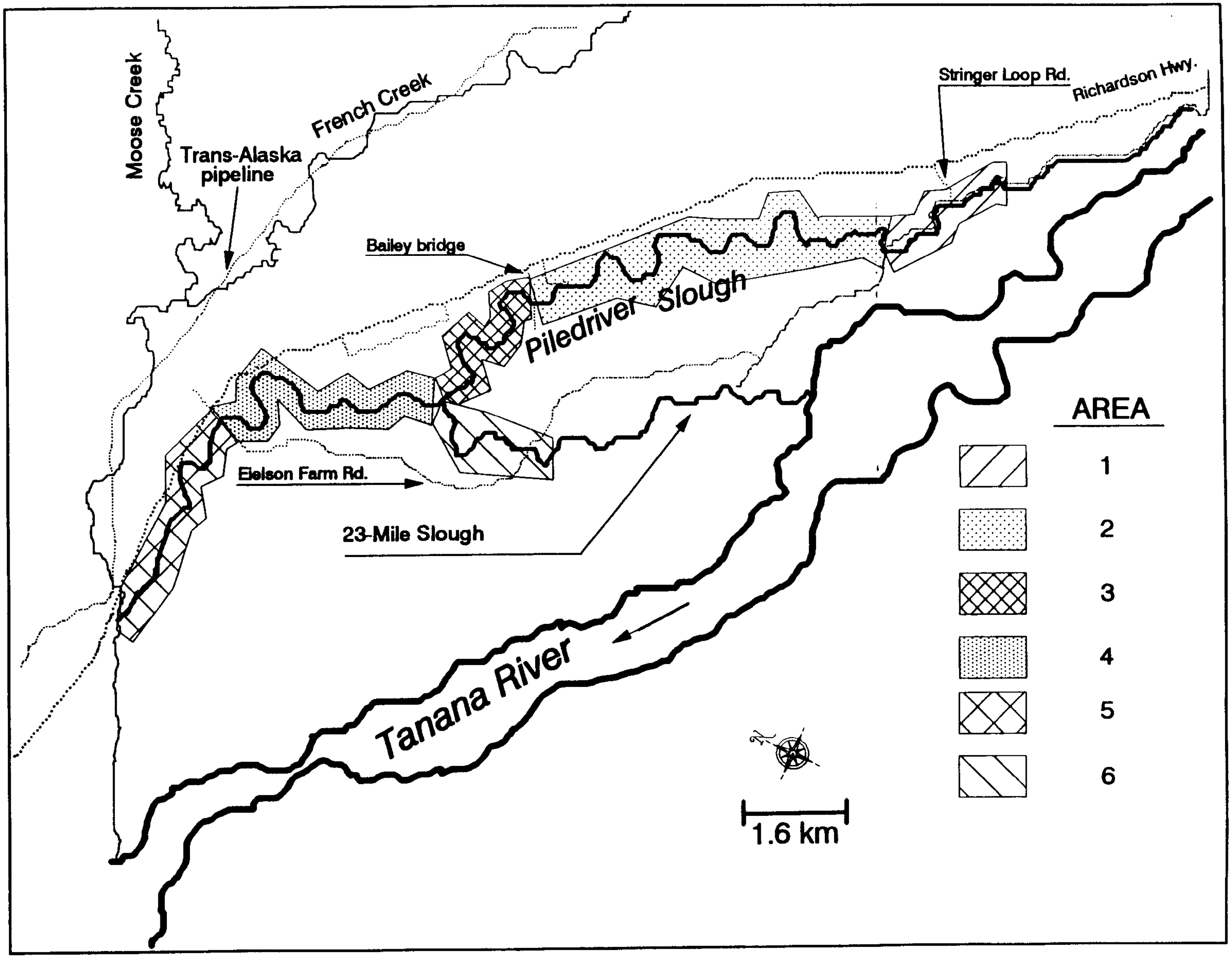

Figure 1. Map of study area encompassing Piledriver Slough, Moose Creek and French Creek.

In 1992, annual survival and exploitation estimates for Arctic grayling in Piledriver Slough were calculated (Fleming and Schisler 1993). The abundance of Arctic grayling was estimated at 14,030 fish (SE = 1,860) ≥ 150 mm FL, and was comprised primarily of fish age 5 and 4 years. Preliminary estimates indicated that only 36% (SE = 4%) of Arctic grayling age 5 years and older in 1991 survived to be 6 years and older in 1992, and that Arctic grayling were heavily exploited by the sport fishery.

In 1993, the objectives of the Piledriver Slough Arctic grayling and stocked rainbow trout assessment programs were to estimate the:

1) abundance of Arctic grayling ≥ 150 mm FL in Piledriver Slough;

2) age composition of the Arctic grayling population in Piledriver Slough;

3) size composition of the Arctic grayling population in Piledriver Slough;

4) abundance of rainbow trout ≥ 150 mm FL in Piledriver Slough; and,

5) size composition of the rainbow trout in Piledriver Slough.

Survival and mortality of Arctic grayling were also estimated for the 1992 fishery.

METHODS

Field Sampling

The mark-recapture experiment in Piledriver Slough in 1993 was of shorter duration than that conducted in previous annual stock assessments. It began on 26 April 1993 in Piledriver Slough, following breakup, and was completed on 30 April along the main stem of Piledriver Slough. Two systematic sampling events were undertaken, using two electrofishing crews of five to seven people, which allowed for efficient and timely coverage of the study area. The short and intense sampling was planned to minimize risks of immigration into or emigration from the surveyed area and assessed stock. Both the mark and recapture sampling events lasted two days.

In 1991, Piledriver Slough was divided into six areas delineated by landmarks, access points, or one crew-day's coverage (Figure 1). For the purpose of between-year consistency, the 1993 study used 1991 geographic delineations whenever possible. The areas of Piledriver Slough are described as follows (from Fleming 1991):

Area 1) Stringer Loop Road area: includes the section from the large beaver dam downstream to the culverts. This area is the headwaters of the slough; it is narrow, with alternating pools and riffles.

Area 2) Culverts to Bailey Bridge: this section of Piledriver Slough is a remote section, accessed from the ends. The stream is generally small with alternating pools, riffles, and minor braiding. The lower portion of this section also includes long runs and larger pools.

Area 3) Bailey Bridge to 23-Mile Slough: this section is easily accessed by a road and a path, respectively. In this section, a habitat transition occurs; the variability seen in the upstream areas is reduced. This section is generally wide and slow moving, with an increased volume.

Area 4) 23-Mile Slough to Eielson Farm Road: this section is easily accessed by a path and a road, respectively. This section is primarily broad and slow, with some deep pools.

