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Abundance, Composition, and Exploitation of Selected Arctic Grayling Spawning Stocks in the Tangle Lakes System, 1991

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ABSTRACT

Results are presented for the fourth year of a study to assess the population of Arctic grayling *Thymallus arcticus* in the Tangle Lakes system above the Delta River falls. The system supports the fifth largest Arctic grayling fishery in Alaska. The major objective of the study was to estimate the angler exploitation rate of three spawning aggregations (stocks) of Arctic grayling in the Tangle River, the predominant harvest location within the system. These stocks were from the tributary of 18 Mile Creek (Tundra Pond) and two lakes of the lower system: Long Tangle and Lower Tangle lakes. Estimates of the abundance and proportion of marks released for each stock during the spawning period were used in conjunction with the recoveries of marks during a partial harvest survey to estimate exploitation rate. Only one stock, Tundra Pond, was found to be exploited at detectable levels. Small harvest samples, lack of mark recoveries, and differences in age and size composition between fish in the harvest and those marked fish released resulted in imprecise estimates of the exploitation rate (4.5%). However, a significant trend in exploitation and migratory behavior of the stocks was inferred from mark-recovery data. The stock closest to the major access point of the system was exploited at a level two to three times that of more distant stocks. Conclusions from the four years of studies and recommendations for future work are also presented.

KEY WORDS: Arctic grayling, *Thymallus arcticus*, Tangle Lakes, Tangle River, abundance, age composition, size composition, Relative Stock Density, spawning sites, exploitation rates, harvest survey.

INTRODUCTION

The Tangle Lakes and River system, hereafter referred to as the Tangle System (Figure 1), supports a large population of Arctic grayling *Thymallus arcticus* and populations of lake trout *Salvelinus namaycush*, burbot *Lota lota*, round whitefish *Prosopium cylindraceum*, and longnose suckers *Catostomus catostomus*. The Tangle System has supported popular fisheries for Arctic grayling, lake trout, and burbot since the opening of the Denali Highway on 4 July 1953 (Wojcik 1953a). Prior to 1953, the Tangle System was inaccessible by road and received little fishing pressure (Wojcik 1953a, 1953b, 1953c, 1953d, 1953e, 1953f, 1953g). Since 1953, the heaviest angling pressure has occurred on Upper and Round Tangle lakes and the interconnecting Tangle River (Figure 1).

The Alaska National Lands Conservation Act of 2 December 1980 established the Tangle Lakes system as The Delta National Wild and Scenic River corridor, a component of the National Wild and Scenic River System. The "scenic" portion lies above the Delta River. The "wild" portion extends from the Delta River headwaters 18.4 km to Eureka Creek, a glacial tributary. A portion of the system comprises a popular float trip that extends 41 km from Round Tangle Lake downstream to the Richardson Highway at Phelan Creek. It includes 28 km of the Delta River (Figure 1).

The recreational fishery in the Tangle System targets Arctic grayling, lake trout, and burbot with the former comprising over 80% of the system's total harvest. From 1978 to 1990, an average of 5,634 angler-days were expended annually for all species. Arctic grayling harvests ranged from 2,467 to 9,590 fish, with an yearly average of 5,219 fish (Mills 1979-1991; Figure 2; Appendix A1). This average annual Arctic grayling harvest is the fifth largest in Alaska (Mills 1979-1991). Lake trout and burbot harvests have averaged 988 and 109 fish per year, respectively, since 1978 (Mills 1979-1991). Depressed population levels in the latter two fisheries necessitated their closure by emergency order in 1987. These closures appear to have indirectly affected the harvest of Arctic grayling in the Tangle System. In 1987, angling pressure dropped to its lowest recorded level and harvest was reduced to 2,467 Arctic grayling (Figure 2). With new regulations in 1988 which allowed a minimum harvest of lake trout and burbot, angling pressure for all species has steadily increased while Arctic grayling harvests have remained constant at about half its yearly average (Mills 1991).

Since 1953, numerous studies have been conducted to assess the population structure of Arctic grayling in the Tangle System (Wojcik 1953a, 1953b, 1953c, 1953d, 1953e, 1953f, 1953g; Warner 1955a, 1955b, 1956, 1957, 1958, 1959; Heckart 1965; Roguski 1967; Roguski and Winslow 1969; Roguski and Tack 1970; Schallock 1966; Peckham 1974, 1977; Holmes et al. 1986; Clark and Ridder 1987, 1988; Baker 1988, 1989; Ridder 1990, 1991a). Prior to 1988, the majority of these studies have presented limited data, quantitative or qualitative, on harvest rates, movements, location-specific population estimates, and age and size compositions. As presented, these data are not comparable from year to year and make stock assessment of the system difficult.

A comprehensive study was begun in 1988 to assess population status through a system-wide sampling program utilizing mark and recapture experiments. As

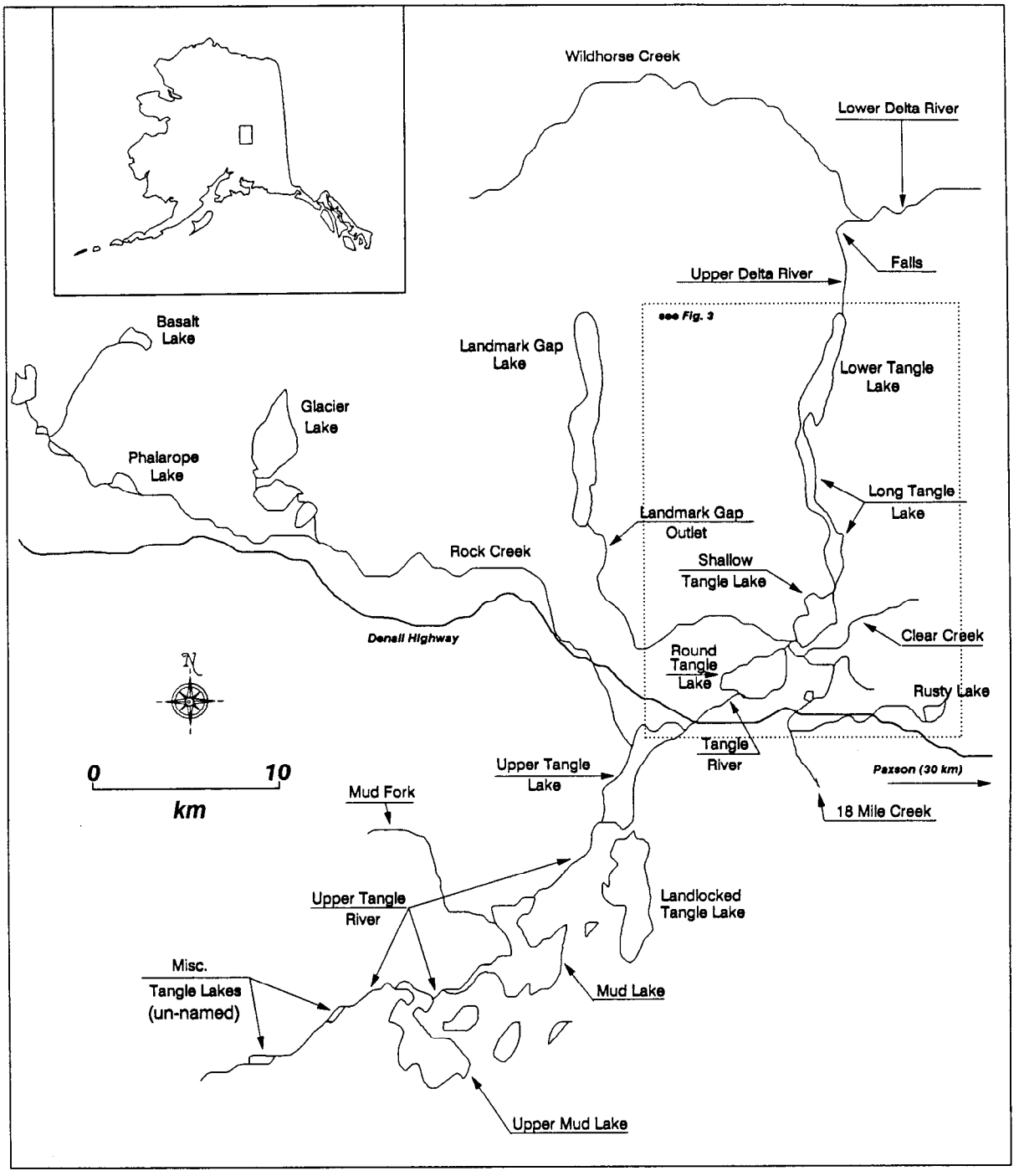

Figure 1. Map of the Tangle Lakes and River system.

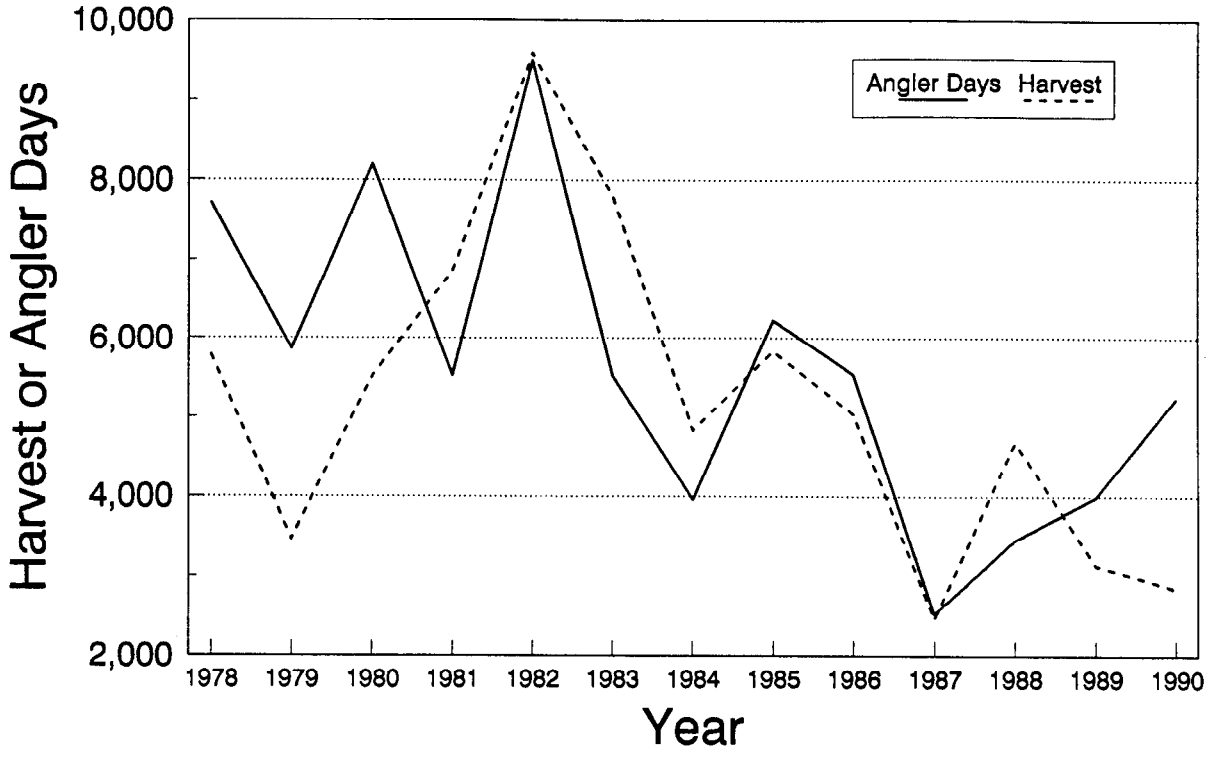

Figure 2. Estimated recreational harvest of Arctic grayling and total angler days on the Tangle Lakes system, 1978 through 1990.

with riverine populations in interior Alaska (Tack 1980; Ridder 1991b), Arctic grayling are highly mobile and migrate throughout the Tangle System between spawning, summer feeding, and overwintering locations (Wojcik 1953d; Warner 1955a,b; Schallock 1966; Ridder 1990). Age and length composition of the population differs significantly depending on temporal and spatial variables (Ridder 1990). In spring, Arctic grayling, predominantly adult fish ≥289 mm fork length (FL), concentrate at or near spawning locations of which 17 have been identified (Ridder 1991a). These concentrations appear to be distinct spawning groups (sub-populations) that home to the same spawning area yearly. After spawning, these fish, in variable proportions depending on spawning group, move to common summer feeding locations which they share with juveniles. The extent of mixing and angler exploitation rates in the feeding areas is unknown. In the fall before ice-up, the fish move back to the larger lakes where they overwinter. Differential harvest rates among feeding locations within the Tangle System could result in overexploitation of one or more spawning stocks.

This report summarizes results from the fourth year (1991) of the project.

