Fishery Data Series No. 95-15

Stock Assessment of Arctic Grayling in Piledriver Slough during 1994

by

Douglas F. Fleming

August 1995

Alaska Department of Fish and Game

Division of Sport Fish

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
metric ton	mt
milliliter	ml
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
ounce	oz
pound	lb
quart	qt
yard	yd

Spell out acre and ton.

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
hour (spell out for 24-hour clock)	h
minute	min
second	s

Spell out year, month, and week.

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

All commonly accepted abbreviations.	e.g., Mr., Mrs., a.m., p.m., etc.
All commonly accepted professional titles.	e.g., Dr., Ph.D., R.N., etc.
and	&
at	@
Compass directions:	
east	E
north	N
south	S
west	W
Copyright	©
Corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
et alii (and other people)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.,
id est (that is)	i.e.,
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
number (before a number)	# (e.g., #10)
pounds (after a number)	# (e.g., 10#)
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S. state and District of Columbia abbreviations	use two-letter abbreviations (e.g., AK, DC)

Mathematics, statistics, fisheries

alternate hypothesis	H_A
base of natural logarithm	e
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	F, t, χ^2, etc.
confidence interval	C.I.
correlation coefficient	R (multiple)
correlation coefficient	r (simple)
covariance	cov
degree (angular or temperature)	°
degrees of freedom	df
divided by	÷ or / (in equations)
equals	=
expected value	E
fork length	FL
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
mideye-to-fork	MEF
minute (angular)	'
multiplied by	x
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
standard length	SL
total length	TL
variance	Var

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by

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ABSTRACT

A mark-recapture experiment was conducted on Arctic grayling *Thymallus arcticus* in Piledriver Slough, near Fairbanks, Alaska during 1994. A weir was used to characterize immigration and capture fish for mark-recapture sampling. The weir was fished over a 51 day period beginning in mid-April. A total of 933 Arctic grayling were passed upstream, and 447 fish passed downstream following the mark-recapture experiment. The upstream weir catches were used as the marking sample while catches from a single downstream pass by an electrofishing crew were used as the recapture sample. An estimated 11,747 (SE = 1,297) Arctic grayling ≥ 150 millimeters fork length were present during the early May spawning period. Use of the weir indicated that closure existed for mark-recapture sampling, as very few fish relative to the population size immigrated after the marking event, and few fish had emigrated by the 2 June completion of the weir project. The 1994 stock was characterized by a higher proportion of legal-sized Arctic grayling (≥ 270 millimeter fork length) than that estimated in 1993, and the age composition was predominated by age 4 fish. The estimated survival was 64%, which indicated more of the stock survived natural and fishery losses in 1993 than in past Piledriver Slough assessments. Restrictions to a no-harvest regulation in 1993 led to lower estimates of exploitation, but estimates of potential exploitation resulting from high catch rates and hooking injury, indicate exploitation rates may still be high.

Key words: Arctic grayling, *Thymallus arcticus*, Piledriver Slough, weirs, 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 slough in 1976. At this time a flood control project consisting of several small dykes blocked inputs of silty, glacial water from the Tanana River. Subsequently, clear water entered the slough channel by upwelling from the Tanana aquifer. 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 has 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. 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.

In response to demands for stream fishing opportunities to catch rainbow trout *Oncorhynchus mykiss* close to Fairbanks, Piledriver Slough has been stocked with rainbow trout since 1987. Research from 1990 through 1993 focused on distribution, reproductive success, and the hold-over survival of stocked rainbow trout in Piledriver Slough. Estimates of holdover survival has ranged from 0.02% between 1990 and 1991 (Timmons 1992) to 0.25% between 1991 and 1992 (Fleming and Schisler 1993). 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 (Table 1). Effort in Piledriver Slough has increased as much as five-fold since 1987; in 1990 it received approximately 15% of the Tanana River drainage effort. The fishery has provided as much as 20% of the

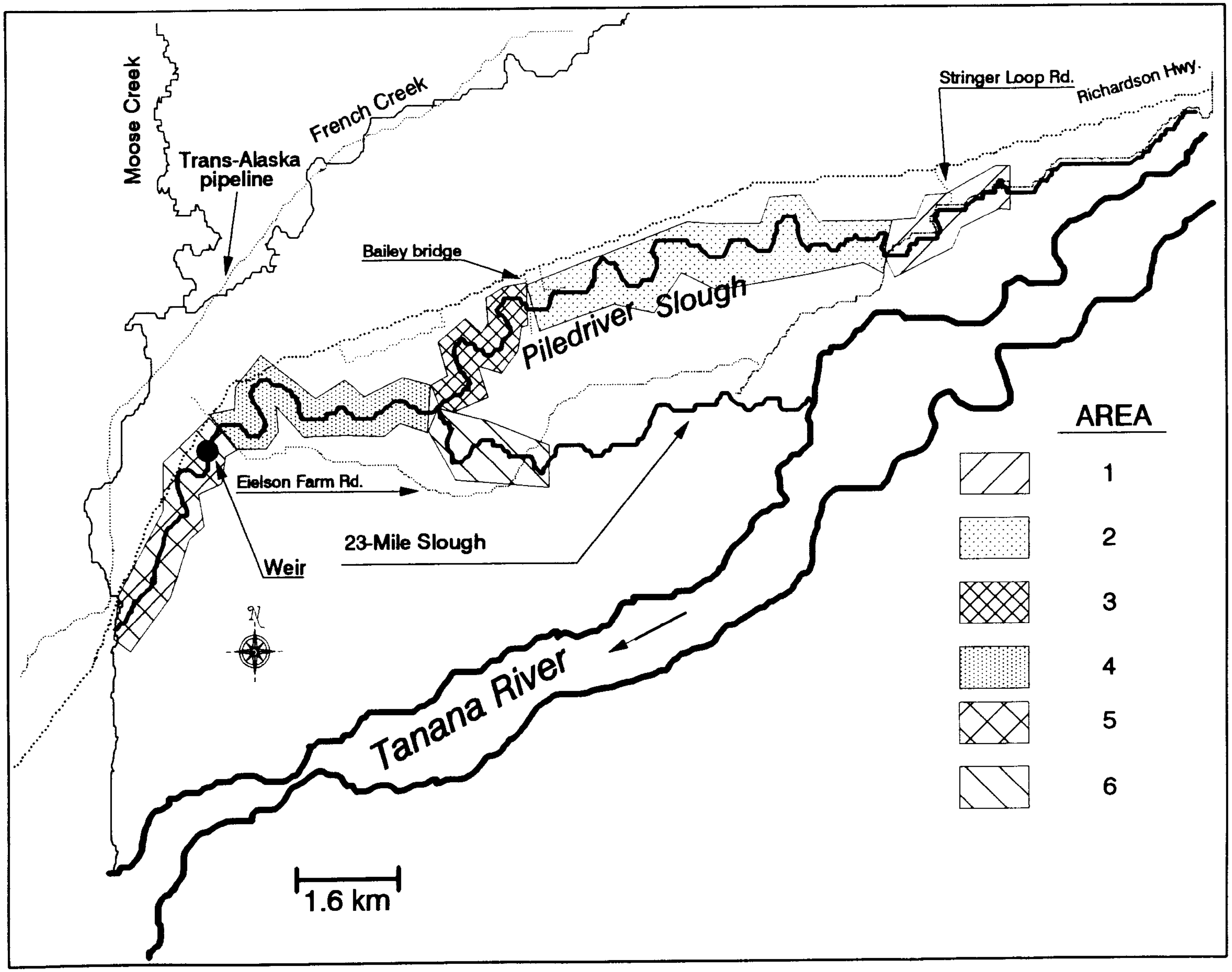

Figure 1.-Map of study area encompassing Piledriver Slough, Moose Creek and French Creek.

Table 1.-Effort, catch, and harvest of Arctic grayling from Piledriver Slough and in the Tanana River drainage, 1983 to 1993.

