FISHERY DATA SERIES NO. 98

STOCK ASSESSMENT AND BIOLOGICAL CHARACTERISTICS OF BURBOT IN LAKES OF INTERIOR ALASKA DURING 1988[1]

By

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May 1989

1 This investigation was partially financed by the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under Project F-10-4, Job N-8-1.

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ABSTRACT

Abundance and/or indices of abundance of burbot *Lota lota* were estimated for populations in 23 lakes in interior Alaska. Sampling occurred from May through September, 1988. Abundance of fully recruited burbot estimated with mark-recapture experiments was greatest in Paxson Lake (3,920) and most dense in Tolsona Lake (10.6 burbot per hectare). Survival rates between years ranged from 35.2 to 82.4 percent per year for populations in Paxson, Fielding, Louise, Tolsona, Tyone, and Round Tangle Lakes. Annual recruitment of juveniles was estimated for populations in Tolsona, Fielding, Paxson, Louise, and Round Tangle Lakes. Average tag loss among all populations was 3 percent within a year and 7 percent between years. Mean catch per unit of effort of fully recruited burbot was above 1.00 burbot per 48-hour set for populations in Tolsona (5.93), Moose (6.95), Hudson (1.20), and Paxson Lakes (1.09). Seasonal declines in mean CPUE from spring to summer observed in previous years occurred during sampling in 1988. Mark-recapture study designs could be changed for deep lakes (250 feet) to reduce mortality caused by decompression without biasing resultant estimates of CPUE or abundance. Size and age composition of burbot populations varied widely among lakes with some lakes having no large burbot at all. Identifying the sex of mature burbot through inspection of gonads was difficult. Parameters in the allometric length-weight relationships for populations in Lake Louise and Tyone Lakes were estimated. Preliminary estimates of sustainable yield are provided for some populations.

KEY WORDS: Burbot, *Lota lota*, lakes, abundance, hoop traps, systematic design, stratified design, otolith, mean length, length-weight, age, catch per unit of effort, survival rates, recruitment, sustained yield.

INTRODUCTION

Since 1977, 80% of the estimated harvest of burbot *Lota lota* in Alaska has come from lakes in the Tanana River drainage and in the vicinity of Glennallen (Mills 1988). Set lines and jigs fished through the ice are the most popular gear in these sport fisheries. Harvest of burbot from 1977 to 1985 has increased annually an average 30% with the greatest harvests occurring a few years prior to 1985 (Mills 1988). However, harvest of burbot from 1986 to 1987 has increased only 1.5%. This sudden drop can be attributed to a reduction of harvest in Lake Louise from 5,810 in 1985 to 506 in 1987 (Mills 1986, 1988). In 1986, the population was 6,519 adult burbot (Parker et. al 1987). By 1987, a sport harvest of 2,954 (Mills 1988) with recruitment resulted in an estimate of 5,250 (Parker et. al 1988). Emergency regulations adopted in 1987 reduced the area bag and possession limit for burbot to five fish and reduced the total number of hooks fished to five. The regulations were effective in reducing the harvest to 506 adult burbot in 1987 (Mills 1988) and, with recruitment, the population stabilized at a level of 5,250 burbot in 1988.

The purpose of this project is to assess the stock status of burbot populations in lakes in interior Alaska and gather biological information germane to the productivity of these populations. Information from this project will be used to estimate a range of harvest levels through which these stocks can be maintained. Preliminary statistics from 1988 and data collected in earlier years by this project were used to change regulations for burbot populations in the Glennallen area. The analysis of these data to estimate sustained yields from these populations are described in a memorandum in the Appendix. The objectives for work in 1988 are to estimate:

1. mean Catch Per Unit of Effort (CPUE) of burbot in 25 lakes as an index of abundance;

2. abundance of burbot in several lakes;

3. mean total length (TL) of captured burbot in 25 lakes;

4. mean length at age of burbot in several populations;

5. parameters in the length-weight relationships of burbot in several lakes; and

6. annual survival rates and growth rates in populations sampled in 1986, 1987, and 1988.

The study lakes in the Tanana River drainage were Fielding, Harding, T, George, Sevenmile, Round Tangle, Shallow Tangle, Upper Tangle, Glacier, Jatahmund, Takomahto, American Wellesley, and Fish lake (Figure 1). The study lakes near Glennallen were Susitna, Crosswind, Hudson, Sucker, Tyone, Moose, Tolsona, Summit, Beaver, Jack, Paxson, and Lake Louise (Figure 1). Each population chosen for this study has (or had) a popular sport fishery

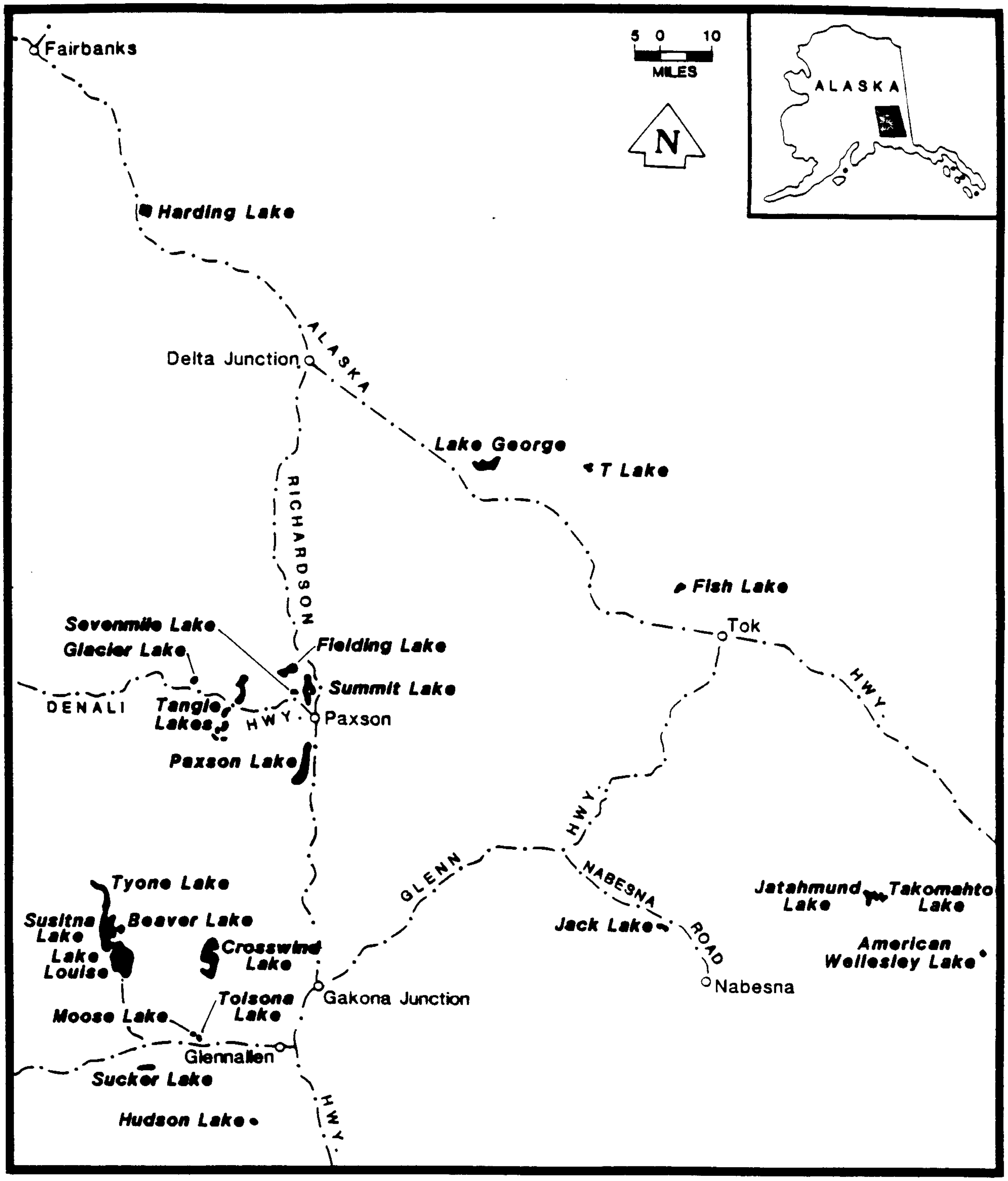

Figure 1. Location of lakes in the Tanana River drainage and near Glennallen that were included in studies of burbot populations in interior Alaska in 1988.

for burbot (according to statistics reported in Mills 1987) or is reasonably accessible to anglers. More detailed descriptions of each study lake are in the Appendix.

METHODS

Gear Description

Burbot were captured in hoop traps 3.05 m long with seven 6.35 mm steel hoops (Figure 2). Hoop diameters taper from 0.61 m at the entrance to 0.46 m at the cod end. Each trap has a double throat (tied to the first and third hoop) which narrows to an opening 10 cm in diameter. All netting is knotted nylon woven into 25 mm bar mesh, held together with No. 15 cotton twine, and treated with an asphaltic compound. Each trap was kept stretched with two sections of 12 mm galvanized steel conduit attached by snap clips to the end hoops. A numbered buoy was attached to the cod end of the trap with polypropylene rope. Each trap was baited with Pacific herring *Clupea harengus pallasi* cut into chunks and placed in a 500 ml perforated plastic, screw-top container. Bait containers were placed unattached in the cod end.

Study Design

Mean CPUE was estimated on 23 lakes with a stratified-systematic survey design (Table 1). First, an overlay with parallel lines was placed across a map of the lake at a randomly chosen position but with the lines in the overlay perpendicular to the long axis of the lake. Distances between adjacent lines[1] in the overlay represented 125 m. Each parallel line had tick marks that represented a distance of 125 m. Next, the desired number of sets was compared with the tick marks that were over the water on the map; parallel lines were randomly excluded until the tick marks and the desired number of sets were similar. Traps were set in transects corresponding to the position of each remaining parallel line. However, the location of the first set along each transect was randomly chosen with every subsequent set along that transect at 125 m. When no mark-recapture experiment was conducted simultaneously with the survey, the desired number of sets for each lake and each survey design was chosen according to the rules in Cochran (1977); last year's estimates and "guesstimates" were used as the *a priori* knowledge of mean CPUE needed to chose sample sizes. When mark-recapture experiments were conducted simultaneously with surveys, the sample sizes in fish were calculated according to rules in Robson and Regier (1964) for sample size in mark-recapture experiments.

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[1] The distance of 125 m between traps was chosen to eliminate gear competition. The effective fishing area of a baited trap was estimated at 0.45 ha by dividing the average CPUE in burbot caught per 48-hour set in 1985 in Fielding Lake by the density of burbot per ha from the mark-recapture experiment (Pearse and Conrad 1986). This estimated fishing area was arbitrarily increased to 1.25 ha to ensure elimination of gear competition; this area corresponds to traps set at a distance of 125 m.

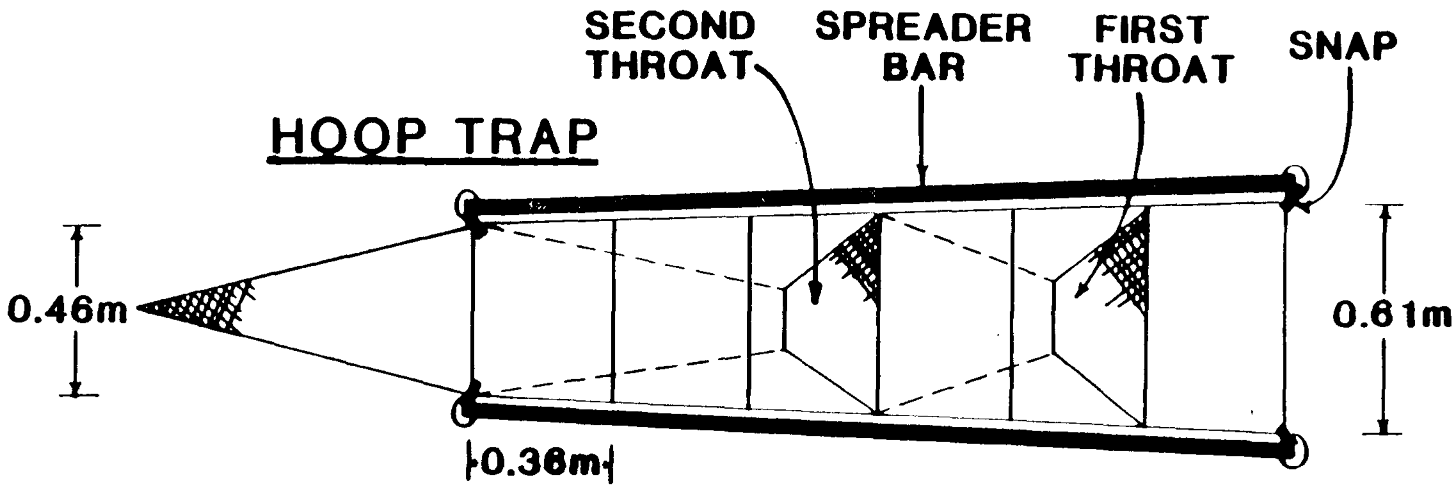

Figure 2. Schematic drawing of hoop traps used to catch burbot in interior Alaska in 1988.

Table 1. Numbers of sets and dates of sampling events for the stock assessment of burbot populations in 25 lakes in interior Alaska in 1988.