The specific objectives in 1991 were to estimate:

1) abundance of Arctic grayling (≥ 150 mm FL) in the Tundra Pond at 18 Mile Creek;

2) abundance of Arctic grayling (≥ 150 mm FL) in the Lower Tangle System (from Shallow Tangle thoroughfare downstream to the outlet of Lower Tangle Lake);

3) age and size compositions of Arctic grayling (≥ 150 mm FL) in the Tundra Pond at 18 Mile Creek and in the Lower Tangle System (from Shallow Tangle Lake downstream to the outlet of Lower Tangle Lake); and,

4) the relative exploitation rates of Arctic grayling released at the Tundra pond at 18 Mile Creek and the Lower Tangle System and harvested in the Tangle River during 24 June through 28 July.

STUDY SITE

The Tangle System is an interconnected lake-stream system located approximately 37 km west of Paxson on the Denali Highway (Figure 1). The highway bisects the system at the Tangle River between Round and Upper Tangle lakes. There are two Bureau of Land Management (BLM) campgrounds located next to the highway at the two lakes. The Tangle System is approximately 900 m in elevation and within its drainage are 12 major lakes and over 100 km of rivers and streams. The lakes range in size from 12 (Rusty Lake) to 304 ha (Landmark Gap Lake) and cumulatively cover a surface area of over 1,500 ha. The open-water season in the Tangle System is about four months (June to the middle of October). However, some open water persists all year at the inlets and outlets of rivers and streams and the thoroughfares between lakes.

The Tangle System is composed of seven main lakes (proceeding upstream; Lower Tangle, Long Tangle, Shallow Tangle, Round Tangle, and Upper Tangle, Mud, and Upper Mud lakes) that are interconnected by the Tangle River[1]. The maximum depth of the lakes is 35 m in Round Tangle Lake. The Delta River drains Lower Tangle Lake into the Tanana River. Approximately 3 km downstream of the Delta River headwaters are a series of falls that prevent upstream fish movement (Peckham 1974)[2]. At the headwaters of the Tangle System above Upper Tangle and Mud lakes, there are a series of unnamed lakes that form the headwaters of the Tangle River. There are also two large tributaries that drain into two of the main lakes. Rock Creek (30 km long) flows into Upper Tangle Lake. It flows through a number of small, shallow lakes near its headwaters and includes the outflow of Glacier Lake (172 ha) near its middle reaches. Landmark Gap Lake flows via 6 km-long Landmark Gap Creek into the thoroughfare between Round and Shallow Tangle lakes.

Abundance of Arctic grayling (≥ 150 mm FL) was estimated during the spawning period in three areas located downstream of the Tangle River: the Tundra Pond of 18 Mile Creek; the head and the two middle thoroughfares of Long Tangle Lake; and, the outlet of Lower Tangle Lake (the head of the Upper Delta River; Figure 3). These areas were located and sampled in 1989 (Tundra Pond and Long Tangle Lake Head) and again in 1990 (all areas). The Long Tangle Lake area is comprised of three sites located within a 4.8 km reach and separated by less than 0.8 km. The outlet of Lower Tangle Lake lies 3.2 km downstream of the lowest Long Tangle Lake site.

METHODS

Data Collection

The mark-recapture experiment in the Tundra Pond of 18 Mile Creek commenced within two days of the break-up of ice in the main channel. All sampling used hook and line with spinning lures, jigs, and artificial flies as terminal gear. The mark event encompassed three days while the recapture event lasted four days. Three days separated the events.

The mark-recapture experiment in the Lower Tangle Lakes began the day when ice conditions on Round Tangle Lake allowed downstream boat access. Sampling occurred on four successive days using an electrofishing boat. The boat was equipped with a pulsed DC variable voltage pulsator (Coffelt Model VVP-15) powered by a 3.5 KW gas generator. Anodes were four 10 mm diameter steel cables 1.5 m long arranged perpendicular to the long axis of the boat and 2.1 m forward of the bow. The unpainted bottom of the boat was the cathode.

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[1] This report refers to the Tangle River as that section connecting Upper and Round Tangle lakes. The river above Upper Tangle Lake is the Upper Tangle River. The shorter interconnecting streams between the major lakes are referred to as thoroughfares and are named by the lake at their head. Long Tangle Lake is actually a series of three lakes connected by two thoroughfares (see Figure 1).

[2] In this report, the river above the falls is called the Upper Delta River and below the falls, the Lower Delta River.

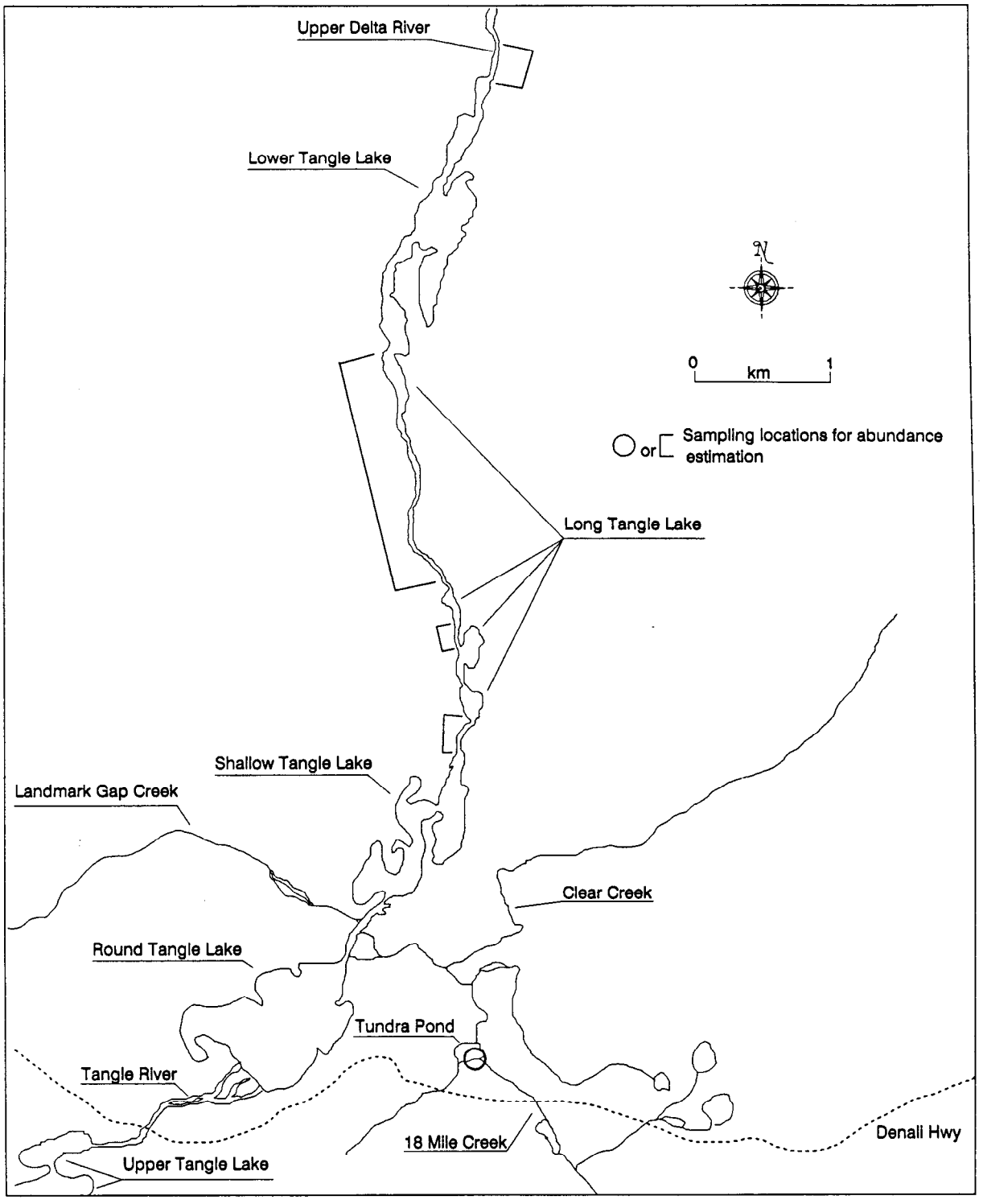

Figure 3. Sampling locations for abundance estimation in the Lower Tangle Lakes system, spring 1991.

Voltages ranged from 270 to 300 volts and current ranged from 1 to 3 amperes. Duty cycle and pulse width were held constant at 40% and 80 Hz, respectively. Conductivity was not recorded in 1991, but was 230 μS (standardized to 25°C) on 9 June 1989 at Upper Tangle Lake (Ridder 1990).

All captured Arctic grayling were measured to the nearest 1 mm fork length (FL). Arctic grayling greater than 149 mm FL were tagged with an individually-numbered Floy internal anchor tag and given a partial clip of the upper lobe of the caudal fin for evaluation of tag loss. Sex was recorded for only those fish determined to be mature. Since sampling occurred during the spawning period, sex and maturity were readily determined by either sexual dimorphism or the release of gametes during handling (Scott and Crossman 1973; Ridder 1983, 1991a; Fleming and Reynolds 1991). Date, location, fork length, sex, finclip, tag number, and gear type were recorded for individual fish on coin envelopes at Tundra Pond and on mark-sense (optical scanning) forms at the Lower System. Data recorded on coin envelopes were later transcribed onto mark-sense forms which were optically scanned into electronic data files (Appendix B). Location codes used were the same as those first used by Baker (1989) in 1988.

For aging of sampled Arctic grayling, two to four scales from all initial captures were removed from an area four to six scale rows above the lateral line just posterior to the insertion of the dorsal fin. Scales were placed in a coin envelope marked with either the above data, or the litho-code and fish number of the mark-sense form. Scales were processed by cleaning in a hot solution of common dish detergent. Scales were inspected for regeneration, and then the two best scales from each fish were mounted on gummed cards. The cards were used to make impressions of the scales on 20 mil acetate film using a Carver press at 137,895 kPa heated to 97°C. Ages were estimated by two readers from single counts of scale annuli using a microfiche reader and then hand entered into the above data files.

Harvest Survey

The sample design for the harvest survey in the Tangle River was developed from creel survey data collected at the Tangle River in 1987 (Baker 1988), and from Arctic grayling migratory behavior and spawning stock mixing rates (Ridder 1991a). Approximately 68% of the total harvest at the Tangle lakes in 1987 occurred at the Tangle River. Peak fishing times during 1987 were 1100 hours through 2000 hours. Arctic grayling spawning is generally completed by mid-June at which time they migrate to summer feeding areas. Approximately equal summer mixing rates (22 to 25%) for spawning stocks from the Upper and Lower Tangle System and Tundra Pond were found for angler recoveries in the Tangle River (Ridder 1990).

The Tangle River is approximately 1.6 km long and is readily accessible from a road that parallels it and connects campgrounds situated at its' head and mouth. These campgrounds also provide boat ramps for access to the upper and lower parts of the system. Using a roving survey, a creel clerk was to contact all anglers who completed fishing between 1100 hours and 2000 hours on Friday, Saturday, Sunday, and Monday of each week from 21 June through 29 July. Problems with hiring truncated this schedule to 28 June through 28

July. The first week was fully sampled (Monday to Monday) and the last Monday of the last period was deleted due to poor catch rates and weather conditions.

All anglers encountered during the survey were interviewed for location fished, hours fished, number of Arctic grayling caught and those that were tagged, and number of Arctic grayling harvested and those that were tagged. Although anglers fishing the Tangle River were targeted, those that fished other areas were also interviewed as conditions warranted (when no anglers were sighted on the Tangle River). Data was put on field forms and later transcribed into a Lotus spreadsheet. All harvested fish were checked for tags, measured to the nearest 1 mm FL, and scales taken and processed as above. Date, location, time (nearest 0.5 hour), tag number and color, length, and fin clip were recorded on mark-sense (optical scanning) forms (Appendix B).

In addition, drop boxes were placed at ten access points to the Tangle System. Anglers were allowed to return tags from Arctic grayling harvested and provide location and date of capture, length of fish, and a scale sample.

Estimation of Abundance

Abundance of Arctic grayling (≥150 mm FL) in 1991 was estimated in the Tundra Pond of 18 Mile Creek with the modified Petersen formula of Chapman (1951):

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

where:

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

The variance of the estimate (Seber 1982) was calculated as:

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

Abundance of Arctic grayling (≥150 mm FL) in 1991 was estimated in the thoroughfares and head of Long Tangle Lake and in the outlet of Lower Tangle Lake with the modified Petersen formula of Bailey (1951, 1952):

$$\hat{N} = \frac{M\ (C + 1)}{(R + 1)} \qquad (3)$$

The variance of this estimate was calculated as:

$$\hat{V}[N] = \frac{M^2 (C + 1) (C - R)}{(R + 1)^2 (R + 2)} \quad (4)$$

The estimate for the Lower Tangle System was the sum of the individual estimates of each lake.

The Bailey estimator was used since the assumption of a random sample in the second event was violated. Electrofishing does not allow for complete mixing of marked and unmarked fish along the entire length of the reaches sampled. However, since the sampling was systematic, it is assumed that localized mixing occurred and that the proportion of fish marked did not change along the reaches' length.

The abundance of components of the populations (sexed adults and those fish larger than 290 mm FL) was estimated using:

$$\hat{N}_i = \hat{p}_i(\hat{N}) \quad (5)$$

where:

$\hat{N}_i$ = the estimated abundance of Arctic grayling of component i; and,

p_i = the proportion of component i from equation 7.