Area 5) Eielson Farm Road to confluence with the Tanana River: this portion of the slough was accessed and sampled using a pulse-DC electrofishing boat. The area is evenly divided between broad and slow and narrow channelized habitats.

Area 6) 23-Mile Slough: this tributary slough is accessed 2 km upstream of the Eielson Farm Road by a path, and exited by a path near the confluence with Piledriver Slough. The habitat in the tributary is similar to area (1), but smaller in scale.

Owing to aufeis accumulations and beaver dams, which caused barriers to upstream migration, several headwater segments of Piledriver Slough that were assessed in 1990 and 1991 were not included in the 1993 mark-recapture experiment. Area (1) and the upper half of area (2), now referred to as area (2a), were closed to immigration by several unbreached beaver dams. Foot surveys and electrofishing in these areas detected several winter-killed fish and no live fish. In area (6) heavy accumulations of aufeis and beaver dams prevented access and use by spawning Arctic grayling.

The upstream limit of the 1993 study section was the beaver dam blockage delimiting areas (2a) and (2b), and the confluence of 23-Mile Slough with Piledriver Slough. The downstream limit of sampling was the Eielson Farm Road (Figure 1). The sampled area included areas (2b), (3), and area (4). Electrofishing techniques followed those of previous assessments (Timmons and Clark 1991, Fleming 1991, Fleming and Schisler 1993). Variable voltage pulsator (VVP) settings were 60 Hz pulse-DC ranging from 200 to 250 volts and amperage from 1.0 to 2.0 A. All initially captured fish greater than 149 mm

FL were measured to the nearest 1 mm FL, fin punched (upper caudal punch), and tagged with an individually numbered green Floy FD-67 internal anchor tag at the base of the dorsal fin. Age sampling was planned and performed only during the recapture sampling event. Several scales were collected from the area approximately six scale rows above the lateral line, just posterior to the dorsal fin's insertion of each Arctic grayling's left flank, and were mounted directly on gum cards. Fork length, finclip and/or fin punch tag number, and sex were recorded on Tagging-Length forms (Version 1.0). Fish with tag losses were given new tags, and previous finclips were noted. Scales from previously marked Arctic grayling were collected on the right side of the fish to avoid collection of regenerated scales. Data collection procedures from previously marked Arctic grayling were similar, but previous finclips, tag losses, tag numbers, and colors were recorded.

Abundance Estimation

A closed-model mark-recapture experiment was used to estimate the abundance of Arctic grayling in Piledriver Slough in 1993, similar to the approach used in 1992. The use of a closed-model abundance estimator using mark-recapture experiments assumes the following (Seber 1982):

1) the population in the study area must be closed, i.e. the effects of migration, mortality, and recruitment are negligible;

2) all Arctic grayling have the same probability of capture during the first sample or in the second sample or marked and unmarked Arctic grayling mix completely between the first and second samples;

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

4) Arctic grayling do not lose their mark between sampling events.

We attempted to meet the closure assumption (#1) by shortening the duration of the mark-recapture experiment. It is highly improbable that substantial migration, mortality, or recruitment occurred during the three-day hiatus. Sampling the majority of Piledriver Slough in both events reduced any effects of recruitment during the experiment and improved the accuracy of the assessment. Assumptions 2 and 3 were examined by testing for differences in capture probability by size and geographic area. Size selectivity was tested with two Kolmogorov-Smirnov (KS) two-sample tests. The first KS test examined the cumulative length frequency distributions of marked Arctic grayling with those recaptured. The second KS test compared cumulative length frequency distributions of Arctic grayling from the first (mark event) and second (recapture event) samples. The results of these tests suggested methods to alleviate size biases (Appendix A1). Spatial differences in capture probability were evaluated through comparisons of area-specific recapture-to-catch ratios. The results of this test determined whether the abundance estimation model must be stratified by area. The last testable assumption was met by double-marking each fish, with a tag and an easily identifying punch.

The two KS tests indicated that sampling during (test statistic value and P value) was size selective, requiring the data to be stratified into size classes. To delimit the stratified size classes, an iterative series of chi-square tests was performed to find maximal differences in capture probability given two size strata. The length at which the chi-square statistic was maximal demarcated the size strata as 150-257 MM and > 257 mm..

Unlike the 1991 mark-recapture experiment, capture probabilities did not vary significantly by areas sampled. Because the assumption of equal capture probability was not rejected, the modified Petersen estimator of Bailey (1951, 1952) was selected. Bailey's modification was used because of the systematic sampling approach and the level of mixing (localized, not complete; Seber 1982) of marked and unmarked fish over the length of the sampling area (Seber 1982). Stratified and unstratified point estimates of abundance were calculated as:

$$\hat{N} = \frac{M(C+1)}{(R+1)} \tag{1}$$

where:
- M = the number of Arctic grayling marked and released during the marking event sample;
- C = the number of Arctic grayling examined for marks during the recapture event;
- R = the number of Arctic grayling recaptured during the second sampling event (recapture); and,
- $\hat{N}$ = estimated abundance of Arctic grayling.

Variance of the abundance estimate was estimated by (Bailey 1951, 1952):

$$V[\hat{N}] = \frac{\hat{N}\,M\,(C-R)}{[(R+1)(R+2)]} \tag{2}$$

<u>Age and Size Composition</u>

Apportionment of the estimated abundance among age or size groupings depends on the extent of sampling biases. The outcome of tests for size selectivity, and chi-square tests to detect geographic differences in capture probabilities, determined the necessary adjustments. Because size selectivity was detected, the sampled age and size compositions were adjusted by size-specific capture probabilities. The second event sample was used to estimate age and size composition. First the conditional fractions based on the area-stratified and/or size-stratified samples were calculated:

$$\hat{p}_{ij} = n_{ij}/n_i \qquad (3)$$

where

- n_i = the number sampled from size stratum i in the mark-recapture experiment;
- n_{ij} = the number sampled from size stratum i that belong to class j; and,
- p_{ij} = the estimated fraction of the fish in class j that are in size stratum i.

Note that $\sum_j p_{ij} = 1$. The variance for p_{ij} was estimated as:

$$\hat{V}[p_{ij}] = \frac{\hat{p}_{ij}(1 - \hat{p}_{ij})}{n_i - 1} \qquad (4)$$

The estimated abundance of class j in the population ($\hat{N}_j$) was calculated as:

$$\hat{N}_j = \sum_i \hat{p}_{ij} \hat{N}_i \qquad (5)$$

where $\hat{N}_i$ = the estimated abundance of size strata i of the mark-recapture experiment.