	Piledriver Slough			Tanana River Drainage			% Tanana River Drainage[b]		
Year[a]	Days Fished	Catch	Harvest	Days Fished	Catch	Harvest	Days Fished	Catch	Harvest
1983[c]	4,148	N/A	5,822	144,981	N/A	91,682	2.8	N/A	6.3
1984[d]	4,651	N/A	3,751	145,142	N/A	82,548	3.2	N/A	4.5
1985[d]	2,133	N/A	2,133	135,745	N/A	62,433	1.6	N/A	3.4
1986[d]	2,079	N/A	2,312	144,814	N/A	45,780	1.4	N/A	5.0
1987[e]	13,247	N/A	4,907	155,346	N/A	38,230	8.5	N/A	12.8
1988[f]	24,375	N/A	8,095	173,706	N/A	51,803	14.0	N/A	15.6
1989[g]	22,746	N/A	4,459	185,715	N/A	53,791	12.2	N/A	8.3
1990[h]	27,705	34,840	2,380	184,887	171,058	28,414	14.9	20.4	8.4
1991[i]	17,703	30,012	3,987	155,662	146,892	33,778	11.4	20.4	11.8
1992[j]	13,607	15,252	1,030	120,848	115,633	14,983	11.3	13.2	6.9
1993[k]	17,263	32,036	759	160,117	193,088	17,658	10.8	16.6	4.3

a Statewide harvest estimates for Arctic grayling in Piledriver Slough began with the 1983 fishery.

b Percent of Tanana River drainage fishery represented by Piledriver Slough.

c Mills (1984).

d Mills, unpublished data *taken from* Timmons (1992).

e Mills (1988).

f Mills (1989).

g Mills (1990).

h Mills (1991).

i Mills (1992).

j Mills (1993).

k Mills (1994).

drainage total catches of Arctic grayling in 1990 and 1991 (Mills 1991, 1992) and as much as 16% of the drainage harvest of rainbow trout in 1988 (Mills 1989).

The continued popularity of this fishery among anglers indicated that annual stock assessment of Piledriver Slough is necessary to assure correct management actions. A stock assessment program was initiated in 1990 to investigate the effects of an increasing recreational harvest on the Arctic grayling stock in Piledriver Slough. Since the estimated abundance in 1991 of 17,323 fish (Fleming 1991), abundance has decreased to 14,030 fish in 1992 (Fleming and Schisler 1993), and 10,587 fish in 1993 (Fleming 1994). Although anglers appear to release a great portion of their catches in Piledriver Slough, the observed decline in abundances led to an Emergency Order in 1993 which changed the regulation for Arctic grayling to catch-and-release angling only.

In 1994, the feasibility of using a picket weir was investigated as an alternate means of assessing the Arctic grayling in Piledriver Slough. Use of a weir was selected to collect information not obtainable from past stock assessments. In past years it had been assumed that Arctic grayling did not overwinter in Piledriver Slough, but returned prior to spawning each year. The weir was used to characterize the entry pattern of Arctic grayling in the spring immigration and to determine whether substantial post-spawning emigration occurred. Ultimately, passage information was used to validate assumptions made in annual stock assessments, such as whether the late-April to early-May timing of abundance estimates was optimal, or if timing was critical to the overall accuracy of the stock assessment program.

OBJECTIVES

The research objectives for 1994 were to:

1. estimate abundance of Arctic grayling greater than 149 mm fork length (FL) in Piledriver Slough;
2. estimate age composition of Arctic grayling in Piledriver Slough;
3. estimate size composition of Arctic grayling in Piledriver Slough; and,
4. count Arctic grayling and monitor their size composition at a weir in lower Piledriver Slough.

METHODS

The 1994 stock assessment experiment in Piledriver Slough took place over a protracted period, beginning with the placement of a picket weir on 12 April, and ending with its removal on 2 June. The overall study consisted of three contiguous field activities. Fish were first sampled and marked as they passed upstream though a weir. Later in early May, a backpack electrofishing crew sampled and examined fish for marks over the portion of Piledriver Slough upstream of the weir; and lastly, the weir was supplemented with a downstream trap to capture and sample emigrating fish.

THE WEIR

In late March, a site for the picket weir was located 185 m downstream of the Eielson Farm Road, at an area where there was a nearly consistent depth and even laminar flow (Figure 1). The site was situated on a mixed gravel run that was 29 m wide, and ranged from 0.45 to 0.6 m in depth. On 12 April, the picket weir was constructed onsite, and oriented so that fish moving upstream would be guided towards a live box for capture. The weir was composed of about 50 welded angle iron panels that were 0.6 m x 1 m (width x height). Each panel held 17 pieces of steel electrical conduit (22 mm diameter x 2.0 m length) spaced 13 mm apart. The collection of panels was held in the stream by a large support structure. Seven reinforced wooden tripods (2 m height) were made from 0.10 m x 0.15 m wooden posts that supported steel pipe (schedule 80; 50 mm diameter x 6.1 m length) which spanned between adjacent tripods. The pipes were attached to the tripods at 0.15 m and 1.0 m height from the stream bottom, to provide a support for the weir panels. During final assembly the panels were placed upstream of the pipes, reclined against the pipes, and then slid against the next adjacent panel. Individual pickets (conduit) were then slid down and into the gravel streambed to make the weir fish-tight and avoid undermining.

An L-shaped live box was constructed from three wooden-frame holding pens (1.2 m^3) that were bolted together. Two of the three units were covered with Vexar™ mesh (15 mm^2) and oriented perpendicular to flow to provide a well aerated holding area. The third unit had panels bearing window screen mesh (2.5 mm^2) and had an adjustable v-notch trap throat which was the uppermost point of the weir. The live box was anchored in place by two large "duckbill anchors" driven 1.0 m into the streambed. Sandbags were used to weight the tripods and the live box, as well as to seal gaps between the weir and banks of the slough. The live box had removable tops that were padlocked and covered with blue plastic tarps to provide shade and cover for trapped fish. Instream water temperatures were collected systematically every 36 min by an Onset Computing™ "Hobo"data-logger in a waterproof case which was attached to the bottom of the live box. On 17 May, a downstream trap was constructed to capture fish passing downstream. After removing one panel of pickets, the frame of a 1.2 m^2 (height *x* width) fyke net with 1 m diameter hoops was fitted through the opening, and spread downstream to a 1.2 m^2 (height *x* width) holding box. The cod-end of the net was fastened to the rim of a 0.3 m diameter plastic bucket, which provided entry to the holding box. The covered and locked holding box was anchored by four pieces of 20 mm steel rebar driven into the streambed.

The weir was closely monitored and cleaned three or more times each day. Buildup of drifting algae and ice pans necessitated periodic cleaning and monitoring at night. This prevented flows from undermining and flowing around the ends of the weir, which could compromise the weir's efficiency to catch migrating fish. On 28 April, ice jams on the Tanana River caused water to flood over the banks and enter Piledriver Slough near its headwaters. On 29 April, resulting high flows in Piledriver Slough broke through the weir. The weir was repaired and fishing again on 2 May.

Fish captured at the weir comprised the marking sample of a mark-recapture experiment to assess the stock of Arctic grayling. All initially captured Arctic grayling greater than 149 mm FL were dipped from the holding box and measured to the nearest 1 mm FL, fin punched or clipped, and released upstream of the weir structure. Fish sampled prior to the breaching of the weir were given an upper caudal fin punch. Fish sampled afterwards were given an upper caudal fin clip until four days prior to sampling upstream. Fish sampled during this hiatus period were given a lower caudal fin punch so they could be excluded from the mark-recapture experiment, since they did not have sufficient time to mix completely with fish upstream. Fork length, coded fin punches or clips, and tag numbers from retained tags were recorded on Tagging-Length forms (Version 1.0). Smaller Arctic grayling were also sampled, but were not marked with fin punches. Captured individuals of all other species were released upstream and noted in a daily log.