The variance of the product N_i was estimated using Goodman's (1960) exact variance of a product:

$$\hat{V}[\hat{N}_i] = \hat{N}^2\hat{V}[\hat{p}_i]+\hat{p}_i^2\hat{V}[\hat{N}]-\hat{V}[\hat{p}_i]\hat{V}[\hat{N}] \quad (6)$$

The necessary assumptions for an accurate estimate are (from Seber 1982):

1) the Arctic grayling population in the study area must be closed;

2) no tags can be lost between samples;

3) all Arctic grayling have the same probability of capture during the first sample or during the last sample or marked Arctic grayling must completely mix with unmarked Arctic grayling between samples;

4) marking must not influence behavior between samples; and,

5) mortality is the same for both marked and unmarked fish between samples.

Arctic grayling populations in the spring are highly mobile in moving between overwintering, spawning, and feeding areas. Yet, the spawning populations in the Tundra Pond and Long and Lower Tangle lakes can be considered closed since

the experiment was conducted over a short time period, 11 and four days, respectively, on predominantly mature fish in spawning sites. Thus, movement of mature fish through the area to spawning or feeding sites was unlikely. During a similar spawning period in the Tundra Pond in 1989, Ridder (1990) observed no fish in upstream areas nor did he capture upstream migrants until 5 June. Tack (1980) found movement to spawning sites commencing at 1°C and spawning beginning at 4°C. With water temperatures during the estimation period in the Tundra Pond ranging from 1 to 7°C and in the Lower System, from 5 to 6°C, it is assumed that all fish destined to spawn in the areas were present during the experiment. The double marking (fin clip and tag) satisfied the second assumption. The third and fourth assumptions were tested with Kolmogorov-Smirnov two sample tests (Appendices C1 and C2). The short time interval and the exclusion of visibly injured fish from the experiment minimized a violation of the last assumption.

Estimation of Age and Size Compositions

Testing of assumptions necessary for accurate abundance estimation may also reveal biases in age and size composition samples. Since age and length information were collected during mark-recapture sampling, bias in mark-recapture samples also would imply bias in age and length data that were collected. Age and size composition were used to apportion the population estimate into age classes or Relative Stock Density (RSD) categories (Gabelhouse 1984), so that age and length information collected during either the marking sample, the recapture sample, or both samples could be used to calculate age and size composition.

Based on the tests for size selectivity, age and size data may be adjusted for size selectivity. If size selectivity was detected (see Appendix C1) the appropriate sample or samples (from the first, second, or both samples) were used to estimate the age and size compositions.

If size selectivity was not detected, the proportion of fish at age, or size group, k was estimated by:

$$\hat{p}_k = \frac{y_k}{n} \qquad (7)$$

where: $\hat{p}_k$ = the proportion of Arctic grayling that were age, or size, k;
y_k = the number of Arctic grayling sampled that were age (size) k; and,
n = the total number of Arctic grayling sampled.

The unbiased variance of this proportion was estimated as:

$$\hat{V}[p_k] = \frac{\hat{p}_k\ (1 - \hat{p}_k)}{n - 1} \qquad (8)$$

Size composition was estimated in a similar manner, replacing age class with the RSD categories. The RSD categories are: "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).

Mean fork length-at-age (FL_a) was estimated for all sample locations during each sampling period as:

$$\hat{\overline{FL}}_a = \frac{\sum_{j=1}^{n_{al}} FL_{aj}}{n_{al}} \qquad (9)$$

where: FL_{aj} = fork length (mm) of fish j that is sampled and age a; and,

n_{al} = number of fish sampled for length that are age a.

The variance of this mean $\hat{V}[\hat{\overline{FL}}_a]$ was estimated as:

$$\hat{V}[\hat{\overline{FL}}_a] = \frac{\sum_{j=1}^{n_{al}} (FL_{aj} - \hat{\overline{FL}}_a)}{n_{al}(n_{al} - 1)} \qquad (10)$$

These estimates are presented in Appendix D1.

Maturity of Arctic grayling was determined and is presented in this report in two ways, either by sexing during the spawning period or by the use of a maturity index developed by probit analysis (Finney 1971) from 1989 Tangle Lake data (Ridder 1990). The index estimated the length (LM_x) at which various percentages ($1\% \leq x \leq 99\%$) of the fish were mature. For stratification of tagged and recaptured fish and the estimation of exploitation rates, fish were classed as adults if they were greater than the estimated LM_{50}, 289 mm FL. All other fish were classed as juveniles.

Estimation of Exploitation Rates

The Tangle Lakes Arctic grayling population consists of a group of discrete spawning stocks (Ridder 1991a). After spawning, these stocks migrate to summer feeding areas throughout the system. Based on mixing rates (the proportion of all recaptures of a group *a* recovered in location *i*) estimated

from angler reports, approximately equal proportions of Arctic grayling spawning stocks tagged in three broad areas of the Tangle Lakes were harvested in the Tangle River during the summer (16 June through 15 August; Ridder 1991a). No other uniformity was found between the mixing rates of these spawning stocks in other feeding areas. Proportional estimates of marked Arctic grayling in three spawning stocks were used in conjunction with the proportions of marked fish in angler creels to estimate the relative exploitation, or contribution, of each stock to the harvest in the Tangle River.

Assumptions necessary for an accurate estimation of exploitation rates are:

1) the proportion of tagged Arctic grayling in angler creels does not vary within a day or among days; and,

2) the proportion of tagged Arctic grayling in angler creels does not vary within a season of the year; or

3) angler creels are sampled in proportion to the number of potential angler creels to be sampled in any given day; and,

4) anglers do not selectively harvest or not harvest tagged Arctic grayling, so that a fish that would otherwise be released (or kept), is kept (or released) because it has a tag.

Assessment of the validity of assumption 1 would require a large number of angler creels be checked each day. Because the number of creels checked each day was small, assumption 1 could not be tested empirically. Changes in the proportion of tagged Arctic grayling, within a day or among days, will most certainly occur. However, changes in the proportion tagged was assessed by season (assumption 2). Assumption 2 was assessed by comparing the proportion of tagged Arctic grayling in angler creels by week during the defined fishing season. Assumption 3 should be valid, but may have been violated if large numbers of anglers finish fishing at once, preventing the creel clerk from sampling angler creels in proportion to the actual number of angler creels. This may have been a problem during the 4th of July weekend. To increase the number of the holiday interviews, an extra creel clerk was used to help check angler creels during 6 and 7 July. Assumption 4 cannot be tested, but creel clerks were instructed to inform anglers that if they catch a tagged fish, but would like to release it, they should not remove the tag or kill the fish just to turn in the tag. In addition, tag return boxes had signs instructing anglers to return tagged fish to the water, with the tag intact, if they did not wish to keep the fish.

From abundance estimation experiments conducted in spring, the proportion of fish marked in Tundra Pond and the two lakes of the Lower Tangle System was estimated by:

$$\hat{p}_t = \frac{m_t}{\hat{N}_t} \qquad (11)$$

where: $\hat{p}_t$ = the estimated proportion of Arctic grayling marked in area t;
m_t = the number of unique Arctic grayling marked in area t; and,
$\hat{N}_t$ = the abundance of Arctic grayling in area t.

The variance of p_t was approximated by:

$$\hat{V}[\hat{p}_t] \approx \frac{m_t^2 \, \hat{V}[\hat{N}_t]}{\hat{N}_t^4} \tag{12}$$

where: $\hat{V}[\hat{N}_t]$ = the variance of abundance of Arctic grayling in area t.

Upon recovery, the proportion of marked fish in angler creels was the ratio of marks to those examined for marks:

$$\hat{p}_m = \frac{m_c}{n_2} \tag{13}$$

where: $\hat{p}_m$ = the estimated proportion of Arctic grayling originally marked in area t and recovered in area m;
m_c = the number of marked Arctic grayling originally from area t that are recovered in area m; and,
n_2 = the number of Arctic grayling examined for marks in area m.

The variance of p_m was the variance of a binomial, or:

$$\hat{V}[\hat{p}_m] = \frac{\hat{p}_m \, (1 - \hat{p}_m)}{n_2 - 1} \tag{14}$$

Exploitation rate of fish from each spawning area that was relative to the harvest from the Tangle River was estimated with these two ratios:

$$\hat{p}_c = \frac{\hat{p}_m}{\hat{p}_t} \tag{15}$$

Variance of the exploitation rate was approximated with the Delta method (Seber 1982; ignoring the hat symbols, all quantities are estimated)

$$V[p_c] \approx \left[\frac{p_m}{p_t}\right]^2 \left[\frac{V[p_m]}{p_m^2} + \frac{V[p_t]}{p_t^2}\right] \tag{16}$$

RESULTS

A total of 1,157 Arctic grayling were sampled in the Tangle System in 1991. The sample included 156 recoveries of fish tagged in previous years (Table 1). All, except one, of the recoveries of fish tagged on spawning sites (n = 87) were made in the same sites. The one fish that strayed was tagged in the Tundra Pond on 25 May 1990 and recovered in Long Tangle Lake on 12 June. During spring sampling of spawning areas, 304 fish were captured in the Tundra Pond of 18 Mile Creek, 414 fish in the thoroughfares of Long Tangle Lake, and 191 fish in the outlet of Lower Tangle Lake. Harvest sampling from 25 June through 28 July counted a harvest of 368 Arctic grayling and obtained data on 211 of these. In addition, 93 tag recoveries were voluntarily reported by anglers. The majority of these reports (n = 71) were obtained from ten tag return boxes located at main access points; the remainder were either reported to the on-site creel census clerk (n = 7) or sent to area offices (n = 15). One verified tag recovery occurred in the Delta Clearwater River of a fish tagged at age 3 in Rock Creek in July 1990.

Sampling of spawning areas occurred from 28 May through 7 June in the Tundra Pond and from 11 through 14 June in the lower system. Late afternoon water temperatures in the Tundra Pond ranged from 3°C on 28 May to 7.5°C on 5 June. Late afternoon water temperatures in the Lower System differed little between 11 and 14 June (5 and 6°C), while temperatures in Tundra Pond ranged from 8 to 10°C. Due to a late and prolonged ice break-up, sampling was six and seven days later, respectively, than sampling in 1990. While the area below Round Tangle Lake was ice free on 5 June, remaining ice on Round Tangle Lake prevented boat access until 10 June (Schandelmier pers. comm.[3]).

Abundance

The estimated abundance of Arctic grayling greater than or equal to 150 mm FL in the Tundra Pond of 18 Mile Creek was 1,211 fish (SE = 229 fish and CV = 19%; Table 2). Catches during the marking event (28 through 30 May) included 115 Arctic grayling; during the recapture event (4 through 7 June), 208 fish were examined and 19 fish were previously marked (Appendix D2). Size composition differed significantly between the two events ($p < 0.01$, Appendix C2). The composition of adult-sized fish (290 mm FL) decreased significantly from 97% in the first event to 77% in the second event ($\chi^2 = 23.33$, df = 1, $p < 0.01$; Figure 4). No significant size bias was detected between size distributions of marked and recaptured fish ($p = 0.22$, Appendix C2). These tests inferred size selectivity in the marking event but not in the recapture event (Appendix C1). Thus length stratification of the data was unnecessary but, all age, length, and maturity compositions were estimated from data collected during the second event.

The four sample events in the two lakes of the lower system could not all be apportioned into mark and recapture events to generate an abundance estimate

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[3] Schandelmier, John. 1991. Personal Communication. Tangle River Inn, Paxson, Alaska 99737.

Table 1. Summary of Arctic grayling caught, marked, and recaptured in the Tangle Lakes system, 28 May through 28 July 1991.

Location	Location Code	Date	Catch				Number of Marks					
							New[a]			Recaptures[b]		
			Total	<199mm	200-289	≥290mm[c]	Total	<290mm	≥290mm	Total	<290mm	≥290mm
Lower Tangle Lake	101	6/11-6/14	191	1	28	162	151	15	136	31	0	31
Long Tangle Lake	210-275	6/11-6/14	414	8	111	295	410	117	293	56	4	52
Tundra Pond (18 Mile Cr.)	391	5/28-5/30,6/4-6/7	304	0	50	254	295	50	245	47	4	43
Harvest Sample	200-690	6/25-7/28	368(248)[d]	12	150	49	NA	---	---	22(12)	2	10
Totals:			1,157	21	339	760	856	182	674	156(146)	10	136

[a] New marks (tags) released.
[b] Recaptures of tags from 1986 through 1990.
[c] The length at maturity for 50% of the population (Ridder 1990).
[d] In parentheses are number of fish actually measured. Of the 248 fish sampled, lengths were obtained from 211.

Table 2. Estimated abundance of Arctic grayling by length category and maturity for three spawning aggregations in the Tangle Lakes system in spring of 1991.