The variance for $\hat{N}_j$ was estimated as a sum of the exact variance of a product from Goodman (1960):

$$V[\hat{N}_j] = \sum_i (V[\hat{p}_{ij}]\hat{N}_i^2 + V[\hat{N}_i]\hat{p}_{ij}^2 - V[\hat{p}_{ij}]V[\hat{N}_i] \qquad (6)$$

The estimated fraction of the population that belongs to class j (p_j) was:

$$\hat{p}_j = \hat{N}_j/\hat{N} \qquad (7)$$

where $\hat{N} = \sum_i \hat{N}_i$.

The variance of the estimated fraction was approximated with the delta method (see Seber 1982; ignoring the hat symbols, all quantities were estimated):

$$V[p_j] \approx \sum_i V[p_{ij}]\left\{\frac{N_i}{N}\right\}^2 \frac{\sum_i \{V[N_i](p_{ij} - p_j)^2\}}{N^2} \qquad (8)$$

Each stock assessment category utilizes the above approach, where substitutions for class are: age classes; Relative Stock Density (RSD) categories of Gabelhouse (1984), and 10 mm FL incremental size groupings. The RSD categories for Arctic grayling were: "stock" (150 to 269 mm FL); "quality" (270 to 339 mm FL); "preferred" (340 to 449 mm FL); "memorable" (450 to 559 mm FL); and, "trophy" (greater than 559 mm FL). Incremental size composition categories were 10 mm FL groupings with mid-points 155 to 395 mm FL.

Survival, Mortality, and Exploitation

An examination of survival, mortality, and exploitation was facilitated by annual stock assessments conducted in 1992 and 1993. The statewide catch and harvest estimates (Mills 1993) provided point estimates of Arctic grayling catches and harvests for the 1992 Piledriver Slough fishery.

Survival was estimated as proportion of the summed abundance from a portion of an age series at one time, that are estimated to be present at a later time (Ricker 1975). Only ages that appear to be fully recruited were used as the portion of an age series. Abundance-at-age estimates for 1991 (Fleming 1991) indicated Arctic grayling age 5 years and older were fully recruited at the time and location of the stock assessment. The age at full recruitment for the present investigation was also assumed to be age 5, so that comparisons with previous estimates of survival, mortality, and exploitation (Fleming and Schisler 1993) could be made. The annual survival rate *S*, was estimated as:

$$\hat{S} = \frac{\hat{N}_{t+1}}{\hat{N}_t} \qquad (9)$$

where:

$\hat{S}$ = the estimated proportion of Arctic grayling age 5 and up (k=5,6,7,8,9,) in year t that survive to year t+1 as age 6 and up (k = 6,7,8,9,10); and,

$\hat{N}_t$ = the summed estimated abundance of Arctic grayling age 5 years and up in year *t*; and,

$\hat{N}_{t+1}$ = the summed estimated abundance of Arctic grayling age 6 years and up in year *t+1*

The variance of $\hat{S}$ was approximated with the delta method (Seber 1982; ignoring hat symbols) as:

$$V[S] \approx \left[\frac{N_{t+1}}{N_t}\right]^2 \left[\frac{V[N_{t+1}]}{[N_{t+1}]^2} + \frac{V[N_t]}{N_t^2}\right] \qquad (10)$$

where the variance for N_t and N_{t+1} were each estimated as a sum of the exact variance of a product from Goodman (1960):

$$V[\hat{N}_t] = \sum_{k=5}^{9}(V[\hat{p}_k]\hat{N}_{92}^2 + V[\hat{N}_{92}]\hat{p}_k^2 - V[\hat{p}_k]V[\hat{N}_{92}] \quad (11)$$

and;

$$V[\hat{N}_{t+1}] = \sum_{k=6}^{10}(V[\hat{p}_k]\hat{N}_{93}^2 + V[\hat{N}_{93}]\hat{p}_k^2 - V[\hat{p}_k]V[\hat{N}_{93}] \quad (12)$$

where:

$\hat{N}_{92}$ = the abundance estimate for Arctic grayling $\geq$ 150 mm FL in 1992; the variance of N_{92} was from the bootstrapped stratified Petersen model (reported in Fleming and Schisler 1993).

$\hat{N}_{93}$ = the abundance estimate for Arctic grayling $\geq$ 150 mm FL in 1993; the variance of N_{93} was from the point estimated variance for the stratified Petersen model.

$\hat{p}_k$ = the estimated adjusted fraction of the fish in age class k from 1992 and 1993 stock assessments.

The annual survival rate was converted into annual and instantaneous rates of mortality with respect to the following relationships (from Ricker 1975):

Z = the instantaneous total mortality rate;
Z = -Ln (S)
F = the instantaneous rate of fishing mortality;
M = the instantaneous rate of natural mortality;
Z = F + M;
A = the annual mortality rate;
A = 1 - e^{-z}, where e ≈ 2.71828;
A = 1 - S

Because statewide catch and harvest estimates have demonstrated that substantial harvest occurs on younger and smaller fish regardless of a 12 inch minimum size limit (Mills 1992, 1993), exploitation and natural mortality rates were estimated for the assessed stock $\geq$ 150 mm FL. For this purpose, the survival rate estimated for fish age 5 and older was assumed to be representative and applied to the entire assessed stock. In order to apportion total instantaneous mortality (Z) among fishing (F) and natural (M) mortality components, Baranov's catch equation (Ricker 1975) was rearranged and solved for *F*:

$$F = \frac{Z}{A} * \frac{C}{N} \quad (13)$$

where:

C = the 1992 estimated harvest of Arctic grayling (Mills 1993) from the Piledriver Slough fishery;

N = the 1992 abundance estimate of Arctic grayling in Piledriver Slough;

Z = the estimated total instantaneous mortality rate calculated for apparently recruited year classes (age 5 and older). Recruited year classes were age classes whose representation (proportion or abundance) had reached a maxima.

Before estimating natural mortality and exploitation parameters, a classification of the Arctic grayling fishery was needed to select estimator formulae. The two types proposed by Ricker (1975) are:

Type 1 = where natural mortality occurs during a time of year other than the fishing season; the population decreases during the fishing season because of catch (harvest) removals only; or,

Type 2 = where natural mortality occurs along with fishing; each occurs at a constant instantaneous rate, or the two rates vary in parallel fashion.