Lake	Area (ha)	Sampling: Event	Sampling: Dates	Number of Sets
American Wellesley	365	1	8/9-15	198
Fielding	538	1	6/29-7/2	178
		2	7/27-31	180
Fish	485	1	8/8-12	80
George	1,863	1	5/24-31	240
Glacier	172	1	7/13-18	180
Harding	1,000	1	9/26-30	180
Jatahmund	975	1	8/9-16	199
Paxson	1,575	1	6/22-30	416
		2	7/19-27	420
Round Tangle	155	1	6/15-19	119
Sevenmile	34	1	6/21-23	40
		2	7/17-19	40
Shallow Tangle	130	1	6/13-16	119
Summit	1,651	1	7/9-11	239
Upper Tangle	142	1	6/18-22	176
Beaver	323	1	6/27-7/1	175
		2	9/22-9/26	178
Crosswind	3,238	1	7/23-7/26	228
Hudson	259	1	7/13-7/18	123
		2	9/29-10/3	125
Jack	150	1	9/8-9/13	240
Louise	6,519	1	6/11-6/26	917
Moose	130	1	5/24-5/26	63
		2	9/16-9/18	60
Sucker	283	1	8/2-8/7	233
		2	9/30-10/4	180
Susitna	3,816	1	6/11-6/26	957
Tolsona	130	1	5/25-5/27	59
		2	9/1-9/3	60
Tyone	389	1	6/7-6/13	186
T	162	1	5/17-21	80
Takomahto	225	1	8/10-14	98
TOTALS	24,709		5/17-10/4	6,966

Traps were set and retrieved during daylight hours beginning on one end of the lake progressing to the other end. In the larger lakes, multiple crews (three members per crew: one person piloted the boat and recorded data while the other two handled traps and took biological information from captured burbot) set and retrieved traps simultaneously. In smaller lakes, single crews set and/or retrieved 50 to 80 traps per eight-hour day. The time of setting and retrieving each set was recorded to the minute. The depth of each set was measured with a fathometer. Each hoop trap was fished approximately 48 hours (a set) to optimize catch (Pearse and Conrad 1986). Each new set received fresh bait. Old bait was discarded on shore.

Burbot were placed in a plastic tank during sampling. Each burbot was measured and those longer than 300 mm TL were marked by removal of the pelvic or dorsal fin and tagged with an anchor-type, individually numbered Floy tag inserted at the base of the dorsal fin. Burbot that exhibited stress from deep-water removal (usually an expanded gas bladder) or trap-inflicted injury were killed and subsequently weighed and dissected. Otoliths were removed and the sex and maturity of these fish recorded. Ages of burbot were estimated from whole, polished otoliths by counting annuli.

Burbot were divided into two groups for analysis: those fully recruited to the sampling gear (≥450 mm TL) and those partially recruited (<450 mm TL). Analysis of probability of capture of burbot (Parker et al. 1987, 1988) in hoop traps showed that in most populations burbot became fully recruited to the gear between 450 and 500 mm TL. Although there were some exceptions to this rule, arbitrarily dividing the population into these size groups negligibly biased estimated statistics for these exceptions.

<u>Abundance, Survival Rates, and Recruitment</u>

For those populations with two sampling events in 1988 less than 4 weeks apart (populations in Paxson, Sevenmile, and Fielding Lakes), the abundance of burbot was estimated with mark-recapture experiments based on the Chapman modification of the Petersen method (see Seber 1982):

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

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

where:

- N = abundance;
- M = number of marked burbot released alive into the populations during the earlier sampling event;
- C = number of burbot caught in the later sampling event; and
- R = number of burbot marked in the earlier event and recaptured during the later event.

With one exception, abundance in mark-recapture experiments with two events in 1988 separated by more than 4 weeks (experiments in Hudson, Sucker, Moose, and Tolsona Lakes) was estimated with the techniques of Jolly (1965) and Seber (1965):

3) $$\hat{M}_{i,i+1} = \frac{R_{i,i+2}M_{i+1}}{R_{i+1,i+2}} + R_{i,i+1} + D_{i,i+1}$$

where:

- M_s = number of marked burbot released alive into the population during sampling event "s";
- $M_{s,t}$ = number of marked burbot released alive into the population during sampling event "s" that are still alive just prior to sampling event "t";
- $R_{s,t}$ = number of marked burbot released in sampling event "s" and recaptured during event "t"; and
- $D_{s,t}$ = number of marked burbot released in sampling event "s", recaptured during event "t", and not returned to the population (usually due to death).

Since all of these populations had mark-recapture experiments in 1987 as well as in 1988, survival rates and recruitment were estimated for these populations as well. The estimate of the survival rate between sampling events "s" and "t" was calculated as:

4) $$\hat{S}_{i,i+1} = \frac{\hat{M}_{i,i+1}}{M_i}$$

Abundance and recruitment were estimated as follows:

5) $$\hat{N}_i = \frac{C_i\hat{M}_{i-1,i}}{R_{i-1,i}}$$

6) $$\hat{A}_{i-1,i} = \hat{N}_i - \hat{N}_{i-1}\hat{S}_{i-1,i}$$

where:

- N_t = abundance just prior to sampling event "t";
- C_t = number of burbot captured during sampling event t; and
- $A_{s,t}$ = number of recruits added to the population between sampling events "s" and "t".

The procedures are based on the same assumptions as is the Petersen method, except that mortality and recruitment are permitted between sampling events.

The statistics in Equations 4-6 (and their variances) were calculated with the program JOLLY as described in Pollock et al. (1985) and Brownie et al. (1986).

For those populations that have been in the stock assessment program since 1986 and earlier, a combination of methods, Jolly-Seber and Petersen, was used to extend the range of estimates according to the approach suggested in Pollock (1982). Since Jolly-Seber methods are unbiased only for situations with large sample sizes and with large numbers of recaptured fish (Gilbert 1973), sampling events separated by 4 weeks or less were pooled into one, annual event for all years but 1988. Then Jolly-Seber methods were used to estimate survival rates for all years but 1988, abundance <u>during</u> all years but 1988 and the first, and recruitment <u>between</u> 1987 and the first. In those instances when an abundance estimate was available for the first year, a population was in the stock assessment program, the abundance estimate was used to produce an estimate of recruitment between the first 2 years of the program with Equation 6. The variance of estimated recruitment was calculated as follows (see Goodman 1960):

$$7)\qquad V[\hat{A}_{o,1}] = V[\hat{N}_1] + V[\hat{N}_o]\hat{S}_{o,1}^{\,2} + \hat{N}_o^{\,2}V[\hat{S}_{o,1}] - V[\hat{N}_o]V[\hat{S}_{o,1}]$$

The one exception mentioned above concerned the population of burbot in Beaver Lake. Work in 1988 was the first stock assessment for this population, and both sampling events were separated by about 12 weeks. Therefore, the methods of Robson and Flick (1964) were to be used to estimate the number of burbot that had grown into the population between sampling events.

Due to higher rates of recapture for burbot greater than 450 mm TL, than those less than 450 mm TL, estimates of abundance for mark-recapture experiments and mean CPUE were generated for both size classes in 18 lakes sampled. However, high elevation lakes, such as Round Tangle, Shallow Tangle, Upper Tangle, Sevenmile, and Glacier Lakes do not have distinguishable size classes of burbot, and thus are regarded as single size populations.

<u>Mean CPUE</u>

Mean CPUE was calculated for partially (<450 mm TL) and fully recruited burbot (≥450 mm TL) in 23 populations during 33 sampling events according to a two-stage sampling design (Sukhatme et al. 1984) with transects as primary units and sets along transects as secondary units. Although all transects had an equal probability of being chosen for a survey, they were of different sizes depending upon the shape of the lake. Under these conditions, the following equation was used to calculate unbiased estimates of mean CPUE:

$$8)\qquad \overline{CPUE} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m_i} x_{ij}}{\sum_{i=1}^{n} m_i}$$

where:

x = catch during each set;
n = number of transects; and
m = number of sets on a specific transect.

Catch was not adjusted for sets with soaks a few hours different from 48 hours because burbot rarely enter traps during the daylight hours (Pearse and Conrad 1986).

The formula for calculating the variance of estimates from Equation 8 requires knowledge of the maximum number of sets (secondary units) in each lake (Cochran 1977; Sukhatme et al. 1984). Because the exact "area" that the average trap fished is unknown, the maximum possible number of sets is not known. Since the variances for estimates from Equation 8 could not be calculated, estimates of mean CPUE based on arithmetic means and their variances were calculated even though they are slightly biased:

$$9)\qquad \overline{CPUE} = \bar{\bar{x}} = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{m_i}\sum_{j=1}^{m_i} x_{ij}$$

$$10)\qquad V[\overline{CPUE}] = \sum_{i=1}^{n}\frac{(\bar{x}_1 - \bar{\bar{x}})^2}{n\,(n-1)} + \sum_{i=1}^{n}\sum_{j=2}^{m_i}\frac{(x_{ij} - x_{i,j-1})^2}{2\,n^2\,m_i\,(m_i - 1)}$$

Equation 10 was composed of elements taken from Sukhatme et al. (1984) for two-stage sampling with primary units of equal size (variance among transects) and from Wolter (1984) for unbiased estimation of variance from systematically drawn samples (variance within transects). The x_{ij} were arranged in serial order along transects for these calculations. In the instance where data from a set are missing, the transect was redefined into smaller transects with contiguous sets. Because the exact "area" that the average trap fished is unknown, the maximum possible number of sets is also unknown, therefore, finite population correction factors were excluded from Equations 10, 14, and 15 and the following formulae for calculating variances.

Estimates of mean CPUE were post-stratified by depth according to procedures described in Sukhatme et al. (1984) and Pearse and Conrad (1986):

$$14)\qquad \overline{CPUE}_{st} = \sum_{h=1}^{L} W_h\,\overline{CPUE}_h$$

$$15)\qquad V[\overline{CPUE}_{st}] = \sum_{h=1}^{L} W_h\,V[\overline{CPUE}_h] + \sum_{h=1}^{L}\frac{(1-W_h)V[\overline{CPUE}_h]}{n}$$

where:

L = the number of strata; and
W_h = ratio of the area covered by stratum h to the area of the lake.

Average catch by depth was plotted for each sampling event in which 20 or more burbot were captured. Depths at which average catch by depth changed dramatically in these plots were chosen as the boundaries between strata. The weights (W_h) were calculated as averages over the years of the fractions of sets that had been within each depth stratum.

When a boundary between strata cut across a transect in the systematic design, each part of the dissected transect was considered a new transect, each within its separate stratum. In those cases where such a new transect consisted of only one set, that datum was excluded from the analysis.

Stratified estimates of mean CPUE were calculated in all instances where average catch by depth changed dramatically. In these instances, unstratified estimates were calculated as well. If the two estimates (stratified and unstratified) were dissimilar by an amount greater than the arbitrary standard of half the standard error of the larger estimate, the stratified estimate was reported as the more accurate estimate. Otherwise, the unstratified estimate was given.

Length and Weight

Parameters of allometric length-weight relationships for burbot were estimated with a computer program that iteratively "fits" nonlinear models to bivariate data. The algorithm of the program follows the Marquardt compromise (Marquardt 1963). Fifty-five separate sets of estimates of the parameters were calculated with each calculation beginning with a new set of initial values. The initial values of the allometric constant ranged from 2.0 to 4.0 by increments of 0.2; the initial values of the linear constant ranged from 4.0 to 12.0 by increments of 2.0. The output from all 44 operations was an isopleth diagram of the sums of squares of the residuals arising from each operation and the set of estimates which corresponded to the lowest sums of squares.

RESULTS

Length Distributions

Of the seven burbot populations sampled twice in 1988, five had significantly different length distributions (Kolmogorov-Smirnov Two-sample Test, $\alpha = 0.05$) (Figure 3). Length distributions of burbot in Paxson and Fielding Lakes shifted towards smaller burbot from June to July. From May to September, length distributions for samples from Moose Lake and from nearby Tolsona Lake shifted towards larger fish. From August to September, length distributions for samples from Sucker Lake shifted towards larger fish. All length distributions from these populations had ascending left limbs. Distributions for

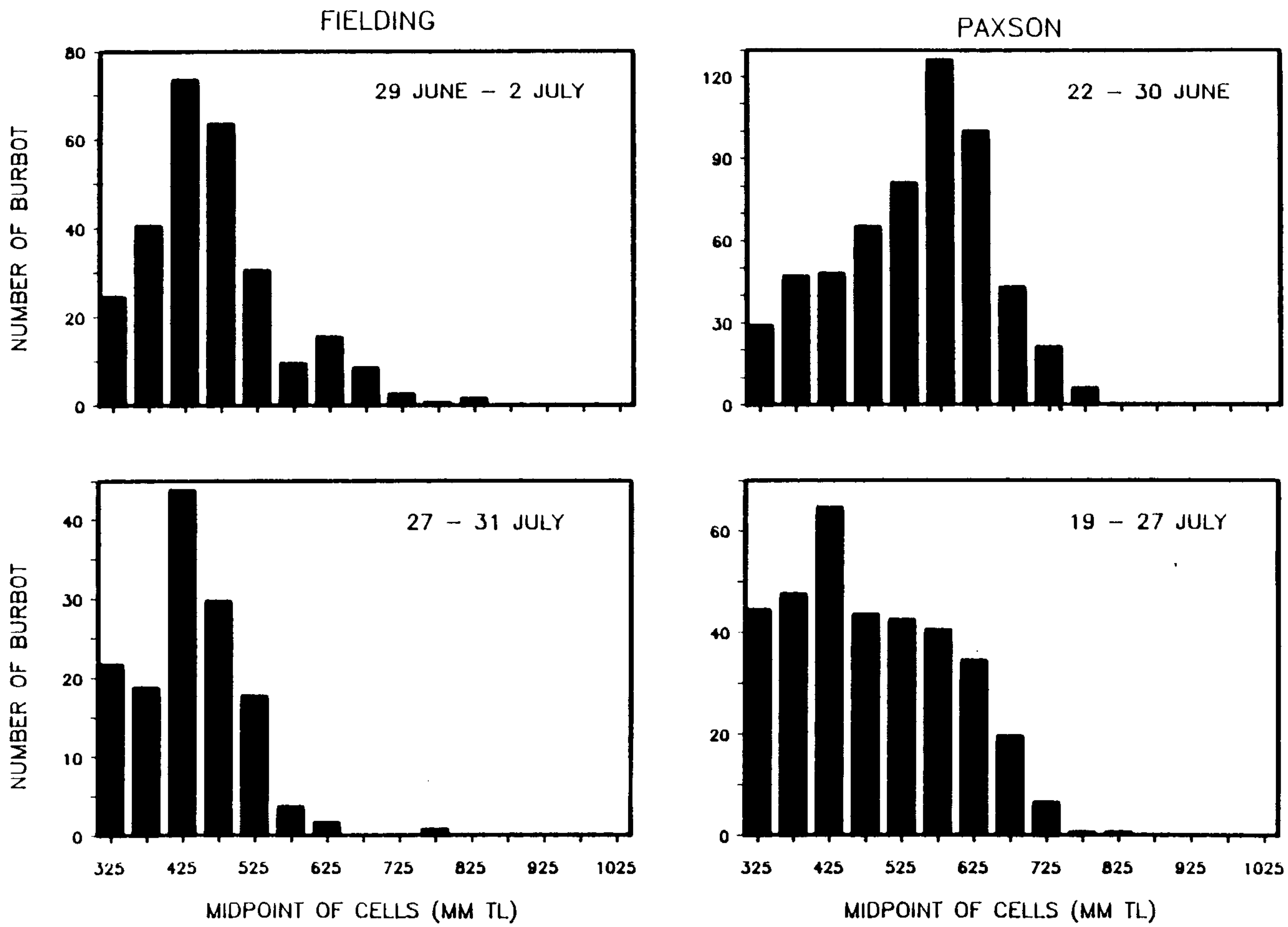

Figure 3. Length-frequency histograms of burbot captured during each sampling event in 1988 in which size distributions were significantly different by event ($\alpha = 0.05$).