UPSTREAM RECAPTURE SAMPLING

The second, or recapture sampling event was conducted by seven member crew using backpack electrofishing gear in portions of Piledriver Slough upstream of the weir. Sampling was conducted systematically; the crew worked from upstream areas downstream to the weir. 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 1994 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 in 1990 and 1991. 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 last assessed in 1990 and 1991 were excluded from the 1994 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. No fish were located in these areas during foot surveys. In area (6) beaver dams located 200 m upstream from the confluence with Piledriver Slough prevented upstream passage of Arctic grayling at the time of sampling.

The upstream limit of the 1994 study section was the beaver dam blockage delimiting areas (2a) and (2b), and the beaver dam blockage in 23-Mile Slough. The downstream limit of sampling was at the weir just downstream of 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). The conductivity was 320 μS and 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 captured fish greater than 149 mm FL were examined for marks (upper caudal punches or clips), measured to the nearest 1 mm FL, fin clipped (lower caudal fin), and several scales were collected for aging. 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 punches were recorded on Tagging-Length forms (Version 1.0). Data collection procedures from previously marked Arctic grayling were similar, but previous tag numbers, and colors were recorded. Scales from previously marked Arctic grayling were collected on the right side of the fish to avoid collection of regenerated scales.

ABUNDANCE ESTIMATION

A closed-model mark-recapture experiment was used to estimate the abundance of Arctic grayling in Piledriver Slough in 1994, similar to the approach used in 1992 and 1993. 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.

Assumption 1 was met by utilizing the weir to quantify all migrants during the recapture sampling period. Since the marking event was interrupted by the breaching of the weir, two marking samples resulted. The resulting early and late recapture-to-mark ratios were examined for differences that would lead to stratification using a chi-square goodness of fit test. Assumptions 2 and 3 were then 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 should be stratified by area. Assumption 4 was satisfied by using easily identified fin clips or fin punches that could not be shed during the study.

The examination of the early and late marking samples concluded that the samples could be pooled. The two KS tests indicated that only first event sampling was size selective, not requiring further stratification of the data. Capture probabilities did not vary significantly among the upstream sampled areas. 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:

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

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):

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

AGE AND SIZE COMPOSITION

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. When no adjustments were required for length selectivity or geographic differences in capture probability, the proportion of fish at age *k* (or length class *k*) was estimated using the appropriate sample (Appendix A1: from the first event, second, or both events) by:

$$\hat{p}_k = \frac{y_k}{n} \quad (3)$$

where:

$\hat{p}_k$ = the proportion of fish that are age or length class *k*;

y_k = the number of fish sampled that are age or length class *k*; and,

n = the total number of fish sampled.

The unbiased variance of this proportion was estimated as:

$$\hat{V}[p_k] = \left[\frac{\hat{p}_k(1-\hat{p}_k)}{(n-1)}\right] \quad (4)$$

Stock assessment category utilizes the above approach, where substitutions for class are: age classes and 10 mm FL incremental size groupings. 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 1993 and 1994. The statewide catch and harvest estimates (Mills 1994) provided point estimates of Arctic grayling catches and harvests for the 1993 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 beginning in 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, Fleming 1994) could be made. The annual survival rate *S*, was estimated as:

$$\hat{S} = \frac{\hat{N}_{t+1}}{\hat{N}_t} \tag{5}$$

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:

$$V[\hat{S}] \approx \left[\frac{N_{t+1}}{N_t}\right]^2 \left[\frac{V[N_{t+1}]}{[N_{t+1}]^2} + \frac{V[N_t]}{N_t^2}\right] \tag{6}$$

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):

$$V[\hat{N}_t] = \sum_{k=5}^{9}(V[\hat{p}_k]\hat{N}_{93}^2 + V[\hat{N}_{93}]\hat{p}_k^2 - V[\hat{p}_k]V[\hat{N}_{93}]) \tag{7}$$

and;

$$V[\hat{N}_{t+1}] = \sum_{k=6}^{10}(V[\hat{p}_k]\hat{N}_{94}^2 + V[\hat{N}_{94}]\hat{p}_k^2 - V[\hat{p}_k]V[\hat{N}_{94}]) \tag{8}$$

where:

$\hat{N}_{93}$ = the abundance estimate for Arctic grayling ≥ 150 mm FL in 1993; the variance of $\hat{N}_{93}$ was from the point estimated variance for the stratified Petersen model (reported in Fleming 1994).

$\hat{N}_{94}$ = the abundance estimate for Arctic grayling ≥ 150 mm FL in 1994; the variance of $\hat{N}_{94}$ was from the point estimated variance for the unstratified Petersen model.

$\hat{p}_k$ = the estimated adjusted fraction of the fish in age class k from 1993 and the unadjusted fraction from the 1994 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; *and* 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, 1994), exploitation and natural mortality rates were estimated for the assessed stock ≥ 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*:

$$F = \frac{Z}{A} * \frac{C}{N} \tag{9}$$

where:

C = the 1993 estimated harvest of Arctic grayling (Mills 1994) from the Piledriver Slough fishery;

N = the 1993 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) <u>had</u> 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):

$$u = 1 - e^{-F} \quad (10)$$

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

$$v = n(1-u) \quad (11)$$

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 1994) was reduced by the estimated harvest to yield an estimate of independent catch-and-release events in 1993. 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 (equations 9 through 11).

RESULTS

FIELD SAMPLING

Although the weir was fishing as early as 12 April, the first Arctic grayling were not captured until 23 April. Five hundred ninety-nine Arctic grayling were captured and released upstream before the weir broke under pressures from high flows on 29 April (Table 2). These catches included 597 Arctic grayling ($\geq$ 150 mm FL) which were marked with upper caudal fin punches. Following the repairs to the weir, an additional 279 Arctic grayling were captured and released between 2-6 May, which was prior to the sampling hiatus separating the first and second sampling events. This sample included the release of 271 marked Arctic grayling ($\geq$ 150 mm FL) bearing upper caudal fin clips. Only 55 additional Arctic grayling were passed upstream at the weir from the start of the three-day sampling hiatus on 7 May, to the removal of the weir on 2 June. These fish were marked with a lower caudal punch so they could be isolated from the mark-recapture experiment. The hiatus was designed to allow marked fish ample time to move upstream and mix with unmarked fish prior to the second sampling event.

Table 2.-Daily weir passage statistics for Arctic grayling in Piledriver Slough, 1994.[a]

Date	Count		Size composition (Fork Length)				
	Up	Down	Mean	Median	Min	Max	SD
12-22 April	0	0	----	----	----	----	----
23 April	2	N/A	258	ND	255	260	ND
24 April	200	N/A	270	274	146	346	35
25 April	107	N/A	262	262	160	353	35
26 April	51	N/A	284	283	225	349	28
27 April	47	N/A	266	264	207	328	26
28 April	192	N/A	264	267	148	382	34
29 April							
30 April			**Weir breached by Tanana River flows**				
1 May							
2 May	146	N/A	235	226	113	315	46
3 May	73	N/A	243	246	156	316	40
4 May	22	N/A	253	260	154	344	45
5 May	27	N/A	238	229	152	335	52
6 May	11	N/A	227	237	156	315	55
7 May	15	N/A	237	232	150	344	53
8 May	14	N/A	255	245	175	346	47
9 May	6	N/A	266	261	228	295	25
10 May	6	N/A	235	240	205	269	24
11 May	7	N/A	249	251	217	276	22
12 May	7	N/A	243	228	218	269	19
13 May	0	N/A	N/A	N/A	N/A	N/A	N/A
14 May	0	N/A	N/A	N/A	N/A	N/A	N/A
15 May	0	N/A	N/A	N/A	N/A	N/A	N/A
16 May	0	N/A	N/A	N/A	N/A	N/A	N/A
17 May	0	37	263	264	158	351	35
18 May	0	29	262	257	187	358	41
19 May	0	62	247	257	149	316	44
20 May	0	5	267	256	233	308	31
21 May	0	111	247	253	159	347	44
22 May	0	5	265	263	214	312	36
23 May	0	11	240	253	192	282	32
24 May	0	3	255	252	224	289	33
25 May	0	56	228	230	148	308	44
26 May	0	5	219	194	168	280	52
27 May	0	1	----[b]	----	----	----	----
28 May	0	0	----	----	----	----	----
29 May	0	31	----	----	----	----	----
30 May	0	21	----	----	----	----	----
31 May	0	70	----	----	----	----	----
1 June	0	0	----	----	----	----	----
Total	933	447					

[a] Although the weir was in operation beginning 12 April, no Arctic grayling were captured until 23 April.