Location	≥150 mm			≥290 mm[a]			Adults[b]		
	N[c]	SE[d]	CV[e]	N[f]	SE	CV	N[f]	SE	CV
Tundra Pond	1,211	229	19%	932	176	19%	873	169	19%
Long Tangle Lk.	2,283	586	26%	1,754	453	26%	1,506	391	26%
Lower Tangle Lk.	438	97	22%	395	88	22%	378	85	22%
Lower Tangle System	2,721	594	22%	2,149	461	22%	1,884	400	21%

[a] The length at maturity for 50% of the population (Ridder 1990).
[b] Adults defined by sexual dimorphism and/or presence of gametes.
[c] Estimated abundance.
[d] Standard error of the estimated abundance.
[e] The coefficient of variation expressed as a percentage.
[f] Estimated abundance based on proportions.

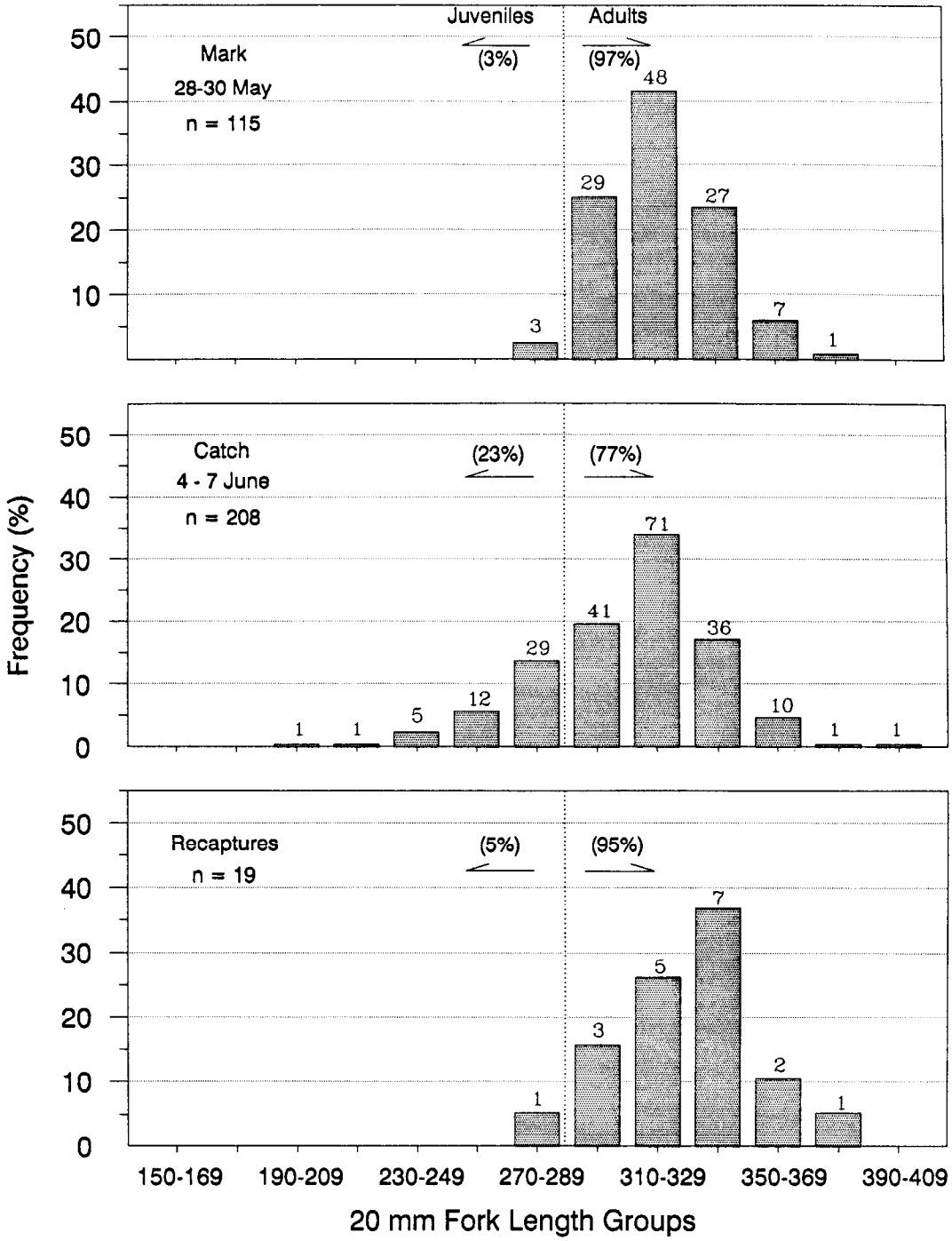

Figure 4. Length compositions for sampling events at Tundra Pond, spring 1991.

for Arctic grayling (≥150 mm FL). There were significant and intuitive differences in size composition in both lakes between fish marked and examined and between those recaptured and not recaptured that warranted size stratification (from Appendix C1; Long Tangle Lake: test A, $p < 0.01$, and test #2, $p = 0.10$; Lower Tangle Lake: test #1, $p = 0.11$, and test B, $p = 0.48$). The differences arose from an increase in the presence of juvenile fish on the last sampling day, 14 June, especially in Long Tangle Lake (Figures 5 and 6). Yet recaptures of marked fish could not be stratified by size since no recaptures less than 290 mm FL occurred. Deleting the last day's sample from the database corrected the compositional problem (Figures 7 and 8; Appendix C2). The first sample (11 June) was then made the marking event and the last two samples (12 and 13 June), the recapture event.

The deletion of the last day's sample also helped alleviate, but not solve, problems with data that caused violation of the assumptions of equal vulnerability and of a closed population. While catch rates in the four spawning areas of the lakes declined over the four sampling days, they were most pronounced on the fourth day (Appendix D3; the fourth day increase in the mid-thoroughfare of Long Tangle Lake was a result of additional effort). Also, one Lower Tangle Lake fish marked on the first day was recaptured twice, on the third day in the lower lake and then on the last day, 3.2 km upstream in Long Tangle Lake. A fish tagged on 4 June in the Tundra Pond was also recaptured in Long Tangle Lake on 11 June.

The estimated abundance of Arctic grayling (≥ 150 mm FL) in the two spawning areas of the Lower Tangle System was 2,721 fish (SE = 594 fish and CV = 22%; Table 2). The Long Tangle Lake sites comprised 84% of the estimate (N = 2,283, SE = 586, CV = 26%) and the outlet of Lower Tangle Lake, 16% (N = 438, SE = 97, CV = 22%). No size selectivity was detected in either sample (Appendix C2; Long Tangle Lake: $p = 0.48$ and $p = 0.95$; Lower Tangle Lake: $p = 0.38$ and $p = 0.25$). Thus stratification of the data by size was unnecessary and all age, length, and maturity compositions were estimated from data pooled from both events.

Age and Size Compositions

The age compositions in the three spawning aggregations were dominated by adult fish age 6 and older. This component (age 6+) ranged from 75% and 77% in the Tundra Pond and Long Tangle Lake to 87% in Lower Tangle Lake (Table 3). Age 7 was the predominant age class in Long and Lower Tangle lakes (37% and 49%, respectively). In the Tundra Pond, ages 6 and 7 were near equally represented and dominated the sample (34% and 33%, respectively).

Relative Stock Density (RSD) indices of the spawning aggregations all favored larger fish, yet differed significantly among themselves ($\chi^2 = 34.11$, df = 4, $p < 0.05$). Quality-sized fish (270 - 339 mm FL) were the dominant category in these samples ranging from 60% in Long and Lower Tangle lakes to 80% in the Tundra Pond (Table 4). There was a decreasing percentage of the preferred category (340 - 449 mm FL) from downstream to upstream areas; Lower Tangle Lake had 31% of the preferred category, Long Tangle Lake had 19%, and Tundra Pond had 11%.

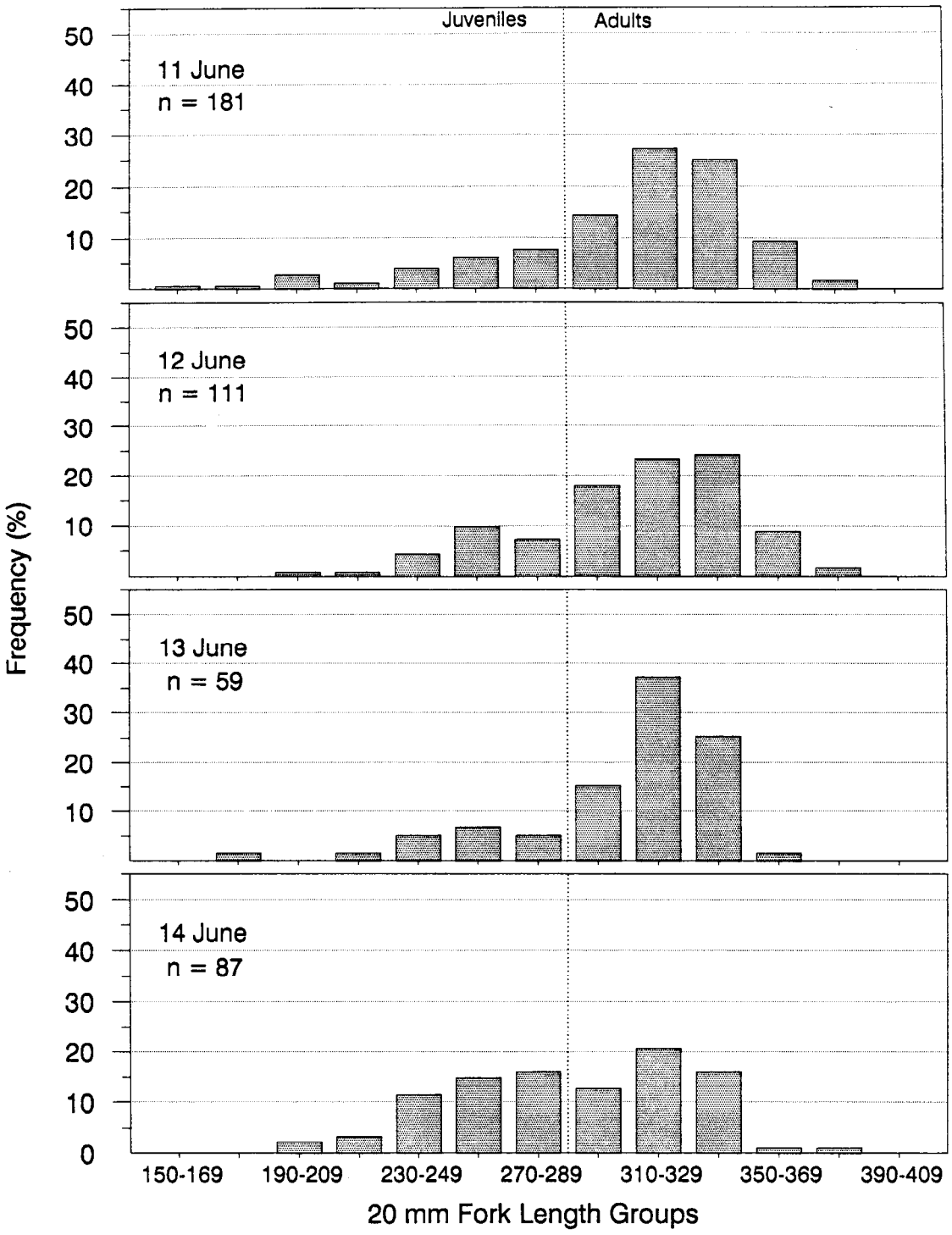

Figure 5. Length compositions by daily sampling events at Long Tangle Lake, spring, 1991.