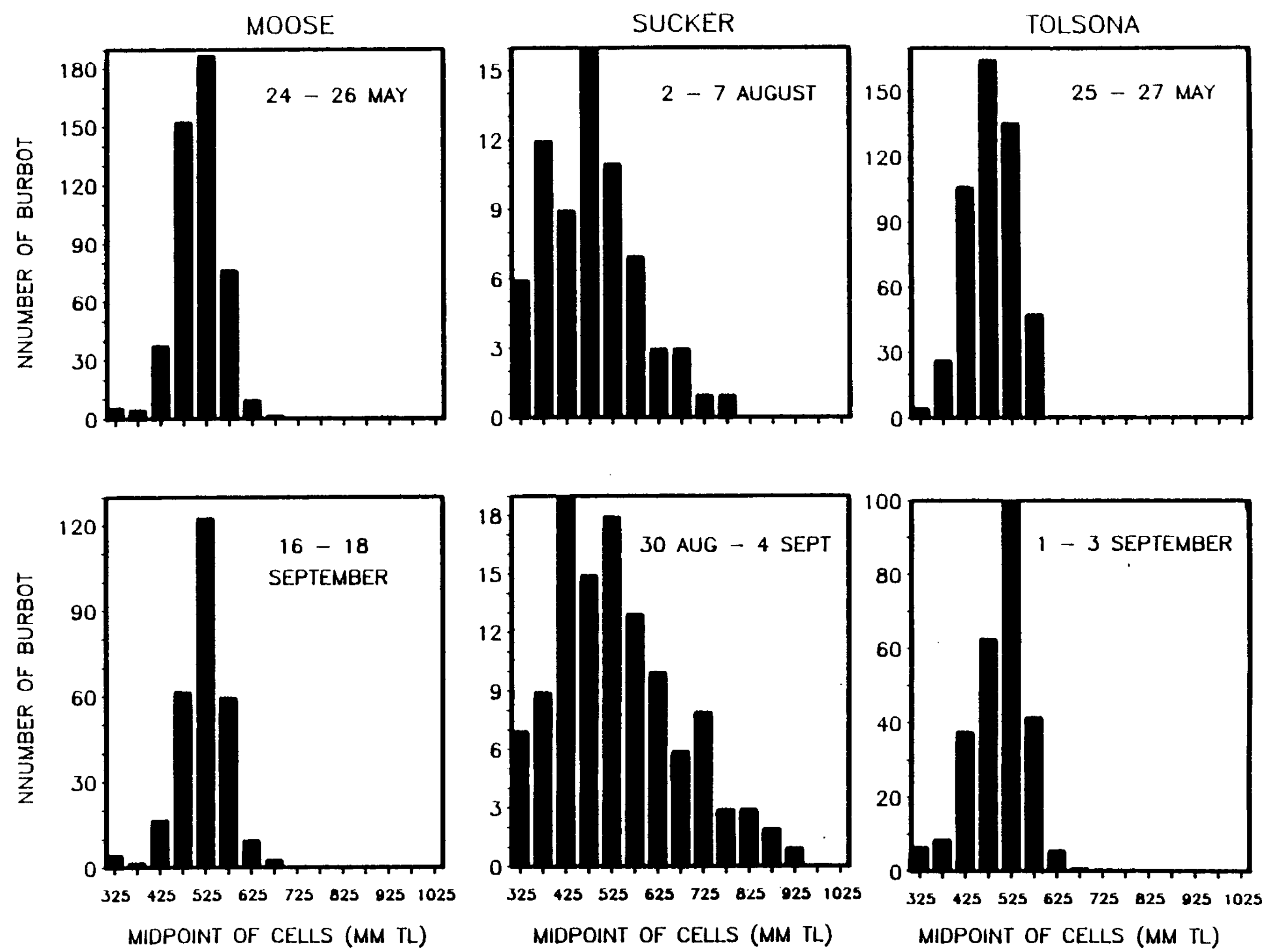

Figure 3. Length-frequency histograms of burbot captured during each sampling event in 1988 in which size distributions were significantly different by event (α = 0.05) (continued).

populations all had modes between 400 and 500 mm TL except for populations from Paxson (June), Tolsona (September), and Moose.

All other populations, except for those near the Denali Highway and Harding Lake, had length distributions with ascending left limbs (Figure 4). Modes ranged from 600 to 650 mm TL for populations in Lake Louise and Jatahmund Lake, 700 to 750 mm TL for the population in American Wellesley Lake, and 400 to 550 mm TL for populations in Beaver, Jack, Crosswind, Hudson, Susitna, Summit, T, and Tyone Lakes. The length distribution from George Lake was bimodal 750 to 800 and 550 to 600 mm TL. As in previous years (Parker et al. 1987, 1988), length distributions for populations in Upper Tangle, Round Tangle, Shallow Tangle, and Sevenmile Lake had no ascending left limbs. No burbot were caught in Fish Lake.

Abundance

All of the burbot populations studied in 1988 were geographically isolated or separated by lengthy rivers except for populations in (1) Louise, Susitna, and Tyone Lakes; (2) Upper, Round, and Shallow Tangle Lakes; and (3) Summit and Paxson Lakes. Lakes in these three complexes are joined directly or by short rivers. Recovery of tagged burbot in these lake complexes showed that burbot travelled between connected lakes. Three burbot released in Tyone Lake in 1986 were recaptured in Susitna Lake in 1987. All three burbot were recaptured near the strait that connects the two lakes. Another burbot, tagged during the first sampling event in Shallow Tangle Lake in 1987, was recaptured in Round Tangle Lake in the second sampling event of the same year. Also, two burbot released in Round Tangle Lake in 1987 were recaptured in Upper Tangle Lake in 1988. These fish were not considered recaptured fish in the mark-recapture experiments. No marked burbot released in Summit or Paxson Lakes have been recaptured elsewhere.

Even though 54 burbot of all sizes lost their tags, they were identified as recaptured fish by their clipped fins (Table 2). The loss rate was 3.9% between sampling events in the same year pooled over all populations. The loss rate was higher between sampling events separated by a winter (7.2%). The loss rate over two winters was 7.4%. There was no evidence of regenerated fins on any of the recaptured burbot with tags.

During the first sampling events in 1988, there were an estimated 3,920 burbot ≥450 mm TL in Paxson Lake, 356 in Fielding Lake, none in Sevenmile Lake (Table 3), and 1,271 in Tolsona Lake (Table 4). Tolsona Lake had the highest density (10.6 fully recruited burbot per ha) (Table 5). Although the population in Sevenmile Lake had no "fully recruited" burbot, there were an estimated 109 partially recruited burbot. There are multiple estimates of abundance for fully recruited burbot in Moose (4,141 to 4,954) and Hudson Lakes (2,953 to 7,185) because of tag loss and uncertainty corresponding to specific secondary marks (missing fins) (Table 6; Appendix Table 5). An unbiased estimate of abundance is unavailable for the population in Beaver Lake because too few burbot were recaptured to use the techniques of Robson and Flick (1965) to cull summer recruits from the stock.

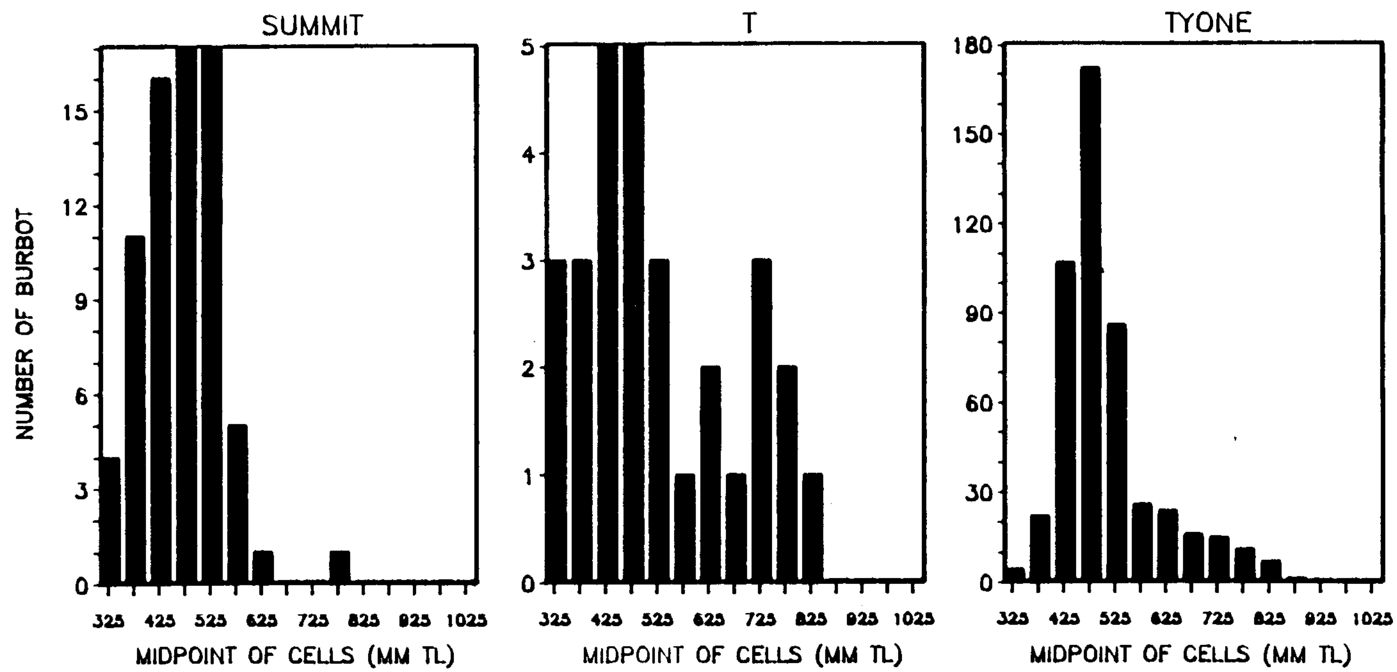

Figure 4. Length-frequency histograms of burbot captured during all sampling events in 1988 in which size distributions were not significantly different ($\alpha = 0.05$).

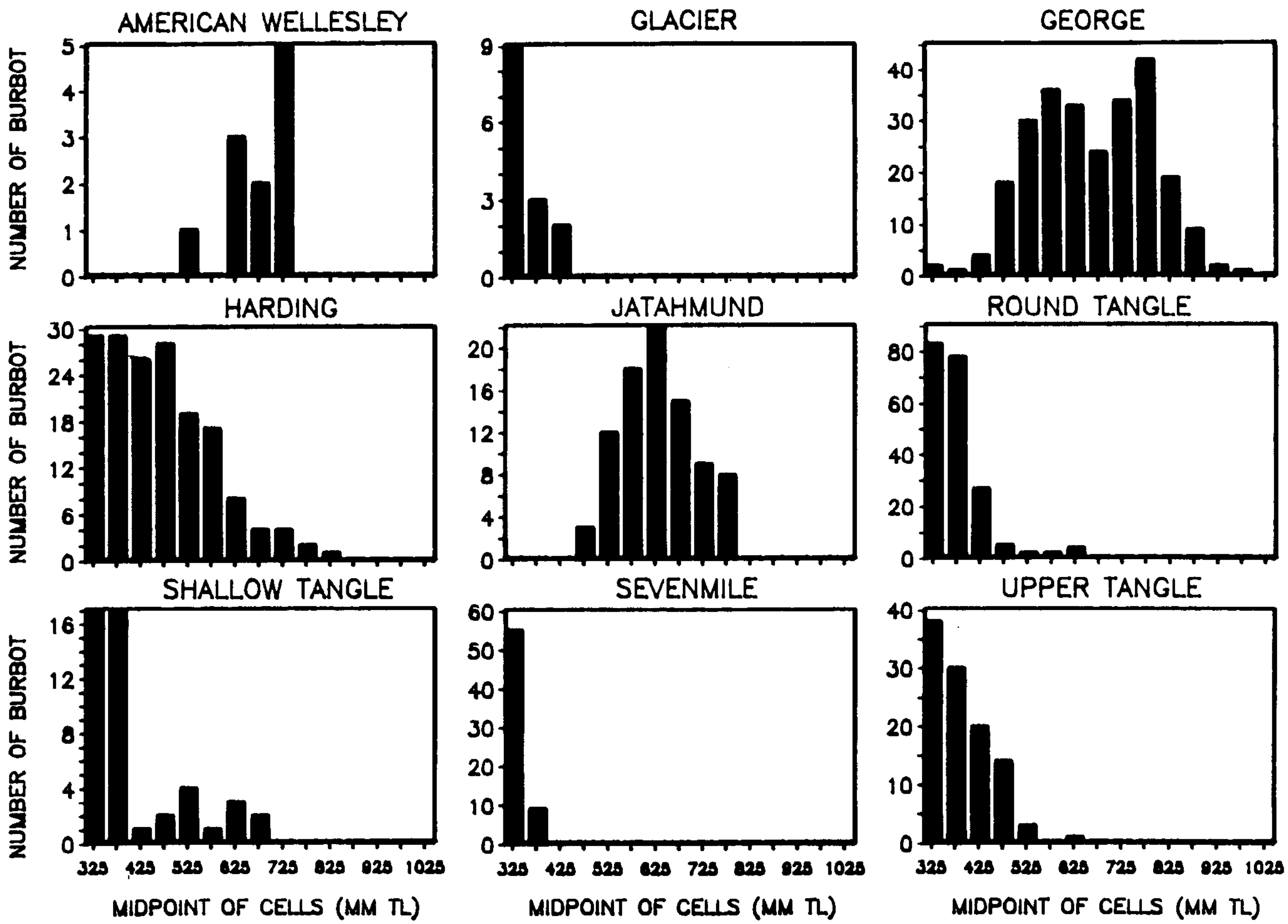

Figure 4. Length-frequency histograms of burbot captured during all sampling events in 1988 in which size distributions were not significantly different ($\alpha = 0.05$) (continued).

