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MOVEMENT, ABUNDANCE AND LENGTH COMPOSITION OF TANANA RIVER BURBOT STOCKS DURING 1987[1]

By

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ABSTRACT

In an ongoing study of burbot *Lota lota* in the Tanana River, a total of 8,399 burbot greater than 299 millimeters have been tagged and released from 1983-1987. Sampling was conducted using baited hoop traps. During 1987, 1,665 net nights of effort were expended to capture 4,516 burbot in 13 sample sections.

A total of 455 tag returns have been obtained through test sampling and from anglers since 1983. Seventy-two percent were recaptured within 8 kilometers of tagging sites, 25 percent moved upstream greater than 8 kilometers, and 3 percent moved downstream 8 kilometers or more. Of the burbot that exhibited movement, the median distance traveled was 27 kilometers, while the maximum distance travelled was 265 kilometers. Relative mixing rates between 12 river sections indicated that there was a higher probability of upstream movement after a period of 1.5-2.5 years than there was after a period of 0.5-1.5 years. Burbot movements through two river sections approximately 100 kilometers in length have not been documented. This indicates the possibility of three or more discrete stocks in the mainstream Tanana River.

Mean lengths of burbot in 13 sample sections did not differ significantly. However, a comparison of length distributions showed significant differences between river sections. Fish captured in the lower and upper river sections were larger than those in the middle river. Fish sampled from two middle river sections were smaller than all other river sections.

Full recruitment of burbot to the gear (hoop traps) began at 450 millimeters. Catch per unit effort estimates were performed for all 13 sample sections. Estimates ranged from 0.19 - 1.11 burbot per net night for small burbot (less than 450 millimeters total length) and from 0.41 - 6.25 burbot per net night for large burbot (greater than 449 millimeters total length).

Population abundance estimates were performed in two 16 kilometer long river sections (Rosie Creek and Healy Lake). The estimated abundance of small burbot in the Rosie Creek section (area of relatively low mean catch per unit effort) was 762, while the estimated abundance of small burbot in the Healy Lake section (area of relatively high mean catch per unit effort) was 1,559. The abundance of large burbot in the Rosie Creek section was estimated to be 2,541, while the Healy Lake section was estimated to have 4,470 large burbot.

KEY WORDS: burbot, *Lota lota*, Tanana River, hoop trap, catch per unit effort, length-at-age, age frequency, migration, tagging, mark-recapture, abundance.

INTRODUCTION

The Tanana River is a large glacial river formed at the confluence of the Chisana and Nebesna Rivers near Northway, Alaska. From its origin, the Tanana River flows northwesterly for 912 km where it drains into the Yukon River, approximately 6 km east of Tanana, Alaska (Figure 1). Its tributaries from the south are primarily glacial streams flowing from the Alaska Range and Wrangell Mountains. Northern tributaries are primarily clear runoff streams flowing from the Tanana Yukon Uplands. Burbot *Lota lota* are found throughout the system.

Burbot fishing has become increasingly popular in the Tanana River drainage in the past 10 years (Figure 2). Harvest has increased approximately 13% per year since 1977 (Mills 1987). In 1986, harvest from the river exceeded 4,000 burbot. The fishery occurs year-round and throughout the entire system, however, most of the effort is during the winter and is concentrated near the communities of Fairbanks, Delta Junction, and Tok, as well as near river access areas along the Richardson Highway. Set lines are the primary fishing gear, although hand-held lines and spears are used as well. Previous regulations allowed anglers to use up to 15 hooks for set lines with no bag or possession limit. In 1987, the Alaska Board of Fisheries adopted a proposal submitted by the Alaska Department of Fish and Game (ADF&G) to limit the daily bag and possession of burbot in flowing waters of the Tanana River drainage to 15 burbot.

A stock assessment program of burbot in the Tanana River was begun in 1983. Between 1983 and 1987, 8,399 burbot were tagged and released in the Tanana River to investigate migratory behavior and to identify potential stocks (Hallberg et al. 1987). Population statistics such as age, length and weight composition, growth, sex ratios, relative abundance (hoop trap catch rates), and population abundance for a 16 km river section were also estimated. This report summarizes progress of this research conducted during 1987 and updates information provided by Hallberg et al (1987).

The long-term goal of the Tanana River burbot investigation is to define sustainable yield of the stock(s) such that rational sport fishery regulations can be developed to maintain the population under increasing fishing pressure. Information is sought about stock structure, abundance, growth, and life history of burbot in the Tanana River. Specific objectives for this investigation in 1987 were as follows:

1. to estimate relative mixing rates of burbot along the river;

2. to estimate an index of abundance (mean catch rate by overnight set of a hoop trap) of all burbot 300 mm total length (TL) and longer in each of 13 sections along the Tanana River;

3. to estimate the mean length of all burbot 300 mm TL and longer in each of 13 sections of the river; and

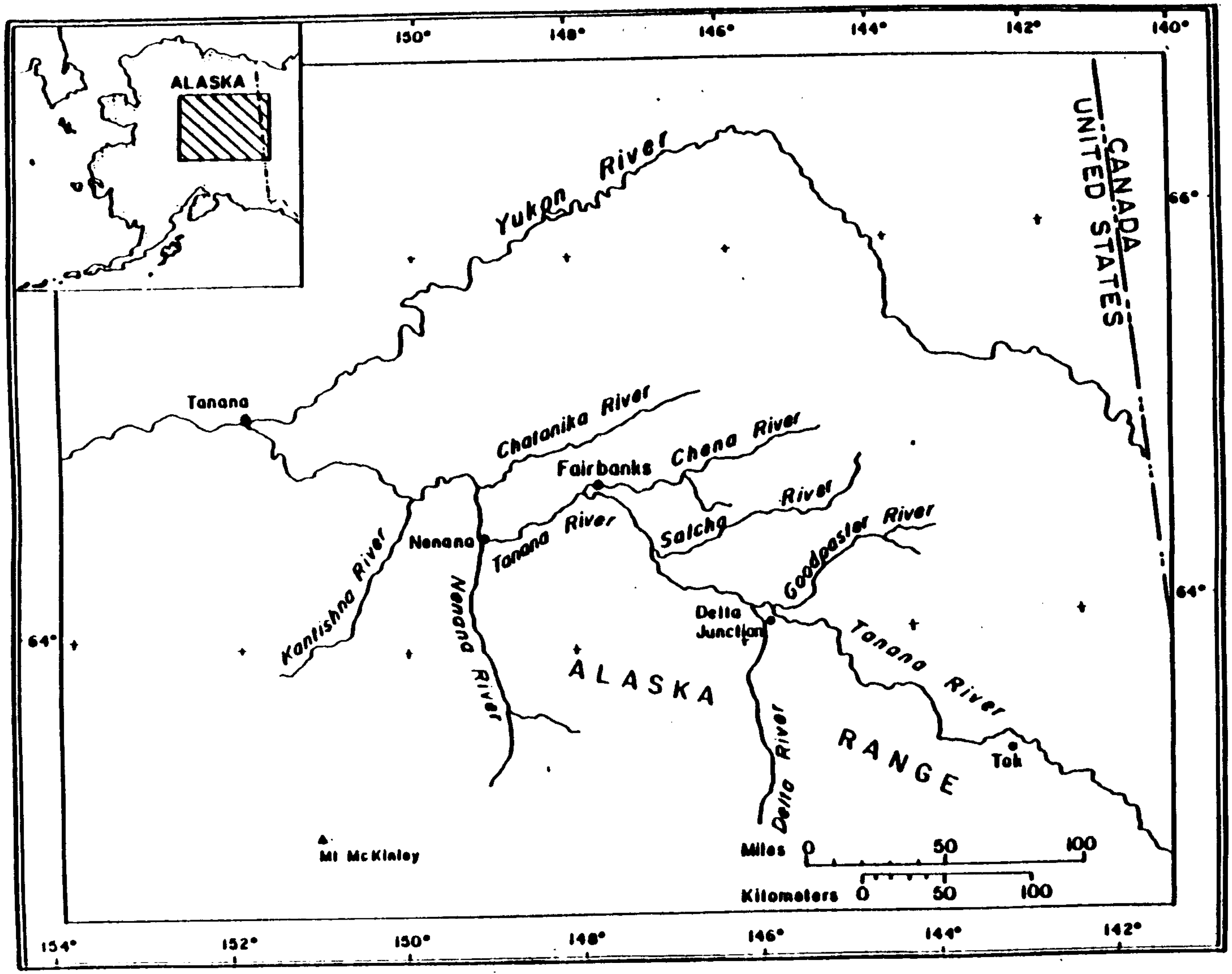

Figure 1. The Tanana River Drainage.

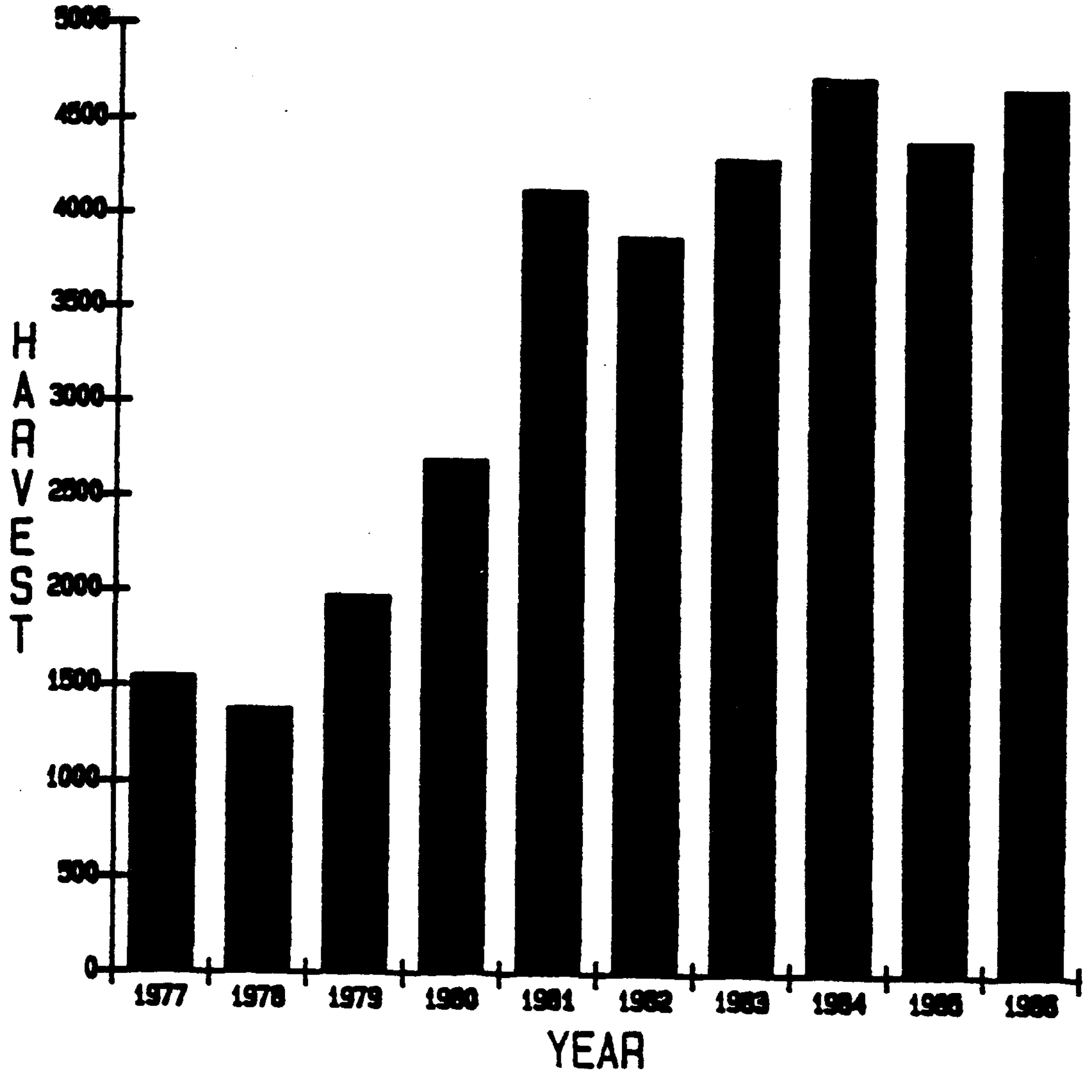

Figure 2. Annual harvest of burbot in the Tanana River drainage from 1977 through 1986.

4. to estimate the abundance of all burbot 300 mm TL and longer in two 16-km sections of the Tanana River (Rosie Creek and Healy Lake Sections).

METHODS

Tagging Study

Sampling of burbot in 1987 was conducted in 13 subsections of the Tanana River. These subsections ranged in length from 11 to 21 km and were located along the river between the mouth of Manley Hot Springs Slough (100 km from the mouth of the Tanana) to the headwaters at the confluence of the Chisana and Nebesna Rivers (915 km from the mouth). Since 1983, 12 river sections accounting for approximately 320 km of the river have been sampled (Figure 3). Sampling was conducted between 1 June and 30 September by two, two man crews.