[b] No length data collected from fish < 150 mm FL between 27 May and 1 June.

The electrofishing crew started the second, or recapture sampling event on 10 May, following the three-day hiatus. At this time a total of 1,014 Arctic grayling ($\geq$ 150 mm FL) were captured over a 4-day period. The sampling occurred during a single downstream pass through three areas which spanned approximately 16 km of Piledriver Slough. Water temperatures in areas upstream of the weir ranged between 6.2° and 10.0°C between 0900 and 1700 hours. Examination of the second event catch yielded the recovery of 54 Arctic grayling released during the early marking period at the weir, and 20 Arctic grayling released during the late period. The overall acute mortality rate from the second event sampling was seven fish out of 1,014 individual Arctic grayling handled, or 0.7%.

ABUNDANCE ESTIMATION

The marking event was interrupted by the breaching of the weir between 29 April and 2 May which resulted in an early and late marking samples. The probabilities of recapturing fish from the two marking samples were found to be statistically similar (χ^2= 0.66, df = 1, P = 0.42). This allowed the two samples to be pooled. A test of cumulative distribution functions (CDF's) from the mark-recapture experiment inferred that size selectivity was present during the marking event (Figure 2A -mark vs recaptures: D = 0.10, P = 0.503; and, Figure 2B - mark vs catch: D = 0.10, P = 0.0009). Capture probabilities were found to be statistically similar between sampled (χ^2 = 4.84, df = 2, P = 0.09). As a result, abundance was estimated using an unstratified approach with respect to size and area, and stock composition estimates were based on the second sampling event (Case II; Appendix A1).

The examination of assumptions led to the use of the Bailey modification of the Petersen estimate. The estimated abundance of Arctic grayling ($\geq$ 150 mm FL) was 11,747 fish (SE = 1,297, CV = 11%) that were resident in the area upstream of the weir at the time of the second sampling event.

AGE AND SIZE COMPOSITION

Ages observed for Arctic grayling in Piledriver Slough ranged from 2 to 9 years, with 4 years as the median age. The predominant age class present in Piledriver Slough was age 4 (33% of the stock; Table 3) followed by age 5 (19% of the stock). Incremental size compositions and abundances for 1991 through 1994 (Figure 3) indicated recent increases in the estimated abundance of legal-sized Arctic grayling ($\geq$ 270 mm FL). In 1994, the estimated abundance of legal-sized Arctic grayling had significantly increased (Z test: Z= 3.92, P = 0.00004) from 2,094 fish (SE = 339 fish) in 1993 to 4,422 fish (SE = 487 fish). In 1994, the estimated recruitment was 2,227 fish (SE = 293 fish) that were age 5 (Figure 4).

SURVIVAL, MORTALITY, AND EXPLOITATION

In 1993, there were an estimated 5,156 fish age 5 years and older (Figure 4). Following the 1993 fishery, and overwintering to 1994, it was estimated that 3,311 fish age 6 years and older, or 64% (SE = 0.08), had survived. The 95% confidence interval range of the survival rate was 47 to 81%. The total instantaneous rate of mortality (Z) was 0.44.

In 1993 it was estimated that 10,587 Arctic grayling inhabited the slough during May, on or about the start of the fishery. Following the 1993 fishing season, Mills (1994) estimated that 32,036 captures of Arctic grayling in Piledriver Slough resulted in 759 fish harvested and 31,277 fish released. The introduction of hooking mortality as a variable increased the reported harvest by 2,815 fish to a potential harvest of 3,573 fish, which was a relative increase of 470%. The

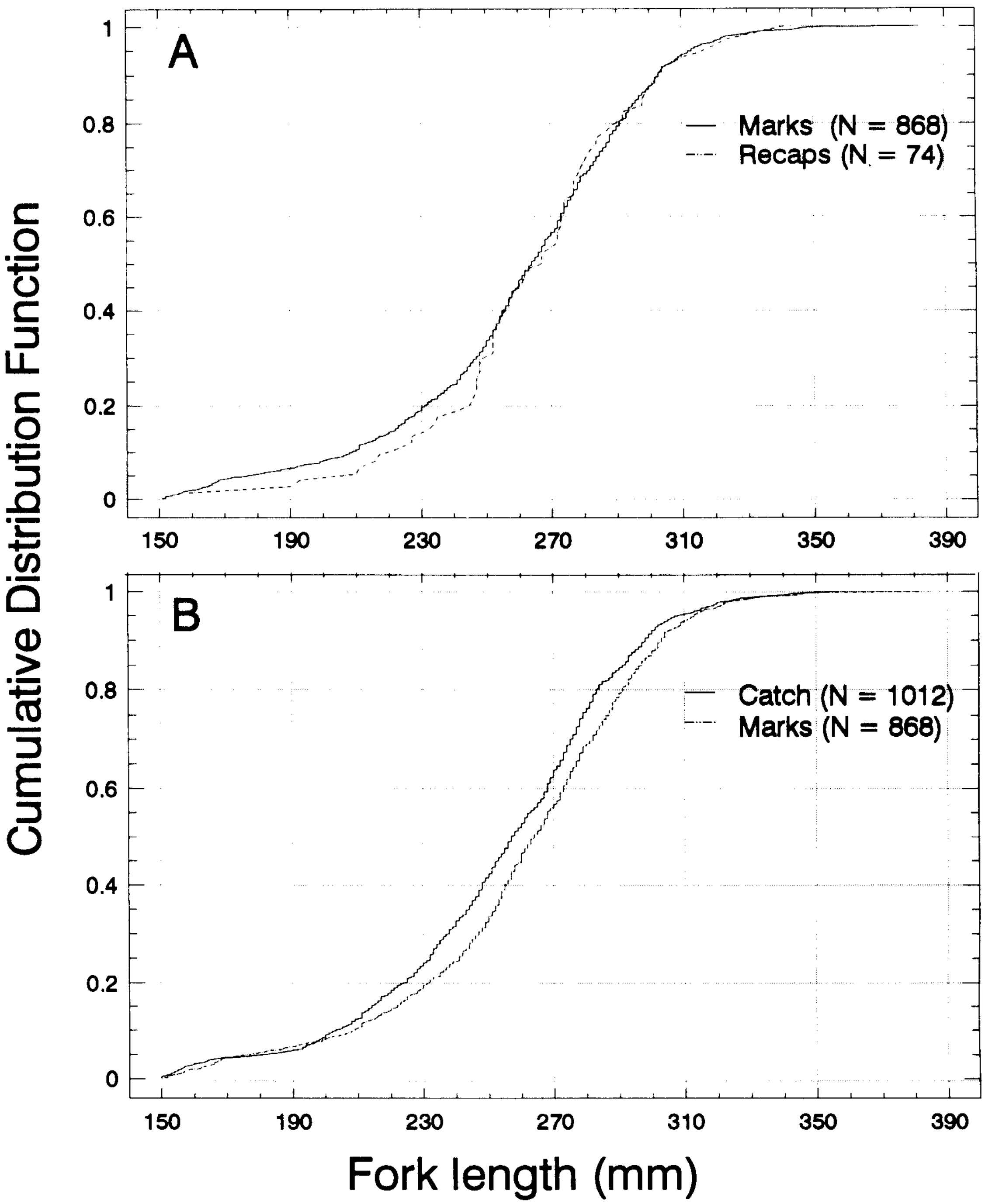

Figure 2.-Cumulative distribution functions of lengths of Arctic grayling marked versus lengths of Arctic grayling recaptured (A) and versus lengths of Arctic grayling examined for marks (B) in Piledriver Slough, 23 April through 13 May, 1994.