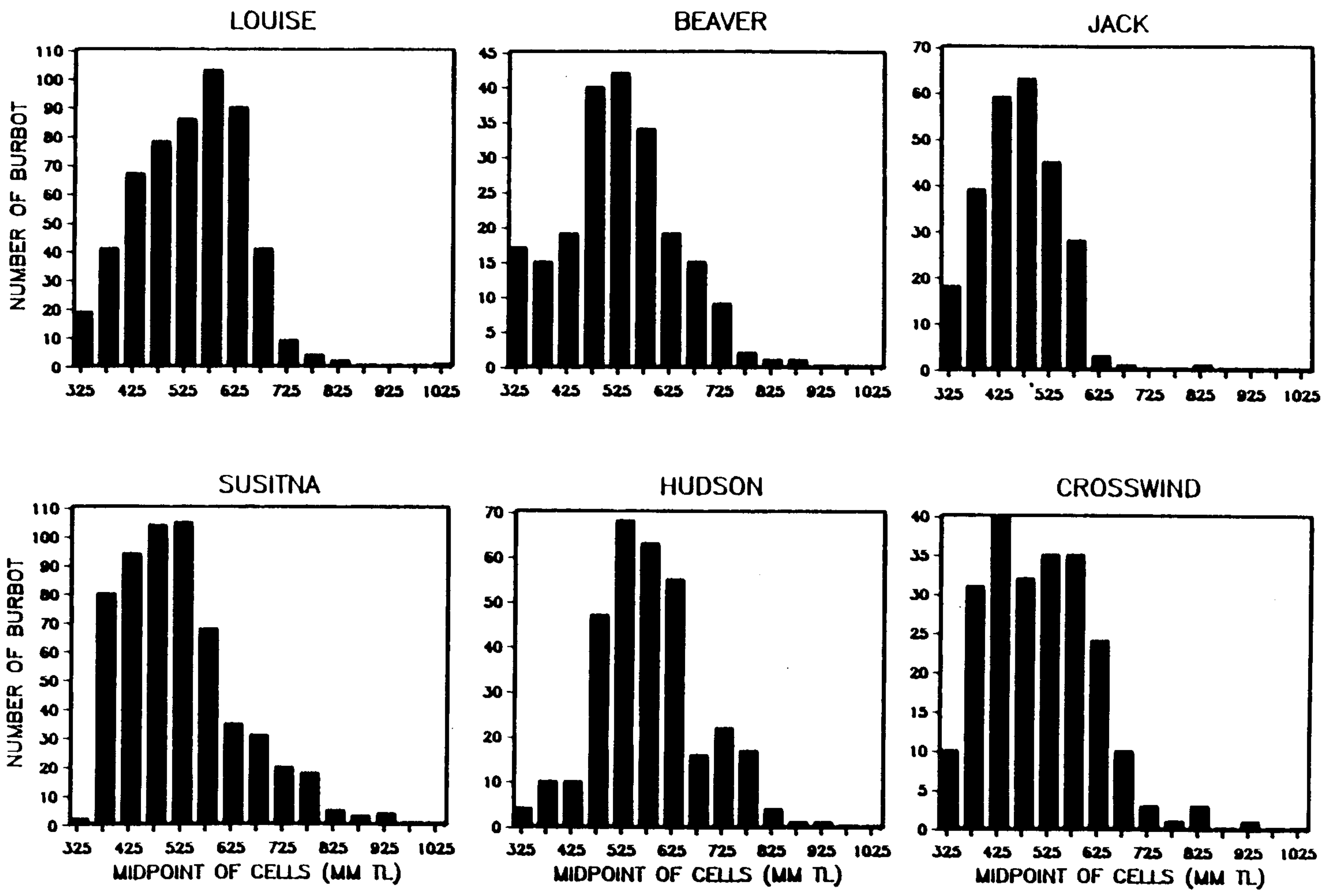

Figure 4. Length-frequency histograms of burbot captured during all sampling events in 1988 in which size distributions were not significantly different ($\alpha = 0.05$) (continued).

Table 2. Rates of tag loss for burbot in interior Alaska.

	During Summer				Overwinter				Two years (1986 - 1988)			
Lakes	Recaptured w/o Tags	Recaptured All	Fraction w/o Tags	SE	Recaptured w/o Tags	Recaptured All	Fraction w/o Tags	SE	Recaptured w/o tags	Recaptured all	Fraction w/o Tags	SE
Crosswind												
Fielding	2	57	0.035	0.025	9	109	0.083	0.026	2	52	0.038	0.027
George					2	7	0.286	0.184				
Harding					3	28	0.107	0.060	0	10	0.000	0.000
Paxson	2	83	0.024	0.017	6	125	0.048	0.019	5	71	0.070	0.036
Round Tangle					3	27	0.111	0.062	2	11	0.181	0.121
Sevenmile	0	13	0.000	0.000	1	10	0.100	0.100	0	8	0.000	0.000
Shallow Tangle					2	5	0.400	0.245	1	1	1.000	0.000
Summit					3	11	0.273	0.141	0	3	0.000	0.000
T					2	14	0.143	0.097	0	2	0.000	0.000
Tolsona	3	26	0.115	0.064	1	113	0.009	0.009				
Upper Tangle					2	19	0.105	0.072	2	5	0.400	0.021
Louise					1	19	0.053	0.053				
TOTAL	7	179	0.039	0.015	35	487	0.072	0.012	12	163	0.074	0.021

Table 3. Estimated abundance (N) of burbot partially and fully recruited[1] to sampling gear from lakes in interior Alaska in 1988.

Lake	Size	Number of Marked Burbot Released	Number Caught Second Event	Number Recaptured	$\hat{N}$	SE[$\hat{N}$]	CV[$\hat{N}$][2]
Paxson	fully	389	200	19	3,920	812	20.7%
	partially	74	151	2	3,800	1,881	49.5%
Fielding	fully	139	55	21	356	58	16.3%
	partially	130	86	10	1,028	277	27.0%
Sevenmile	fully	0	0	0			
	partially	30	34	9	109	28	27.6%

[1] For all populations, burbot ≥ 450 mm TL were considered fully recruited to the gear while smaller fish were considered to be partially recruited.

[2] Coefficient of variation.

Table 4. Estimates of survival rates, recruitment, and abundance from Jolly-Seber and other methods for six populations of burbot (longer than 449 mm TL) from interior Alaska.

	Date and Abundance	Recruitment	Survival Rate	Date and Abundance	Recruitment	Survival Rate	Date and Abundance	Recruitment	Survival Rate	Date and Abundance	Recruitment	Survival Rate	Date and Abundance
FIELDING	10/5/84		355 days	9/25/85		332 days	9/2/86		325 days	7/24/87		341 days	6/30/88[1]
Estimate	N/A		55.1%	276	185	54.0%	322	38	61.2%	209	190	74.0%	328
SE			10.3%	69	67	6.4%	56	31	6.9%	24	50	15.6%	74
TOLSONA	10/2/86		237 days	6/3/87		348 days	5/26/88						
Estimate	1,901	138	63.1%	1,338	467	58.9%	1,271						
SE	120	209	6.1%	157	122	8.5%	194						
PAXSON	7/10/86		365 days	7/10/87		336 days	6/26/88						
Estimate	9,111	(1,787)	55.7%	3,288	875	82.3%	3,552						
SE	1,996	1,392	7.7%	483	446	21.7%	957						
LOUISE	6/27/86		381 days	7/13/87									
Estimate	6,990	1,864	35.2%	4,324									
SE	2,131	2,032	11.9%	1,714									
TYONE	7/20/86		392 days	8/16/87									
Estimate	N/A		67.0%	2,426									
SE			39.1%	1,653									
ROUND[2] TANGLE	8/05/86		370 days	8/10/87									
Estimate	1,241	332	40.5%	834									
SE	379	466	14.9%	364									

1 Date of the middle of each sampling event or group of sampling events.

2 Statistics for the population in Round Tangle Lake are for burbot larger than 299 mm TL.

Table 5. Estimated density of burbot in six lakes in interior Alaska during 1988.

Fully Recruited[1]			Partially Recruited		
Lake	Number per ha	SE	Lake	Number per ha	SE
Tolsona	10.6	1.6	Paxson	2.4	1.2
Paxson	2.5	0.5	Fielding	1.9	0.5
Fielding	0.7	0.1	Sevenmile	3.2	0.8

[1] For all populations, burbot $\geq$ 450 mm TL were considered fully recruited to the gear while smaller fish were considered to be partially recruited.

Table 6. Possible extremes in estimates of survival rates, recruitment, and abundance for fully recruited burbot ($\geq$450 mm TL) in mark-recapture experiments compromised through tag loss and uncertainty on the timing of secondary marks.

	Date and[1] Abundance	Recruitment	Survival Rate	Date and Abundance
		———346 days	———	———5/24/88
		2,690	63.2%	4,141
MOOSE	6/12/87	1,017	12.4%	962
Estimate	2,296			
SE	264	3,219	75.6%	4,954
		1,294	16.1%	1,225
		———357 days	———	———7/15/88
		1,459	40.7%	2,953
HUDSON	6/27/87	1,917	20.8%	1,740
Estimate	3,671			
SE	705	3,548	99.1%	7,185
		6,448	74.6%	5,819

[1] Estimates for 1987 were obtained from Parker et al. (1988).

The overwinter and annual survival rates of fully recruited burbot between 1987-1988 ranged from an estimated 35.2% in Lake Louise to 82.3% in Paxson Lake, while estimated recruitment ranged from 190 fish in Fielding Lake to 875 in Paxson Lake during the same period (Table 2). The SEs for all of the estimates were below 12% except for the rates in Tyone (1986-1987), Paxson (1987-1988), and Fielding Lakes (1987-1988). The survival rate from 1986-1987 for the population of all burbot ≥300 mm TL in Round Tangle Lake was 40.5% (SE=14.9%). The estimated overwinter recruitment to the population in Paxson Lake from 1987-1988 was 875 fish ≥ 450 mm TL (SE=446) while that during the previous year was negative (-1,787 with a SE=1,392). Estimated survival rates and recruitment for populations in Moose Lake and Hudson Lakes were compromised by tag loss and uncertainty corresponding to specific secondary marks (missing fins) (Table 6; Appendix Table 5). Mark-recapture histories for all other populations are in Appendix Tables 1-4.

Mean CPUE

Because abundance estimates were split into partially and fully recruited burbot, so too were estimates of mean CPUE. Mean CPUE ranged from 6.95 fully recruited burbot per set in Moose Lake in late May to 0.05 in American Wellesley Lake in mid August (Table 7). No fully recruited burbot were caught in Sevenmile Lake. Mean CPUE for partially recruited burbot ranged from 2.37 in Tolsona Lake in late May to 0.07 in Hudson Lake in mid July (Table 8). For those populations where recruitment to the gear was not considered (Table 9), mean CPUE ranged from 0.07 in Glacier Lake in mid July to 1.12 in Round Tangle Lake in mid June. Studies were aborted at George Lake and no unbiased estimates of mean CPUE are available for that population. No burbot were caught in Fish Lake. Post-stratification of CPUE by depth was tried for fully recruited burbot in Jatahmund Lake and for partially recruited burbot captured in Louise and Susitna Lakes and during the first sampling events in Beaver Lake. Since post-stratification did not significantly change estimates of mean CPUE for any of the populations, the unstratified estimates are listed in Tables 7 and 8. Potential loss in precision from post-stratification was discussed in Parker et al. (1988). Frequency of sets by depth and of average catch by depth of fully and partially recruited burbot are in Appendix Figures 1-11 for all lakes.

Age and Length

Mean length of fully and partially recruited burbot varied among lakes and among sampling events in lakes (Table 10). On average, George and American Wellesley Lakes contained the largest burbot fully recruited to the gear over both events (667 and 660 mm TL, respectively). Jatahmund, T, Sucker, and Hudson Lakes contained the next largest (626, 602, 599, 598 mm TL, respectively) and Upper Tangle Lake contained the smallest of the fully recruited burbot (490 mm TL). No burbot ≥450 mm TL were captured in Sevenmile and Glacier Lakes. All the estimates of mean lengths of fully recruited burbot based on large sample sizes were similar between sampling events in the same lake.

Age and sex composition and mean length at age were reported for populations for which at least 10 fish were sampled (Table 11). Standard errors for

Table 7. Estimated mean CPUE of burbot fully recruited (≥450 mm TL) to the sampling gear from stratified and unstratified systematic sampling events in most[1] populations studied in 1988.