Burbot were captured using commercially manufactured hoop traps. Hoop traps were 1 m in diameter and 4 m long with 25 mm square mesh nylon netting attached to seven fiberglass hoops (Figure 4). The hoop traps were baited with cut Pacific herring *Clupea harengus* placed in perforated plastic containers. Two sections of plastic pipe, 3.3 m long with snaps on each end, were used as spreader bars to keep the trap extended. Hoop traps were attached to shore and placed on the river bottom with the trap throats facing downstream. A large outboard-powered river boat was used to set, move, and retrieve the traps.

For each of the 13 river subsections, one crew typically fished 25 hoop traps for a period of 4 days. Traps were moved each day and supplied with fresh bait, thus fishing effort for each section averaged 100 net nights (NN) per week. Attempts were made to set traps at equal intervals throughout each section. However, because of the braided channel pattern of the Tanana River and seasonal fluctuations in water flow, trap locations were selected in the field and the spacing of traps often varied. All trap locations were marked on 1:63,360 USGS maps and were recorded to the nearest river kilometer.

All burbot greater than 299 mm TL were measured to the nearest millimeter, tagged using Floy internal anchor tags, finclipped (right pelvic), and released at the capture sight. Otoliths (sagitta) and vertebrae (2 or 3 centra collected just posterior to the axis) were collected from all mortalities for age analysis. The number of burbot and other species caught in each trap as well as the length and tag number of each burbot released was recorded along with the trap location and date. Lengths and tag numbers of recaptured burbot were also recorded.

Mean Length and Mean Growth

Mean length of all captured burbot larger than 299 mm and mean growth of recaptured burbot were estimated. Because all means are distributed normally (according to the Central Limit Theorem), simple averages and squared deviations from the mean were used to calculate means and variances of length and growth as shown below:

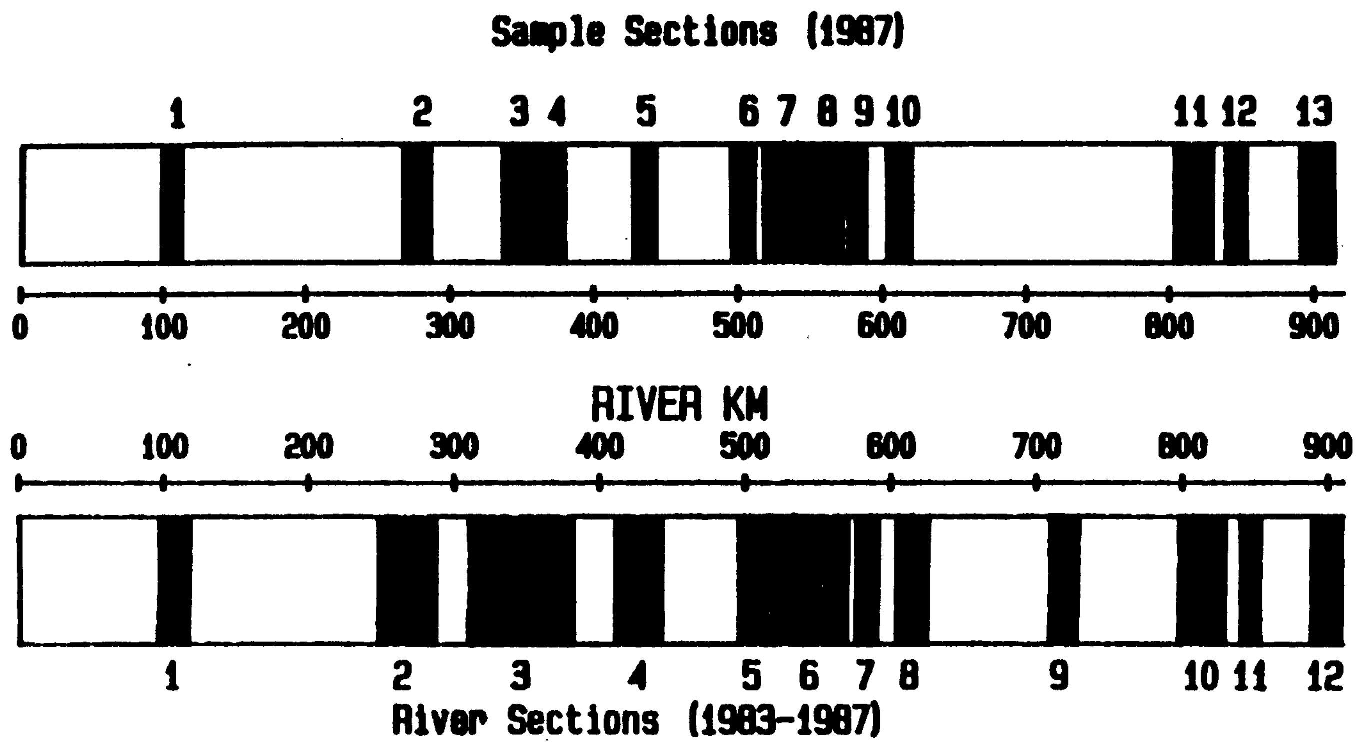

Figure 3. Relative sizes and locations of the 12 river sections sampled (shaded areas) from 1983 through 1987, and the 13 subsections sampled during 1987.

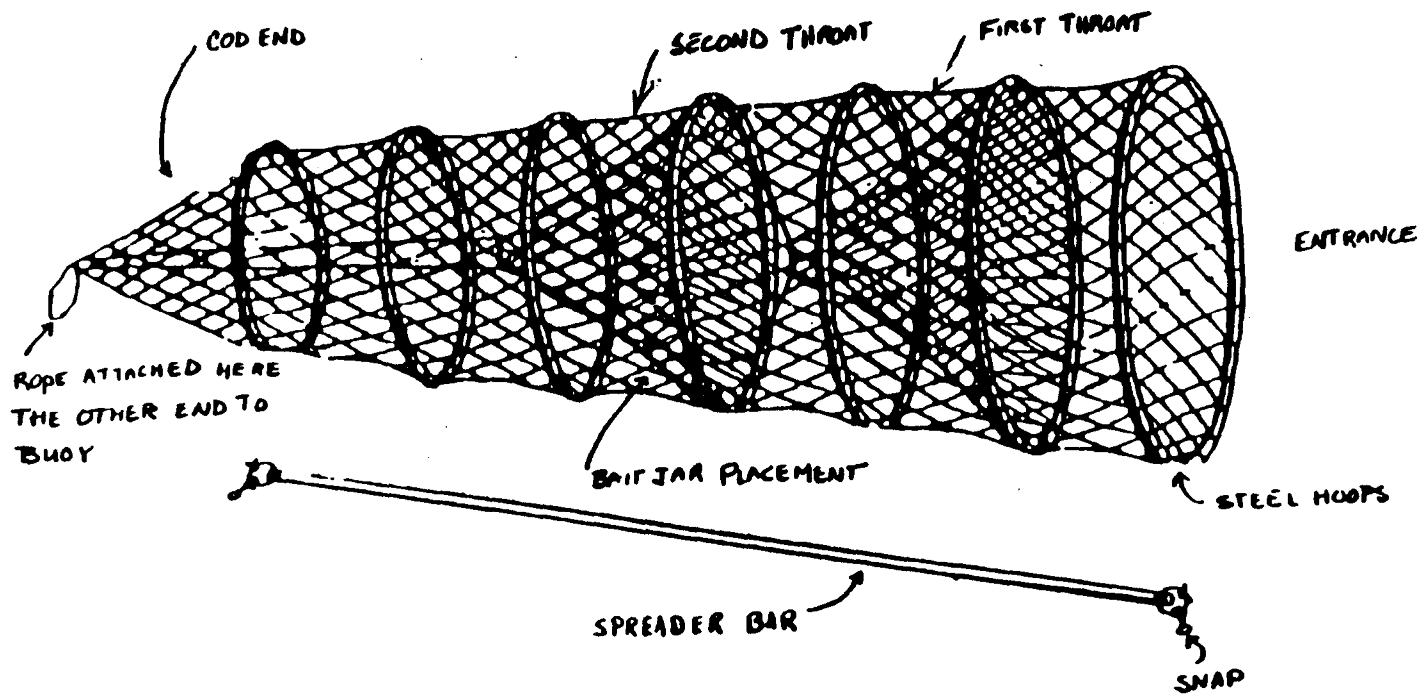

Figure 4. Diagram of hoop trap gear used to sample burbot in the Tanana River.

$$(1)\quad \bar{x} = \sum_{i=1}^{n} \frac{x_i}{n}; \qquad (2)\quad V[\bar{x}] = \sum_{i=1}^{n} \frac{(x_i - \bar{x})^2}{n\,(n-1)}$$

where:

n = the number of samples; and

x_i = the length or growth of burbot i.

Lengths of burbot fully recruited to the gear (≥ 450 mm TL) were compared between river sections using a Kruskal-Wallis Test. Multiple comparisons test (Conover 1980) were used to evaluate differences in length distribution between pairs of river sections.

Movements

Relative mixing rates of burbot were determined using multinomial proportions based on all burbot recaptured since 1983. By considering only recaptured fish, grouping of data across years is permitted. Also, this restriction makes valid any comparison of proportions dependent on a single assumption: equal probability of capture of tagged burbot among river sections in the same year. Because traps were set at near equal density along the river in all sections, this condition was satisfied.

The marginal proportions in this multinominal distribution were:

$$(3)\quad \hat{p}_{ij} = \frac{r_{ij}}{r_{i.}}; \qquad (4)\quad V[\hat{p}_{ij}] = \frac{\hat{p}_{ij}(1 - \hat{p}_{ij})}{r_{i.} - 1}$$

where:

$r_{i.}$ = the number of burbot marked in section i;

r_{ij} = the number of burbot marked in section i and recaptured in section j; and,

p_{ij} = the relative mixing rate of burbot tagged in section i and recovered in section j.

Additional information concerning burbot movements provided by tag returns included average, median, and maximum distance moved for burbot travelling both upstream and downstream and an interpretation of seasonal movements. An ANOVA was conducted to determine if there was any significant difference between mean lengths of recaptured fish moving upstream, downstream, or those that remained relatively stationary.

CPUE Estimates

Mean CPUE (burbot/NN) for each river section and its associated variance were calculated from the number of burbot caught per net night for the entire week of sampling based upon the following equations from Wolter (1984):

$$(5)\quad \overline{CPUE} = \bar{x} = n^{-1} \sum_{i=1}^{n} x_i \qquad (6)\quad V[CPUE] = \frac{\sum_{i=2}^{n} (x_i - x_{i-1})^2}{2n(n-1)}$$

where:

n = the number of hoop traps fished; and

x_i = the catch of burbot in the i^{th} hoop trap set in ascending order from downstream to upstream.

In some cases, a trap was considered not to be fishing effectively. This occurred when water levels rose or fell causing the trap to become silted into the river bottom or washed ashore, when the bait container drifted out of the trap, or when a beaver or otter chewed large holes in the trap. In these cases, the trap was not included in the calculation of mean CPUE.

Full recruitment to the sampling gear for burbot of all sizes was investigated with contingency table analyses in conjunction with the mark-recapture population estimates (see below). The purpose of this investigation was to determine if all burbot greater than 299 mm TL were fully recruited to the gear. If recruitment began at some larger size, CPUE estimates would be made for two groups of burbot: those fully recruited to the gear and those not.

In addition, mean CPUE for each river kilometer within a sample section was plotted to determine if post stratification by river kilometer would improve the precision of the overall CPUE estimate.

Population Abundance Estimates

Mark recapture experiments were performed in two 16 km long sections of river. Fish were captured using the same techniques as described for estimating mean CPUE. The first river section was located near Rosie Creek, approximately 8 km downstream from Fairbanks. The second mark-recapture experiment was performed near the outlet of Healy Lake, approximately 64 km upstream from Big Delta (Figure 1). Each 16 km section was divided into three subsections of 5, 6, and 5 river kilometers each. Three weeks of marking effort by one crew, accounting for 263 net nights, was performed at the Rosie Creek section, while 2 weeks of marking effort by one crew, accounting for 187 net nights, was performed at the Healy Lake section. After a hiatus of 10 days following the initial marking periods for each section, a recapture effort was carried out. At the Rosie Creek section, sampling was done by two crews working 1 week, accounting for 184 net nights of sampling effort. At the Healy Lake section, one crew working for 1 week accounted for 83 net nights of sampling effort.

Population abundance was estimated using a modification (Bailey 1951, 1952) of the formula for a Petersen estimator:

$$(7) \quad \hat{N} = \frac{n_1 (n_2 + 1)}{m_2 + 1}$$

where:

$\hat{N}$ = the estimated abundance;

n_1 = the number of burbot released with a tag;

n_2 = the number of burbot inspected for tags; and

m_2 = the number of tagged burbot recaptured.