Based upon present insights into the basic life history for Arctic grayling, the Type 1 classification was selected. The rate of exploitation (u) estimated for a Type 1 fishery was (Ricker 1975):

$$u = 1 - e^{-F} \tag{14}$$

The expectation of natural death was estimated (Ricker 1975):

$$v = n(1-u) \tag{15}$$

where:

v = expectation or probability of natural death; and,

n = conditional rate of natural mortality, which is calculated as (from Ricker 1975): $n = 1-e^{-M}$

Because catch-and-release induced mortalities are likely to be latent, and not represented in reported harvests of Arctic grayling, the expectation of natural mortality is likely biased high. To offset this, a sensitivity analysis was conducted in which additions were made to the reported harvest at a level which would approximate hooking mortality. To accomplish this, the estimated catch (Mills 1993) was reduced by the estimated harvest to yield an estimate of independent catch-and-release events in 1992. This estimate was multiplied by the incidence of hooking mortality, which was set at 0% and 9%. These bounds of hooking mortality correspond to the 95% confidence interval from a study of hooking mortality on Arctic grayling (Clark 1991). The product of this multiplication represented an estimate of fish that died following catch and release. Following the addition of these deaths to the reported harvest, parameter estimates were re-calculated using the aforementioned formulae.

RESULTS

Field Sampling

A total of 1,804 Arctic grayling ($\geq$ 150 mm FL) were captured over a 5-day period in April. A lack of captured rainbow trout in both sampling events (two fish marked and one fish examined for marks) precluded further assessment. Hereafter the use of "fish" will imply Arctic grayling. Water temperatures ranged between 2.2° and 8.0°C between 0900 and 1700 hrs. The maximum daily change observed was 4.8°C. During the marking event, 887 fish were marked and released alive over approximately 16 km of Piledriver Slough, in the four areas. A three-day hiatus separated the marking and recapture sampling events in any one sampling area. During the recapture event, 1,020 fish were captured in a single downstream pass, which included the recovery of 103 Arctic grayling tagged and released in the mark event. The tag shedding rate from the marking to the recapture event was 1.0%, based upon one tag shed out of the 103 recaptured fish. The overall acute mortality rate from the experiment was one fish out of 1,804 individual Arctic grayling handled, or 0.06%.

Abundance Estimation

A Kolmogorov-Smirnov comparison of cumulative distribution functions (CDF's) from the mark-recapture experiment showed that size selectivity was present in both sampling events (Figure 2A -mark vs recaptures: D = 0.25, P = 2.0×10^{-5}; and, Figure 2B - mark vs catch: D = 0.04, P = 0.43). As a result, the abundance was estimated using a stratified approach with adjustments for size selectivity, and stock composition estimates were based upon pooled samples from both events (Case III; Appendix A1). Size strata selected for abundance estimation and corrections to stock composition estimates were: 150 to 257 mm FL, and 258 mm FL and larger (χ^2 = 26.48, df = 1, P < 0.01), based on maximal differences of capture probability.

Capture probabilities for both the smaller and larger size strata were found to be statistically similar among sampled areas when the recapture-to-catch ratios were examined by chi-square goodness of fit tests (χ^2 = 0.06, df = 1, P = 0.81 for the smaller size stratum; χ^2 = 0.55, df = 1, P = 0.46 for the larger size stratum).

The examination of assumptions led to the use of the Bailey modification to the Petersen estimate with size stratification. The estimated abundance of small Arctic grayling, from 150 mm to 257 mm FL, was 7,674 fish (SE = 1,315, CV = 17%; Table 1). The estimate for Arctic grayling larger than 257 mm FL was 2,913 fish (SE = 311 , CV = 10.6%). The sum of stratified estimates for We estimated that there were 10,587 Arctic grayling (SE = 1,351) $\geq$ 150 mm FL in Piledriver Slough in April 1993, including 7,674 (SE = 1.315) fish 150-257 mm FL and 2,913 (SE = 311) fish > 257 mm FL (Table 1).