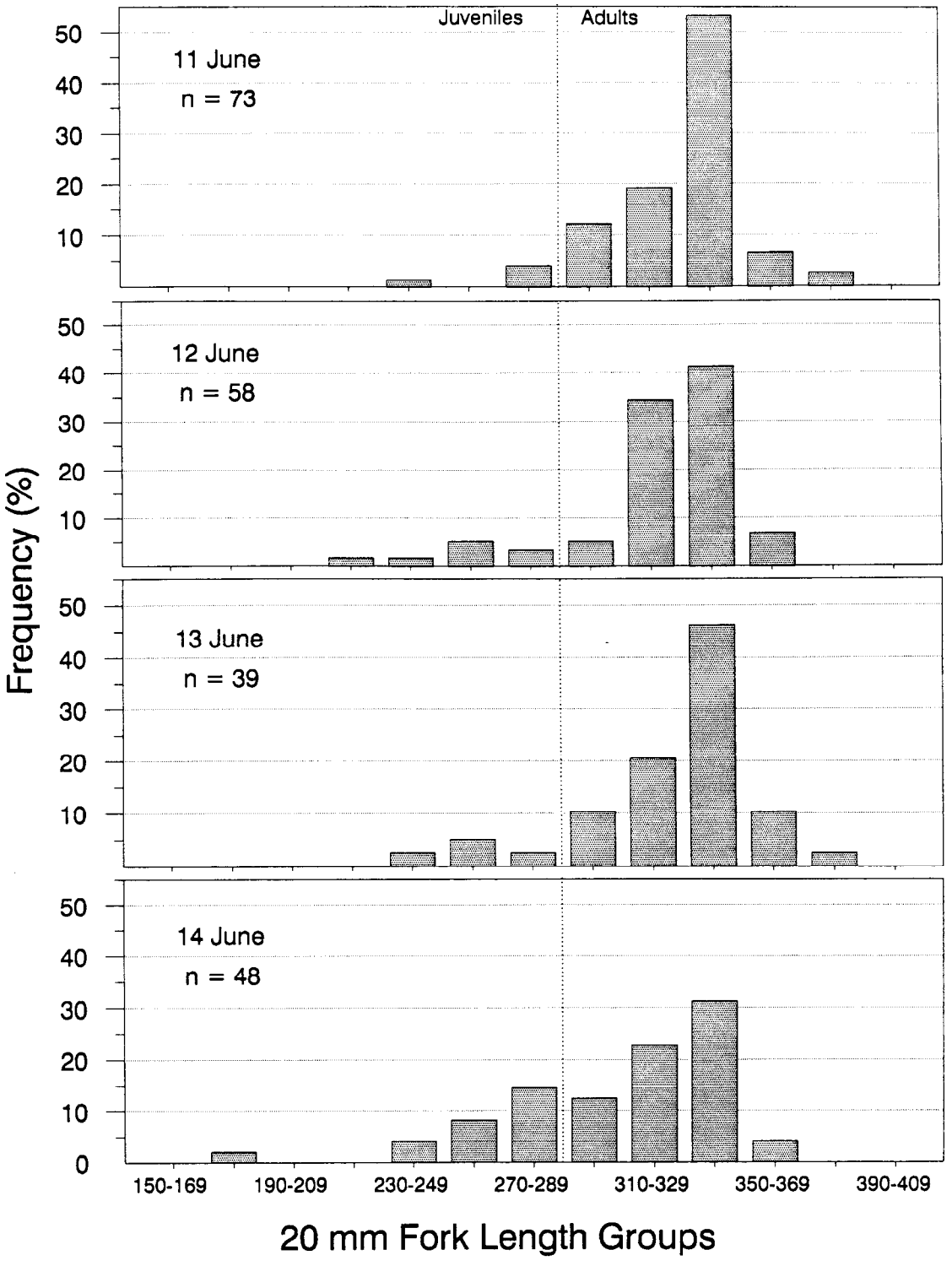

Figure 6. Length compositions by daily sampling events at Lower Tangle Lake, spring, 1991.

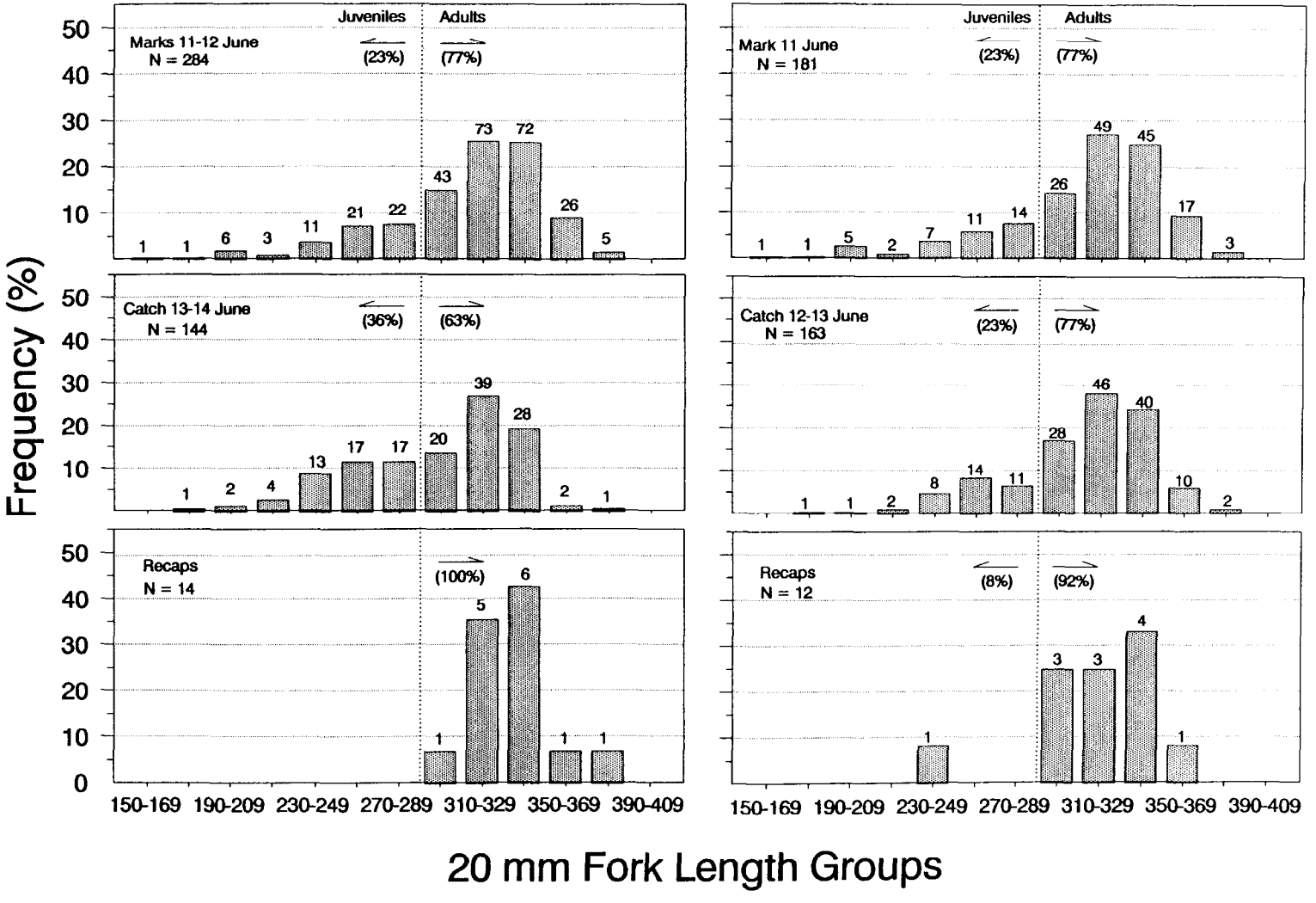

Figure 7. Length compositions for two sets of mark-recapture events at Long Tangle Lake, spring, 1991.

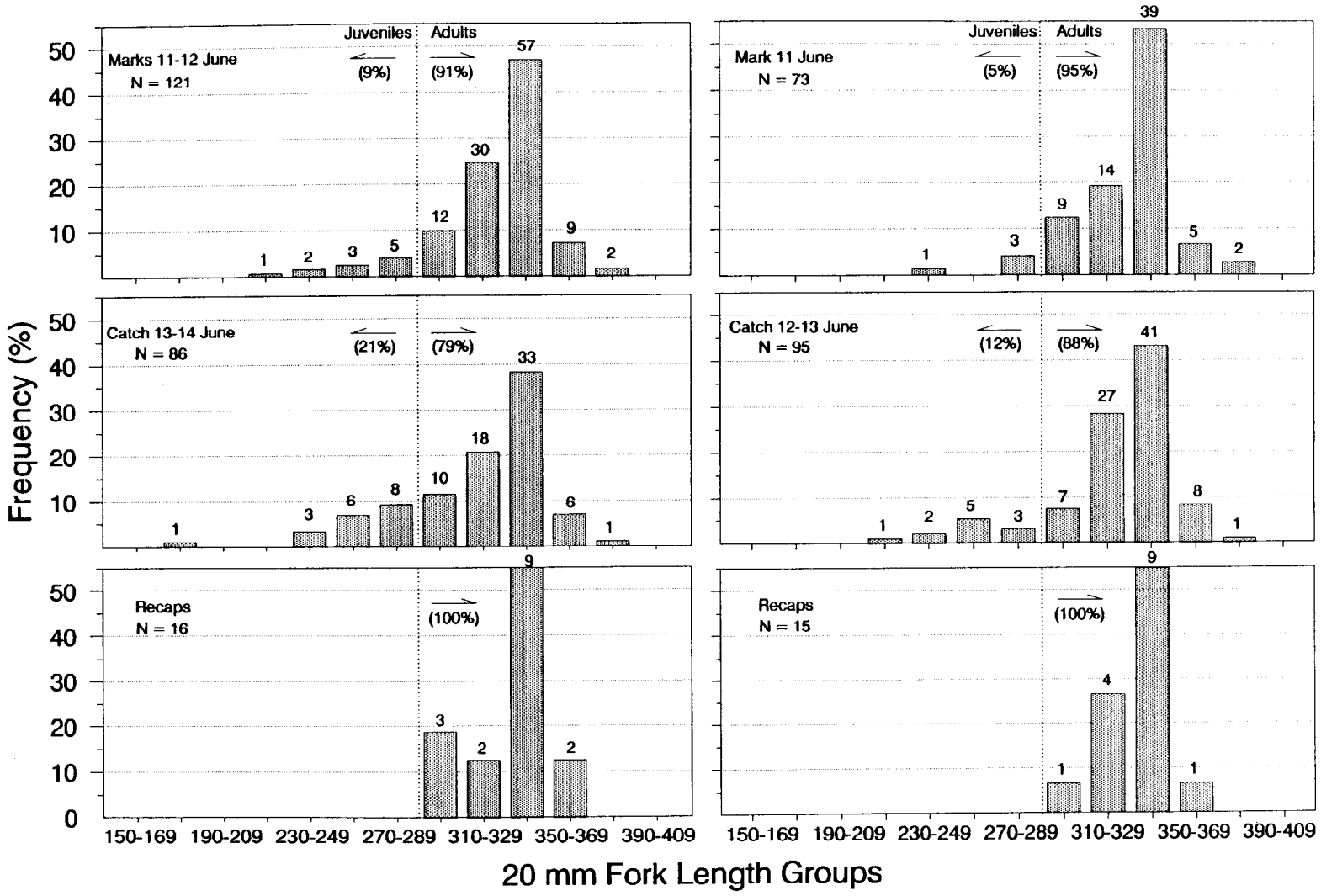

Figure 8. Length compositions for two sets of mark-recapture events at Lower Tangle Lake, spring 1991.

Table 3. Age composition estimates by gear type and location for Arctic grayling (≥150 mm FL) sampled in the Tangle Lakes system, 4 June through 28 July 1991.

										Harvest Sampling:								
	Lower Tangle LK 11 - 13 June Electrofishing			Long Tangle Lk 11 - 13 June Electrofishing			Tundra Pond 4 - 7 June Hook and Line			Tangle River and Mouth 25 June - 28 July Hook and Line			Other[a] 25 June - 28 July Hook and Line			All 25 June - 28 July Hook and Line		
Age Class	n[b]	%	SE[c]	n	%	SE	n	%	SE	n	%	SE	n	%	SE	n	%	SE
1	0	---	---	0	---	---	0	---	---	1	0.8	0.8	0	---	---	1	0.5	0.5
2	0	---	---	3	1.0	0.5	0	---	---	20	15.6	3.2	2	2.4	1.4	22	10.4	2.1
3	0	---	---	7	2.2	0.8	2	1.1	0.8	61	47.7	4.4	42	50.7	2.5	103	48.8	3.4
4	6	4.5	1.8	32	10.2	1.7	16	8.6	2.0	20	15.6	3.2	16	19.3	2.3	36	17.1	2.6
5	12	9.0	2.5	30	9.5	1.7	28	15.0	2.6	3	2.3	1.3	7	8.4	2.4	10	4.7	1.5
6	38	28.4	3.9	88	27.9	2.5	63	33.6	3.5	8	6.3	2.1	5	6.0	3.5	13	6.2	1.7
7	65	48.5	4.3	116	36.8	2.7	62	33.2	3.4	11	8.6	2.5	8	9.6	2.5	19	9.0	2.0
8	13	9.6	2.6	38	12.1	1.8	15	8.0	2.0	4	3.1	1.5	2	2.4	1.0	6	2.8	1.1
9	0	---	---	1	0.3	0.3	1	0.5	0.5	0	---	---	1	1.2	---	1	0.5	0.5
Total	134	100.0		315	100.0		187	100.0		128	100.0		83	100.0		211	100.0	

[a] Other: Upper Tangle Lake, n = 41; 18 Mile Creek, n = 25; Lower System, n = 6; Rock Creek, n = 8; Landmark Gap Creek, n = 3.

[b] n = sample size.

[c] SE = standard error of the percentage.

Table 4. Summary of Relative Stock Density (RSD) indices for Arctic grayling (≥150 mm FL) sampled in the Tangle Lakes System by area and gear type, 4 June through 28 July 1991.

		RSD Category[a]				
		Stock	Quality	Preferred	Memorable	Trophy
Lower Tangle Lake Outlet:						
11 June - 13 June						
Electrofishing	n[b]	9	97	47	0	0
	%[c]	5.9	63.4	30.7	---	---
	SE[d]	1.9	3.9	3.7	---	---
Long Tangle Lake:						
11 June - 13 June						
Electrofishing	n	52	218	62	0	0
	%	15.7	65.7	18.7	---	---
	SE	2.0	2.6	2.1	---	---
18 Mile Creek:						
4 June - 7 June						
H&L[e]	n	19	167	22	0	0
	%	9.1	80.3	10.6	---	---
	SE	2.0	2.8	2.1	---	---
Tangle River:						
25 June - 28 July						
Harvest Sample	n	90	30	9	0	0
	%	69.8	23.3	7.0	---	---
	SE	4.0	3.7	2.2	---	---
Other Locations:						
25 June - 28 July						
Harvest Sample	n	48	24	8	0	0
	%	60.0	30.0	10.0	---	---
	SE	5.5	5.1	3.4	---	---

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

[b] n = sample size in RSD category.