Conditions for the accurate use of the Petersen mark-recapture procedure in this experiment are:

1. the burbot population in the study area must be closed to growth recruitment, immigration, and emigration between sampling events;

2. all burbot have the same probability of capture during the first series of sampling events or during the last sampling event or tagged burbot must completely mix with the untagged burbot between sampling events;

3. no tags can be lost between sampling events;

4. tagged burbot must behave (enter traps and migrate) as do untagged burbot between sampling events; and

5. tagged burbot must have the same mortality rate as untagged burbot between sampling events.

By finclipping all tagged fish, possible bias associated with condition 3 was measurable. Inspection of recaptured burbot and of autopsied burbot suggested that tagging mortality was minimal.

Although the short hiatus between sampling events minimized recruitment to the population through growth, recruitment through migration was likely to occur across the arbitrarily chosen boundaries of the study subsection. To compensate for this recruitment, a new estimator was derived (see Appendix 3) based on the following conditions and movements of burbot within the study area:

6. no burbot tagged in the center subsection migrate out of the study area; and

7. a single process causes upstream movement, and a single process causes downstream movement.

The new estimator based on the seven conditions is:

$$(8)\quad \hat{N} = \frac{\{ \{ M_1(1-\hat{\theta}_d) + M_2 + M_3(1-\hat{\theta}_u) \} \{C + 1\}}{R_{..} + 1}$$

where:

M_x = the number of burbot marked in the first series of sampling events in Section X (X = 1, 2, and 3 for the downstream, midstream, and upstream subsections, respectively);

$R_{..}$ = the number of burbot recaptured during the last sampling event;

θ_z = the probability that a burbot will move out of a subsection in the "z" direction (upstream or downstream);

C = the catch made during the last sampling event; and

N = the abundance of burbot in all the subsections at the start of the last sampling event.

Estimates for the probabilities of movements into or out of the study section were:

$$(9)\quad \hat{\theta}_d = \frac{M_2(R_{32} + R_{21})}{R_{2.}(M_3 + M_2)} \qquad (10)\quad \hat{\theta}_u = \frac{M_2(R_{12} + R_{23})}{R_{2.}(M_1 + M_2)}$$

where:

R_{xy} = the number of burbot that were marked in subsection X during the first series of sampling events and were recaptured in subsection Y during the last sampling event; and

$R_{2.}$ = the number of burbot that were marked in the midstream subsection during the first series of sampling events and were recaptured during the last sampling event.

Because no recaptures were made beyond 5 km from the point of release in a similar study of the Rosie Creek section by Hallberg et al. (1987), and because the midstream section is at least 5 km from either end of the study area, there is no reason to believe that condition 6 is not satisfied. The last condition was tested by a contingency table analysis on the recapture of marked fish. Recruitment of unmarked burbot into the study subsections does not bias the new estimator, but makes the estimate germane to the abundance just before the last sampling event. A bootstrap analysis of data was used to investigate bias and calculate the variance of this estimator according to procedures in Efron (1982).

RESULTS

Movements

During 1987, 1,665 net nights of effort were expended to capture 4,516 burbot in 13 sections of the Tanana River. Of these, 3,818 were tagged, 269 were recaptured fish tagged during previous years, 282 were recaptured fish tagged in 1987 obtained during the two population estimates, and 147 were less than 299 mm and were released untagged. Since 1983 a total of 8,399 burbot have been tagged and released (Table 1).

From 1983 through 1987, 455 burbot were recaptured (not including recaptures obtained during the mark-recapture experiments). Of these, 306 were obtained through ADF&G sampling and 149 through angler returns. Seventy-two percent of recaptured burbot remained stationary (within 8 km of tagging site), whereas only 28% moved upstream or downstream (more than 8 km from tagging site). Of the burbot that did move, a greater percentage moved upstream (89%) than downstream (11%) (Table 2). There was no significant difference in the average length of burbot that moved upstream or downstream or that remained relatively stationary ($P > 0.50$)) (Table 3). Most of the recaptures, both from ADF&G sampling and angler tag returns, were obtained less than 1 year following tagging. Large movements (100 km or more) occurred less frequently for fish that had been tagged less than 1 year than for fish that had been tagged for longer than 1 year. A greater percentage of movement was documented during the summer (June, July, and August) and winter (December, January, and February) than in the fall (September, October, and November) and spring (March, April, and May)(Figure 5). Of fish captured in winter, almost 70% had made significant movements (usually in an upstream direction). These movements are probably associated with spawning. The relatively high proportion of movements documented in the summer may be correlated with feeding.

The 455 burbot that have been recaptured since 1983 provide a picture of burbot movements between river sections. For burbot that were at large for a period of 0.5 to 1.5 years, the highest probability of recapture occurred in the same section in which it was tagged in seven of 11 possible river sections (Table 4). Only burbot tagged in the Healy Lake section had a probability of being recaptured in a downstream river section, and only burbot tagged in the Rosie Creek and Cathedral Bluffs sections had a probability of being recaptured in more than one river section upstream. Over a period of 1.5 to 2.5 years, the highest probability of recapture continued to be in the section in which the burbot was tagged in three of five river sections (Table 5). There was zero probability of recapturing a burbot in a downstream river section, and the probability of recapturing a burbot more than one river section upstream had increased in all sections except Healy Lake.

Table 1. Summary of sample sections in the Tanana River and the number of burbot tagged in each section from 1983-1987.

River Section/ Boundaries (km)	Total Number Tagged	1983 Portion Sampled (km)	1983 Number Tagged	1984 Portion Sampled (km)	1984 Number Tagged	1985 Portion Sampled (km)	1985 Number Tagged	1986 Portion Sampled (km)	1986 Number Tagged	1987 Portion Sampled (km)	1987 Number Tagged
1. Manley 99-117	542							99-117	332	102-112	210
2. Nenana 250-286	569							250-286	423	270-285	146
3. Rosie Cr. 312-381	1,639	346-360	99	312-328	100	336-376	294	338-381	565	339-378	581
4. Salcha 413-442	319					413-442	168			430-442	151
5. Shaw Cr. 498-514	273					498-514	144			498-510	129
6. Goodpaster 520-569	1,268					528-597	391	528-537	414	520-571	459
7. Healy Lk. 578-590	2,575					586-587	39	584-590	1,090	578-587	1,446
8. George Cr. 606-625	176							614-626	131	606-619	45
9. Cath. Bl. 712-728	221							712-728	221		
10. Tok 800-829	479							800-816	271	806-829	208
11. Tetlin 842-853	232									842-853	232
12. Northway 894-915	806							898-912	595	894-915	211

Table 2. Summary of burbot movements in the Tanana River based on 455 recaptured burbot obtained from ADF&G sampling and angler returns, 1983-1987.

	Sampling Returns	Angler Returns	Total Returns
<u>Number of Recaptures</u>			
1983	0	3	3
1984	1	6	7
1985	7	10	17
1986	29	60	89
1987	269	70	339
1983-1987	306	149	455
Number of Burbot Moving 0-8 km	225	101	326
Number of Burbot Moving 8 km or More	81	48	129
Average Distance Moved (km) of Burbot Moving 8 km or More	58	43	53
Median Distance Moved (km) of Burbot Moving 8 km or More	29	24	27
Number of Burbot Moving 8 km or More Upstream	72	43	115
Maximum Distance of Movement Upstream (km)	265	210	265
Number of Burbot Moving 8 km or More Downstream	9	5	14
Maximum Distance of Movement Downstream (km)	58	79	79
Mean Days of Freedom (All Recaptured Burbot)	369	205	316

Table 3. Analysis of variance table[1] comparing lengths of recaptured burbot for three categories[2].

Source of Variation	Sum of Squares	df	Mean Square	F ratio
Between Categories	1,139	2	570	$F = \frac{570}{12,906} = .044$
Within Categories	4,542,743	352	12,906	$F_{0.95}$ (2,352) = 4.11
Total	4,543,882	354		(Fail to Reject H_o)

[1] One-way analysis of variance with $H_o: \mu_1 = \mu_2 = \mu_3$ and $\alpha = 0.95$.

[2] The categories considered in this analysis were: mean lengths of burbot moving upstream, mean lengths of burbot moving downstream, and mean lengths burbot remaining stationary. A movement was considered 8 km or greater.

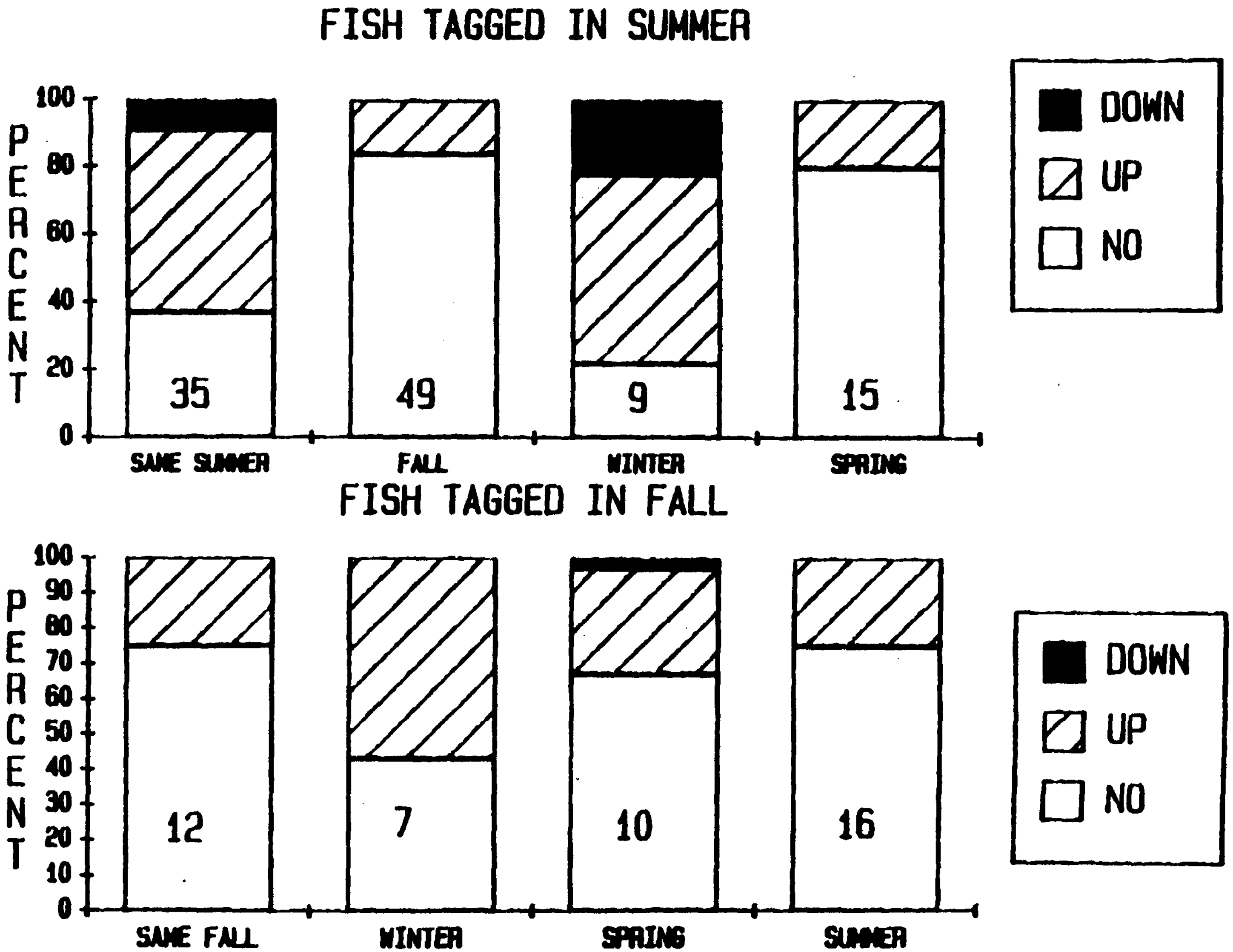

Figure 5. Frequency of burbot movements (greater than 8 km) during summer, fall, winter, and spring based on recaptures obtained within one year of tagging date.