Table 3.-Estimates of the sampled contributions by each age class and 10 mm FL incremental size groupings for Arctic grayling (≥150 mm FL) captured in Piledriver Slough, 10 through 13 May 1994.

Age [a]	Count[b]	P-hat[c]	SE[d]	Length	Count[b]	P-hat[c]	SE[d]
1	0	0.00	----	155	29	0.03	<0.01
				165	14	0.01	<0.01
2	40	0.05	0.01	175	6	<0.01	<0.01
				185	9	0.01	<0.01
3	122	0.15	0.01	195	28	0.03	<0.01
				205	38	0.04	0.01
4	273	0.33	0.02	215	57	0.05	0.01
				225	56	0.05	0.01
5	156	0.19	0.01	235	82	0.08	0.01
				245	100	0.10	0.01
6	139	0.17	0.01	255	106	0.10	0.01
				265	106	0.10	0.01
7	74	0.09	0.01	275	133	0.13	0.01
				285	86	0.08	0.01
8	16	0.02	< 0.01	295	74	0.07	0.01
				305	40	0.04	0.01
9	3	<0.01	< 0.01	315	23	0.02	<0.01
				325	12	0.01	<0.01
10	0	---	----	335	5	<0.01	<0.01
				345	7	0.01	<0.01
11	0	---	----	355	1	<0.01	<0.01
				365	0	----	----
				375	0	----	----
				385	0	----	----
				395	0	----	----
Total	823	1.00	----	Total	1,012	1.00	----

[a] Age sampling occurred only during the second event, 10 through 13 May, 1994.

[b] p = unadjusted proportion of Arctic grayling in the assessed stock at the time of the second sampling event, 10 through 13 May, 1994.

[c] N= number of individuals sampled in each age or 10 mm FL incremental size class.

[d] SE = standard error of the proportional contribution.

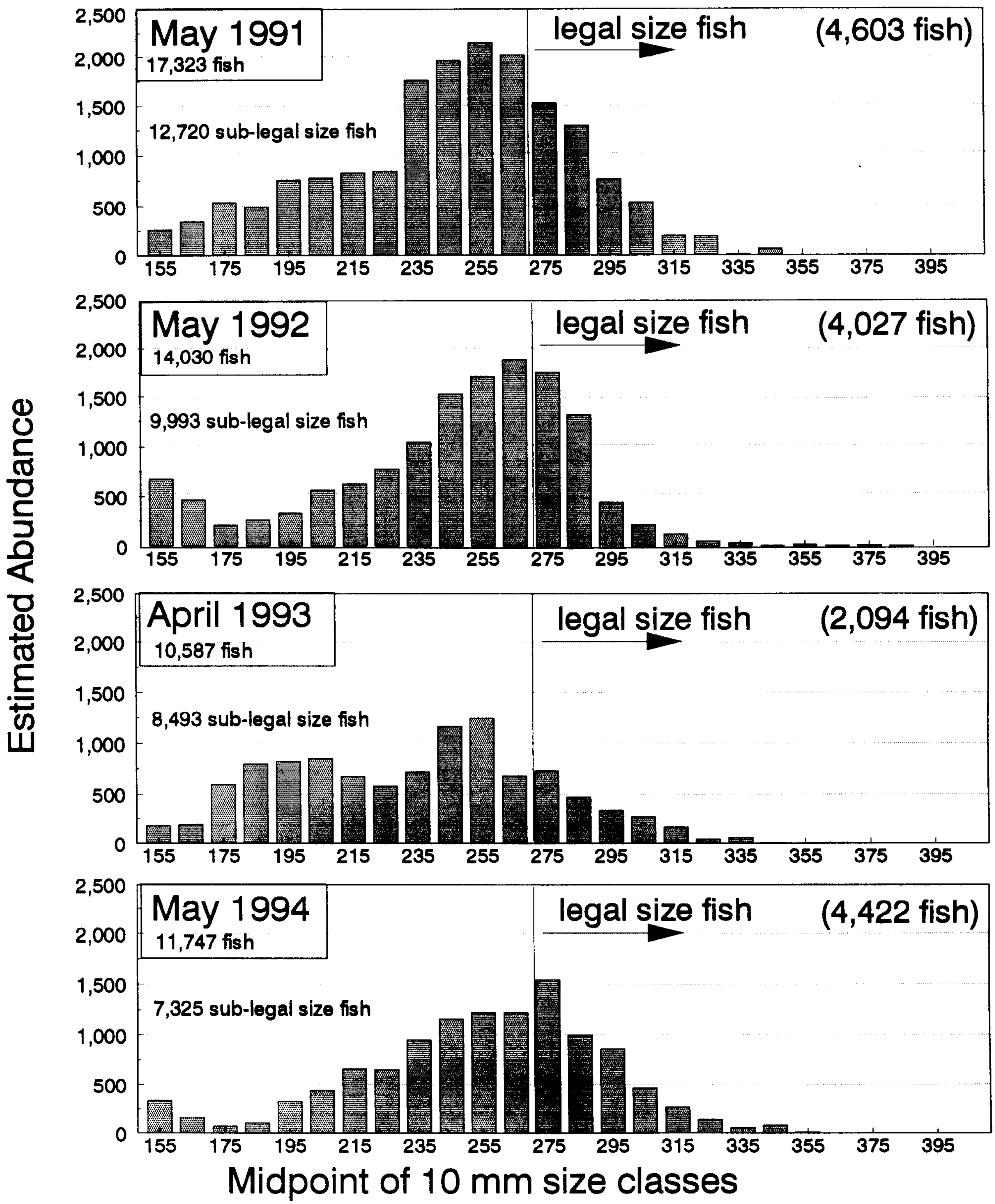

Figure 3.-Apportionment of estimated abundance across 10 mm FL incremental size categories for Arctic grayling (≥150 mm FL) present in Piledriver Slough, 1991 through 1994.