Lakes and Dates	Strata	Number of Sets and	Transects	Mean CPUE Unbiased	Biased	%Δ	SE	CV
American Wellesley								
	All depths	192	36	0.05	0.03	-34.8%	0.02	51.6%
Beaver								
	All depths	173	19	0.43	0.40	-6.6%	0.08	20.9%
	All depths	177	20	0.48	0.54	13.1%	0.11	19.6%
Crosswind								
	All depths	242	30	0.58	0.53	-9.2%	0.09	16.7%
Fielding								
	All depths	178	31	0.80	0.76	-6.0%	0.14	18.2%
	All depths	180	32	0.31	0.28	-9.2%	0.06	22.5%
Harding								
	All depths	180	11	0.49	0.46	-6.3%	0.10	21.6%
Hudson								
	All depths	123	14	1.14	1.08	-5.2%	0.17	15.3%
	All depths	124	15	1.20	1.19	-0.7%	0.13	11.2%
Jack								
	All depths	239	36	0.59	0.55	-6.4%	0.09	15.1%
Jatahmund[2]								
	All depths	*199*	*23*	*0.43*	*0.41*	*-4.9%*	*0.12*	*27.8%*
Louise								
	All depths	900	66	0.58	0.58	0.3%	0.07	11.7%
Moose								
	All depths	62	13	6.95	6.89	-0.8%	1.18	17.1%
	All depths	59	12	4.40	4.21	-4.3%	0.60	14.2%

-Continued-

Table 7. Estimated mean CPUE of burbot fully recruited (≥450 mm TL) to the sampling gear from stratified and unstratified systematic sampling events in most populations studied in 1988 (continued).

Lakes and Dates	Strata	Number of Sets and Transects		Mean CPUE Unbiased	Biased	%Δ	SE	CV
Paxson								
	All depths	412	58	1.09	1.07	-1.8%	0.09	8.5%
	All depths	419	57	0.47	0.46	-2.6%	0.05	11.1%
Sucker								
	All depths	230	38	0.18	0.17	-6.9%	0.04	23.1%
	All depths	176	30	0.43	0.39	-8.1%	0.08	20.4%
Summit								
	All depths	232	42	0.18	0.18	-0.5%	0.04	22.6%
Susitna								
	All depths	955	133	0.30	0.34	14.7%	0.04	12.6%
Tee								
	All depths	80	11	0.23	0.17	-27.4%	0.07	40.4%
Tolsona								
	All depths	59	11	5.93	6.00	1.3%	0.83	13.8%
	All depths	60	13	3.58	4.01	11.9%	0.71	17.8%
Tyone								
	All depths	171	41	1.97	1.72	-12.7%	0.22	12.6%

[1] No estimates of mean CPUE are available for populations in George and Jack Lakes for 1988. In the former situation, only half the lake was covered with the systematic survey design; in the latter situation, sets were spaced closer than 125 m and gear competition may have occurred.

[2] Italics denotes that CPUE was stratified by depth with no improvement in precision or difference in means.

Table 8. Estimated mean CPUE of burbot partially recruited to the sampling gear (<450 mm TL) from stratified and unstratified systematic sampling events in most[1] populations studied in 1988.

Lakes and Dates	Strata	Number of Sets and	Transects	Mean CPUE Unbiased	Biased	%Δ	SE	CV
Beaver[2]								
	All depths	*173*	*19*	*0.14*	*0.15*	*8.3%*	*0.05*	*30.2%*
	All depths	177	20	0.15	0.19	22.3%	0.08	39.0%
Crosswind								
	All depths	242	30	0.34	0.26	-22.0%	0.07	24.9%
Fielding								
	All depths	178	31	0.76	0.66	-13.8%	0.11	17.3%
	All depths	180	32	0.48	0.50	4.8%	0.14	26.8%
Harding								
	All depths	180	11	0.45	0.39	-11.4%	0.10	24.6%
Hudson								
	All depths	123	14	0.08	0.07	-10.9%	0.04	48.4%
	All depths	124	15	0.12	0.12	2.0%	0.05	41.2%
Jack								
	All depths	239	36	0.51	0.50	-1.0%	0.07	14.4%
Louise								
	All depths	*900*	*66*	*0.16*	*0.13*	*-16.9%*	*0.03*	*19.5%*
Moose								
	All depths	62	13	0.83	0.93	11.2%	0.31	32.8%
	All depths	59	12	0.37	0.38	3.9%	0.14	37.0%
Paxson								
	All depths	412	58	0.30	0.31	3.6%	0.05	16.2%
	All depths	419	57	0.36	0.37	4.3%	0.05	12.2%
Sucker								
	All depths	230	38	0.11	0.11	-0.6%	0.03	31.0%
	All depths	176	30	0.21	0.22	7.0%	0.05	24.2%

-Continued-

Table 8. Estimated mean CPUE of burbot partially recruited to the sampling gear (<450 mm TL) from stratified and unstratified systematic sampling events in most populations studied in 1988 (continued).

Lakes and Dates	Strata	Number of Sets and Transects		Mean CPUE Unbiased	Biased	%D	SE	CV
Summit								
	All depths	232	42	0.12	0.10	-10.4%	0.04	32.2%
Susitna								
	All depths	*955*	*133*	*0.27*	*0.23*	*-14.4%*	*0.03*	*12.0%*
Tee								
	All depths	80	11	0.12	0.07	-37.7%	0.04	54.5%
Tolsona								
	All depths	59	11	2.37	2.52	6.5%	0.04	14.0%
	All depths	60	13	0.85	0.84	-0.7%	0.21	25.3%
Tyone								
	All depths	179	41	0.65	0.53	-18.3%	0.12	21.8%

[1] No estimates of mean CPUE are available for populations in George and Jack Lakes for 1988. In the former situation, only half the lake was covered with the systematic survey design; in the latter situation, sets were spaced closer than 125 m and gear competition may have occurred. Also, no burbot <450 mm TL were captured in Jatahmund and Sucker Lakes.

[2] Italics denotes that CPUE was stratified by depth with no improvement in precision or difference in means.

Table 9. Estimated mean CPUE of all burbot from stratified and unstratified systematic sampling events in populations studied during 1988 from Glacier, Sevenmile, Round Tangle, Shallow Tangle, and Upper Tangle Lakes.

Lakes and Dates	Strata	Number of Sets and Transects		Mean CPUE Unbiased	Biased	%D	SE	CV
Glacier								
	All depths	180	23	0.07	0.09	20.4%	0.04	46.0%
Round Tangle								
	All depths	180	27	1.12	0.90	-20.2%	0.17	18.7%
Sevenmile								
	All depths	39	9	0.76	0.76	-0.9%	0.29	38.1%
	All depths	40	8	0.85	0.88	4.2%	0.30	34.1%
Shallow Tangle								
	All depths	116	32	0.39	0.34	-12.2%	0.09	26.5%
Upper Tangle								
	All depths	174	39	0.54	0.56	3.2%	0.13	23.4%

Table 10. Mean lengths (mm TL) of burbot measured during sampling events in 23 lakes[1] in interior Alaska in 1988.

Lake	Statistic	First Event			Second Event			Both Events
		Partially	Fully[2]	All	Partially	Fully	All	Fully
Fielding	Mean	397	533	465	386	506	433	526
	SE	3	7	6	5	7	6	5
	Samples	140	141	276	86	55	141	196
George	Mean	378	667	658				
	SE	22	7	8				
	Samples	8	248	256				
Harding	Mean	371	548	464				
	SE	5	9	9				
	Samples	80	88	168				
Jatahmund	Mean		626	626				
	SE		8	8				
	Samples		87	87				
Paxson	Mean	379	555	540	380	555	486	577
	SE	6	4	4	4	6	6	3
	Samples	51	525	576	139	212	351	651
Sevenmile	Mean	329		329	326		326	
	SE	3		3	4		4	
	Samples	30		30	34		34	
Shallow Tangle	Mean	354	565	408				
	SE	5	22	15				
	Samples	35	12	47				
Summit	Mean	397	512	467				
	SE	7	8	9				
	Samples	28	44	72				
T	Mean	383	602	527				
	SE	14	30	28				
	Samples	10	19	29				

-Continued-

Table 10. Mean lengths (mm TL) of burbot measured during sampling events in 23 lakes in interior Alaska in 1988 (continued).

		First Event			Second Event			Both Events
Lake	Statistic	Partially	Fully	All	Partially	Fully	All	Fully
Upper Tangle	Mean	361	490	382				
	SE	4	11	6				
	Samples	90	18	108				
Round Tangle	Mean	359	543	371				
	SE	3	17	4				
	Samples	188	13	201				
Crosswind	Mean	396	567	506				
	SE	4	7	7				
	Samples	81	144	225				
American Wellesley	Mean		660	660				
	SE		20	20				
	Samples		11	11				
Glacier	Mean	355		355				
	SE	11		11				
	Samples	14		14				
Beaver	Mean	384	562	506	377	572	526	523
	SE	9	8	10	8	10	11	8
	Samples	24	76	100	26	86	112	212
Louise	Mean	393	573	533				
	SE	4	4	5				
	Samples	122	420	542				
Hudson	Mean	378	587	574	394	598	580	577
	SE	14	8	8	9	9	9	6
	Samples	10	144	154	14	150	164	318
Moose	Mean	412	520	509	404	530	520	515
	SE	5	2	3	9	3	3	2
	Samples	48	431	479	22	260	282	761

-Continued-

Table 10. Mean lengths (mm TL) of burbot measured during sampling events in 23 lakes in interior Alaska in 1988 (continued).

		First Event			Second Event			Both Events
Lake	Statistic	Partially	Fully	All	Partially	Fully	All	Fully
Sucker	Mean	384	544	481	390	599	535	515
	SE	8	12	12	7	13	13	9
	Samples	27	42	69	35	79	114	183
Susitna	Mean	379	558	470				
	SE	3	6	5				
	Samples	279	290	569				
Tolsona	Mean	415	507	482	407	520	497	487
	SE	3	2	2	5	3	4	2
	Samples	136	354	490	53	213	266	756
Tyone	Mean	418	538	507				
	SE	2	5	4				
	Samples	129	362	491				
Jack	Mean	396	515	412				
	SE	4	4	5				
	Samples	115	142	257				

[1] One or fewer burbot were caught in Fish and American Wellesley Lakes.

[2] Burbot partially recruited to the gear are <450 mm TL and fully recruited burbot are ≥450 mm TL.

Table 11. Estimated mean length at age for burbot sampled from ten lakes in interior Alaska in 1988.

	Harding				Jatahmund				Paxson				Round Tangle			
Age	n[1]	M[2]	F[3]	Both	n	M	F	Both	n	M	F	Both	n	M	F	Both
0	0				0				0				0			
1	0				0				0				0			
2	0				0				0				0			
3	3	352	359	357	0				1	317		317	3	302	245	265
4	8	439	431	433	0				5	374	393	385	4	265	341	323
5	1	466		466	1	510		510	8	418	470	438	3	338	357	351
6	2	479		479	0				0				1	377		377
7	1	549		549	0				2	520		520	0			
8	1	680		680	1		621	621	1	680		680	0			
9	0				4	641	614	621	4	628	596	612	0			
10	0				1	680		680	0				0			
11	0				2	723		723	1		657	657	0			
12	0				3	724	671	689	2	610	745	678	0			
13	0				5	734	739	736	0				0			
14	0				0				1		740	740	0			
All	16	485	413	449	17	689	660	676	25	481	538	506	11	320	330	320

	Lake Louise				Crosswind				Beaver				Susitna			
Age	n	M	F	Both	n	M	F	Both	n	M	F	Both	n	M	F	Both
0	0				0				0				0			
1	0				0				0				0			
2	0				0				0				0			
3	3		309	309	4		403	403	0				3		308	308
4	38	372	381	366	12	426	378	393	1				9	364	342	352
5	37	451	457	454	27	422	408	395	0				25	332	394	371
6	13	467	514	485	5	442	444	420	7	408	338	390	22	412	371	391
7	14	515	516	515	7	483	493	488	2		339	339	9	460	427	438
8	5	543	543	543	6	531	581	548	3	484	545	495	2		445	445
9	2		541	541	3	552	580	570	5	463	528	515	3		565	565
10	0				3	526		526	1		579	579	0			
11	0				2		533	533	2	536		536	0			
12	0				0				5	687	719	694	0			
13	0				0				2	646	600	623	0			
14	0				0				1	665		665	0			
All	152	450	437	431	69	496	469	439	28	562	526	526	73	400	386	388

-Continued-

Table 11. Estimated mean length at age for burbot sampled from ten lakes in interior Alaska in 1988 (continued).

	Hudson				Jack			
Age	n	M	F	Both	n	M	F	Both
0	0				0			
1	0				0			
2	0				0			
3	0				0			
4	0				2	331	355	343
5	3	515		515	2	329		329
6	3		503	503	7	377	475	426
7	9	565	595	578	5	508	470	458
8	10	605	600	603	4	532	576	496
9	6	534	662	598	2		488	488
10	4	635	639	637	2		537	537
11	4	732	734	733	0			
12	2	750	764	757	1		585	585
13	1	782		782	0			
14	0				1		631	631
15	0				0			
16	0				0			
All	42	607	626	613	26	439	467	461

[1] Sample size.
[2] Males.
[3] Females.

estimates of length at age are in Appendix Table 6. Recognition of the sex of burbot by inspection of their gonads proved difficult as differences between gonads of different "sexes" were subtle. Since these data were collected long after the spawning season had ended (February-April), there was no chance to verify our determinations.

In Lake Louise and Tyone Lake, data collection was limited to that needed to estimate allometric length-weight relationships (Figure 5). The sample sizes from other populations were not robust enough to provide reliable estimates (see Appendix Figure 12). When sample sizes were low or over a short range of lengths, the length-weight algorithm used to estimate the parameters would either produce a range of estimates, all with near equal predictive qualities, or provide no estimates at all. Data from populations in Lake Louise and Tyone Lakes were collected from 1986-1988. Length-weight relationships for populations in Paxson and Harding Lakes were described in Parker et al. (1987) and in Fielding and Crosswind Lakes in Parker et al. (1988).