Table 4. Relative mixing rates of burbot between 12 river sections of the Tanana River (0.5 - 1.5).

p_{ij}[1] $SE(p_{ij})$	p_{i1}	p_{i2}	p_{i3}	p_{i4}	p_{i5}	p_{i6}	p_{i7}	p_{i8}	p_{i9}	p_{i10}	p_{i11}	p_{i2}
p_{1j}	1.00	0	0	0	0	0	0	0	0	0	0	0
	0.007	0	0	0	0	0	0	0	0	0	0	0
p_{2j}	0	0.30	0.70	0	0	0	0	0	0	0	0	0
	0	0.003	0.005	0	0	0	0	0	0	0	0	0
p_{3j}	0	0	0.88	0.05	0	0.02	0.05	0	0	0	0	0
	0	0	0.007	0.002	0	0.001	0.002	0	0	0	0	0
p_{4j}	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
p_{5j}	0	0	0	0	1.00	0	0	0	0	0	0	0
	0	0	0	0	0.007	0	0	0	0	0	0	0
p_{6j}	0	0	0	0	0	0.11	0.89	0	0	0	0	0
	0	0	0	0	0	0.002	0.005	0	0	0	0	0
p_{7j}	0	0	0	0	0	0.02	0.98	0	0	0	0	0
	0	0	0	0	0	0.002	0.011	0	0	0	0	0
p_{8j}	0	0	0	0	0	0	0	1.00	0	0	0	0
	0	0	0	0	0	0	0	0.008	0	0	0	0
p_{9j}	0	0	0	0	0	0	0	0	0.39	0	0.22	0.39
	0	0	0	0	0	0	0	0	0.006	0	0.005	0.006
p_{10j}	0	0	0	0	0	0	0	0	0	0.95	0.05	0
	0	0	0	0	0	0	0	0	0	0.008	0.001	0
p_{11j}	Sampled for first time in 1987											
p_{12j}	0	0	0	0	0	0	0	0	0	0	0	1.00
	0	0	0	0	0	0	0	0	0	0	0	0.007

[1] The probability of recapturing a burbot in section j which was tagged in section i. Locations of sections 1-12 are given in Table 1.

Table 5. Relative mixing rates of burbot between 12 river sections of the Tanana River (1.5 - 2.5 years).

p_{ij}[1] / $SE(p_{ij})$	p_{i3}	p_{i4}	p_{i5}	p_{i6}	p_{i7}	p_{i8}
p_{3j}	0.75	0	0	0.06	0.13	0.06
	0.007	0	0	0.002	0.003	0.002
p_{4j}	0	0.67	0	0	0.33	0
	0	0.008	0	0	0.006	0
p_{5j}	0	0	0.33	0	0.67	0
	0	0	0.007	0	0.010	0
p_{6j}	0	0	0	0.18	0.41	0.41
	0	0	0	0.006	0.008	0.003
p_{7j}	0	0	0	0	1.00	0
	0	0	0	0	0.026	0

[1] The probability of recapturing a burbot in section j which was tagged in section i. Locations of sections 1-12 are given in Table 1.

Mean Length and Mean Growth

Mean lengths of burbot larger than 299 mm TL sampled in each of the 13 river sections ranged from a low of 435 mm for the Shaw Creek section (river km 498-510), to a high of 587 mm for the Manley section (river km 102-112) (Table 6). The mean length of burbot in all sections was 533 mm (n = 4,092). This compares to a mean length of 540 mm (n = 3,588) for all sections in 1986 (Hallberg et al. 1987). Lengths of burbot sampled in the Tanana River ranged from 300 mm to 1,079 mm with a modal length of 500 to 525 mm (Figure 6).

A nonparametric analysis of variance (Kruskal-Wallis Test) on burbot fully recruited to our gear (≥ 450 mm TL by 10 mm increments) indicated that the size of burbot varied by river section (ap <0.005). A multiple comparison test from Conover (1980) with P = 0.05 for each two section comparison showed the smallest fish in the Shaw Creek and Goodpaster Sections (river km 498-537), and the largest burbot in the Manley Section (river km 102-112) and in the Northway and Tetlin Sections (river km 842-853. Samples from all other sections were of similar, intermediate size.

Based on tag returns obtained from ADF&G sampling, the average annual growth of burbot in the Tanana River was 24 mm (n = 246, SE = 1.8).

Age-Length Relationships

Because of the low mortality rate associated with hoop trap sampling, aging structures were primarily obtained from carcasses provided by anglers. Age-length data was pooled from all samples obtained from 1983 through 1987. A total of 480 samples were analyzed (age range 0-20)(Table 7). Males and females have nearly identical growth rates until age 10. After age 10, females are observed to have slightly higher growth rates and greater longevity than males (Figure 7). Length frequencies of males and females are similar up to 500 mm (TL). A higher frequency of males was observed between 500 and 700 mm, while a higher frequency of females was observed at lengths greater than 700 mm (Figure 8). The observed sex ratio for all lengths was approximately 1:1.

CPUE Estimates

A contingency table analysis comparing lengths of tagged and recaptured burbot sampled during the Healy Lake abundance estimate determined that full recruitment of burbot to the sampling gear began at 450 mm TL (Table 8, Figure 9). CPUE estimates for all 13 sample sections were therefore stratified into two size classes: small burbot (300-449 mm TL) and large burbot (larger than 449 mm TL). CPUE for small burbot ranged from 0.19 burbot per net night (BB/NN) for the George Creek section (river km 606-619) to 1.11 BB/NN for the Goodpaster section (river km 520-536). CPUE for large burbot ranged from 0.41 BB/NN for the George Creek section to 6.25 BB/NN for the Healy Lake section (river km 578-594). The section with the highest ratio of large burbot to small burbot (CPUE large/CPUE small) was the Manley section (10.00) (river km 102-112), while the section with the smallest ratio of large burbot to small burbot was the Shaw Creek section (0.54) (river km 498-510) (Table 9).

Table 6. Average lengths and length ranges of burbot captured in 13 sample sections of the Tanana River in 1987.

Section Name (Number)	Sub-Section Boundaries (km)	Total Catch	Length (mm TL)		
			Range	Mean	SE
Manley (1)	102-112	222	302-866	587	7
Nenana (2)	270-285	158	307-790	514	8
Rosie Creek (3)	339-354	563	304-1,079	531	6
Moose Creek (4)	360-378	117	312-937	477	11
Salcha (5)	430-442	156	305-952	492	10
Shaw Creek (6)	498-510	131	300-743	435	7
Goodpaster (7)	520-536	255	308-750	469	6
Volkmar (8)	553-571	237	300-933	514	7
Healy Lake (9)	578-594	1,923	312-962	555	3
George Cr. (10)	606-619	51	318-810	523	17
Tok (11)	806-829	227	305-1,000	497	9
Tetlin (12)	842-853	246	326-985	564	8
Northway (13)	894-915	241	307-1010	557	9

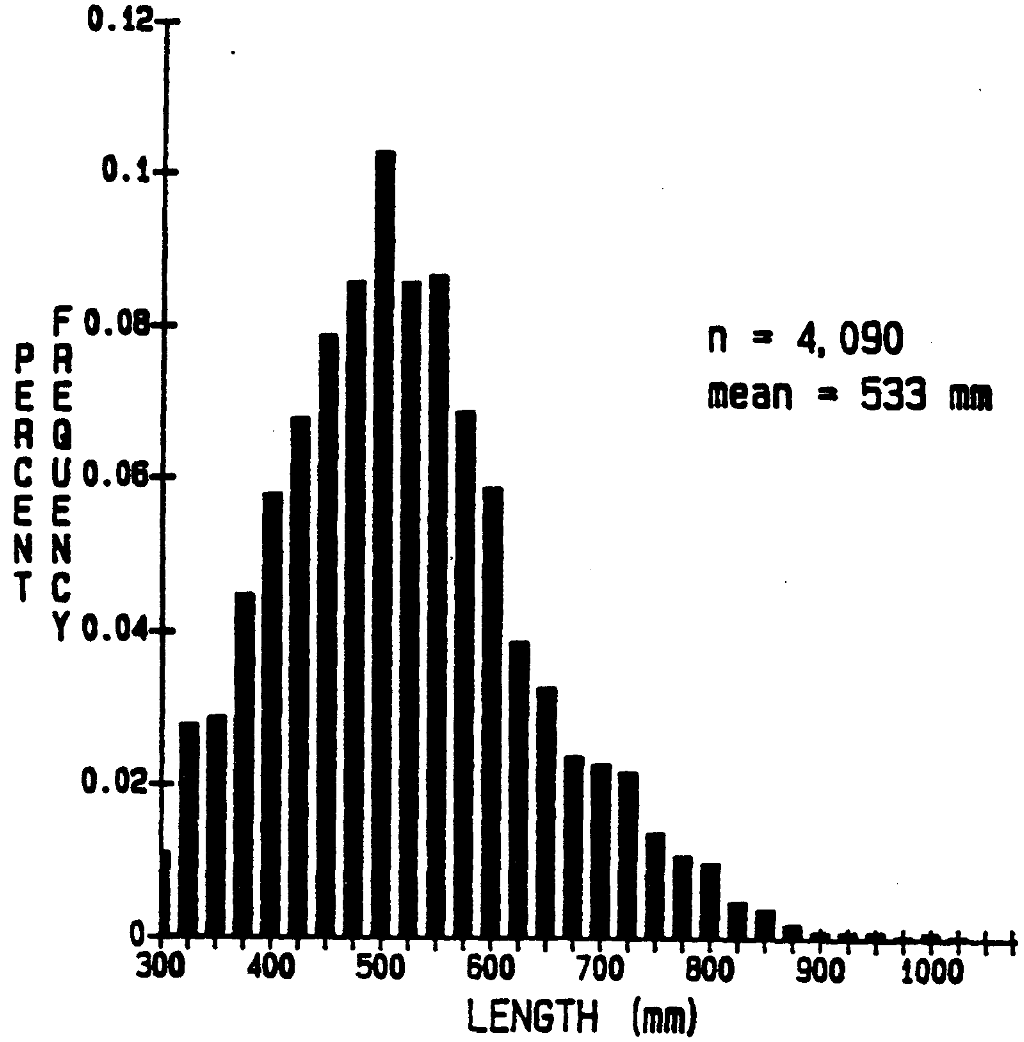

Figure 6. Length frequency distribution of all burbot tagged in the Tanana River during 1987.

Table 7. Mean length at age of Tanana River burbot sampled from 1983 through 1987.

Age	Sample Size	Length (TL mm) Mean	Range	SE
0	4	141	133-152	6
1	10	172	162-184	3
2	1	300	-300-	---
3	19	312	220-470	15
4	31	386	290-547	10
5	38	461	372-634	10
6	60	516	405-648	7
7	72	555	426-865	8
8	54	583	436-800	9
9	57	628	450-762	8
10	40	699	510-915	11
11	28	749	560-882	14
12	19	769	690-875	10
13	15	814	620-955	22
14	11	889	785-1035	24
15	6	896	825-950	22
16	7	934	822-1022	27
17	4	956	915-1016	21
18	1	1076	-1076-	---
19	2	1099	1080-1117	19
20	1	1135	-1135-	---

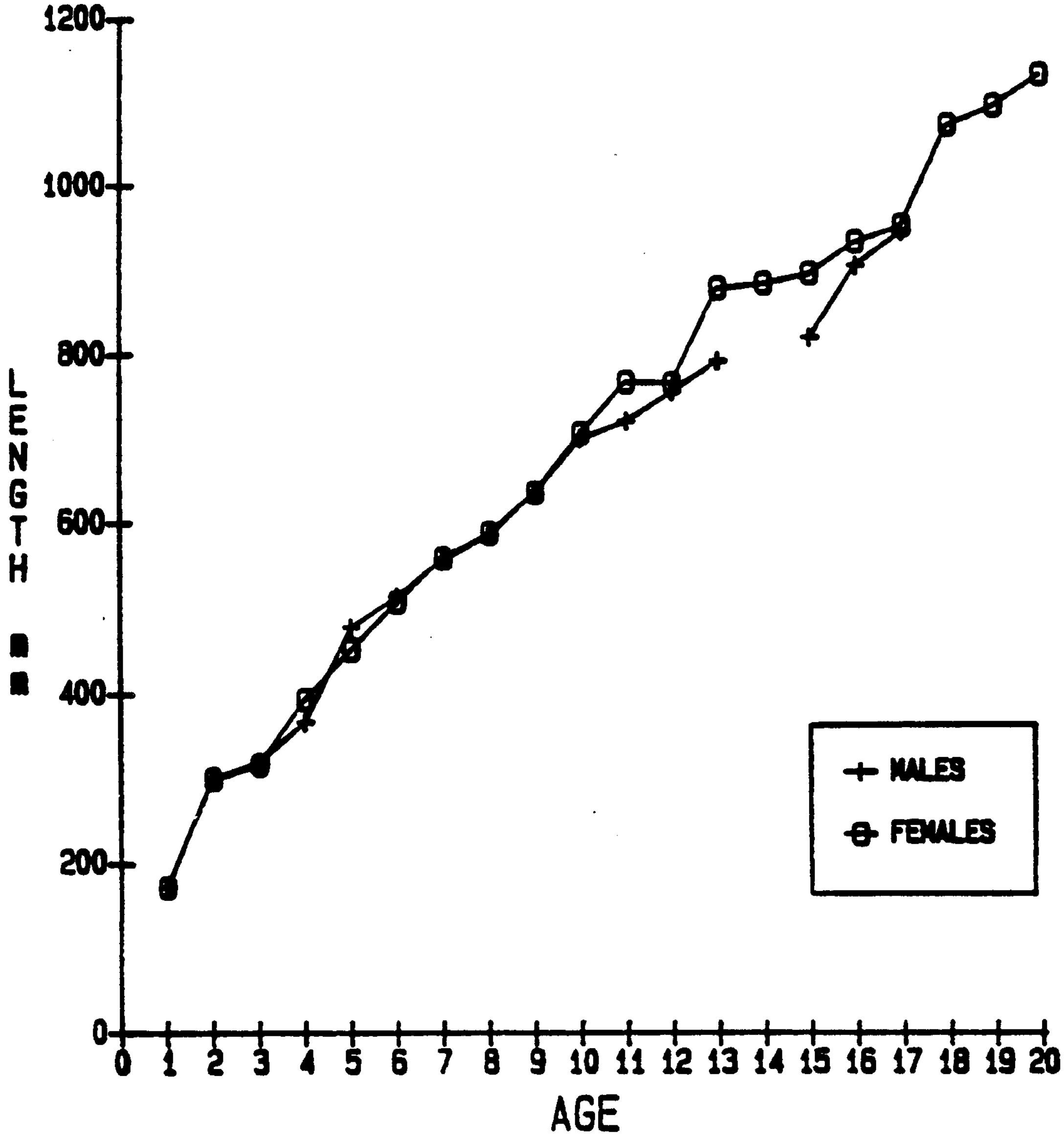

Figure 7. Mean length at age for male and female Tanana River burbot sampled from 1983 through 1987.