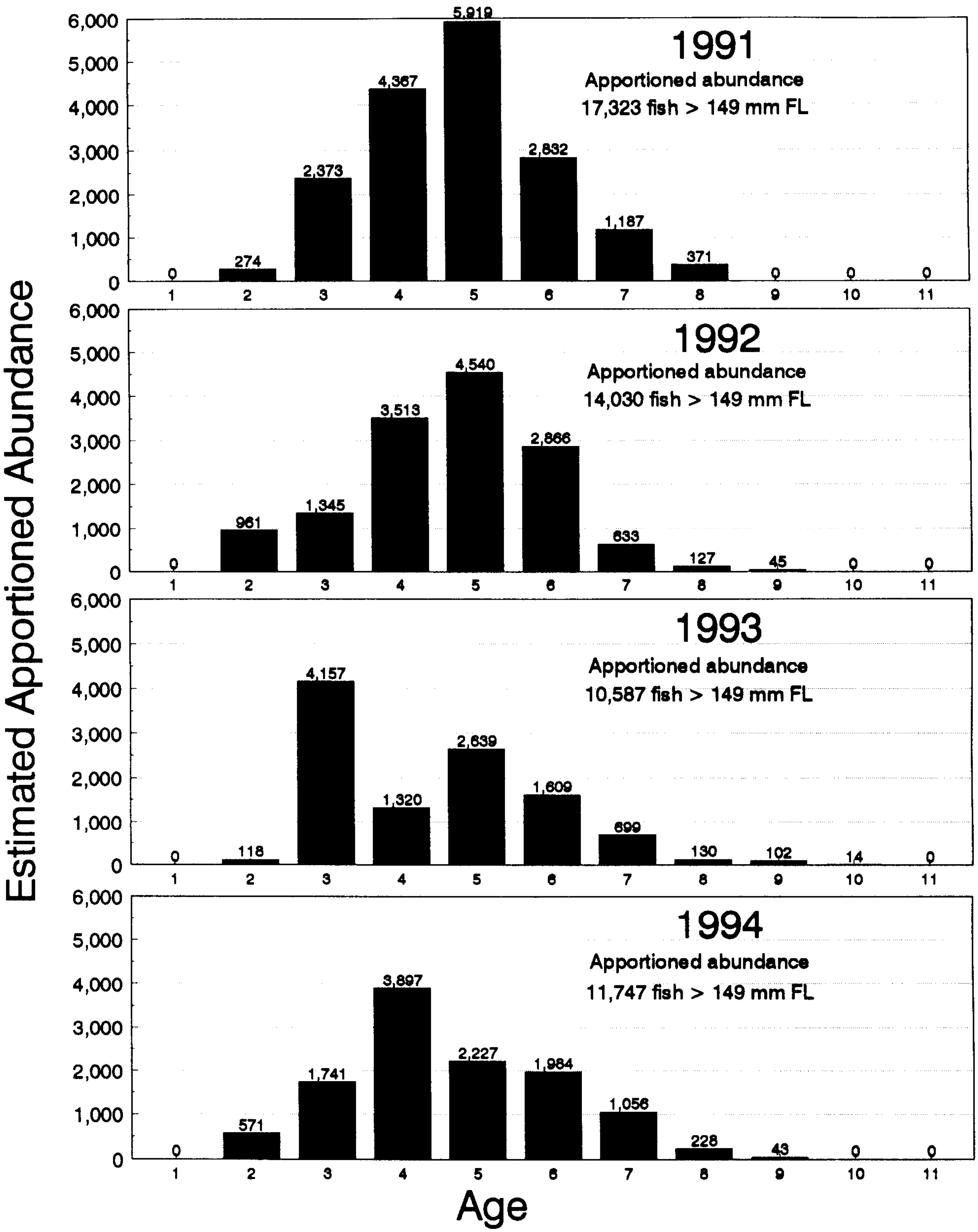

Figure 4.-Apportionment of estimated abundance across age classes for Arctic grayling (≥150 mm FL) present in Piledriver Slough, 1991 through 1994.

instantaneous rate of fishing mortality (*F*) was calculated with Baranov's catch equation using each harvest scenario. Instantaneous fishing mortality (*F*) was 0.09 for the reported harvest, and when adjusted for hooking mortality *F* was 0.42. 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	1993 estimated Harvest	1993 estimated Harvest *with* Hooking Mortality
Fishery:	$u = 0.09$	$u = 0.34$
Natural:	$v = 0.27$	$v = 0.02$
Total:	A = 0.36	A = 0.36

Upstream Weir Catches

During the 51 days that the weir operated, the primary species captured was Arctic grayling. The first fish captured was a rainbow trout on 19 April, and the first Arctic grayling was captured on 23 April, 11 days after the weir began operation. The highest daily passage rate was 200 Arctic grayling occurring on 24 April. Catches through the next four days included 64% of all weir captured Arctic grayling during the study (Table 4). Most fish (77%) entered the trap in the evening, between 2000 and 2400 hours. During the nights when catches were high, schools of fish were seen immediately downstream of the trap's entrance. On these days, peak water temperatures ranged between 1 and 4°C (Figure 5), but fish often entered the trap at times when the temperature was substantially less. There was no apparent relationship between water temperature and movements into the trap. The water temperatures when initial fish activity and movements occurred during the first six days were:

Date and Time:			Water Temperature at Weir	Arctic grayling captured
23	April	2130	0.0	2
24	April	2130	0.0	200
25	April	2130	0.0	107
26	April	2130	2.5	51
27	April	2130	2.7	47
28	April	2130	3.8	192

The size of upstream migrating Arctic grayling ranged between 113 and 382 mm FL, and the daily median size varied between 226 and 274 mm FL (Table 2). During the period when the weir was not operational, it is likely that some fish may have passed upstream. Information from anglers and foot surveys in areas (3) and (4) on 26 April, indicated that many fish were present upstream prior to the high water event.

In the course of operating the weir, other species of fish were also captured. Round whitefish *Prosopium cylindraceum*, and longnose suckers *Catostomus catostomus*, predominated upstream captures (Table 4). Additionally, there were captures of humpback whitefish *Coregonus*

Table 4.-Upstream weir counts of all species at Piledriver Slough, 1994[a].

Date	Arctic grayling	Round whitefish	Humpback whitefish	Least cisco	Rainbow trout	Burbot	Longnose sucker	Other species
12-22 April	0	0	0	0	1	0	0	0
23 April	2	1	0	0	0	0	0	0
24 April	200	0	1	0	0	0	0	0
25 April	107	0	1	0	0	0	0	0
26 April	51	0	1	0	0	0	0	1 lake chub
27 April	47	5	1	0	1	1	0	0
28 April	192	3	1	0	0	0	0	0
29 April								
30 April	Weir breached by Tanana River flows							
1 May								
2 May	146	2	0	0	0	0	0	0
3 May	73	0	0	0	0	0	0	0
4 May	22	0	0	0	0	1	0	0
5 May	27	2	0	0	0	0	0	0
6 May	11	1	0	0	0	0	0	0
7 May	15	1	0	0	0	0	0	0
8 May	14	3	1	0	0	0	0	0
9 May	6	5	4	0	0	0	0	0
10 May	6	17	0	0	2	0	2	0
11 May	7	8	0	0	0	0	44	0
12 May	7	40	0	0	1	0	3	0
13 May	0	0	0	0	0	0	0	0
14 May	0	7	6	0	0	0	0	0
15 May	0	1	1	0	0	0	0	0
16 May	0	1	1	0	0	0	12	0
17 May	0	0	2	0	0	0	3	0
18 May	0	0	3	0	0	0	0	0
19 May	0	0	0	0	0	0	0	0
20 May	0	0	0	0	0	0	0	0
21 May	0	0	0	0	0	0	0	0
22 May	0	0	0	1	0	0	0	1 northern pike
23 May	0	1	1	0	0	0	1	1 northern pike
24 May	0	0	0	0	0	0	0	0
25 May	0	0	0	0	0	0	0	0
26 May	0	0	0	0	0	0	0	0
27 May	0	0	0	0	0	0	0	0
28 May	0	0	0	0	0	0	0	0
29 May	0	0	0	0	0	0	0	0
30 May	0	0	0	0	0	0	0	0
31 May	0	0	0	0	0	0	0	0
1 June	0	0	0	0	0	0	0	0
								0
Totals	933	98	24	1	5	2	65	

[a] Although the weir was in operation beginning 12 April, no Arctic grayling were captured until 23 April.