[c] % = percent of RSD category in total sample.

[d] SE = standard error of percentage.

[e] H&L = hook and line.

The age composition of the harvest samples are the inverse of those found in the spring samples; only 19% of the combined harvest sample was age 6 and older (Table 4). This percentage of older fish remained unchanged even when the sample was divided into its' two components: the Tangle River and its mouth (the target fishery) and all other areas (incidentally surveyed). Age 3 predominated in both components (48% and 51%, respectively).

Relative Stock Density indices in the harvest samples favored stock size fish (150 - 269 mm FL) which represented 70% of the Tangle River sample and 60% of the combined sample from other areas (Table 5). Relative Stock Density indices did not differ significantly among areas sampled ($\chi^2 = 2.14$, df = 2, $p > 0.25$).

Exploitation Rates

The percentage of marked fish in the three spawning stocks was estimated at 18% in Long Tangle Lake, 24% in the Tundra Pond, and 43% in Lower Tangle Lake (Table 5).

Harvest Sampling Summary:

Completed trip interviews were obtained from 337 anglers who had fished six areas of the Tangle Lakes system from 25 June through 28 July 1991 (Table 6). They harvested 368 Arctic grayling which represented 22% of the total catch of 1,708 fish. Included in this harvest were 20 tag recoveries of which five tags (26% of the recoveries), came from the 1991 marking efforts in Tundra Pond (n = 3) and Long Tangle Lake (n = 2). The fact that no anglers were interviewed that had fished below Long Tangle Lake was likely the reason that no recoveries were made of Lower Tangle Lake tags.

The harvests in Table 6 were adjusted prior to estimation of exploitation rates to compensate for unequal effort between periods. Delays in hiring the creel clerk prevented sampling the first scheduled Friday through Monday period (21 - 24 June) until 25 June (Tuesday). To insure that sampling effort was proportional among periods (weekends only), data from the first period was not used in the analysis. Tag recoveries from marks released in 1991 were not affected.

It should be noted that due to the emphasis on obtaining completed trip data, some anglers were interviewed after processing and/or eating their catch. Thus only 248 fish were visually inspected and of these, 211 were able to be measured and had scales sampled. It was assumed that any tagged fish in the unseen harvest were noted and reported by the angler. Of harvested tags, only one tag was reported without the necessary tag number and color.

The target fishery at the Tangle River accounted for over 60% of the interviews and 50% of the harvest (n = 219 and 196, respectively; Tables 6 and 7). Of the nine tags recovered, only two tags, both from Tundra Pond, came from marking in 1991. Of the seven other tags, four were tagged in the Tundra Pond during the spawning period in 1989 and 1990 (n = 1 and 3, respectively), one was tagged 8 June 1988 in Upper Tangle Lake, and one was tagged 4 July

Table 5. Estimated proportions of marks released by size category at three spawning locations, Tangle Lakes system, 1991.

Location	Abundance		Marks		
	Category	N	n	p_t[a]	SE[b]
Long Tangle Lake	>150	2,283	410	0.180	0.046
	>289	1,754	293	0.167	0.043
Lower Tangle Lake:	>150	438	189	0.432	0.096
	>289	395	160	0.405	0.090
Lower System Totals:	>150	2,721	599	0.220	0.048
	>289	2,149	453	0.211	0.045
Tundra Pond	>150	1,211	295	0.244	0.046
	>289	932	245	0.263	0.050

[a] p_t = proportion of marks (tags) released.
[b] SE = standard error of the proportion.

Table 6. Number of angler interviews, hours fished (effort), and catch and tag recoveries of Arctic grayling by area from a harvest survey at the Tangle Lakes system, 25 June through 28 July, 1991.

	Interviews		Catch[a]		Harvest[b]	
Area	Anglers	Effort[c]	Total	Tags	Total	Tags[d]
Lower System[e]	30	87.6	224	3	45	3(2)
Landmark Gap Creek	4	10.0	42	3	17	3(1)
18 Mile Creek	10	18.1	83	1	31	0
Tangle River	219	328.2	1,026	16	196	9(2)
Rock Creek	13	35.8	121	6	19	3
Upper System[f]	61	145.5	212	2	60	2
Totals	337	625.1	1,708	31	368	20(5)

[a] Catch is divided into total number caught and total number bearing tags.
[b] Harvest is divided into total number harvested and total number harvested bearing tags.
[c] Effort is hours fished by interviewed anglers.
[d] In parenthesis are number of tags recovered from releases in 1991.
[e] Lower System includes Round Tangle Lake (excepting that area at the mouth of the Tangle River) downstream to the Delta River Falls.
[f] Upper System includes Upper Tangle Lake above the head of the Tangle River upstream to the headwaters.

Table 7. Number of angler interviews, hours fished (effort), and catch and tag recoveries of Arctic grayling by time period from a harvest survey at the Tangle River[a], 25 June through 28 July 1991.

		Interviews		Catch[b]		Harvest[c]	
Period	Days	Anglers	Effort[d]	Total	Tags	Total	Tags
6/25 - 6/27	3	19	41.7	128	7	21	1
6/28 - 7/01	4	38	48.3	213	1	36	1
7/05 - 7/08	4	42	62.5	284	3	62	2
7/12 - 7/15	4	30	42.9	92	5	35	5(2)[e]
7/19 - 7/22	4	53	81.2	158	0	31	0
7/26 - 7/28	3	37	51.6	151	0	11	0
Totals	22	219	328.2	1,026	16	196	9(2)[e]

[a] The Tangle River here includes the lake area around its' head and mouth.
[b] Catch is divided into total number caught and total number caught bearing tags.
[c] Harvest is divided into total number harvested and total number harvested bearing tags.
[d] Effort is hours fished by interviewed anglers.
[e] In parenthesis are number of tags recovered from releases in 1991.

1990 in lower Rock Creek. One tag was lost by the angler and its origin unknown.

While Tangle River was the target fishery during harvest sampling, those interviews from the Upper and Lower systems were assumed to be indicative of actual angling effort and success (Table 6). Interviews from the other three areas were truly incidental and occurred only by departing the target area. The only access points to these areas were within the target area and exiting anglers may have been interviewed in proportion to their abundance.

The Lower System interviews yielded a harvest of 45 Arctic grayling and three tag recoveries. Two of these recoveries represented 1991 marks and both came from the Lower System, specifically, Long Tangle Lake. The remaining tag recovery originated in Tundra Pond in May 1990.

A harvest of 60 Arctic grayling, with two tag recoveries, was sampled from the Upper System. One tag was from Upper Tangle Lake (September 1989) and the other was from the Mud Lake spawning area (1 June 1990).

Exploitation Rate for Tundra Pond:

All assumptions necessary for an accurate estimate of exploitation were considered met. Although tag recoveries from all sources varied greatly among periods (Table 7), it was assumed that anglers were interviewed in proportion to their abundance. The average number of anglers interviewed in a 9 hr day was low (from Table 7; 7.5 to 13.3 interviews per day) and easily handled by a single clerk. The expected increase in anglers over the Fourth of July holiday period never materialized. Only 42 interviews were made with a harvest of 62 fish (in 1989, 92 fish were harvested and sampled in the river in only two days of interviews; Ridder 1990).

Two fish initially tagged at Tundra Pond were recovered out of 175 Arctic grayling harvested in the Tangle River. The relative exploitation rate of Arctic grayling tagged at Tundra Pond in the river was 4.5% with a 90% confidence interval of 0 to 10.3% (Table 8).

The inference that exploitation of Tundra Pond fish is low may be prejudiced by the extreme differences in composition between the harvest and the marks released at Tundra Pond. The sampled harvest was predominantly juvenile fish while the Tundra Pond marks were predominantly adults (Figure 9). Also, the recovered marks were both adults. Partitioning the harvest and marks released into adult-sized fish only, gave a higher exploitation rate of Tundra Pond fish in the Tangle River of 19% (90% CI of 0 to 41.8%; Table 8)).

In addition to the two Tundra Pond tags recovered in the harvest sample, anglers voluntarily reported recoveries of 13 fish tagged in Tundra Pond in 1991, 12 of which were specific to location (Appendix D4). Eight of these recoveries were made within the time frame of harvest sampling. Three of these 12 tags were recovered in the Tangle River, two each in Upper, Round, and Long Tangle lakes and 18 Mile Creek and one in Landmark Gap Creek.

Table 8. Relative exploitation rates of spawning stocks of Arctic grayling from Tundra Pond and Long Tangle Lake in the Tangle River and Lower Tangle system, 28 June - 28 July 1991.

	Fishery					Exploitation			
Category	Location	C[a]	R[b]	p_m[c]	SE[d]	Stock	p_c[e]	SE	90% CI
≥150 mm	Tangle River	175	2	0.011	0.008	Tundra	0.045	0.035	0 - 0.103
≥290 mm	" "	40	2	0.050	0.035	Pond	0.190	0.138	0 - 0.418
≥150 mm	Lower Tangle	39	2	0.051	0.036	Long	0.283	0.213	0 - 0.634
≥290 mm	System	ND[f]				Tangle	ND		

[a] C = the total number of harvested Arctic grayling censused.
[b] R = The number of marks from the release location in the harvest census.
[c] p_m = proportion of marks recovered in the harvest survey.
[d] SE = standard error of the proportion.
[e] p_c = exploitation rate of stock in fishery.
[f] ND = no data.

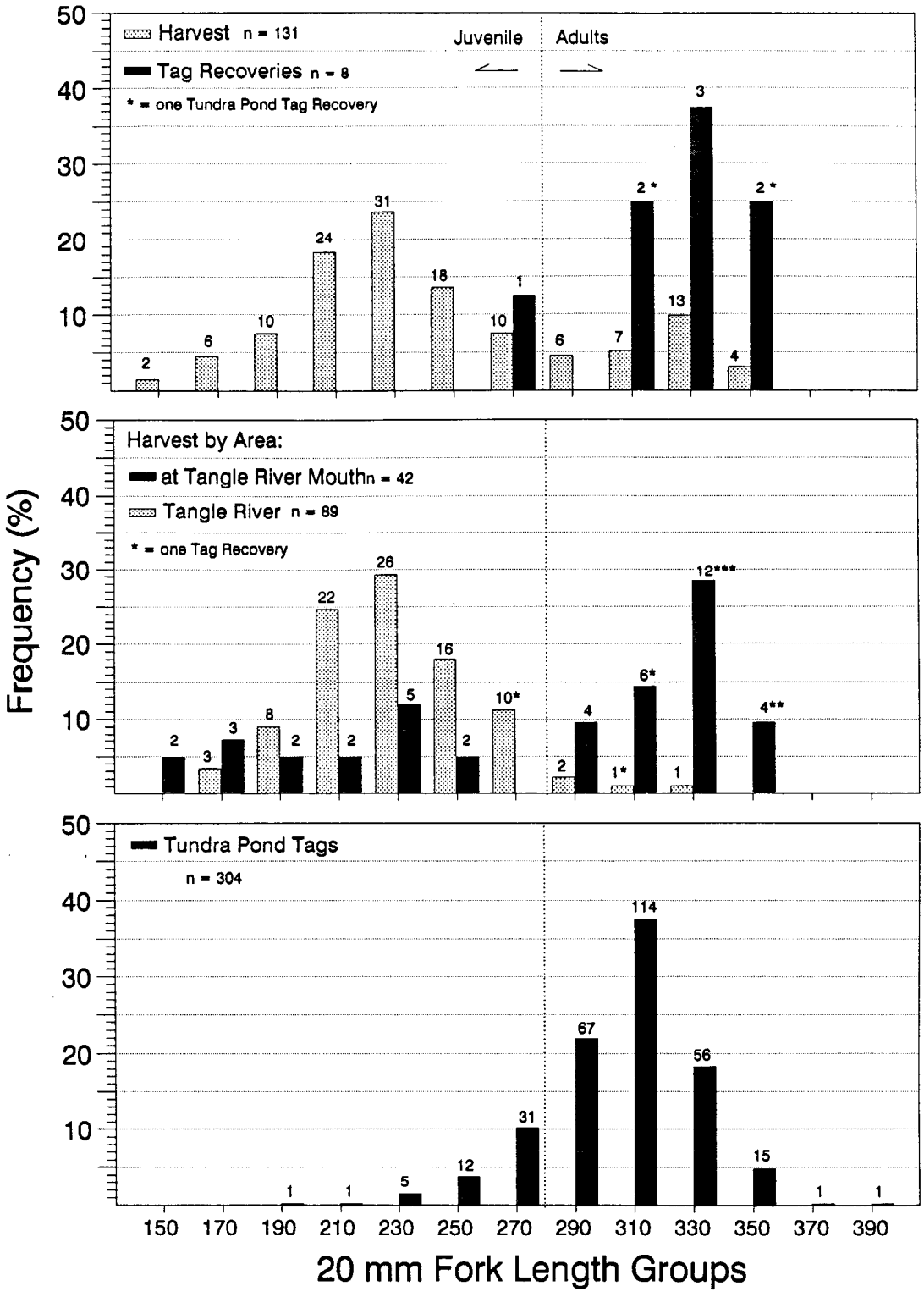

Figure 9. Length composition comparisons between the harvest components from Tangle River and tag releases from Tundra Pond, 1991.