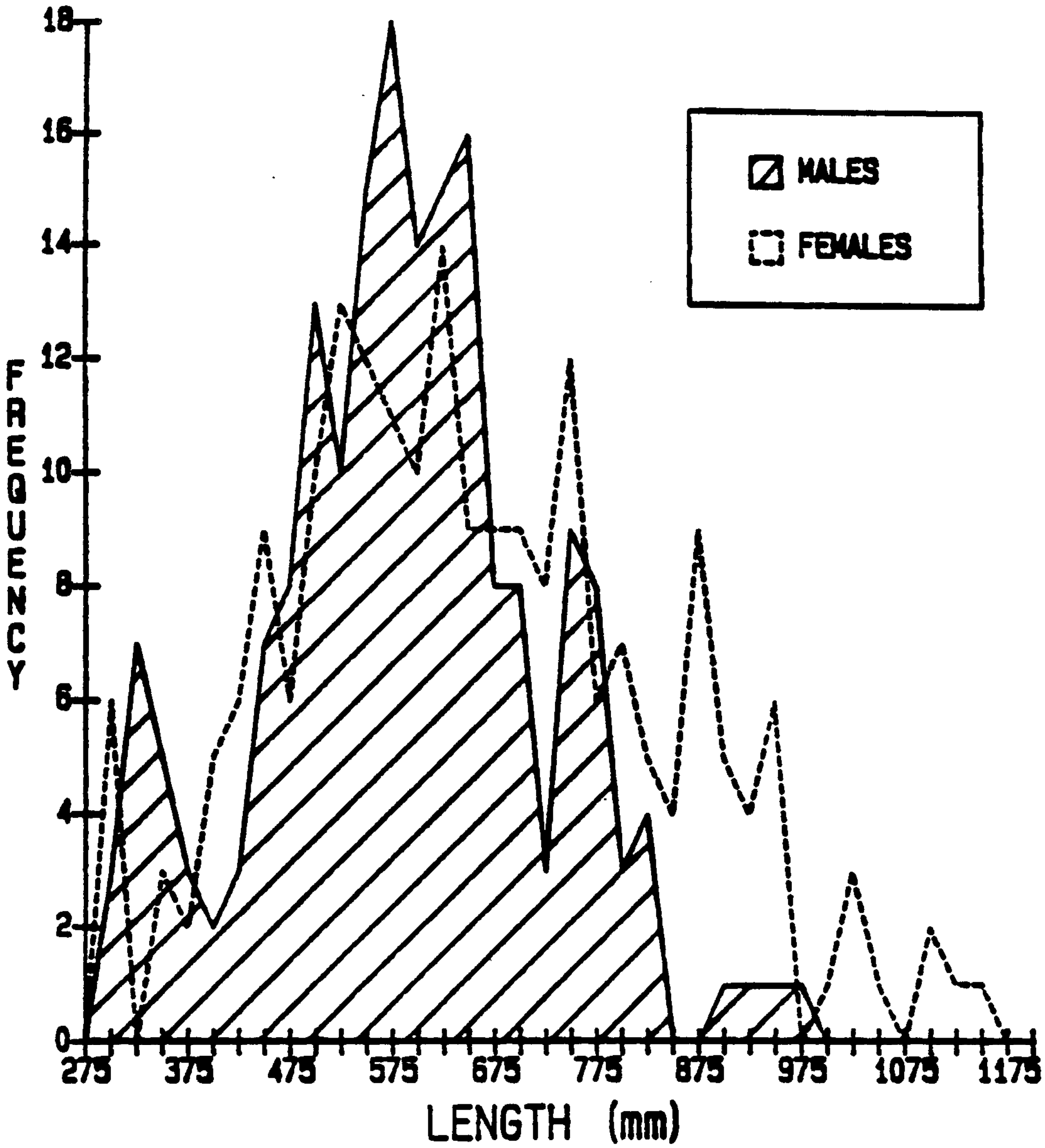

Figure 8. Length frequencies of male and female Tanana River burbot sampled from 1983 through 1987.

Table 8. Results of contingency table analysis of the recapture rates of tagged burbot by length from the mark recapture experiment in the Healy lake section.

	Test Breaks[1] (mm TL) 300 350 400 450 480 500 550 600 650 700 >	Significance Tests[2]
(1)	---------------><--------------------------------	P<.005 Reject H_o
(2)	<--------><---><---><---><---><---	P>.05 Fail to Reject H_o
(3)	---------------><--->	.01<P<.025 Reject H_o

[1] The symbols "><" correspond to the boundaries between adjacent categories for each of the three tests.

[2] Tests are RxC contingency tables and χ^2 statistics for H_o: $p_i = p$ where p_i = probability of catching a burbot in the i^{th} length group. The numbers of marked and unmarked fish caught during the final sampling event were used in the contingency table.

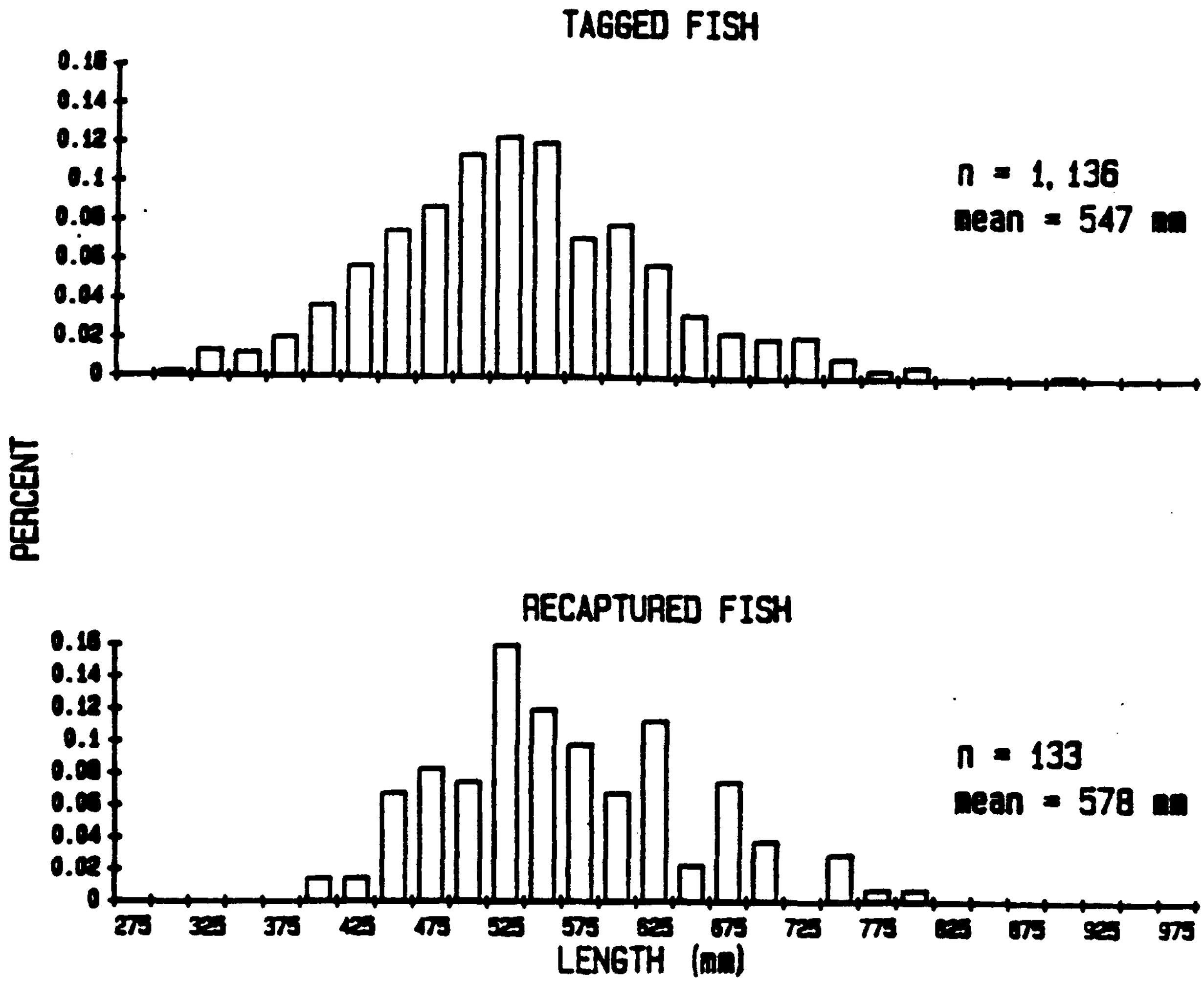

Figure 9. Length frequency distributions of tagged burbot and recaptured burbot obtained in the Healy Lake population abundance estimate.

Table 9. Mean CPUE[1] of large and small[2] burbot in 13 sample sections of the Tanana River during 1987.

Sample Section	Trap Nights	Large Burbot Catch	Large Burbot $\overline{CPUE}$	Large Burbot $SE(\overline{CPUE})$	Small Burbot Catch	Small Burbot $\overline{CPUE}$	Small Burbot $SE(\overline{CPUE})$	Ratio $\frac{CPUE\ large}{CPUE\ small}$
1. Manley	89	196	2.20	0.25	20	0.22	0.07	10.0
2. Nenana	54	113	2.09	0.36	42	0.78	0.16	2.7
3. Rosie Cr.								
Week 1	77	50	0.65	0.09	25	0.33	0.02	2.0
Week 2	106	83	0.78	0.09	76	0.72	0.10	1.1
Week 3	79	53	0.67	0.10	31	0.39	0.08	1.7
Week 4	183	195	1.07	0.11	49	0.27	0.05	4.0
Total	446	381	0.85	0.05	181	0.41	0.04	2.1
4. Moose Cr.	79	60	0.76	0.11	58	0.73	0.12	1.0
5. Salcha	87	87	1.00	0.15	68	0.78	0.13	1.3
6. Shaw Cr.	87	46	0.53	0.11	85	0.98	0.14	0.5
7. Goodpaster	97	145	1.49	0.18	107	1.11	0.13	1.3
8. Volkmar	101	179	1.77	0.21	58	0.58	0.10	3.1
9. Healy Lk.								
Week 1	96	468	4.88	0.51	98	1.02	0.16	4.8
Week 2	91	633	6.96	0.84	78	0.86	0.14	8.1
Week 3	82	579	7.06	0.94	57	0.70	0.11	10.0
Total	269	1680	6.25	0.42	233	0.87	0.08	7.2
10. George Cr.	86	35	0.41	0.07	16	0.19	0.05	2.2
11. Tok	97	136	1.40	0.15	91	0.94	0.12	1.5
12. Tetlin	77	198	2.57	0.27	48	0.62	0.10	4.1
13. Northway	93	194	2.09	0.23	47	0.51	0.10	4.1

[1] Mean CPUE and SE(CPUE) for each section were calculated according to equations 5 and 6.

[2] Small burbot are 300-449 mm (TL), while large burbot are greater than 450 mm (TL).

Plots of mean CPUE per river kilometer within each river section (Appendix 2) demonstrated no clear trend of increasing or decreasing CPUE in an upstream direction. Therefore, post-stratification of CPUE estimates within a section was not warranted.