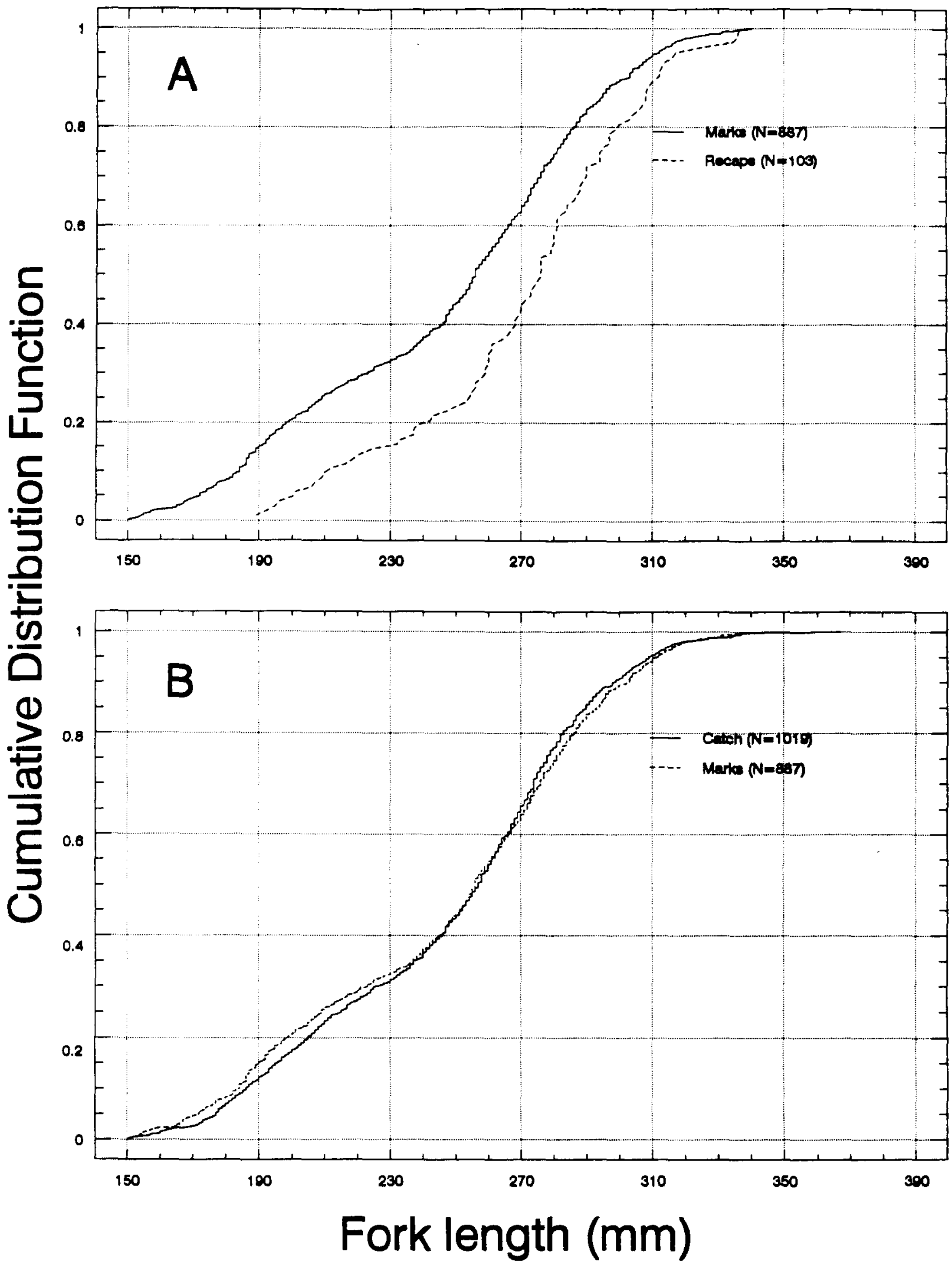

Figure 2. Cumulative distribution functions of lengths of Arctic grayling marked versus lengths of Arctic grayling recaptured (A) and versus lengths of Arctic grayling examined for marks (B) in Piledriver Slough, 26 through 30 April, 1993.

Table 1. Size-stratified abundance estimates of Arctic grayling ($\geq$ 150 mm FL) in Piledriver Slough, April 1993.

Length category	Mark M	Catch C	Recap R	ρ[a]	N[b]	SE[N][c]
150 to 257 mm	461	515	30	0.06	7,674	1,315
> 257 mm	426	505	73	0.14	2,913	311
Total	887	1,020	103	___	10,587	1,351
Unstratified	887	1,020	103	0.10	8,708	805

[a] ρ is the point estimated probability of capture.
[b] N is the point estimated abundance in a stratified length category or unstratified population.
[c] SE[N] is the standard error of N.

Age and Size Composition

Ages observed for Arctic grayling in Piledriver Slough ranged from 2 to 10 years, with 5 years as the median age. The predominant age class present in Piledriver Slough was age 3 (38% of the stock; Table 2) followed by age 5 (25% of the stock). Stock-sized fish comprised 80% of the assessed stock, while 20% were of quality-size (Table 3). Incremental size compositions and abundances for 1991, 1992, and 1993 (Figure 3) indicated declines as great as 50% in the apportioned abundance of legal-sized Arctic grayling ($\geq$ 270 mm FL) available to anglers (Figure 3).

Survival, Mortality, and Exploitation

Survival was estimated for the fully recruited portion of the population, which for the Piledriver Slough stock included Arctic grayling age 5-years and older. In 1992, there were an estimated 8,207 fish age 5 years and older (Table 4). Following the 1992 fishery, and overwintering to 1993, it was estimated that 2,562 fish age 6 years and older, or 31% (SE = 4), had survived. The 95% confidence interval range of the survival rate was 22 to 40%. The total instantaneous rate of mortality (Z) was 1.16.

In 1992 it was estimated that 14,030 Arctic grayling inhabited the slough during May, on or about the start of the fishery. Following the 1992 fishing season, Mills (1993) estimated that 15,252 captures of Arctic grayling in Piledriver Slough resulted in 1,030 fish harvested and 14,222 fish released. The introduction of hooking mortality as a variable increased the reported harvest by 1,280 fish to a potential harvest of 2,310 fish, which was a relative increase of 120%. The instantaneous rate of fishing mortality (F) was calculated with Baranov's catch equation using each harvest scenario. Instantaneous fishing mortality (F) was 0.12 for the reported harvest, and when adjusted for hooking mortality F was 0.28. Exploitation rate, or expectation of death attributable to the fishery (u), and the expectation of natural death (v) were estimated under both harvest scenarios for the sensitivity analysis. The rates were as follows:

Source of Mortality:	Mills 1992 Harvest	Mills 1992 Harvest *with* Hooking Mortality
Fishery:	$u = 0.12$	$u = 0.24$
Natural:	$v = 0.57$	$v = 0.45$
Total:	A = 0.69	A = 0.69

Table 2. Estimates of the sampled and adjusted contributions by each age class for Arctic grayling (≥ 150 mm FL) captured in Piledriver Slough, 29 through 30 April 1993.

	Sampled						Adjusted[a]		
Age	n[b]	p[c]	SE[d]	FL[e]	SD[f]	n[g]	N[h]	p[i]	SE[j]
1	0	0.00	---			0	0	0.00	---
2	7	0.01	<0.01	166	22	7	115	0.01	<0.01
3	247	0.28	0.01	194	18	247	4,031	0.38	0.03
4	87	0.10	0.01	238	19	86	1,284	0.12	0.01
5	227	0.25	0.01	258	19	227	2,594	0.25	0.01
6	187	0.21	0.01	275	19	187	1,607	0.15	0.02
7	98	0.11	0.01	288	21	98	707	0.07	0.01
8	19	0.02	<0.01	301	19	19	131	0.01	<0.01
9	15	0.02	<0.01	310	19	15	104	0.01	<0.01
10	2	<0.01	<0.01	310	7	2	14	<0.01	<0.01
	889	1.00					10,587	1.00	

[a] Age composition was adjusted only for size selectivity.
[b] n = sample size.
[c] p = proportion of sampled Arctic grayling from recapture event.
[d] SE = standard error of the sampled proportion.
[e] FL = mean fork length-at-age based upon 888 age:length combinations from the recapture event, 29 through 30 April 1993.
[f] SD = sample standard deviation.
[g] n = sample size for mean fork length at age.
[h] N = estimated abundance by age classes at the time of recapture event.
[i] p = adjusted proportion of Arctic grayling (≥ 150 mm) in stock.
[j] SE = standard error of the adjusted proportion.

Table 3. Summary of Relative Stock Density (RSD) indices for Arctic grayling (≥ 150 mm FL) captured at Piledriver Slough in 1991, 1992, and 1993.