Exploitation Rate for Long Tangle Lake:

No tags from the Long Tangle Lake spawning stock were recovered in the Tangle River. Exploitation of the stock occurred only in the Lower Tangle system at a rate of 28% (Table 8). Small sample sizes led to imprecision with the estimate's 90% confidence interval of 0 to 63%.

Anglers voluntarily reported eight recoveries of these Long Tangle tags with seven being specific to location (Appendix D4). Six were recovered in Long Tangle Lake and one in the Tangle River. All seven tags were captured within the time frame of the harvest survey.

DISCUSSION

Abundance

While the abundance and compositional estimates of the population of the Lower Tangle System were sufficient for estimation of angler exploitation in the Tangle River, they should be used with caution in characterizing the population. Electrofishing selected for male Arctic grayling on these spawning grounds (Appendix D2; Ridder 1991a) biasing not only estimates of spawner abundance (low) but also age and size compositions. Male Arctic grayling are older and larger than females (Ridder 1990, 1991a; Beauchamp 1990). Comparisons between samples collected with different gear types may be erroneous if not adjusted for a 1:1 sex ratio which available data suggests may be the norm for Arctic grayling stocks (Ridder 1983, 1989, 1991a; Clark 1991, *in prep*; Beauchamp 1990). The differences in age and size (RSD) compositions seen in this study between the Tundra Pond and the two sites in the Lower System were likely the result of this bias (Tables 3 and 4, Appendix D2).

Abundance estimation of spawning aggregations of Arctic grayling can be compromised by fish behavior, environmental conditions, and the timing and method of sampling. The estimation experiments in Long Tangle Lake are a prime example. The prolonged and late break-up in 1991 may have compromised abundance estimates by delaying sampling to the latter part of the spawning period. Few ripe adults, especially females, were encountered during sampling. Decreasing catches, compositional changes from large to small fish, and the recovery of a tagged fish from both Tundra Pond and Lower Tangle Lake in Long Tangle Lake, indicated that movements to feeding areas were underway during the experiment. The sample data and abundance estimate in Long Tangle Lake are therefore biased to an unknown degree.

There was no difference in the abundance of mature fish in the Tundra Pond (N = 873, 95% CI = 542 - 1,204; Table 2), in 1991 compared to the 1990 estimate (N = 1,162, 95% CI = 680 - 1,644; Ridder 1991a). The general lack of age 6 fish in Tundra Pond and other spawning stocks in 1991 suggests variable recruitment and thus some decline in abundance would have been expected. Age 6 was the predominant class in spawning aggregations in 1989 and 1990 and also represents the age at maturity for 90% of the population (Ridder 1990, 1991a).

Exploitation Rates

The relative exploitation rates of the two spawning stocks found in a portion of the Tangle River and Lower Tangle System harvests were not significantly different from 0% exploitation. This imprecision was caused by apparently low capture probabilities of tagged fish. The imprecision and lack of recaptures was, in turn, most likely due to three factors. First, the harvest was predominantly juvenile fish while the tagged fish were mostly adults. Second, feeding area locations of the three stocks differed. Analysis of tag recoveries from fish in specific spawning sites (Appendix D4) and not from those grouped by broad areas of the system (as reported by Ridder 1991) indicated feeding areas of the lower system stocks are near spawning locations. Only those closest to the Tangle River, Tundra Pond and the head of Long Tangle Lake, have been recovered in the Tangle River. Third, the harvest survey methodology may have been flawed. The sampling period was not a factor since 70% of all fish tagged in the spring and recovered by anglers in the Tangle River over all years have been made prior to 16 July. Considering the number of tags voluntarily reported by anglers from all areas during the time of the harvest survey (n = 15 or triple the five 1991 tags from the harvest survey), sampling effort was either insufficient, inefficient, or both.

Despite the imprecision, it should be noted that the exploitation rates estimated for the Tundra Pond and Long Tangle Lake spawning stocks are relative parameters describing only their contributions to a portion of the Tangle Lakes Arctic grayling harvest. They do not describe the absolute exploitation rates of the stocks themselves.

While this study failed to achieve accurate and precise estimates of relative exploitation rates, the results do support a significant trend that has been detected from angler recoveries of these stocks over the three years of tagging, not only in the Tangle River (Appendix D5) but throughout the system (Appendix D4). For any given tagging year, the spawning stock utilizing the Tundra Pond of 18 Mile Creek was exploited by anglers at rates two to three times greater than any of the other four defined spawning stocks (exploitation defined by recovery rates, Appendix D4). The spawners using the outlet of Lower Tangle Lake were exploited the least. Whether this exploitation of the Tundra Pond spawning stock is sustainable cannot be determined with the available data but an approximation of absolute exploitation can be made.

The estimation of absolute exploitation rates is relatively simple for a single population: harvest divided by abundance. The determination for a mixed stock fishery is more complex. Estimates of abundance are needed for each stock as well as harvest and each stock's contribution in the harvest. Harvest contributions can be obtained directly from harvest sampling, as in this study, or implied from angler returns. These returns are dependent upon the percentage of anglers reporting tags which can be quite variable. Ridder (1985) found that angler reporting rates ranged from 10 to 41% for a spring fishery at Shaw Creek. Using a range of angler reporting rates and 1990 harvest and abundance estimates apportioned to adult fish and assuming all tag recoveries represented adults, the absolute exploitation for adult-sized fish in 1990 from the Tundra Pond stock ranged from 9.1% if all anglers reported

tags (n = 23, Appendix D4), to 18% if only 50% of recovered tags were reported, to 37% if only 25% of tags were reported. Angler reporting rates for the Tangles are likely high due to the publicity afforded by the tag return posters and drop boxes placed throughout the system, so the true exploitation for these adult fish was likely less than 20%. Absolute exploitation rates have ranged from 16 to 20% in Fielding Lake which lies just northeast of the Tangle Lakes and from 25 to 37% in the Chena River (Clark pers. comm.[4]). Rates less than 20% are considered sustainable for populations while the adult component can sustain higher rates (Clark, pers. comm.[5]).

Conclusions

Sub-populations, or stocks, of Arctic grayling are found in the Tangle Lakes system based on the affinity of mature fish to home to spawning areas. This type of homing behavior has been implied in other interior Alaska populations as well (Ridder 1991b). While the concept of stock has been defined in several ways (Hop 1985), it essentially excludes interbreeding and refers to discrete populations that are self-perpetuating, i.e. progeny replacing parents. For such a population, homing to natal areas would be assumed and this has not been proven for Arctic grayling populations. Thus, while various levels of angler exploitation on adult stocks are seen in the Tangle Lakes, these levels can be quite different when juveniles are included. And juveniles are the predominant component of the Tangle Lakes fishery. Since the great majority of sampling, tagging, and recoveries of juveniles has occurred in feeding areas on mixed stocks, little data is available to support or disprove the stock concept or to adequately assess the system's population and fishery. For if the stock concept is invalid (spawning stocks recruit from a group of juveniles from differing natal areas), the exploitation of spawning stocks may be sustainable at much higher rates than 20%.

The angler exploitation of a particular spawning stock in the Tangle Lakes System is influenced not only by angler effort but also by the stock's accessibility. The Tundra Pond stock is the most exploited because its spawning area is adjacent to the road and its choice of feeding areas is the most varied, and accessible, of all the stocks. Feeding areas extend from the Tangle River downstream throughout the lower lakes and include Landmark Gap Creek (Appendix D4). Fish tagged in Tundra Pond have also been recovered in Rock Creek (Ridder 1991a). Fish are vulnerable while on their spawning grounds. In the Tangle Lake system, the Tundra Pond offers the first fishery of the season. At spawning time and given the right weather conditions on the Memorial Day Holiday, exploitation can be quite high as in 1990 when 26 of the year's total of 40 angler recoveries were made in the pond. In contrast, in 1991 only five of 15 angler recoveries were made in the pond (in 1989, it was two of seven angler recoveries). While there exists a possibility that the population could be easily overexploited, it has yet to occur.

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[4] Clark, Robert. 1991. Personal Communication. ADFG, 1300 College Rd., Fairbanks, Alaska 99701.

[5] Clark, Robert. 1991. Personal Communication. ADFG, 1300 College Rd., Fairbanks, Alaska 99701.

Recommendations

Ideally, an assessment of the Tangle Lakes Arctic grayling population would include an applicable definition and identification of stocks and their movements, distributions, abundance, dynamics (mortality and recruitment), and respective harvests. This assessment of a large, complex, and mostly inaccessible system would need a major commitment of time and money for at least a six year period. One generation of the population (birth to maturation) would need to be monitored. While it is intriguing from a research perspective, from a management perspective, it is not feasible nor warranted. The population appears not to be in danger from its fishery. Yet, management, and research, need additional knowledge of the population to adequately qualify and quantify what is already known. The minimal approach would then be to assume fidelity of stocks to spawning and feeding areas and concentrate efforts on the one stock that affords the best attributes, or presents the most need, for study.

At the least, mark-recapture experiments should continue on the spawning aggregation of Arctic grayling in the Tundra Pond of 18 Mile Creek. Of the experiments on all stocks conducted to date, the Tundra Pond stock can provide the best data due to its accessibility, small and manageable size, ease of sampling and its meeting the necessary assumptions for a valid experiment. Additional experiments will provide estimates of mortality, and more importantly, recruitment. Expansion of the study to include a harvest sample that represents a true proportion of the Tangles' harvest will provide more precise and accurate estimates of absolute exploitation. Expanding the study further to include juveniles, specifically distribution, movements and abundance of young of the year, will eventually help define the stock concept in the system.

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APPENDIX A

Appendix A. Estimated recreational harvest of Arctic grayling and total angling effort on the Tangle Lakes system, 1978 through 1990[a].

Year	Effort[b]		Harvest	CPUE[d]
	Anglers	Angler-days		
1978	NA[c]	7,711	5,786	0.75
1979	NA	5,864	3,466	0.59
1980	NA	8,198	5,522	0.67
1981	NA	5,530	6,858	1.24
1982	NA	9,502	9,590	1.01
1983	NA	5,513	7,794	1.41
1984	1,707	3,954	4,829	1.22
1985	4,112	6,225	5,827	0.93
1986	3,742	5,545	5,038	0.91
1987	2,460	2,530	2,467	0.98
1988	2,413	3,456	4,675	1.35
1989	3,658	3,991	3,136	0.79
1990	2,836	5,228	2,853	0.55
Averages	2,990	5,634	5,219	0.93

[a] Data sources: Mills (1980 - 1991).
[b] Effort estimates includes effort expended for all species.
[c] NA = data not available.
[d] CPUE = the number of Arctic grayling harvested per man-day.

APPENDIX B

Appendix B. Data files[a] from test and harvest sampling of Arctic grayling in the Tangle Lakes System, 1991.

Data file	Description
U0150LA1	Mark/Recapture experiment data for the Tundra Pond of 18 Mile Creek, 1991.
U0150LB1	Mark/Recapture experiment data for Long and Lower Tangle Lakes, 1991.
U0150LC1	Harvest sampling, 1991.
U0150LD1	August test sampling, Lower and Upper Tangle lakes, 1991.

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

APPENDIX C

Appendix C1. 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.