Population Abundance Estimates

One hundred sixteen small burbot and 173 large burbot were captured during the first sampling events in the Rosie Creek section (Table 10). Forty-five small burbot were caught in the second sampling event, of which six had tags. The estimated abundance in this 16 km section of river was 762 burbot (SE = 265). One hundred ninety large burbot were captured during the final sampling event in the Rosie Creek section, of which 12 had tags. The estimated abundance of large burbot in the Rosie Creek section was 2,541 burbot (SE = 680). In the Healy Lake section, 165 small burbot and 971 large burbot were captured during the first sampling events (Table 10). Fifty-six small burbot were caught in the second sampling event, of which five had tags. The estimated abundance of small burbot was therefore, 1,568 burbot (SE = 606). Five hundred seventy-nine large burbot were caught in the final sampling event at Healy Lake. Of these, 125 had tags. Therefore, the estimated abundance of large burbot in this 16 km section of river was 4,470 burbot (SE = 352).

On the average, burbot recaptured in the Rosie Creek section moved 1.0 km (SE = 0.3). In the Healy Lake section, all recaptured burbot had moved an average of 1.3 km (SE = 0.1). The maximum documented movements of any burbot over the length of the mark-recapture experiments were 3.2 km and 8.0 km for the Rosie Creek and Healy Lake sections respectively. Movement of burbot from one river subsection to another were recorded (Table 10). Using this information, a modification of the Peterson estimator designed to compensate for movement in an open system was evaluated (Appendix 2). For both big and small fish in the Healy Lake section and for small fish in the Rosie Creek section, the estimates were virtually identical. However, for large fish in the Rosie Creek section, there was about a 15% difference in the estimators. However, attempts to evaluate bias and variance of the estimate showed that the estimate was unstable due to small numbers of recaptures made in the study area.

DISCUSSION

Morrow (1980) reported that burbot are generally sedentary. Monitoring of 20 radio tagged burbot in the Susitna River, Alaska (Sundet and Wenger 1984), indicated that movements occur primarily before and after their mid-winter spawning period, while little movement occurs during spawning or during the summer months. Hallberg (1984) confirmed both upstream and downstream movement during the winter spawning months while tracking four radio tagged burbot in the Tanana River near Fairbanks, Alaska. Breeser et al. (1986), while monitoring 21 radio tagged burbot in the Tanana River near Northway, Alaska, noted movements during all seasons, with the longest movements occurring during November-March. Their study documented movements of up to

Table 10. Population abundance estimates for two sections of the Tanana River sampled during 1987.

	Rosie Creek		Healy Lake	
	Small Burbot	Large Burbot	Small Burbot	Large Burbot
M_1	27	45	10	50
M_2	59	90	151	919
M_3	30	38	4	2
C	45	190	56	579
R..	6	12	5	125
R_{33}	3	3	0	0
R_{32}	0	2	0	0
R_{31}	0	0	0	0
R_{23}	0	1	0	1
R_{22}	3	5	4	113
R_{21}	0	0	0	5
R_{13}	0	0	0	0
R_{12}	0	2	1	6
R_{11}	0	0	0	0
θ_d	0	0.28	0	0.04
θ_u	0	0.27	0.23	0.06
$\hat{N}$ (Peterson)	762	2,541	1,568	4,470
$SE(\hat{N})$	265	680	606	352
Density (BB/km)	48	159	98	279
Mean CPUE (BB/NN)	0.41	0.85	0.87	6.25

67 km downstream and 84 km upstream from release sites. The greatest distance travelled by an individual burbot was 125 km.

The results of this study indicate movements during all seasons with the highest frequency of movements occurring during the winter and summer. A small percentage of downstream moving fish were recaptured within a period of 1.5 years from tagging date, but no fish were noted to move significantly downstream after a period of 1.5 years. Seventy-two percent of the recaptures obtained in this study were caught within 8 km of their tagging site. This figure may be biased high due to the fact that sampling during 1986 and 1987 (when most of the recaptures were obtained) was conducted in the same areas where tagging occurred. Therefore, the probability of recapturing a burbot that had not moved was higher than if sample sections were in new areas. The remaining 28% of the recaptures did exhibit movement greater than 8 km, with the median distance travelled being 27 km, and the maximum distance travelled being 265 km. Ten percent of these fish moved distances of 100 km or greater.

Because of the frequency of seasonal movements documented in this study and the radio telemetry studies of Hallberg (1984) and Breeser et al. (1986), as well as the distance travelled during these movements relative to the size of the sample sections in this study, it can be concluded that interchange occurs between burbot in the sample sections and burbot in other nearby river sections throughout the course of a year. This is particularly true during the well documented winter spawning migrations (Hallberg 1984; Hallberg et al. 1987; Breeser et al. 1986; and Sundet and Wenger 1984) when burbot often move great distances upstream and downstream. Thus, burbot sampled in the summer in any given sample section may be comprised of a number of spawning stocks. This information implies that no definite stocks can be inferred within sample sections as small as those in this study.

However, even though significant movement of burbot did occur, there are two river sections through which no movement (either upstream or downstream) has presently been documented. One of these is a 103 km area between the Manley and Nenana sections in the area of the Tolovana River. The second is a 93 km area between the George Creek and Cathedral Bluffs sections. This lack of interchange between major river sections supports conclusion of the existence of separate stocks.

No significant difference in mean lengths between the 13 sample sections was noted, which could be considered argument against the existence of multiple stocks. However, Kruskal-Wallis comparisons of burbot lengths (by 10 mm increments) between river sections on burbot fully recruited to the gear ($\geq$ 450 mm) indicated that size of burbot did vary by river section. In the one river section sampled in the lower Tanana River (Manley Section) and the two river sections sampled in the upper river (Northway and Tetlin Sections) the burbot tended to be larger than other areas. The smallest burbot were found in two river sections (Shaw Creek and Goodpaster River sections) in the middle river. These differences in size of burbot and the occurrence of stock separation in three areas (as evidence by the lack of migration through two sections of river) argue for the presence of three separate stocks of burbot in the Tanana River: 1) below the Tolovana River (lower river stock); 2) between the Tolovana River and George Creek (middle river stock); and 3) above

George Creek (upper river stock). These stocks are defined for management purposes (as opposed to reproductively isolated stocks) since the possibility still exists for the transfer between areas of burbot that are too small to tag. This movement is especially likely in a downstream direction since burbot larvae are pelagic. In 1988, sampling is scheduled in sections within the two areas through which migration has not been documented. This will hopefully refine our knowledge of stock separation through comparison of size of burbot in these areas as well a by increasing the probability of tag recoveries from upstream and downstream sections.

Age-length data (480 samples) were pooled from all samples collected since 1983. Trap mortalities were generally low. However, during 1985, a random sample of burbot were collected from hoop trap and fyke net gear (Hallberg 1986). All carcasses provided by anglers were caught using set lines. Due to the nature of the set-line fishery, the hook is generally swallowed, thus most fish caught are retained. The combination of these two sampling techniques minimizes sampling bias, but may still be biased toward larger fish. Thus, the length frequencies of male and female burbot as shown in Figure 8 may not be indicative of the actual population.

Burbot densities based on hoop trap CPUE were quite high. The abundance estimate for the Rosie Creek section, which was an area of relatively low average CPUE, was 48 small burbot per kilometer and 125 large burbot per kilometer. This compares to an estimate of 24 burbot per kilometer greater than 350 mm TL in a section of the Susitna River (Sundet and Wenger 1984).

Overall, the abundance of burbot in the mainstream Tanana River seems to be quite high compared to overall harvest. Information gathered to date suggests that no changes in management strategies are warranted. However, I recommend the burbot tagging program be continued in 1988 with the same level of sampling effort. This should provide a great deal of additional information concerning stock identification. In addition, the Alaska Statewide Sport Fisheries Harvest Report is expected to subdivide the Tanana River into smaller sections, which will more accurately define harvest concentrations. Information from the 1988 harvest surveys and tagging program will be evaluated prior to the 1989 meeting of the Alaska Board of Fisheries to determine if new management strategies are needed.

ACKNOWLEDGEMENTS

The author extends his thanks to Jerry Hallberg who has acted as project leader since the study began in 1983 and was in charge of all field operations during 1987. Appreciation is extended to sport fishermen in the Tanana Drainage who have assisted in this study by providing tag returns and carcasses throughout the past years. The author extends thanks to Dick Peckham and Al Mathews who assisted with much of the field work associated with this study. Thanks to Rocky Holmes and Dave Bernard for their assistance with parts of the statistical procedures, data analysis, and editing. Appreciation is also extended to John Clark for support and guidance in conceiving and implementing aspects of this research. And lastly, thanks is extended to the U.S Fish and Wildlife Service for partially funding this work.