	RSD Category[a]				
	Stock	Quality	Preferred	Memorable	Trophy
1991					
Number sampled	882	320	4	0	0
Adjusted RSD[b]	0.73	0.26	<0.01	---	---
Standard Error	0.01	0.01	<0.01	---	---
CV (%)	2	6	50	---	---
Abundance[c]	12,645	4,504	52	---	---
1992					
Number sampled	683	375	8	0	0
Adjusted RSD[d]	0.71	0.28	<0.01	---	---
Standard Error	0.01	0.01	<0.01	---	---
CV (%)	2	4	45	---	---
Abundance	10,017	3,970	28	---	---
1993					
Number sampled	656	361	2	0	0
Adjusted RSD[e]	0.80	0.20	<0.01	---	---
Standard Error	0.02	0.02	<0.01	---	---
CV(%)	2	10	53	---	---
Abundance	8,470	2,075	42	---	---

[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] The required adjustment made in the 1991 analysis involved a differential capture probability by area, but no changes were made to the RSD sample proportion by size specific capture probabilities.

[c] Apportioned abundances from the 1991 (Fleming 1991), 1992 (Fleming and Schisler 1993), and 1993 (this report) stock assessments.

[d] Adjustments for size selectivity were used in the 1992 assessment.

[e] Adjustments for size selectivity were used in the 1993 assessment.

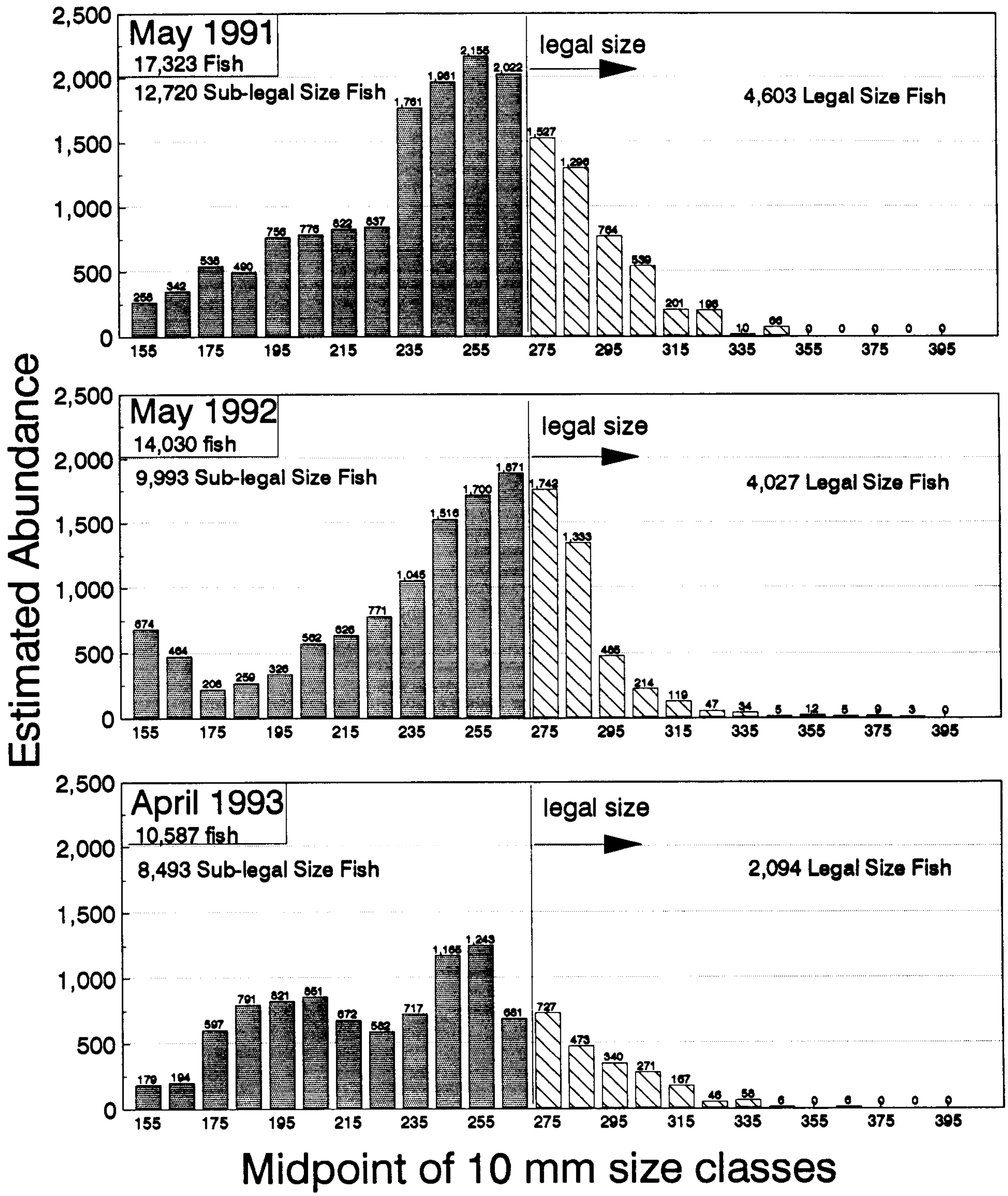

Figure 3. Apportionment of estimated abundance across 10 mm FL incremental size categories for Arctic grayling (≥150 mm FL) present in Piledriver Slough during 1991, 1992, and 1993 stock assessments.

Table 4. Estimates of age-specific abundances and standard errors for Arctic grayling (≥ 150 mm FL) resident in Piledriver Slough during May 1992, and April 1993.

	May 1992 estimate[a]:				April 1993 estimate[b]:			
Age Class	p[c]	n[d]	SE[e]	CV[f]	p[g]	n	SE	CV
1	0.00	0	---	--	0.00	0	---	--
2	0.07	961	219	23	0.01	115	45	40
3	0.10	1,345	186	14	0.38	4,031	586	14
4	0.25	3,513	428	12	0.12	1,284	215	17
5	0.32	4,540	513	11	0.25	2,594	369	14
6	0.20	2,866	367	13	0.15	1,607	265	16
7	0.05	633	167	26	0.07	707	144	20
8	0.01	127	44	35	0.01	131	38	29
9	<0.01	45	15	36	0.01	104	33	32
10	0.0	0	--	--	<0.01	14	9	69
Totals	1.0	14.030	---	--	1.0	10,587	---	--

[a] Stock assessment was conducted between 13 and 18 May. Bailey's modification to the Petersen estimator was used.
[b] Stock assessment was conducted between 26 and 30 April. Bailey's modification to the Petersen estimator was used.
[c] p = the adjusted proportion at age at the time of the first (marking) event, 13 to 16 May 1992. Adjustments were made to composition estimates to compensate for differential capture probability by size.
[d] n = estimated abundance apportioned for each age.
[e] SE = standard error of the age-apportioned abundances (n).
[f] CV = coefficient of variation of n expressed as a percentage.
[g] p = the adjusted proportion at age at the time of the second (recapture) event, 29 to 30 April, 1993. Adjustments were made to composition estimates to compensate for differential capture probability by size.