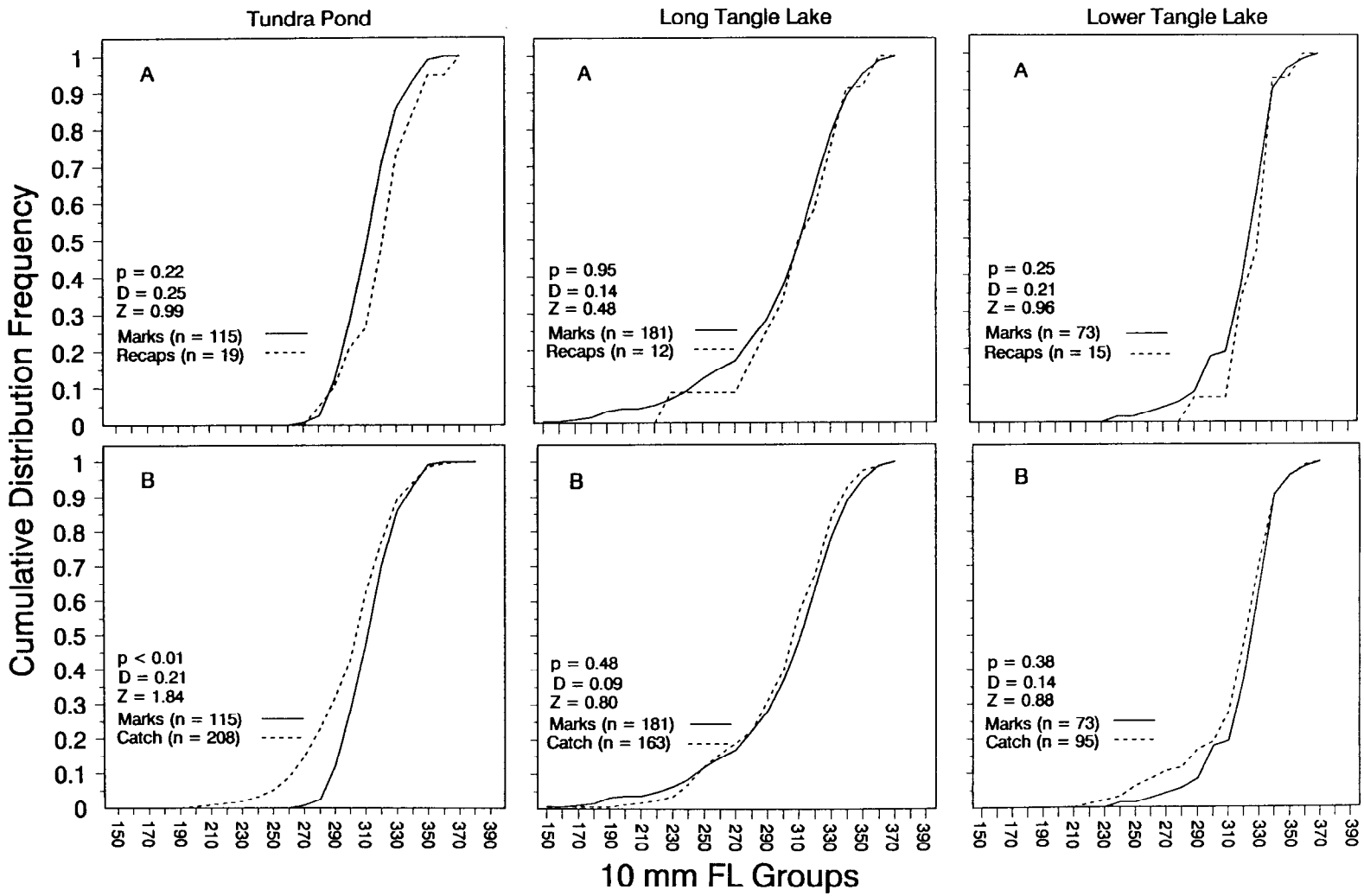
[b] The second K-S test is on the lengths of fish marked during the first event versus the lengths of fish captured during the second event. H_0 for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish sampled during the second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



Appendix C2. 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) for the Tundra Pond and Long and Lower Tangle lakes, 1991. Statistics are from the Kolmogorov-Smirnov two-sample test.

APPENDIX D

Appendix D1. Mean fork length at age for Arctic grayling sampled in the Tangle Lake system, 28 May through 28 July 1991.

	Test Sampling:									Harvest Sampling:					
	Lower Tangle LK 11 - 14 June Electrofishing			Long Tangle Lk 11 - 14 June Electrofishing			Tundra Pond 28 May - 7 June Hook and Line			Tangle River and Mouth 25 June - 28 July Hook and Line			Other[a] 25 June - 28 Jul Hook and Line		
Age Class	n[b]	FL[c]	SD[d]	n	FL	SD	n	FL	SD	n	FL	SD	n	FL	SD
1	0	---	---	0	---	---	0	---	---	1	141	0	0	---	---
2	1	186	0	3	171	8	0	---	---	20	201	19	2	218	1
3	1	236	0	12	207	13	2	232	17	61	236	16	42	247	19
4	8	247	10	49	249	11	16	253	17	20	265	23	16	265	18
5	23	280	13	50	278	15	33	290	14	3	288	3	7	288	12
6	49	320	13	103	309	15	97	311	15	8	327	21	5	328	11
7	75	336	11	132	330	15	107	321	15	11	338	9	8	337	8
8	16	349	13	44	346	16	23	341	12	4	344	8	2	350	13
9	0	---	---	1	367	0	1	336	0	0	---	---	1	384	0
Total	173	321	30	394	305	39	279	312	26	128	255	48	83	270	39

[a] Other: Upper Tangle Lake, n = 41; 18 Mile Creek, n = 25; Lower System, n = 6; Rock Creek, n = 8; Landmark Gap Creek, n = 3.
[b] n = sample size.
[c] FL = mean fork length at age.
[d] SD = sample standard deviation of FL.

Appendix D2. Summary of mark and recapture data apportioned by length category and maturity for abundance estimation of Arctic grayling (≥ 150 mm FL) in three spawning aggregations in the Tangle Lakes system in spring of 1991.

Location	Event	Number					M:F[b]
		≥150mm	≥290mm[a]	Adults	Males	Females	
Tundra Pond	Mark	115	112	105	56	49	1.1:1
	Catch	208	160	150	72	78	1.0:1
	Recaptures	19	18	18	14	4	3.5:1
	Test A[c]	<0.01	0.70	0.84	ND	ND	
	Test B[d]	0.22	0.16	0.25	ND	ND	
Long Tangle Lk.	Mark	181	140	122	103	19	5.4:1
	Catch	163	126	108	89	19	4.7:1
	Recaptures	12	11	11	10	1	10.0:1
	Test A	0.48	0.32	0.06	ND	ND	
	Test B	0.95	0.91	0.65	ND	ND	
Lower Tangle Lk.	Mark	73	69	68	58	10	5.8:1
	Catch	95	84	79	76	3	25.3:1
	Recaptures	15	15	15	14	1	14.0:1
	Test A	0.38	0.68	0.70	ND	ND	
	Test B	0.25	0.31	0.34	ND	ND	

[a] The length at maturity for 50% of the population (Ridder 1990).
[b] Ratio of males to females.
[c] Test A = Probabilty from Kolmogorov-Smirnov two-tailed test between fish marked and those examined for marks (Catch).
[d] Test B = Probabilty from Kolmogorov-Smirnov two-tailed test between fish marked and those recaptured.

Appendix D3. Summary of sampling locations, timing, effort, and catch from electrofishing the lower Tangle Lake System, 11 through 14 June 1991.

Location (Code)	Date	Time (hrs)[a] Start	Effort	Number Passes[b]	Catch[c] N	R	CPUE[d]
Long Tangle Lake	6/11	0930	0.23	4	41	---	176
Head	6/12	1100	0.23	4	46	2	197
(251)	"	1800	0.23	3	22	3	94
	6/13	1130	0.20	3	17	4	85
	6/14	0930	0.32	4	16	0	51
sub-total			1.22	18	142	9	117
Long Tangle Lake	6/11	1000	0.25	3	16	---	64
First Thoroughfare	6/12	1200	0.22	3	8	1	37
(210)	6/13	1230	0.22	3	7	3	32
	6/14	1100	0.13	2	1	0	8
sub-total			0.82	11	32	4	39
Long Tangle Lake	6/11	1130	0.45	2	46	---	102
Mid-Thoroughfare	"	1700	0.43	2	84	---	194
(225)	6/12	1700	0.43	2	36	2	83
	6/13	1300	0.50	2	35	4	70
	6/14	1100	0.72	4	70	6	98
sub-total			2.53	12	271	12	107
Lower Tangle Lake	6/11	1230	0.25	3	43	---	172
Outlet	"	1600	0.15	2	30	---	200
(101)	6/12	1230	0.22	4	25	4	115
	"	1530	0.25	3	34	7	136
	6/13	1600	0.22	3	39	7	180
	6/14	1300	0.28	3	31	7	109
	"	1600	0.22	2	18	3	83
sub-total			1.58	20	220	28	139
Totals			6.15	61	655	53	108

[a] Time: Start is military time; effort is in tenths of hours.
[b] A pass is one electrofishing run through the area. A pass was always taken along each bank. Additional passes were taken in midstream never covering the same path twice.
[c] Catch: N = total caught; R = recaptures of fish tagged on previous days.
[d] CPUE = Catch per hour of electrofishing.

Appendix D4. Angler recovery locations of Arctic grayling tagged between 15 May and 15 June in five spawning areas of the Tangle Lakes system, 1989 through 1991.

Location	Tags Year	Total	Recovery Locations[a] 1989 1	2	3	4	5	6	7	8	R	1990 1	2	3	4	5	6	7	8	R	1991 1	2	3	4	5	6	7	8	R	Total	R/M[b] %
Lower Tangle Lake Outlet	1989	0									0									0									0	0	NA[c]
	1990	122									-					1			1	2									0	2	1.6
	1991	187									-									-									0	0	0
Long Tangle Lake Thoroughfares	1989	6									0									0									0	0	0
	1990	318									-				2	1		2		5						1	3		4	9	2.8
	1991	275									-									-				2			4		6	6	2.2
Long Tangle Lake Head	1989	242			1						1			1	1			1		3			2				3		5	9	3.7
	1990	171									-							3		3				2			5		7	10	5.8
	1991	132									-									-			1	2					3	3	2.3
Tundra Pond (18 Mile Cr.)	1989	244			2	2	2	1			7			3	1	1	11	1		17			1			1			2	26	10.7
	1990	300									-			5	2	1	15			23			4			2	1		7	30	10.0
	1991	295									-									-			5	2	2	2	2		15	15	5.1

-continued-

Appendix D4. (Page 2 of 2).

Location	Tags Year	Tags Total	Recovery Locations 1989 1	2	3	4	5	6	7	8	R	1990 1	2	3	4	5	6	7	8	R	1991 1	2	3	4	5	6	7	8	R	Total	R/M %
Mud Lake Head	1989	38				1					1	1								1									0	2	5.2
	1990	244									-	3	2							5	4	1	1	1					7	12	4.9
	1991	0									-									-									0	-	NA

[a] Recovery locations: 1 = Upper Tangle Lake to Upper Tangle River,
2 = Rock Creek drainage,
3 = Tangle River and mouth,
4 = Round to Shallow Tangle Lake,
5 = Landmark Gap drainage,
6 = 18 Mile Creek,
7 = Shallow Tangle Thoroughfare through Long Tangle Lake,
8 = Lower Tangle Lake through Upper Delta River, and
R = Total recoveries for year.

[b] R/M = recapture rate, recaptures divided by number marked times 100.

[c] NA = not applicable, none tagged.

Appendix D5. Tag recoveries[a] by anglers in the Tangle River and river mouth from Arctic grayling tagged in seven areas of the Tangle Lakes system between 15 May and 15 June, 1988 through 1991.

At Tagging			Tangle River Recoveries					R/M[b]
Location	Year	Number[c]	1988	1989	1990	1991	Total	%
Lower Tangle Lake Outlet	1990	122(15)	---	---	0	0	0	0
	1991	187(38)	---	---	---	0	0	0
		309(53)	---	---	0	0	0	0
Long Tangle Lake Thoroughfare	1989	6	---	0	0	0	0	0
	1990	318(82)	---	---	0	0	0	0
	1991	275(125)	---	---	---	0	0	0
		599(207)	---	0	0	0	0	0
Long Tangle Lake Head	1989	242(23)	---	1	1	2(1)	4(1)	1.7
	1990	171(52)	---	---	0	0	0	0
	1991	132(33)	---	---	---	1	1	0.8
		545(108)	---	1	1	3(1)	5(1)	1.0
18 Mile Creek	1989	244(57)	---	2	3(1)	1	6(1)	2.5
	1990	300(28)	---	---	5	4	9	3.0
	1991	295(50)	---	---	---	5	5	1.7
		839(135)	---	2	8(1)	10	20(1)	2.4
Upper Tangle Lake	1988	348(189)	7(3)	7(5)	0	1	15(8)	4.3
	1989	168(112)	---	0	0	0	0	0
	1990	13(10)	---	---	0	0	0	0
		529(311)	7(3)	7(5)	0	1	15(8)	2.8
Upper Tangle River	1988	23(23)	1(1))	0	0	0	1(1)	4.3
	1989	93(71)	---	5(4)	1(1)	0	6(5)	6.5
	1990	19(16)	---	---	0	0	0	0
		135(110)	1(1)	5(4)	1(1)	0	7(6)	5.2

-continued-

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At Tagging			Tangle River Recoveries					R/M
Location	Year	Number	1988	1989	1990	1991	Total	%
Mud Lake Head	1989	38	---	0	0	0	0	0
	1990	244(81)	---	---	0	1(1)	1(1)	0.4
		282(81)	---	0	0	1(1)	1(1)	0.4
Totals		3,238(1,015)	8(4)	15(9)	10(2)	15(1)	48(16)	1.5

[a] Recoveries come both harvest sampling and voluntary angler reports 1988 through 1991.

[b] R/M = recovery rate (recaptures divided by number tagged) expressed as a percentage.

[c] In parenthesis are numbers of fish tagged as juveniles. Based on length when 50% of Tangle Lakes grayling are mature (290mm FL; Ridder 1990). Fish < 290mm FL are classed as juveniles.