DISCUSSION

The accuracy of estimates of abundance based on mark-recapture experiments are predicated on certain conditions (Ricker 1975): (1) equal probability of capture for all burbot during at least one sampling event or complete dispersal of tagged burbot throughout the population; (2) ability to identify marked fish; (3) no recruitment between sampling events; and (4) equal probability of survival and capture of marked and unmarked fish. In all our sampling events, sampling effort and the fish tagged were spread throughout each lake. Therefore, the first condition need hold only for local areas, not for the whole lake, for our estimates to be unbiased. Even though sampling events in 1988 were sometimes a few weeks apart, this hiatus was long enough for marked burbot to become completely mixed with unmarked burbot (Bernard et al. in press; see Appendix Figure 13). Calculation of separate estimates for large and small burbot relieved problems with different gear selectivity for burbot of different sizes. As for the second condition, there was no evidence of fin regeneration even though there was some loss of tags. As for the third condition, sampling events were often a few weeks apart so there was little time for recruitment through growth except for populations in Tolsona, Beaver, Hudson, and Moose Lakes.

Estimates of abundance from the Chapman modification of the Petersen estimator and from the Jolly-Seber method were at variance in two mark-recapture experiments in 1988. The "Petersen" estimate for the population of fully recruited burbot in Fielding Lake was 356 (SE=58) while the "Jolly-Seber" estimate for the same period was 328 (SE=74). The Petersen estimate for fully recruited burbot in Paxson Lake was 3,920 (SE=812) and Jolly-Seber estimate for the same period was 3,552 (SE=957). These discrepancies result from the way "p" is calculated. In the Petersen method, abundance is calculated by estimating the fraction of the population that is marked p. In the Jolly-Seber method, abundance is calculated by estimating the probability of capture "ρ". In the Petersen method, p is estimated as the fraction of marked burbot in the catch from the last sampling event; in the Jolly-Seber method, ρ is the fraction of marked burbot extant just prior to the

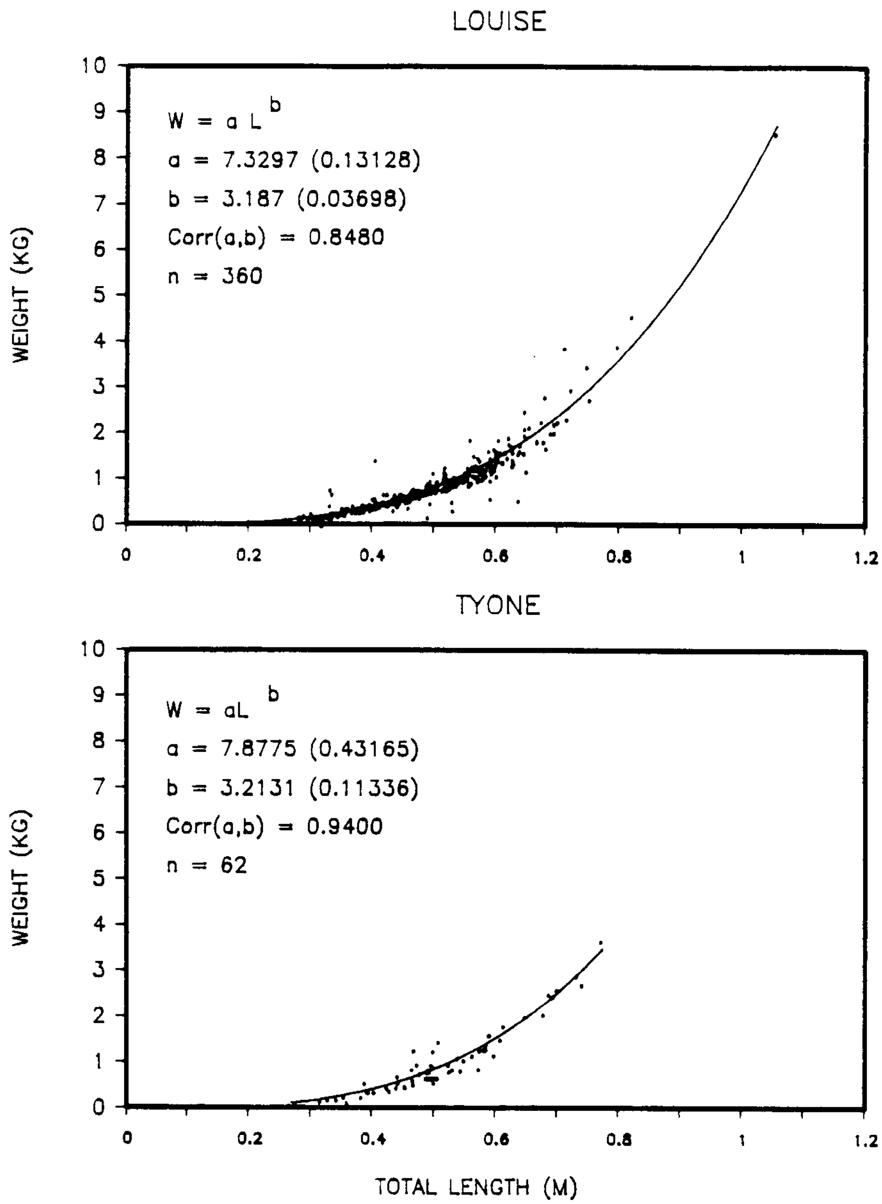

Figure 5. Estimates of parameters in the length-weight relationships for burbot in Lake Louise and Tyone Lake based on data collected in 1986-1988. Values in parentheses are SEs of estimates.

penultimate sampling event that were caught in that event. Both estimates of p and ρ are subject to sampling error and will thus likely differ, but not significantly so, unless sample sizes for both are large. This is the case here. The estimate of ρ has the advantage of being immune to recruitment between the last and penultimate sampling events. However, if no recruitment occurs between these events (which is also the case here), the estimate with the lowest CV is most likely the most desirable.

The effect of tag loss on mark-recapture experiments can be corrected with a rigorous program to apply secondary marks. Population statistics of burbot in Moose Lake were compromised by using several secondary marks within a single year or sampling event; they were compromised for the experiment in Hudson Lake by using the same secondary mark over 2 years. A different secondary mark should be used in different years. This strategy permits all sampling events within a summer to be pooled for the Jolly-Seber models with minimal bias.

The mark-recapture experiment on the population in Beaver Lake showed that when a population is first studied, sampling events should be close together. Few burbot were recaptured during late September from the release in late June, too few to correct an estimate of abundance for growth recruitment and too few to adequately use Jolly-Seber methods in 1989 to estimate abundance in 1988. A better approach would have been to have sampling events close in time, so that they could be pooled to increase the precision of statistics from Jolly-Seber methods.

The seasonal and bathymetric changes in mean CPUE in 1988 were the same as in earlier years. A casual inspection of Tables 7-8 shows decline of CPUE of burbot of all sizes between spring and summer observed in 1986 (Parker et al. 1987) and 1987 (Parker et al. 1988) occurred again in 1988 in Moose, Tolsona, Paxson, and Fielding Lakes (all other sampling occurred within the summer). Parker et al. (1988) discussed the implications of this seasonal change in mean CPUE to mark-recapture experiments and CPUE surveys. Further analysis of the bathymetric changes in mean CPUE in 1986-1988 for populations in deep lakes (>15 m deep) at high elevation (≈600 m and higher) (see Appendix Figure 14) shows that: (1) the distribution of partially recruited burbot is deep in the spring while the distribution of fully recruited burbot is shallow to uniform; and that (2) the distribution of all burbot in the summer is uniform. In contrast, the distribution of burbot of all sizes in lakes of low elevation tend to be deep at all times of the year (see Appendix Figure 15).

The uniform distributions of burbot by depth can be used to design sampling schemes that minimize the death of burbot from decompression. In 1988, 401 burbot were killed in 23 lakes (see Appendix Table 7), of which about 7,590 were caused by decompression.[2] Because fully recruited burbot are distributed uniformly in high-elevation lakes, hoop traps need only be set

[2] On several occasions, notably in Hudson, Sucker, and Beaver Lakes, burbot in hoop traps were dead upon retrieval from deep water. Since these fish had rigor mortis, death was not from decompression. Most of these sets were in the deeper parts of these shallow lakes.

≤15 m to obtain an unbiased estimate of mean CPUE for these fish (see Appendix Figure 16). This procedure will reduce the mortality of burbot due to rapid decompression when sets are retrieved; however, the estimates of mean CPUE for partially recruited burbot will be biased low during the spring (but generally not during the summer). However, such a sampling strategy in low-elevation lakes would bias mean CPUE for burbot of all sizes during all seasons (see Appendix Figure 16). Whenever a mark-recapture experiment is involved in the sampling, there is a danger that sampling only part of the lake will prevent the mixing of marked and unmarked fish. However, information on recaptured fish by depth indicates that marked fish are evenly distributed across depth regardless of where they were first captured (see Appendix Figure 13).

Statistics that describe populations in Sevenmile, Round Tangle, Upper Tangle, Shallow Tangle, and Glacier Lakes were not stratified by recruitment to the sampling gear because there was no indication at what length that stratification should occur. No fish, or few fish, ≥450 mm TL have been captured in these lakes during 1988 or during previous years (Parker et al. 1987, 1988). Secondly, the length-frequencies of samples from these populations had the ascending left limbs, a characteristic of partial recruitment to the gear. However, treating all burbot in these lakes as fully recruited to the gear is not the answer. For example, the abundance estimates of burbot in Sevenmile Lake are 537 (SE=133) in 1986, 939 (SE=265) in 1987, and 109 (SE=28) in 1988. Using Jolly-Seber methods on the mark-recapture information in Appendix Table 3 produces spontaneous generation of burbot (annual survival rates greater than unity). Such inconsistent statistical behavior can be tolerated under a hypothesis of bias through size-selectivity of the sampling gear.

ACKNOWLEDGEMENTS

We are grateful to the field crews: Dave Waldo, Eric Adey, Doug Edwards, Eric Gerke, Jeff Barnard, Richard Ervin, and Doug Dawson; also Gary Pearse and Jerry Hallberg who provided sampling assistance on lakes in Region III; to Cathy Adler who provided much of the data processing and editing for Region II. Equipment and personnel were shared with Wildlife Conservation and FRED division of the Alaska Department of Fish and Game, the Department of Public Safety, and the Bureau of Land Management. Dinty Bush Services and Bill Hernandez provided lodgings. We thank Rocky Holmes, Bob Clark, John H. Clark, and Doug Vincent-Lang for their editorial comments. And lastly, we thank the U.S. Fish and Wildlife Service for partially funding this work, and their cooperation while sampling lakes on the Tetlin Wildlife Refuge.

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APPENDIX A

Lake Descriptions

AMERICAN WELLESLEY LAKE (63°31′ W, 141°15′ W) is located 63 km southeast of Northway and within the Tetlin National Wildlife Refuge and only 5 km from the Canadian border. American Wellesley is 365 ha with a maximum depth of 24 m and an elevation of 619 m. The U.S. Fish and Wildlife Service maintains a public-use cabin which is the only one on the lake. There is moderate fishing pressure during the summer months for northern pike *Esox lucius* at this lake. The only other species caught is burbot.

BEAVER LAKE (62°25′ W, 146°33′ W) is located 0.8 km north by trail from Cliff Bay in Lake Louise, or 0.5 km east of Susitna Lake by trail. Beaver Lake is 324 ha with a maximum depth of 16 m and an elevation of 725 m. The outlet of Beaver Lake drains into Susitna Lake. There are no cabins or public recreational facilities. Fishing for burbot through the ice with set lines has been popular at Beaver Lake. This lake also contains lake trout *Salvelinus namaycush*, round whitefish *Prosopium cylindraceum*, grayling *Thymallus arcticus*, and longnose suckers *Catostomus catostomus*.

CROSSWIND LAKE (62°20′ N, 146°00′ W), also known as Charley Lake, is 32 km northwest of Glennallen. Crosswind Lake is 3,232 ha with a maximum depth of 37 m and an elevation of 640 m. There are no public recreational facilities at the lake, although there are numerous private and commercial cabins. For its size and location, this lake receives very light fishing pressure. Crosswind Lake contains lake trout, Arctic grayling, round whitefish, burbot, and longnose suckers.

FIELDING LAKE (63°10′ N, 145°42′ W) is accessible by road 3 km southwest of the Richardson Highway. Fielding Lake is 538 ha with a maximum depth of 24 m and an elevation of 906 m. Campground facilities and a lodge operated during the summer are located at the mouth of the outlet, also 15 to 20 recreational cabins are located along the south shore. Fielding Lake contains Arctic grayling, lake trout, round whitefish, and burbot.

FISH LAKE (62°37′ N, 143°16′ W) is located 12 km north (by float plane) of Tanacross. Fish Lake is in the middle of a three lake system, connected to Mansfield and Wolf lakes. The outlet drains in the Tanana River through Fish Creek. Fish Lake is the smallest of the three lakes at 485 ha with a maximum depth of 4 m and an elevation of 473 m. Aquatic vegetation covers the entire lake during the summer months making boating efforts very difficult. Two trapper's cabins are located along the shores. Round whitefish and northern pike are the only species found in summer sampling, burbot have been reportedly caught during the winter months under the ice.

GEORGE LAKE (63°47′N, 144°31′ W) is located approximately 72 km southeast of Delta Junction across the Tanana River. George Lake is accessible by plane or boat in the summer months and by snowmachine during a limited time when the Tanana River is frozen (February 1-April 15). The lake is 1,863 ha with a maximum depth of 11 m and a elevation of 389 m. There are only two private recreational cabins on George Lake. The Dot Lake Native Corporation (Dot Lake, Alaska) owns most of the shoreline, and permission is required for access for recreational purposes. Sport fishing for northern pike is popular just as the ice leaves the lake in the spring when these fish congregate at the shallow west end of the lake to spawn. George Lake also contains longnose suckers, round and humpback whitefish *Coregonus pidschian*, least cisco *Coregonus sardinella*, burbot, and Arctic grayling.

GLACIER LAKE (63°07′ N, 164°15′ W) is a semi-remote lake located 3 km north of the Denali Highway. The lake is accessible by trail or all terrain vehicle. Glacier Lake is 172 ha with a maximum depth of 26 m and an elevation of 1,124 m. No habitable dwellings exist on this glacially colored lake. Glacier Lake has populations of lake trout, Arctic grayling, round whitefish, and burbot.