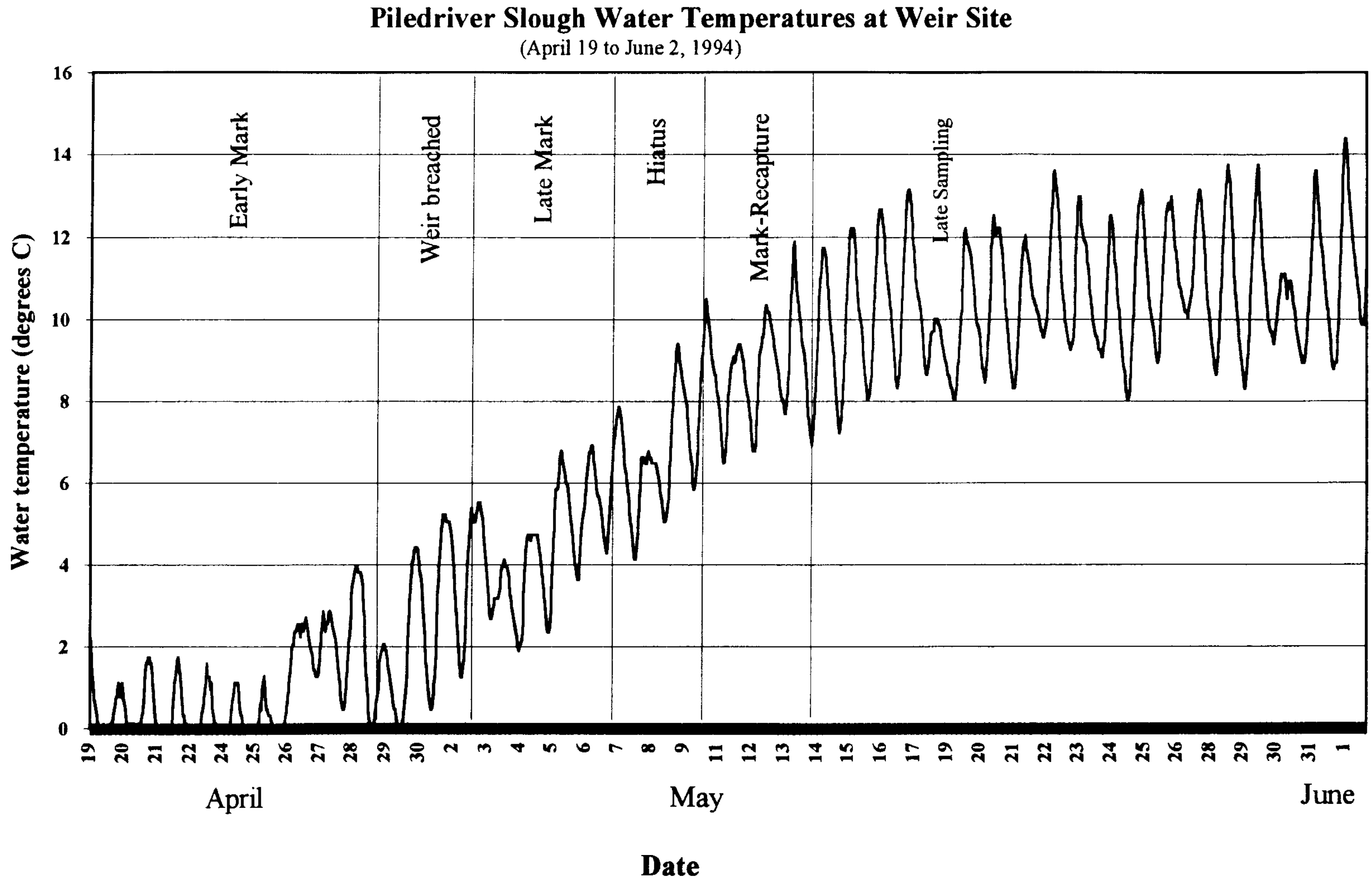

Figure 5.-Piledriver Slough water temperatures collected at the weir site, 19 April to 2 June, 1994.

pidschian, least cisco *Coregonus sardinella*, rainbow trout, burbot *Lota lota*, lake chub *Couesius plumbeus*, and northern pike *Esox lucius*. The overall acute mortality rate for all species captured in the upstream trap was 0%.

DOWNSTREAM WEIR CATCHES

A trap to capture fish moving downstream was constructed and fished from 17 May to 2 June. Several days prior to this, numbers of Arctic grayling, humpback whitefish, and longnose suckers had been observed schooling immediately upstream of the weir. Fish quickly passed into the trap when it became available. Between 17 May and 2 June, a total of 1,280 fish passed downstream (Table 5). The total downstream catch included 447 Arctic grayling of varying size (Table 2), ranging to 358 mm FL. In addition to species previously captured in the upstream trap, the downstream trap also captured a juvenile sheefish *Stenodus leucichthys*, and several coho salmon *Oncorhynchus kisutch* smolts. Based on the variability in sizes, there were no indications that emigrating Arctic grayling were primarily composed of post-spawning adults. A total of 322 Arctic grayling (≥ 150 mm FL) of the estimated 11,747 Arctic grayling passed downstream while the trap was operating. The overall acute mortality rate from the downstream trap was five fish out of 447 individual Arctic grayling handled, or 1.1%.

DISCUSSION

In 1994, the methods used to assess Arctic grayling in Piledriver Slough were changed from previous investigations for several reasons. One reason was to determine whether use of a weir could replace existing electrofishing gear and methods employed during past mark-recapture studies. Another reason to use a weir was to look at how the assessed stock of Arctic grayling assembled in Piledriver Slough over a longer period of time. This information allowed validation of the assumption of closure which is used in many mark-recapture investigations. In other studies involving weirs, it has been observed that immigration by Arctic grayling stocks to spring spawning areas can be protracted over several weeks to more than a month (Tack 1976, 1980; Ridder 1985; Hughes 1986; Fleming 1989). Additionally, composition estimates taken from post-spawning emigrations may not accurately represent the stock, with a bias towards adult fish (Tack 1980). Given the nature of Arctic grayling spring migrations, assessments that violate the assumption of closure could have severe biases.

A mark-recapture experiment was completed using the weir during the first sampling event, and electrofishing was used in the second sampling event. The numbers of fish trapped and passed upstream of the weir were not adequate to enumerate the stock's abundance, but fulfilled sampling needs for a mark-recapture experiment. The 1994 abundance and composition estimates indicate some level of improvement to the stock status seen in 1993 (Fleming 1994). Although the 1994 estimated abundance was not significantly greater than the 1993 estimate, a significant increase in the estimated abundance of legal size fish did occur. Additionally, the pre-recruited abundance of age 4 fish may indicate strong recruitment for 1995. It is likely that catch-and-release regulations beginning on June 26, 1993 conserved enough legal-sized fish in 1993, so that when combined with growth recruitment, the harvestable stock appeared to be recovering.

Another indication of the effectiveness in the 1993 management action is an increased survival rate. Estimates from earlier assessments indicated significantly lower survival of fish 5 years and older:

Table 5.-Downstream weir counts of all species at Piledriver Slough, 1994 [a].

Date	Arctic grayling	Round whitefish	Humpback whitefish	Least cisco	Rainbow trout	Burbot	Longnose sucker	Other species
17 May	37	6	39	1	0	0	56	1 juvenile sheefish
18 May	29	11	12	3	0	1	52	1 northern pike
19 May	62	8	31	7	0	0	58	1 northern pike
20 May	5	1	19	4	2	0	51	0
21 May	111	11	46	8	1	0	24	0
22 May	5	2	11	6	2	0	35	0
23 May	11	5	16	11	0	1	16	0
24 May	3	5	21	15	0	0	1	0
25 May	56	17	50	24	5	0	6	0
26 May	5	1	8	2	0	0	6	0
27 May	1	2	4	0	0	0	6	0
28 May	0	0	0	0	0	0	0	0
29 May	31	4	25	3	0	0	3	1 coho smolt
30 May	21	1	36	3	1	0	4	0
31 May	70	1	13	2	0	0	0	1 coho smolt
1 June	0	0	0	0	2	0	0	0
Totals	447	75	331	89	13	2	318	

[a] Although the weir was in operation beginning 12 April, the downstream trap was not operated until 17 May.