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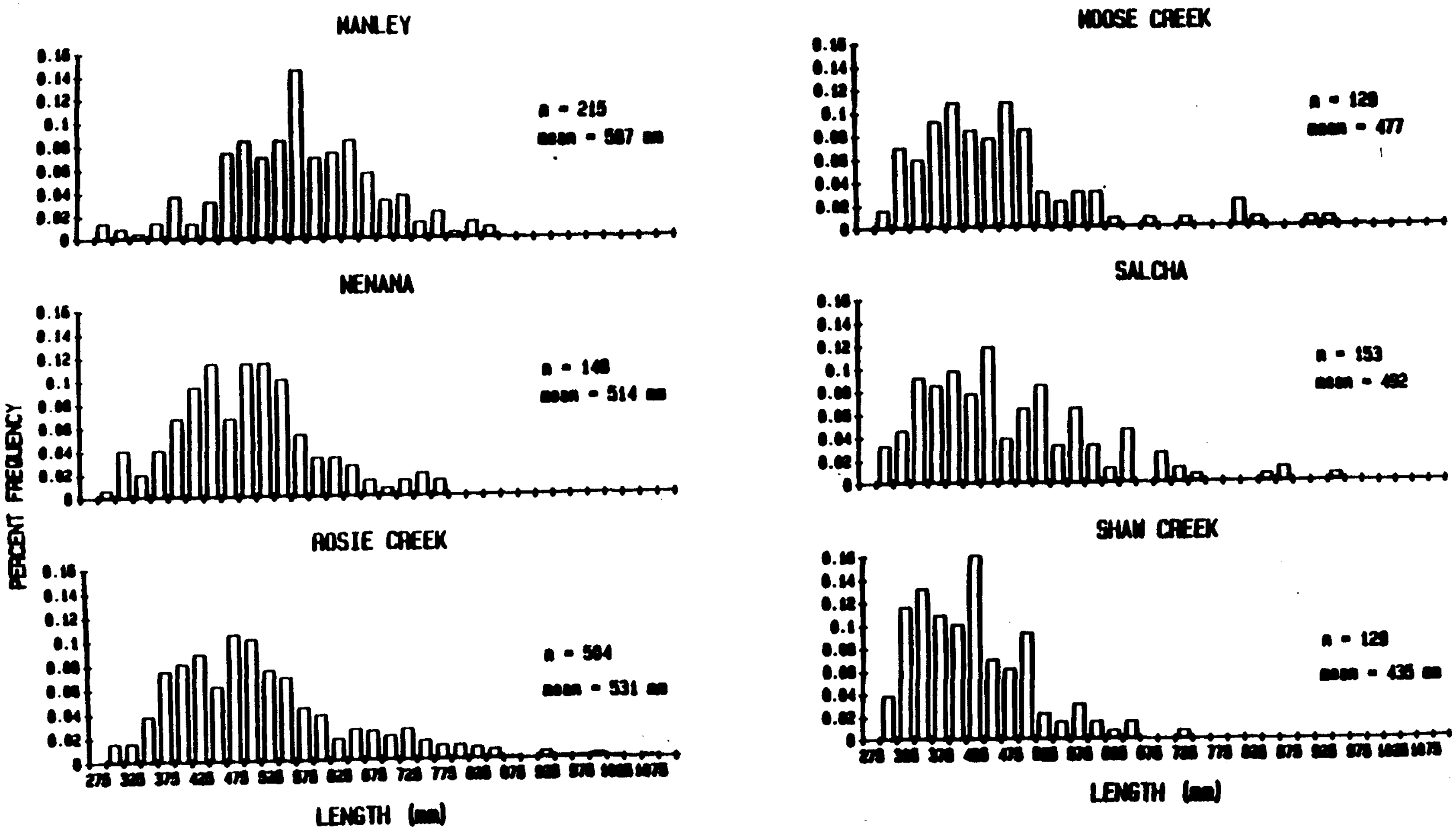
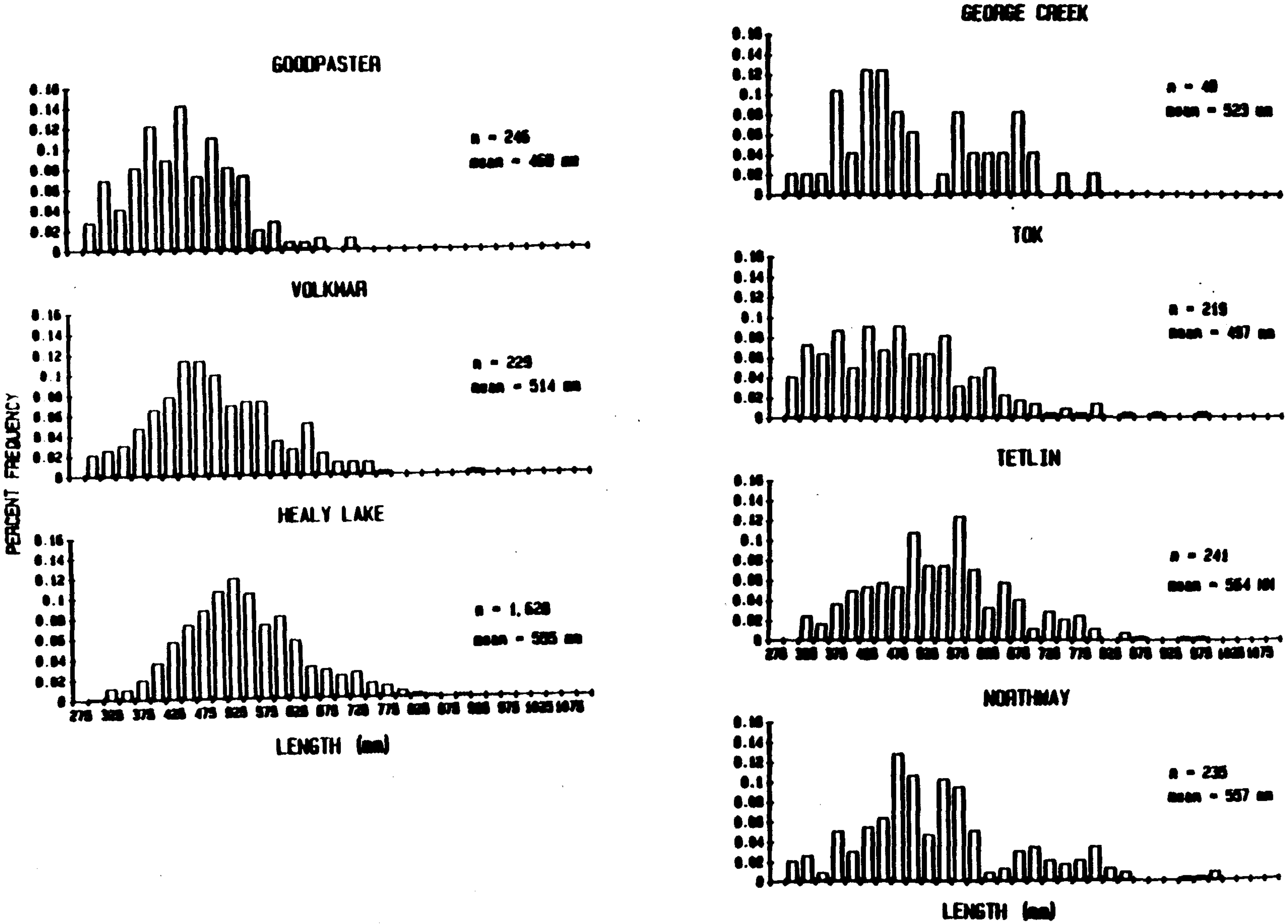
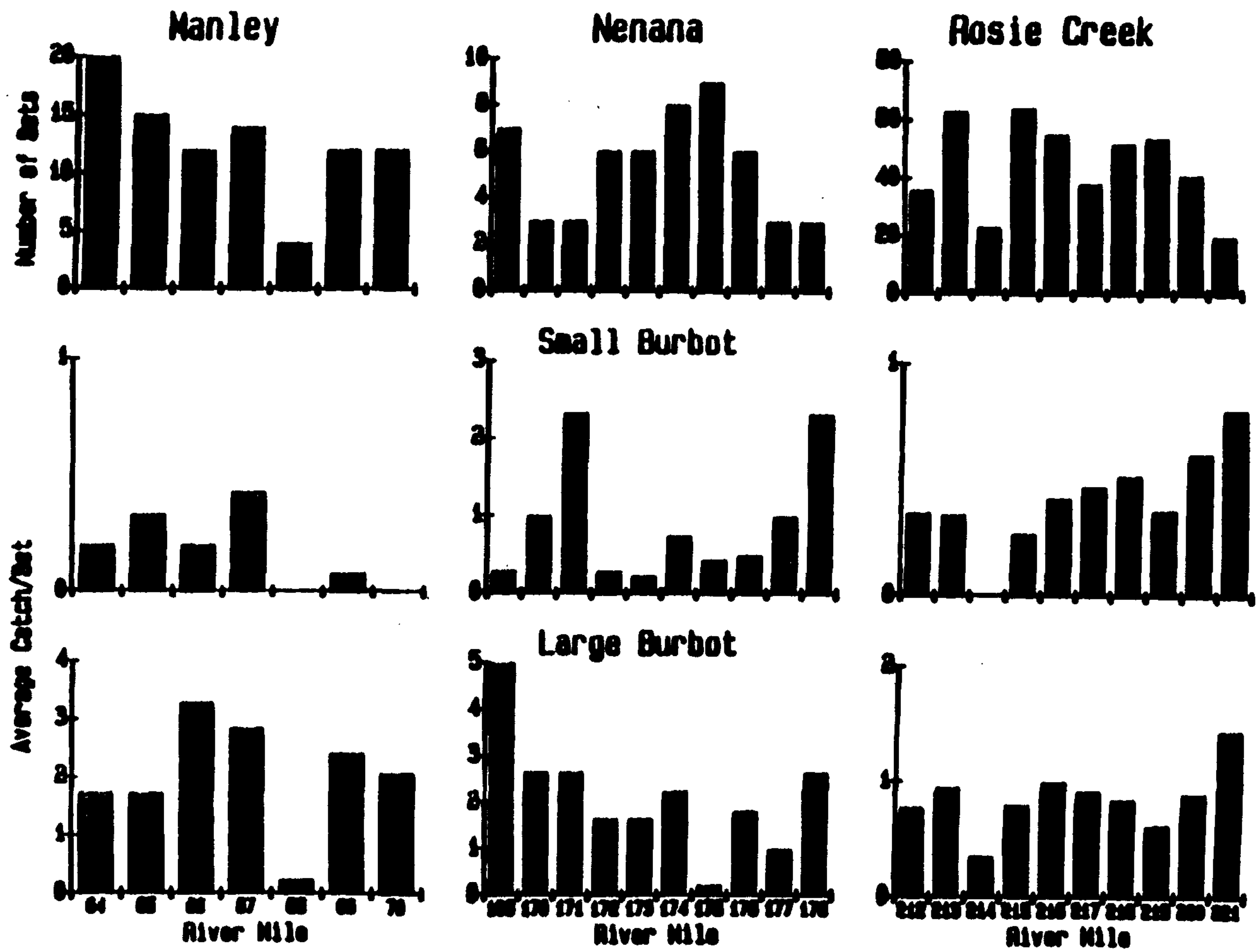
APPENDICES



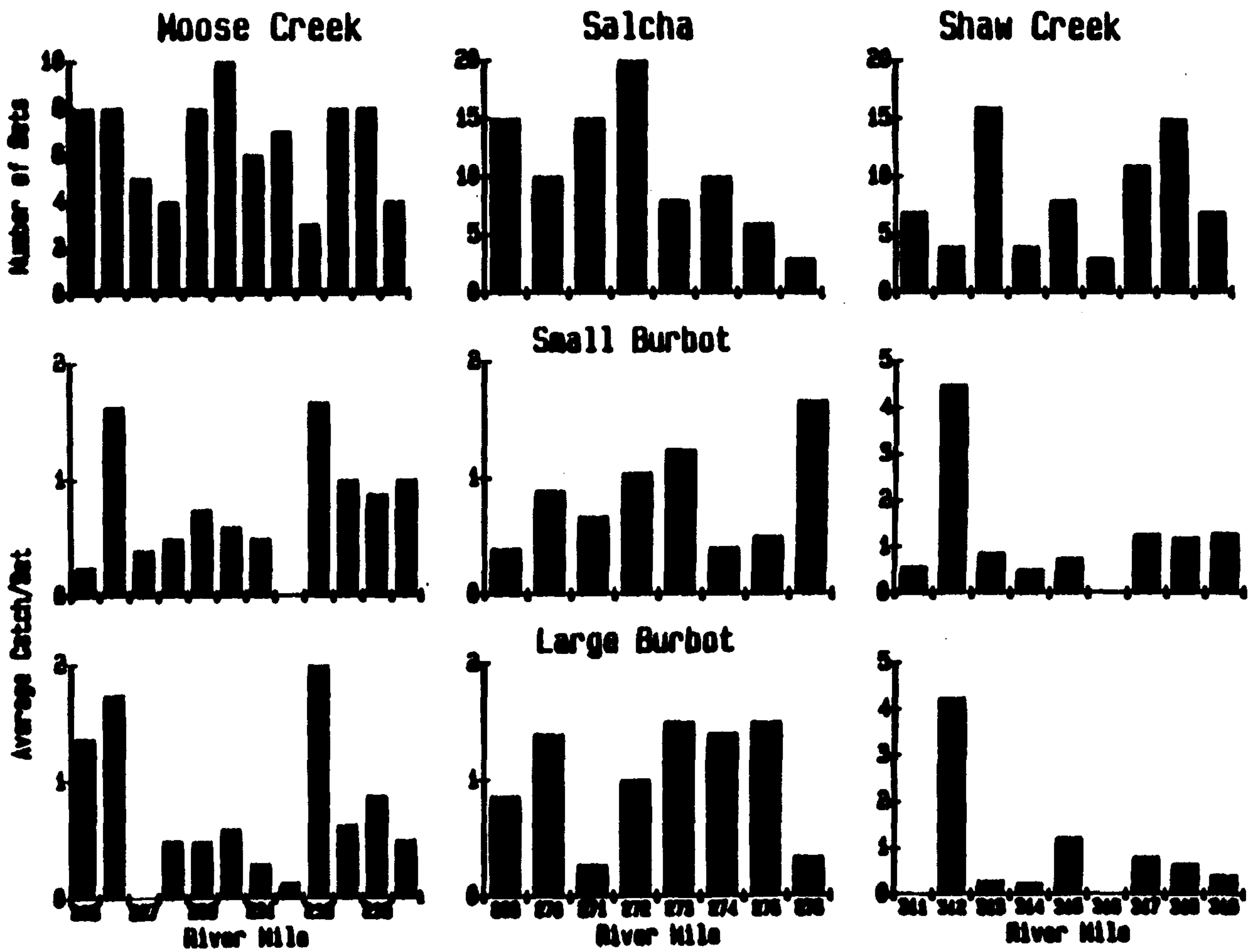
Appendix 1a. Length frequency distributions of burbot sampled from the Manley, Nenana, Rosie Creek, Moose Creek, Salcha, and Shaw Creek sections of the Tanana River during 1987.



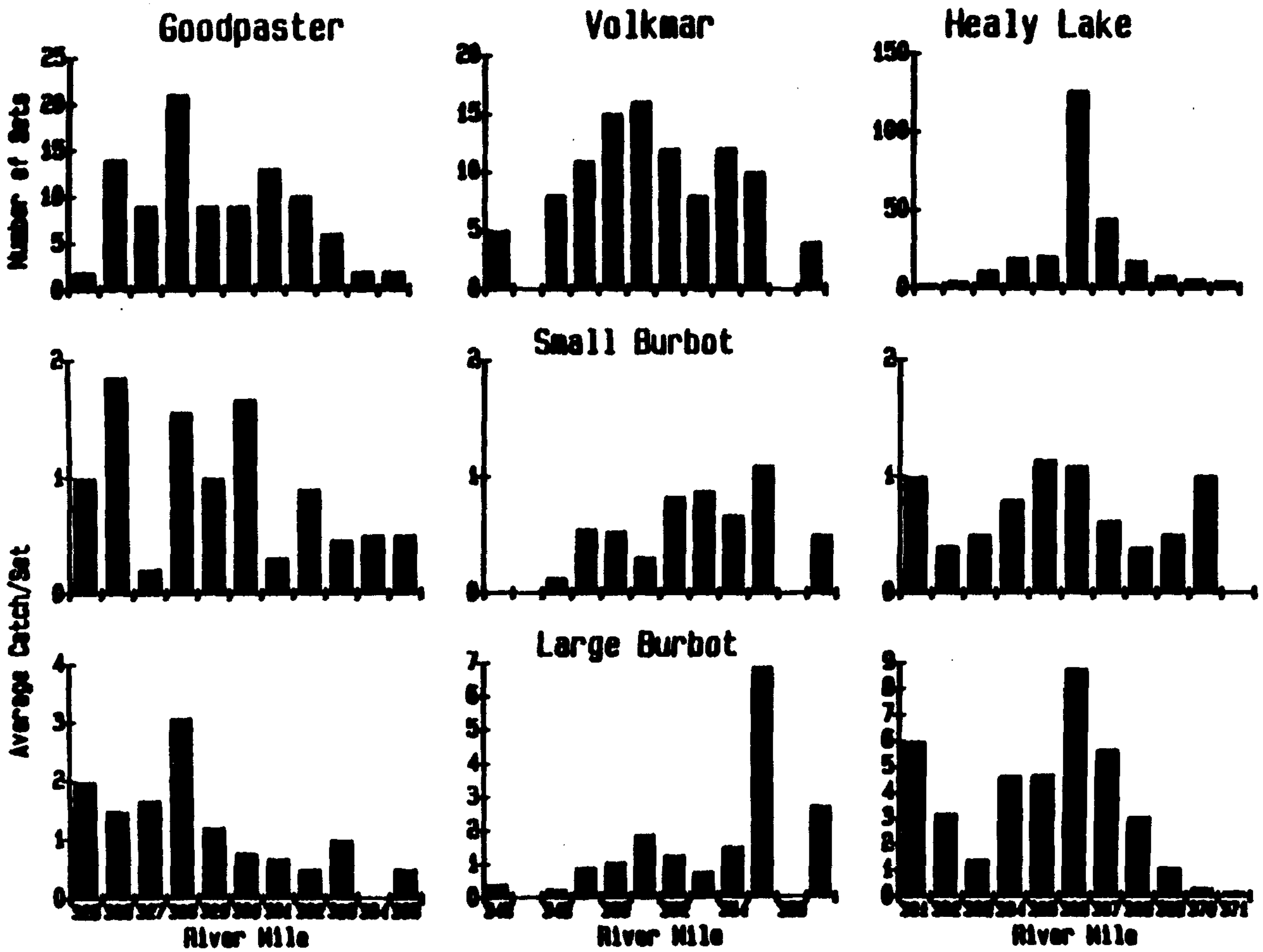
Appendix 1b. Length frequency distributions of burbot sampled from the Goodpaster, Volkmar, Healy Lake, George Creek, Tok, Tetlin, and Northway sections of the Tanana River during 1987.