HARDING LAKE (64°25′ N, 146°50′ W) is accessible by road, located 72 km southeast of Fairbanks along the Richardson Highway. Harding Lake is 1,000 ha with a maximum depth of 47 m and an elevation of 218 m. Campground facilities and a boat launch are located on the west shore of the lake; recreational cabins and houses are located along the shoreline. Harding Lake contains indigenous species of northern pike, least cisco, slimy sculpin *Cottus cognatus*, and burbot. Transplanted species include lake trout, rainbow trout *O. mykiss*, Arctic grayling, sheefish *Stenodus leucichthys*, and coho salmon *Oncorhynchus kisutch*.

HUDSON LAKE (61°53′ N, 145°40′ W) is a remote lake 19 km southwest of Copper Center. Hudson Lake is 259 ha with a maximum depth of 16 m and an elevation of 655 m. Although there are no cabins or public recreational facilities at the lake, there is a large winter ice fishery for burbot. Hudson Lake contains Arctic grayling, round whitefish, longnose suckers, burbot, and rainbow trout.

JACK LAKE (62°31′ W, 143°17′ W) is located south of the Nabesna Road 45 km east of the Glenn Highway. There is a 2.4 km, private road available for access to the lake. The outlet drains into the Nabesna River. Jack Lake is 150 ha with a maximum depth of 30 m and an elevation of 915 m. Jack Lake is within the Wrangell-Saint Elias National Preserve; there are limited recreational facilities on the lake which consist of a float plane dock, guiding services, and rental cabins. A few private cabins are found along the shores. There is light to moderate fishing pressure, primarily for lake trout and burbot, during the winter. Other species present include Arctic grayling, round whitefish, and longnose suckers.

JATAHMUND LAKE (62°37′ W, 142°00′ W) is located within the Tetlin National Wildlife Refuge approximately 40 km by air south of Northway. Jatahmund Lake is 975 ha with a maximum depth of 30 m and an elevation of 662 m. The U.S. Fish and Wildlife Service maintains a cabin on the lake, and there is only one other private cabin. Jatahmund Lake is unusual in that the water is clear; Takomahto Lake within 0.5 km, as well as all other lakes in the vicinity, are heavily stained. There is light fishing pressure, primarily for lake trout, during the summer. Other species present are northern pike, least cisco, burbot, and slimy sculpin.

LAKE LOUISE (62°20′ N, 146°30′ W) is the largest lake in a three-lake system that is accessible by the Glenn Highway on a 25 km gravel road. Lake Louise is 6,519 ha with maximum depth of 51 m and an elevation of 720 m. A state campground with boat launch is available. Four lodges are found along the south end of the lake, and numerous cabins are located around the shore. Lake Louise supports year round fishing for lake trout, burbot, Arctic grayling, and round whitefish.

MOOSE LAKE (62°07′ N, 146°05′ W) is accessible from Tolsona Lake by all-terrain vehicle on a 1 km trail from the north end of Tolsona Lake. Moose Lake is 130 ha with a maximum depth of 6 m and an elevation of 625 m. There are four cabins located along the lake shore and no public recreational facilities. Moose Lake receives fishing pressure largely during the winter months for burbot. Moose Lake contains burbot, Arctic grayling, longnose suckers, and rainbow trout.

PAXSON LAKE (62°50′ N, 145°35′ W) is directly accessible from the Richardson Highway 8 km south of Paxson. Paxson Lake is 1,575 ha with a maximum depth of 29 m and an elevation of 778 m. There are numerous cabins along the shore and the Bureau of Land Management maintains a public campground and boat launch. Paxson Lake is the start of a popular float trip on the Gulkana River to Sourdough. This lake is popular for its wide variety of fishing as well as hunting opportunities. Paxson Lake contains lake trout, burbot, sockeye salmon *O. nerka*, Arctic grayling, round whitefish, and other species.

ROUND TANGLE LAKE (63°02′ N, 145°48′ W) is located north of the Denali Highway. Round Tangle Lake is 155 ha with a maximum depth of 29 m and an elevation of 851 m. A public boat launch, campground facilities, and lodge accommodations are available through the spring and fall. During the winter months, the Denali Highway is closed and the Tangle Lakes receive very little fishing pressure. Round Tangle Lake has Arctic grayling, lake trout, round whitefish, burbot, and longnose suckers.

SEVENMILE LAKE (63°06′ N, 145°38′ W) is located 1 km by road from the Denali Highway. Sevenmile Lake is 34 ha with a maximum depth of 12 m and an elevation of 991 m. A public boat launch and campsites are available at the south end of the lake. Sevenmile Lake contains lake trout and burbot populations. No other species are known to exist in the lake.

SHALLOW TANGLE LAKE (63°02′ N, 145°48′ W) is located north of Round Tangle Lake. Shallow Tangle Lake is accessible by boat through Round Tangle Lake and a 500 m river between the two lakes. Shallow Tangle Lake is 130 ha with a maximum depth of 24 m and an elevation of 849 m. Shallow Tangle Lake has Arctic grayling, lake trout, round whitefish, burbot, and longnose suckers.

SUCKER LAKE (62°01′ N, 146°20′ W) is 6.5 km south of Milepost 158 on the Glenn Highway. Sucker Lake has 283 surface ha with a maximum depth of 7 m and an elevation of 616 m. There are no private or public facilities at the lake, but it does support a large winter ice fishery for burbot. Sucker Lake contains burbot, Arctic grayling, round whitefish, and longnose suckers.

SUMMIT LAKE (63°12′ N, 145°33′ W) is directly accessible from the Richardson Highway just 6 km north of Paxson. Summit Lake is 1,651 ha with a maximum depth of 72 m and an elevation of 979 m. Public facilities are available for launching boats only. There is one lodge and a private recreational vehicle campground along the lake. Summit Lake contains lake trout, sockeye salmon, burbot, and round whitefish.

SUSITNA LAKE (62°25′ N, 146°38′ W) is the second lake in a three-lake system and is accessible by a connecting channel of 100 m to Lake Louise. Susitna Lake is 3,816 ha with a maximum depth of 37 m and an elevation of 720 m. There are many private recreational cabins scattered along the shores of Susitna Lake, however, no commercial accommodations are present. Susitna Lake has lake trout, burbot, longnose suckers, and round whitefish.

T LAKE (63°48′ N, 143°53′ W) is a remote fly-in lake, located approximately 18 km from the village of Dot Lake along the Alaska Highway. T Lake is 162 ha with a maximum depth of 18 m and an elevation of 434 m. Only one permanent recreational structure exists on the lake. T Lake contains northern pike, humpback whitefish, least cisco, and burbot.

TAKOMAHTO LAKE (62°37′ W, 141°56′ W) is located within the Tetlin National Wildlife Refuge approximately 40 km by float plane south of Northway and only 1/2 mile east of Jatahmund Lake. Takomahto Lake is 225 ha with a maximum depth of 38 m and an elevation of 661 m. The outlet drains to the east and eventually into the Chisana River, whereas Jatahmund lake drains to the west and into the nearby Nabesna River. Only one cabin exists on this remote lake. Very little fishing pressure occurs which is for northern pike. The only other species is least cisco.

TOLSONA LAKE (62°06′ N, 146°04′ W) is accessible from the Glenn Highway. Tolsona Lake is 130 ha with a maximum depth of 4 m and an elevation of 625 m. Tolsona Lake has numerous cabins and one lodge. No public recreational facilities are available. This lake has had a popular burbot fishery in the winter in recent years. Tolsona Lake has burbot, Arctic grayling, stocked rainbow trout, longnose suckers, and other species.

TYONE LAKE (62°30′ N, 146°45′ W) is the first lake in a three-lake system and is accessible by a connecting channel of 100 m to Susitna Lake. Tyone Lake is 389 ha with a maximum depth of 9 m and an elevation of 720 m. There is the abandoned remains of an Indian settlement (Tyone Village) and only a handful of private cabins located on this lake. Tyone Lake has Arctic grayling, lake trout, burbot, longnose suckers, and round whitefish.

UPPER TANGLE LAKE (63°00′ N, 146°04′ W) is located south of the Denali Highway but drains through a 500 m long river into Round Tangle Lake. Upper Tangle Lake is 142 ha with a maximum depth of 30 m and an elevation of 868 m. There is a boat launch and campground facilities available at the mouth of this lake. Upper Tangle Lake has Arctic grayling, lake trout, round whitefish, burbot, and longnose suckers.

APPENDIX B

Memo

MEMORANDUM *STATE OF ALASKA*

To: Kevin Delaney
Management Biologist
Glennallen Area
Sport Fish Division
Anchorage

Date: 2 November, 1988

File No.:I.600.1200.200

Phone No.: 267-2380

From: David R. Bernard
Biometrician, Research and Technical Services
Sport Fish Division
Anchorage

Subject:

Sustainable Harvests from Some Burbot Populations in the Glennallen Area

Although we do not have enough information to say with certainty what the sustainable yields are for many of our populations, we can say what yields are not sustainable under current conditions.

BACKGROUND

The population dynamics of exploited fish populations are most simply modeled through the concept of surplus production (Ricker 1975):

$$SP = rN(1 - N/N_{\infty})$$

where SP = surplus production, r = intrinsic rate of increase, N = abundance[1], and N_{∞} is the carrying capacity. Usually, r, N_{∞}, and subsequently surplus production are estimated from years of data on stock size or CPUE from fisheries in which abundance is constant (i.e., the fishery and population are in equilibrium) over a number of years. Obviously, we are not in this situation in most of our populations.

But we do have some information on the intrinsic rate of increase and the carrying capacity of some of our populations. Empirically, Gulland (1985) has shown that for many fish populations:

$$SP_{max} = (0.3)MN_{\infty}$$

where SP_{max} = maximum sustained yield and M = annual instantaneous rate of natural mortality. From the theory behind the surplus production model:

$$SP_{max} = \frac{rN_{\infty}}{4}$$

[1] Usually, biomass is used in surplus production models. However, for our purposes, we can use abundance just so long as we remember that there is about a six-year lag between the effects of adults (spawning) and the contribution of their progeny (recruitment) to surplus production. This hiatus is the time needed for young to hatch and grow into the fishery.

Equating the empirical with the theoretical gives an estimate of the intrinsic rate of increase:

$$r = 4(0.3)M$$

LAKE LOUISE

From the summer of 1986 through the summer of 1987, the estimate of the annual instantaneous rate of total mortality (Z) is 0.74[2] and the annual recruitment to the fishable population is 2,015 for burbot in Lake Louise (Parker et al. in press). From Mills (1987), the harvest of burbot from Lake Louise in 1986 was 2,954; from Mills (in press), the harvest in 1987 was 506. Our mortality and recruitment statistics are relative to the "fiscal" year while the catch statistics are relative to the "calendar" year. Therefore, the catch for the fiscal year can be estimated as:

$$C_{86-87} = C_{86}/2 + C_{86}/2 = 2{,}954/2 + 506/2 = 1{,}730$$

The abundance in 1986 was 6,990 ($=N_{86}$) (Parker et al. 1987). From the Baranov catch equation when recruitment (R) occurs throughout the period:

$$C_{86-87} = \frac{F}{Z} N_{86} (1 - e^{-Z}) + \frac{F}{Z^2} R(e^{-Z} + Z - 1)$$

where F = the annual instantaneous rate of fishing mortality. Plugging our statistics into the catch equation and solving for the rate of fishing mortality gives F = 0.30 thereby making the estimate of the instantaneous rate of natural mortality M = 0.44[3]. This makes our estimate of the intrinsic rate of increase r = 0.53.

We can bracket the true value of the carrying capacity by looking at past harvests of burbot from Lake Louise and by looking at the current abundance. In the summer of 1986, our estimate of abundance was 6,990 fully recruited burbot. Since there has been a long-standing fishery on this population, we know that the abundance has been pushed below the carrying capacity, therefore $N_\infty > 6{,}990$. The largest harvest recorded from Lake Louise was 3,710 in 1985 (Mills 1986). If this harvest represented SP_{max}, then $N_\infty = SP_{max}(4)/r = 3{,}710(4)/0.53 = 28{,}000$[4]. However, since both the catches and the abundance have declined since that year (Mills 1987, in press; Parker et al. 1987, in press), an annual harvest of 3,710 is not sustainable which makes the above estimate of N_∞ too high. In summary:

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[2] The survival rate for the population in Lake Louise reported in Parker et al. (in press) is 46% from early July, 1986 to late July, 1987 (381 days). Therefore, the annual instantaneous rate of mortality for this period is $-\ln(0.46)(365)/381 = 0.74$

[3] Note that $Z = F + M$.

[4] Calculated from the relationship $SP_{max} = rN_\infty/4$.

$$r = 0.53$$

$$6,990 < N_\infty < 28,000.$$

With these estimates and knowledge that the current abundance of burbot in Lake Louise is about 5,250[5]:

$$rN_{88}(1 - N_{88}/N_{\infty,min}) \quad < \quad SP \quad < \quad rN_{88}(1 - N_{88}/N_{\infty,max})$$

$$0.53(5,250)(1 - 5,250/6,990) < SP < 0.53(5,250)(1 - 5,250/28,000)$$

$$695 \quad < \quad SP \quad < \quad 2,260$$

The current harvest of 506 burbot is sustainable and is less than our best estimates of surplus production for the population in its present state. Therefore, the population of burbot in Lake Louise should increase by at least 200 recruits next year. This expected increase is a minimum estimate because it is based on $N_{\infty,min}$. Also, the current abundance has been reached through a decline from a higher one, which means the recruitment coming next year will be from a larger population than is now extant.