Assessment Period:	Survival estimate
1991 to 1992	36%
1992 to 1993	31%
1993 to 1994	64%

While it appears that changes to the stock were positive, i.e. greater numbers of legal sized fish, the potential losses by hooking mortality appear to have had a more important role influencing the exploitation rate in 1993. Unlike other assessed stocks in the Tanana River drainage, estimated catches of Arctic grayling in Piledriver Slough have annually exceeded estimated abundances each year since 1990, by as much as a 3:1 ratio (Mills 1991-1994). Latent hooking mortalities of released fish can occur on all sizes of fish in the assessed stock, with an upper 95% confidence limit of 9% (Clark 1991). Several recent Piledriver Slough investigations have quantified exploitation rates based on Statewide Harvest Survey estimates and from adjustments to harvest that may reflect hooking mortalities (Fleming and Schisler 1993; Fleming 1994, present):

Fishery Year	Fishery Status	Abundance ≥ 150 mm	Harvest (Mills)	Δ Harvest[a]	Survival (*S*)	Exploitation (*u*) %		
						Harvest (only)	Δ Harvest	Total
1991	Open	17,323	3,987	+2,342	36%	31%	13%	44%
1992	Open	14,030	1,030	+1,280	31%	12%	12%	24%
1993	C&R[b]	10,587	759	+2,815	64%	8%	26%	34%

[a] Δ Harvest refers an adjustment to reflect catch and release mortality at a level of 0.09

[b] In 1993 the fishery was open until it was closed to harvest by Emergency Order on 26 June.

The exploitation rate estimated from the harvest might be considered as a minimum since some level of hooking mortality is assumed to exist. Similarly, the total exploitation might be considered as a maximum estimate. Data from the 1993 fishery may indicate that although direct harvests were lowered, exploitation rates from high catches and latent hooking injuries (Δ Harvest) may exceed the exploitation rate cap, which was set at 20%. Based on these findings, it will be important to reevaluate the stock and its dynamics after an additional year of catch-and-release management in 1995.

Placing a weir in a stream to capture the spring migration of Arctic grayling has been attempted in the past by investigators in Alaska (Tack 1976; MacPhee and Watts 1976; Ridder 1985; Hughes 1986; Tilsworth and Travis 1986; and Fleming 1989). In some investigations, Arctic grayling were present within the stream before conditions were suitable for operating weirs. The same result was also found in the present study, but unlike other studies, the upstream abundance was estimated with a supplemental gear type (electrofishing), and the proportion passing the weir was approximated. During the operation of the weir, 868 or 7.3% of the estimated 11,747 fish abundance were passed upstream. Because the Tanana River flooded Piledriver Slough and temporarily suspended monitoring the immigration, the estimated proportion that immigrated between 12 April and 13 May to the upstream study area is a minimum estimate. If the weir was operational and catch rates for the three days were as great as the maximum observed (200 per day: 24 April), then the immigrating fraction might have reached 12.5%. In 1975 and 1985 investigations at Badger Slough (Tack 1976, Hughes 1986), weir catches of immigrating Arctic grayling were similar to the present study. The authors concluded that the weir(s) placement under ice cover may have allowed fish to evade capture. The Piledriver Slough picket weir was situated in an area of open water, which allowed crews to quickly see and repair problems with the weir's integrity. Unlike Hughes (1986) study, we found that all fish sampled in the upstream trap were unmarked; there were no indications that the weir was not fish-tight.

Although the staffing costs associated with the operation of the weir at Piledriver Slough were high relative to previous assessments, the information collected on timing lends credence to past assessments, and offers guidance for future assessments. After the marking event was completed on 6 May, only 55 additional fish were passed upstream of the weir. No fish were observed schooling on the upstream side of the weir, trying to leave, until after 16 May. Between 17 May and 1 June, 322 Arctic grayling left the study area through the downstream trap. In this year's study the relative bias from 55 additional immigrants or 322 emigrants is small at the population level, 0.4% and 2.7%, respectively. If fish behaved similarly in other assessment years, then estimates in those years would be relatively unbiased, and the late-April to mid-May assessment timings were optimal. Based on the present findings, future assessments in Piledriver Slough should occur in May.

Although the majority of the stock did not pass through the weir, ample numbers of Arctic grayling were marked and released to allow abundance estimation upstream of the weir. It is likely that most of the estimated 11,747 fish either spent the winter under the ice, or migrated upstream prior to 12 April. During a 1993-1994 overwintering study conducted on Arctic grayling, dissolved oxygen was monitored in several locations of Piledriver Slough on two occasions (M. Evenson, Alaska Department of Fish and Game, Fairbanks, personal communication). Dissolved oxygen levels in December were lower than in March, and water in upstream areas held more oxygen than downstream areas:

Sample site:	Relative location:	December sample:	March sample:
Bailey Bridge	upper	3.2 ppm	5.8 ppm
Scout Lake	middle	2.3 ppm	N/A
Eielson Farm Road	lower	0.5 ppm	5.3 ppm

The reversal in oxygen levels over time in Piledriver Slough may be uniquely tied to its hydrological and limnological situation. The Tanana River's aquifer supplies oxygenated water to Piledriver Slough on a year-round basis through a multitude of spring seeps. These visible seeps have appeared most abundant in the areas (1) and (2). During summer, large masses of algae accumulate in areas (3) and (4), which later die and remove oxygen from the water. Based on limited data it appears likely that losses of oxygen may be cumulative as water moves through the areas with decaying matter, and could lead to localized depletions such as the sample collected in December at the Eielson Farm Road.

A differing pattern of oxygen depletion with respect to time and area may influence the quantity, quality, and location of available overwintering habitat for different fish species. Rahel (1990) reported a species-selective winter-kill associated with low oxygen levels in a Wyoming lake where rainbow trout failed to survive, while five other species survived the winter. Interestingly, Arctic grayling and longnose suckers were two of the surviving species. It is possible that extremely low survival rates for stocked rainbow trout in Piledriver Slough (Timmons 1992, Fleming and Schisler 1993), also resulted from oxygen stress, and a shortage of habitat suitable for rainbow trout. In Piledriver Slough the presence of dissolved oxygen in late winter may have influenced the low numbers of Arctic grayling migrating past the weir.

Ancillary information gathered from angler reports and foot surveys indicated that substantial numbers of Arctic grayling either overwintered in Piledriver Slough or immigrated late in the winter. Following the 12 April start of the weir project, no Arctic grayling were seen for 11 days at the weir location. Reports from anglers and foot surveys indicated that Arctic grayling were present in the area between 23 Mile Slough and Scout Lake prior to high water that disabled the weir. The high estimates of Arctic grayling abundance above the weir in the present study further corroborated these observations. In other assessed Arctic grayling spawning streams, hydrological and limnological conditions often prevent overwintering or access prior to melting conditions and breakup. In weir studies conducted on Caribou Creek, a tributary in the Tanana River drainage (Ridder 1985), and Fish Creek, in the Nenana River drainage (Fleming 1989) investigators observed differing patterns of immigration. These bog-fed spawning streams host spring migrations of Arctic grayling at the time of breakup. In Caribou Creek, the stream was frozen solid and anoxic conditions were noted in the lower reaches prior to assessment (W. Ridder, Alaska Department of Fish and Game, Delta Junction, personal communication). Similarly, dissolved oxygen levels were zero in Fish Creek prior to assessment in 1988. Although weirs at Fish Creek and Piledriver Slough were deployed at similar times, it appeared that a greater portion of the Fish Creek stock immigrated, and was susceptible to capture by the weir.

The results of the present study suggest that Piledriver Slough Arctic grayling have a life history which is more like river-resident populations in the Chena River than fish that ascend bog-fed streams for spawning, like Caribou and Fish creeks. In the future, investigators should determine when Arctic grayling are present during the winter. Knowledge of the winter distribution of Arctic grayling and dissolved oxygen (*by* area and time) may enhance information on life history for this stock of Arctic grayling.

At this time, some positive changes to the stock were detected in the present assessment. The weir project supplied valuable information that could not otherwise have been gathered. Since the assumption of closure was validated, there are no compelling reasons to use a weir in future assessments. Future assessments will need to continue evaluation of the closure to sport harvest of Arctic grayling in Piledriver Slough. Future sustainability of the fishery may require continued monitoring and possibly may require further management action to reduce exploitation.

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APPENDIX A

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

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.