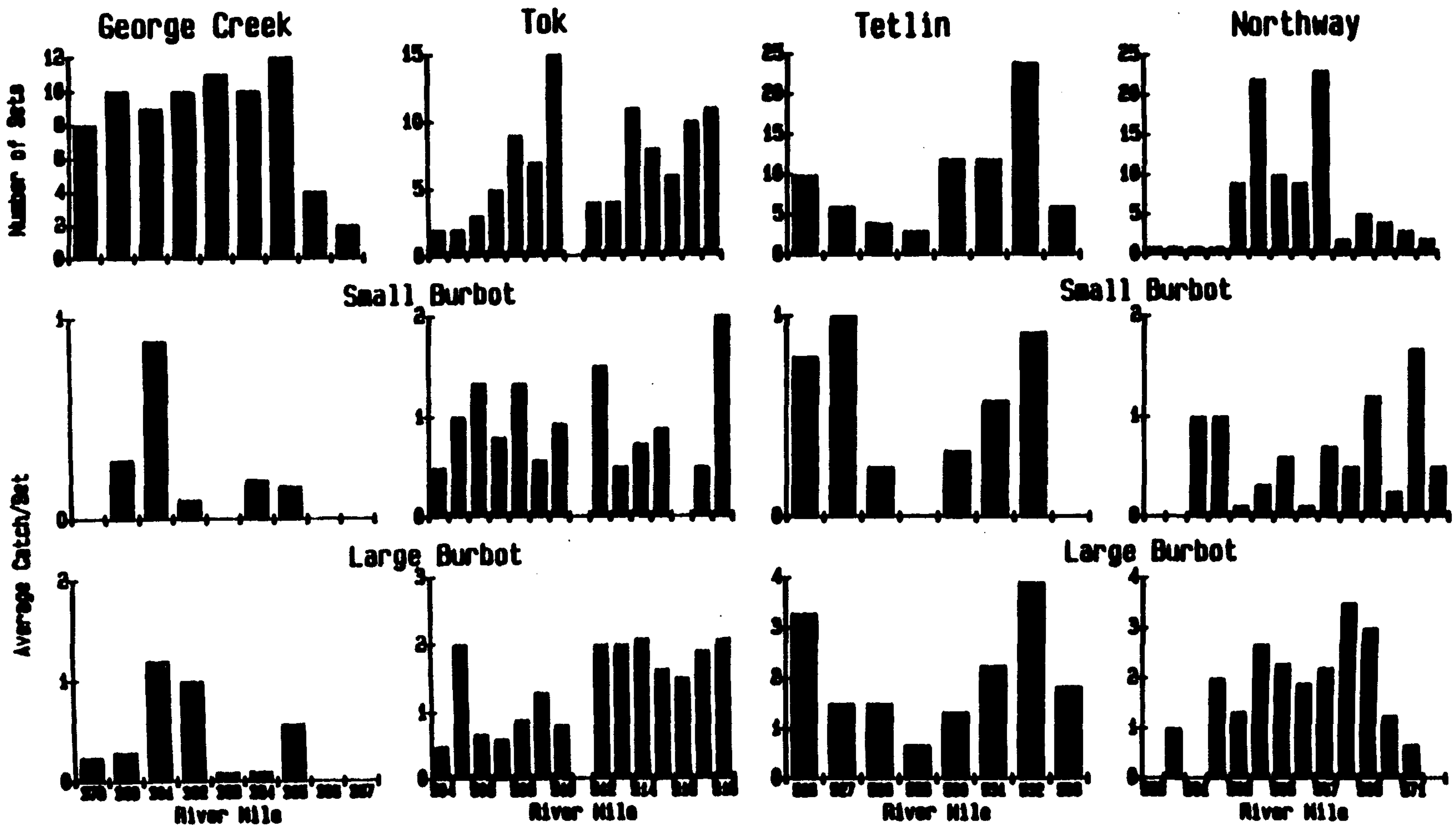
Appendix 2a. Average catch per set for small (less than 450 mm TL) and large (450 mm TL and larger) burbot per river mile for Manley, Nenana, and Rosie Creek.



Appendix 2b. Average catch per set for small (less than 450 mm TL) and large (450 mm TL and larger) burbot per river mile for Moose Creek, Salcha, and Shaw Creek sections of the Tanana River sampled during 1987.



Appendix 2c. Average catch per set for small (less than 450 mm TL) and large (450 mm TL and larger) burbot per river mile for Goodpaster, Volkmar, and Healy Lake sections of the Tanana River sampled during 1987.



Appendix 2d. Average catch per set for small (less than 450 mm TL) and large (450 mm TL and larger) burbot per river mile for George Creek Tok, Tetlin, and Northway sections of the Tanana River sampled during 1987.

Appendix 3. Description of a Petersen mark recapture abundance estimate for open rivers.

The text below is a description of a Petersen mark-recapture abundance estimator for open rivers. The development of this estimator is based on a study area that is divided (or can be divided) into three subsections after the completion of both sampling events. The subsections must be defined such that fish in the midstream section during the first sampling event can not or will not leave the study area between sampling events. Also, each marked fish must be individually identifiable. Each sampling event encompasses the entire study area. The following notation is used in this Appendix:

M_x = the number of fish marked in the first sampling event in Subsection x (x = 1, 2, and 3 for the downstream, midstream, and upstream subsections, respectively);

m_x = the number of fish that were marked in Subsection x during the first sampling event and still remain in one of the three subsections at the start of the second sampling event;

R_{xy} = the number of fish that were marked in Subsection x during the first sampling event and were recaptured in Subsection y during the second sampling event;

$R_{..}$ = the number of recaptures made during the second sampling event;

$R_{2.}$ = the number of recaptures made during the second sampling event of fish tagged in Subsection 2, the midstream section;

θ_z = the probability that a fish will move out of a subsection in the "z" direction (upstream or downstream);

p = the probability that a fish in the study area will be caught in the second sampling event;

Φ_z = the probability that a fish will move out of a subsection in the "z" direction (upstream or downstream) and be caught in the second sampling event (note that $\Phi_z = p\theta_z$);

C = the catch made during the second sampling event; and,

N = the abundance of fish in all the subsections at the start of the second sampling event.

The binomial joint probability density function (PDF) for the number of marked fish recaptured during the second sampling event and the number of marked fish available for recapture at the start of the second sampling event is:

Appendix 3. (continued)

$$P[R_{..},m_1,m_3] = \qquad (1)$$

$$Comb[C,R_{..}] \left[\frac{m_1+M_2+m_3}{N} \right]^{R_{..}} \left[1 - \frac{m_1+M_2+m_3}{N} \right]^{C-R_{..}} \cdot$$

$$Comb[M_1,m_1]\ \theta_d^{M_1-m_1} (1-\theta_d)^{m_1}\ Comb[M_3,m_3]\ \theta_u^{M_3-m_3} (1-\theta_u)^{m_3}$$

where $m_1+M_2+m_3$ = the number of marked fish that are still in the study area at the start of the second sampling event and where the subscripts "*d*" and "*u*" on θ denote downstream and upstream movements, respectively. Note that M_2 is used in the PDF (Eq. 1) instead of m_2 because all fish tagged in the midstream subsection are presumed unable (unwilling) to move far enough to leave the study area between sampling events. The Maximum Likelihood Estimate (MLE) of N is therefore:

$$\hat{N} = \frac{(m_1+M_2+m_3)\ C}{R_{..}} \qquad (2)$$

Because the m_x are unknown in Eq. 2, the MLE(m_x) must be used in their place. The PDF for m_1 is:

$$P[m_1] = Comb[M_1,m_1]\ (1-\theta_d)^{m_1}\ \theta_d^{M_1-m_1} \qquad (3)$$

Note that in Eq. 3, the probability $(1-\theta_d)$ of a fish marked in Subsection 1 <u>staying</u> in the study area between sampling events is the complement of the probability (θ_d) of it leaving Subsection 1 by moving downstream. Therefore the MLE(m_1) is:

$$\hat{m}_1 = M_1\ (1-\theta_d) \qquad (4)$$

The MLE(m_3) can be found in the same manner, only the upstream probability of movement is used in the calculations.

Finally, the probabilities of movement, θ_d and θ_u, can be estimated with information on recaptured fish among the subsections. The probabilities of recapturing R_{32} <u>and</u> R_{21} marked fish downstream from where they were released and R_{32} <u>and</u> R_{21} marked upstream are two binomial joint PDFs:

$$P[R_{32}]P[R_{21}] = \qquad (5)$$

$$Comb[M_3,R_{32}]\ \Phi_d^{R_{32}} (1-\Phi_d)^{M_3-R_{32}}\ Comb[M_2,R_{21}]\ \Phi_d^{R_{21}} (1-\Phi_d)^{M_2-R_{21}}$$

Appendix 3. (continued)

$$P[R_{12}]P[R_{23}] = Comb[M_1,R_{12}]\ \Phi_u^{R_{12}}(1-\Phi_u)^{M_1-R_{12}}\ Comb[M_2,R_{23}]\ \Phi_u^{R_{23}}(1-\Phi_u)^{M_2-R_{23}} \tag{6}$$

Note that Φ_d and Φ_u are each presumed to be the same for two out of the three subsections, which can only be so when the two subsections are the same size <u>and</u> when the probability of capture is the same for all fish throughout the study area. From Eq. 5 and 6, the MLEs of Φ_d and Φ_u are:

$$\hat{\Phi}_d = \frac{R_{32} + R_{21}}{M_3 + M_2} \qquad \hat{\Phi}_u = \frac{R_{12} + R_{23}}{M_1 + M_2} \tag{7}$$

To obtain estimates of Θ_d and Θ_u for substitution into Eq. 2, the following PDF is used:

$$P[R_{2.}] = Comb[M_2,R_{2.}]\ p^{R_{2.}}(1-p)^{M_2-R_{2.}} \tag{8}$$

The MLE(p) is $R_{2.}/M_2$. Remember that $\Phi_z = p\Theta_z$. Substitution of this relationship and MLE(p) into Eq. 7 gives:

$$\hat{\Theta}_d = \frac{M_2(R_{32} + R_{21})}{R_{2.}(M_3 + M_2)} \qquad \hat{\Theta}_u = \frac{M_2(R_{12} + R_{23})}{R_{2.}(M_1 + M_2)} \tag{9}$$

Substitution of Eqs. 4 & 9 into Eq. 2 gives the estimator of abundance for fish:

$$\hat{N} = \frac{\{\ M_1(1-\hat{\Theta}_d) + M_2 + M_3(1-\hat{\Theta}_u)\ \}\ (C + 1)}{R_{..} + 1} \tag{10}$$

The quantities (C+1) and ($R_{..}$+1) are substituted for C and $R_{..}$, respectively, in Eq. 2 to correct the bias in the binomial approximation of the hypergeometric probability distribution that is the actual PDF for recaptures (Bailey 1951, 1952) in Eq. 2. The exact bias of Eq. 10 is unknown, but will be measured with resampling techniques as described in Efron (1982). If this analysis shows that Eq. 10 is a biased estimator, then expectations of the joint PDFs will be used to investigate means to change Eq. 10 to correct this bias.