DISCUSSION

The annual stock assessment of Arctic grayling and rainbow trout in Piledriver Slough occurred in late-April along a 16 km portion of the 32 km long slough. The absence of rainbow trout during sampling precluded assessment of their abundance, composition, and survival. As in 1992, heavy accumulations of aufeis and several beaver dams blocked spring migrations of Arctic grayling to headwater areas of Piledriver Slough and 23-Mile Slough. Foot surveys and electrofishing in these areas detected several winter-killed fish and an absence of live fish. This resulted in the same study area as in 1992, but markedly reduced from 1990 and 1991 investigations. Short-term consequences of the blockages include reductions to available habitat, consolidation of the population to more accessible areas, and an increased vulnerability to exploitation by angling. Ultimately substantial losses of habitat could eventually reduce growth and recruitment, and yield from the fishery.

Since 1992, the mark-recapture experiments have not required area-stratification for the estimation of abundance. Prior to 1993, sampling in the upper headwater areas often resulted in higher probabilities of capture. It was thought to occur due to the small size of the slough in these areas (Fleming 1991). Instead, adjustments for size-selective sampling of fish larger than 149 mm FL were needed to estimate abundances and reduce bias in composition estimates. Approximately 10,587 fish greater than 149 mm FL were present in Piledriver Slough at the end of April 1993, indicating a decline in estimated abundance at Piledriver Slough since 1991 (17,323) and 1992 (14,030). Because of the relative imprecision of the estimates, only the 1991 and 1993 estimates were significantly different from each other when 95% confidence intervals were examined.

The age and size compositions of Arctic grayling appeared to have changed markedly from past assessments (Figures 3 and 4). In 1993, age 3 Arctic grayling were clearly predominant, while strength of the age 4 through age 6 cohorts seen in 1992 had dissipated. Estimated abundances of age 3 Arctic grayling, though only partially recruited, may indicate a strong recruitment potential from this cohort over the next several years. In 1993, the number of fish age 4 through 6 years appears to have declined by as much as 50%, from an estimated 10,919 down to 5,485 fish (Figure 4). It is unlikely that the potential strength of the age 3 cohort can offset the declining abundances of the age 4-6 cohorts.

Estimates of size composition from 1991-1993 assessments indicate problems in sustaining harvest consumption in the Arctic grayling fishery in Piledriver Slough (Figure 3). First, the abundance of fish that are of legal size (greater than 269 mm FL, or 12 inches total length) appears to have declined between 1992 and 1993. Secondly, although the partially-recruited abundance of age 3 fish appears higher than past years, the overall estimated abundances of sublegal sized fish shows a decline. Based on these findings and overall

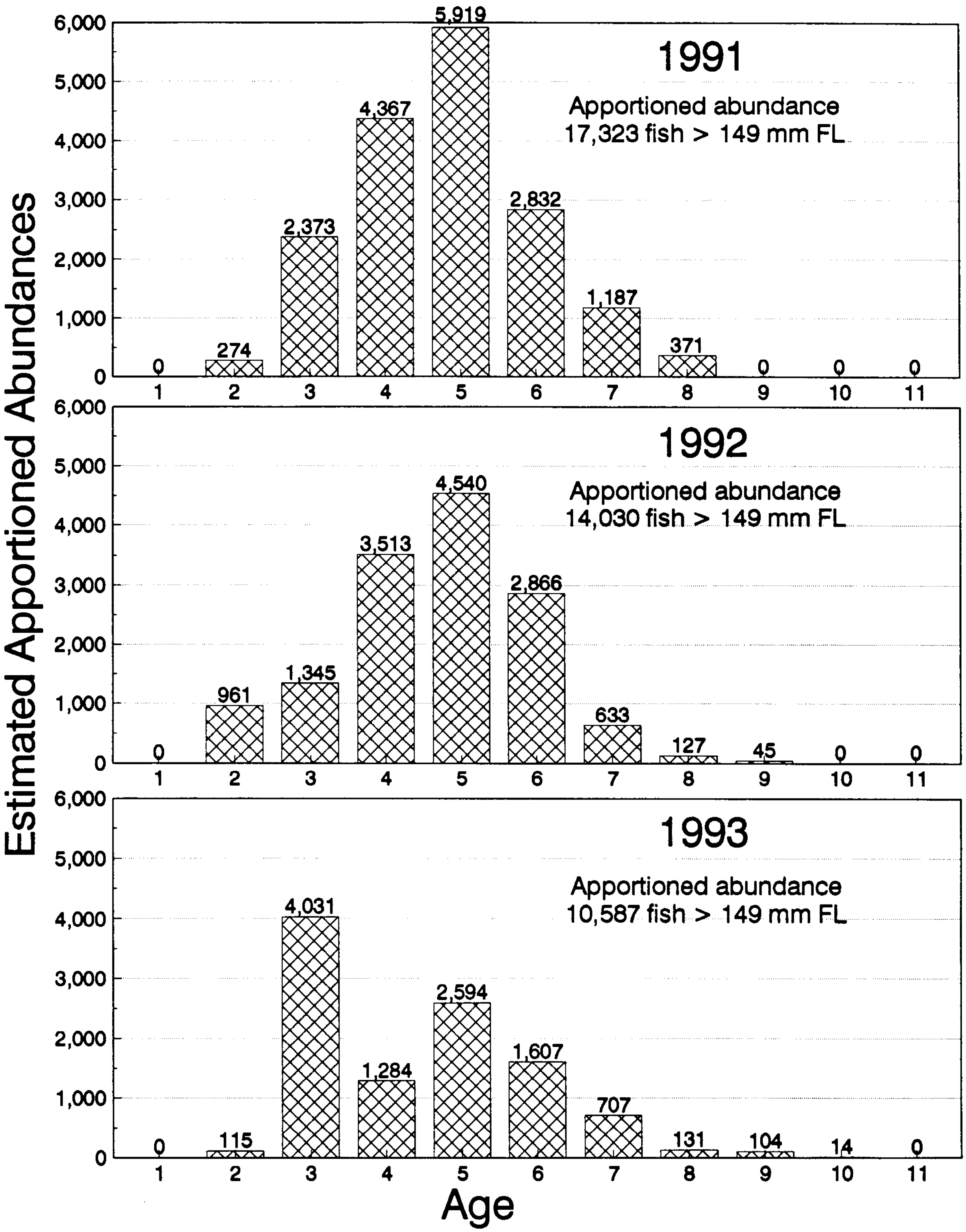

Figure 4. Apportionment of estimated abundance across age classes for Arctic grayling (≥150 mm FL) present in Piledriver Slough during 1991, 1992, and 1993 stock assessments.

declining abundances, the Piledriver Slough Arctic grayling fishery was restricted by emergency order on 26 June 1993 to catch-and-release fishing only.

Although angling exploitation may adequately explain declining numbers of larger fish, other variables may influence the declining numbers of smaller fish. The age at full recruitment for Arctic grayling in Piledriver Slough has been thought to be at age 5, when the fish average 258 mm FL in length, nearly legal size. The timing of recruitment is roughly two years later than other assessed Tanana drainage stocks (Fleming and Schisler 1993). Because of this, many of the sublegal fish belong to partially recruited cohorts, which increases the uncertainty about their actual abundance. Although regulations specify harvesting of fish 12 inches and larger, harvests of sublegal-sized Arctic grayling have been reported in past Alaska statewide harvest surveys. Mills (1992) estimated that 1,835 sublegal Arctic grayling were harvested from Piledriver Slough during 1991 from a catch of 20,815, despite a 12-inch minimum size regulation. In 1992, it was estimated that 118 sublegal Arctic grayling were harvested from a catch of 10,934 (Mills 1993). These illegal harvests may account for between 11% (1992) and 46% (1991) of the total estimated harvests.

The vulnerability of Arctic grayling to sport fishing gear and the resulting high catch rate can create another source of fishery exploitation. Unlike other assessed stocks in the Tanna drainage, estimated catches of Arctic grayling in Piledriver Slough have exceeded estimated abundances each year since 1990 by as much as a 2:1 ratio (Mills 1991-1993). Therefore, Piledriver Slough anglers could potentially catch and handle every fish present in the stock at least once, and sometimes twice during each fishing season. Losses of fish of all sizes can occur through latent hooking mortalities of released fish, which may occur at levels as high as 9% (Clark 1991). A potential result of high reported catches in Piledriver Slough and hooking mortality is that as many as 1,700 sublegal fish in 1991, and 975 in 1992 may have died in addition to the reported harvests. The combination of sublegal harvest and losses due to latent hooking mortalities may account for removals of up to 28% of the sublegal fish present in 1991, and 11% in 1992 that would be part of recruitment for this stock. In the future, similar levels of recruitment over fishing may need to be addressed in management of the Piledriver Slough fishery.

A second estimate of overall survival was calculated using information from 1992 and 1993. Approximately 31% of fish 5 years and older in May 1992, survived fishery and natural losses. This estimate follows a similar survival rate of 36% estimated in 1992 (Fleming and Schisler 1993). The two subsequent estimates of survival, which appear to be unsustainably low, suggest that this may not be a "true" (life or death) survival rate. Instead, it may be a compound measure of "true" survival *and* annual fidelity to Piledriver Slough at the time of spawning. The current approach to estimating survival might not be optimal, since through tagging studies some fish have been found to leave and go elsewhere. This results in these fish being categorized as natural mortalities, in error.

Although assumptions of closure have routinely been validated for the purpose of abundance estimation at specific times, closure between years has not been examined. Perhaps "true" survival might be better estimated using a combination of closed and open-model abundance estimators, such as a robust design, which is a variant of the Jolly-Seber model (Pollock et al. 1990). This approach could yield supplemental estimates of survival based on tags, independent of errors associated with ages, ages at recruitment, and apportioning abundances. Unfortunately, several important assumptions supporting these methods may have already been invalidated, based on past and present investigations. Size-selective sampling has been detected during the 1992 and present assessments. A second assumption holds that every fish must have the same probability of capture during each sampling event. No information exists to show that fish tagged in Piledriver Slough and subsequently found in other areas, return to Piledriver Slough prior to <u>each</u> annual stock assessment. One last impediment to using such models is the current method of marking. Other than numbered tags, the secondary marks are often partial fin clips or punches on the caudal fin. These marks are quickly identified when the fish is measured, but do not permanently identify the tagging cohort as needed by Jolly-Seber estimators.

Although the two estimates of survival since 1991 were similar, estimates of exploitation and mortality varied considerably with changes in the reported harvests and catches. Estimates of exploitation fell from 0.31 (0.44 with hooking mortality) resulting from the 1991 fishery (Fleming and Schisler 1993), to 0.12 (0.24) following the 1992 fishery. Although the sensitivity analysis with hooking mortality led to a 30% relative increase in 1991 estimates of exploitation, it resulted in a 100% relative increase during 1992. The cause of this change lies in the magnitude and ratio of estimated harvests relative to estimated catches in these years. Because hooking injury and latent mortalities are generally not addressed by harvest estimates, they are often incorrectly "lumped" with natural mortality, which can lead to underestimation of exploitation rates and increased management risks. Findings from the 1992 and present assessments may have strong management implications for fisheries where harvests are seemingly low relative to catches, or in catch-and-release fisheries. Since deaths attributable to hooking mortality cannot be empirically estimated annually, a high level of uncertainty around the "true" exploitation rate needs to be considered even in management of lightly-harvested fisheries.

At this time, stock assessment data has indicated fishing pressure on Piledriver Slough Arctic grayling reached unsustainable levels within the last several years. Future assessments will need to evaluate whether the recent closure to sport harvest of Arctic grayling in Piledriver Slough can rebuild abundances and compositions to previous levels. Because of Piledriver Slough's small size and close proximity to many anglers, it appears likely that relatively high use by anglers can quickly lead to overexploitation, even on sublegal sized fish. Sustainability of the fishery will require continued close monitoring and continued measures to reduce exploitation of all sizes of fish in the future. Uncertainty surrounding estimates of population parameters must be considered when planning management actions in fisheries such as these.

ACKNOWLEDGEMENTS

The author wishes to thank Bob Clark, Bill Ridder, Tim McKinley, Don Roach, Peggy Merritt, Keith Webster, Cal Skaugstad, Mike Doxey, John Burr, Fronty Parker, Renate Riffe, for help in the field. Thanks also go to Renate Riffe for aging scales, Allen Bingham for statistical and editorial support, and to Bob Clark for assistance with many aspects of the project. John H. Clark and Peggy Merritt are also to be thanked for their administrative support for the project. Thanks also go to Sara Case for final preparation and publication of the report. This project and report were made possible by partial funding provided by the U.S. Fish and Wildlife Service through the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under Project F-10-9, Job No. R-3-2(c).

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APPENDIX A

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

Result of first K-S test[a]	Result of second K-S 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 K-S (Kolmogorov-Smirnov) 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 K-S 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.