TOLSONA LAKE

The same approach can be used to estimate unsustainable harvests for Tolsona Lake, except for calculation of the intrinsic rate of increase. For this population, the estimated survival rate for early October, 1986 to early June, 1987 was 56% (Parker et al. in press) and for late June, 1987 to late May, 1988 was 49% (preliminary estimates). Unfortunately, the first statistic is appropriate for the winter only and is therefore inappropriate for the calculation of M for the entire year. Although the second statistic is annual, it can't be used to estimate M because there is no information on the catch from this population after December 31, 1987 (Mills in press). Therefore, M = 0.5 was used to calculate r = 0.66. The estimated abundance in early October, 1986 was 1,910 (Parker et al. 1987). Since this population has had a fishery for years prior to 1986, N$ > 1,910. The largest harvest of burbot from Tolsona Lake was 1,050 in 1985 (Mike Mills, personal

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5 The estimate of abundance for late July 1987 was 5,251 (Parker et al. in press). Although there is no direct estimate of abundance for the summer of 1988, the CPUE statistic for early July, 1988 (0.53) is down 45% from the same month two years earlier (0.97) (Parker et al. 1987). This is about the same percentage drop observed from late July, 1986 (0.60) to late July, 1987 (0.40) which implies that the abundance during the summer 1988 was similar to that in 1987, but lower than in 1986.

6 An instantaneous annual rate of natural mortality of 0.5 is similar to the 0.44 for the population in Lake Louise. It is also similar to the instantaneous annual rates of total mortality (fishing and natural) of 0.61, 0.54, and 0.65 estimated for 1984-7 for the population in Fielding Lake (Parker et al. in press) which has virtually no fishery (Mills 1986, 1987, in press). It is also similar to the estimate for Paxson Lake (0.41) estimated later in this memo.

communication)7. If this harvest represented SPmax, then N$ = SPmax(4)/r = 1,050(4)/0.6 = 7,000. However, since both the catches and the abundance have declined since 1985 (Mills 1987, in press; Parker et al. 1987, in press), an annual harvest of 1,050 is not sustainable which makes the above estimate of N$ too high. In summary:

$$r = 0.6$$

$$1,910 < N_{\infty} < 7,000$$

With these estimates and knowledge that the current abundance of burbot in Tolsona Lake is about 1,250:

$$rN_{88}(1 - N_{88}/N_{\infty,min}) < SP < rN_{88}(1 - N_{88}/N_{\infty,max})$$

$$0.6(1,250)(1 - 1,250/1,910) < SP < 0.6(1,250)(1 - 1,250/7,000)$$

$$260 < SP < 616$$

The current estimate for annual harvest of burbot from Moose and Tolsona Lakes combined is 684 for 1987 (Mills in press). However, this statistic is for the latter half of 1987 only, since during the first half the fishery on these two populations was closed by emergency order.

HUDSON LAKE

Stock assessment of the burbot in Hudson Lake in 1988 is based on CPUE and the estimate of abundance in 1987. The estimate for abundance in June, 1987 was 3,761 (SE = 705) and the CPUE in early July was 2.96 (SE = 0.41) (Parker et al. in press). A year later, the CPUE had dropped to 1.17 in early July, 1988 (preliminary estimate). The second sampling event in 1988 (late September) produced a CPUE of 1.20 (preliminary estimate). This is at least a 60% drop in abundance from 1987 to 1988. This drop indicates an abundance in 1988 of 1,468 burbot [=.40(3,671)].

Unfortunately, the mark-recapture experiment in 1988 was a failure. We had planned the experiment based on an abundance of 3,500 fish and a CPUE of three burbot per lift. However, with the low CPUE, only 106 burbot were released with tags in July, 1988 and at least two, and as many as five burbot, were recaptured in late September. The ambiguity on the number of recaptured fish arose because the same fin was clipped as a secondary mark in 1988 and in 1987. We don't know if two, three, four, or five fish were

7 The harvest of burbot from Moose and Tolsona Lakes combined in 1986 was 1,243 (Mills 1987). From this harvest, 79 and 10 tags were voluntarily returned from anglers fishing in Tolsona and Moose Lakes, respectively (Butch Potterville, personal communication). During early June, 1987, 86 out of 180 burbot sampled from Tolsona Lake and 131 out of 473 sampled from Moose Lake had tags (Parker et al. 1987). With this information, an estimated 1,021 burbot were harvested from Tolsona Lake in 1986 and 222 from Moose Lake.

recaptured in 1988. In any case, the number of recaptured fish is too low to be of much help.

To gain some insight on the sustainable yield from a population of 1,468 burbot in Hudson Lake, an intrinsic rate of increase of 0.6 was assumed. Unfortunately, when the mark-recapture experiment failed, annual survival rates could not be calculated with confidence[8]. So, the same rationale was used to find a substitute for the population in Hudson Lake as was in finding one for burbot in Tolsona Lake[6].

We can estimate the lower bounds of the carrying capacity in Hudson Lake, but not the upper. Since there was a fishery before 1987[9] when the abundance was an estimated 3,671 burbot, $N_\infty > 3,671 = N_{\infty,min}$. Unfortunately, there is no dependable information on $N_{\infty,max}$. The 60% drop in abundance over the winter from 1987-1988 is due to either a recruitment failure or to intense fishing. Pre-recruits made up a small portion (10%) of the captured population in our sampling in 1987, and the estimated catch that winter until 1 January, 1988 was low. However, fishing pressure in the spring (1988) was intense with 100 set-lines counted during a single visit to the lake (Butch Potterville, personal communication). Without resolution of the effects of fishing and recruitment to the decline in abundance, annual harvest can not be shown to have pushed the abundance down and therefore there is no estimate of SPmax and subsequently N$,max.

In summary, $r = 0.6$, $N_{88}=1,468$, and $N_{\infty,min} = 3,671$. Therefore:

$$rN_{88}(1 - N_{88}/N_{\infty,min}) < SP$$

$$0.6(1,468)(1-1,468/3,671) < SP$$

$$537 < SP$$

The second sampling event in 1988 occurred in late September to early October and produced about the same CPUE as did the first event in July (1.20 vs. 1.17). Since CPUE generally increases from summer to fall for the same abundance (Parker et al. 1987), this similarity in CPUE between sampling events indicates that the population in Hudson Lake is lower than 1,468. Also, 38 of the 144 burbot caught during the first sampling event were dead and stiff in the traps (Butch Potterville, personal communication). Since all of these traps were in deeper water, something in this part of the lake was lethal to burbot.

8 The 60.4% drop in abundance does not translate into a 39.6% survival rate because the recruitment from 1987 to 1988 is unknown.

9 An estimated 1,211 burbot were caught in 1986 and 446 in 1987 in Hudson Lake (Mike Mills, personal communication).

PAXSON LAKE

Because the estimate of abundance from the mark-recapture experiment in Paxson Lake during 1986 is imprecise, the abundance in 1986 was reestimated with changes in CPUE and the estimate of abundance for 1987. Abundance was estimated at 9,111 with a SE = 1,996 in 1986 (Parker et al. 1987) and 3,246 with a SE = 351 in 1987 (Parker et al. in press). The estimate for 1987 is about an order of magnitude more precise than that in 1986. Also, the "negative" recruitment for this population during 1986-1987 reported in Parker et al. (in press) is further testament that the estimate from the mark-recapture experiment in 1986 is too high. Mean CPUE for the first sampling event (early July) in Paxson Lake during 1986 is 2.28 with a SE = 0.17 (Parker et al. 1987); the mean CPUE for the first sampling event in 1987 is 1.79 with a SE = 0.15 (Parker et al. in press). The new estimate of abundance ($N_{86,cpue}$) is:

$$N_{86,cpue} = N_{87,mr} \frac{CPUE_{86}}{CPUE_{87}} = 3,246 \frac{2.28}{1.79} = 4,135$$

where $N_{87,mr}$ = estimated abundance from the mark-recapture experiment in 1987.

Next, the intrinsic rate of increase is estimated. The estimated survival rate from 1986-1987 is 61% with a SE = 10% (Parker et al. in press), therefore, the estimate of the instantaneous mortality rate (Z) is 0.49. The recruitment can be estimated as per instructions in Ricker (1975):

$$R = N_{87,mr} - N_{86,cpue}e^{-Z} = 3,246 - 4,135(.61) = 724$$

The harvest of burbot from Paxson Lake was estimated at 452 and 119 for the calendar years 1986 and 1987, respectively (Mills 1987, in press). The harvest of the winter of 1986-1987 is estimated as:

$$C_{86-87} = C_{86}/2 + C_{86}/2 = 452/2 + 119/2 = 286$$

From the Baranov catch equation when recruitment (R) occurs throughout the period, the estimated instantaneous rate of fishing mortality F = 0.08, which makes the instantaneous rate M = 0.41 (=0.49-0.08) and the intrinsic rate of increase r = 0.49 [=4(0.3)0.41].

Because the harvests and fishing effort for burbot in Paxson Lake have been relatively stable for the last 11 years (see Mills 1987 and its predecessors), maximum sustained yield can be calculated directly for this population. Since 1979, the annual harvest has averaged 370 burbot[10]. Since this harvest has been "sustained" more or less over the past 11 years, well beyond the age of maturation for a single year class of burbot, it is de

[10] From 1979 through 1983, the harvest from Paxson and Summit Lakes were combined. Since this time, the harvest from Paxson Lake has averaged 87% of the total for these two populations. Eighty-seven percent of the harvests before 1984 average 348 burbot; those harvests after 1983 average 401 burbot.

facto the sustained yield. The relationship between this sustained yield and the stable abundance is:

$$SP = rN_e(1 - N_e/N_\infty)$$

where N_e = the current, stable abundance. In this case, the estimate of stable abundance would be the average of estimates for 1986-1988, N_e = 3,766 (=4,135/3+3,246/3+3,918/3). Putting this value and the average catch into the above equation and solving for the carrying capacity gives N$ = 4,710. With the equations to calculate SPmax:

$$SP_{max} = \frac{rN_\infty}{4} = \frac{0.49(4,710)}{4} = 577^{11}$$

MOOSE LAKE

Direct estimation of sustained yield from the population of burbot in Moose Lake is compromised by some of the problems with tag loss in this study. The rates of tag loss in Moose Lake during the summer of 1986 and over the winter of 1986-1987 were estimated at 19% and 37%, respectively (Parker et al. in press); in 21 other populations, these rates were 5% and 15% on average. Although the rate of summer tag loss in 1987 had dropped to 2% (preliminary estimates), some confusion in 1988 with directions for removing fins of newly captured fish and recording the fins removed on recaptured fish made estimation of rates of overwinter and of summer tag loss impossible. Because of these problems (along with others documented in a memo from Sandy Sonnechson to Dave Bernard, dated 12 October, 1988), data collected in 1986 were excluded from further analysis.

The statistics on abundance, survival rate, recruitment, and CPUE from 1987-1988 are N_{87} = 2,662 (SE = 714), N_{88} = 4,954 (SE = 1,224), e^{-Z} = 0.65 (SE = 0.19), R = 3,327 (SE = 954), $CPUE_{87}$ = 5.75 (SE = 0.64), and $CPUE_{87}$ = 7.15 (preliminary estimates). Most of these estimates are not very precise. Also, the survival rate is for a period with incomplete catch information (winter 1987-1988). The estimate of abundance and CPUE both increased from 1987 to 1988 which is consistent with a growing population. Unfortunately, sampling in 1987 was a week later than in 1988 which may account for the difference (see Parker et al. 1987; Parker et al. in press for discussion of declining CPUE with the approach of summer). The estimated survival rate is slightly better than the rate for the neighboring population in Tolsona Lake.

A limit can be estimated for the sustained yield of burbot in Moose Lake by comparing its productivity to that of neighboring Tolsona Lake. Since there is no estimate of harvest to complement estimated survival rate, the Baranov catch equation can't be used to estimate F, M, and subsequently r. Still,

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[11] If N_e is used to calculate annual recruitment, $R = N_e - e^{-Z}N_e$ = 1,469 which is over twice the value for R used in the above analysis. However, when R = 1,469 is placed in the Baranov catch equation along with SP = 370 and N_e = 3,767, solved for F, then M, r, the carrying capacity, and finally maximum sustained yield, SP_{max} = 560.

the standard values of $M = 0.5$[6] and $r = 0.6$ can be used. However, our biggest problem is estimating the carrying capacity. The highest known estimate of abundance below the carrying capacity is the current estimate (4,954). In this situation with the population obviously not in equilibrium, we can not estimate a meaningful, conservative lower bound for the carrying capacity. And since our only estimate of harvest (222)[7] has no associated estimate of abundance to precede it ($N_{86} = ?$), a liberal upper bound for carrying capacity can't be calculated either.

However, the liberal upper bound of carrying capacity for the population in Tolsona Lake (7,000) could be used as a surrogate. Both lakes are about the same size and depth and are located side by side (Parker et al. 1987). Since SP_{max} occurs when $N = N_\infty/2$, the population is not as productive as it could be with increased fishing. Therefore:

$$SP_{max} < \frac{rN_{\infty,max}}{4} = \frac{0.6(7,000)}{4} = 1,050$$

$$SP_{max} < 1,050$$

Harvests over 1,050 are demonstrably unsustainable. Our one and only estimate of harvest for this population is 222.

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APPENDIX C

Tables

Appendix Table 1. Mark and recapture histories of burbot by sampling event for 16 populations studied from 1982 through 1988.

	GEORGE			SUMMIT					HARDING				T				SUCKER			
DATE:																				
Year	1987	1987	1988	1986	1986	1987	1987	1988	1985	1986	1987	1988	1986	1987	1987	1988	1987	1987	1988	1988
Beginning	6/01	6/22	5/24	7/12	8/26	7/13	9/02	7/06	7/22	9/08	6/16	9/26	6/11	5/26	9/21	5/17	6/10	6/29	8/02	9/30
Ending	6/11	6/30	5/31	7/17	9/04	7/21	9/20	7/11	7/26	9/14	6/20	9/30	6/19	6/01	9/25	5/21	6/14	7/01	8/07	10/4
NUMBER OF FULLY RECRUITED BURBOT:[1]																				
Recaptured from Event 1	0	8	5	0	3	6	2	1	0	0	2	0	0	2	4	0	0	5	xx	1
Recaptured from Event 2	0	0	1	0	0	2	0	0	0	0	14	3	0	0	14	1	0	0		0
Recaptured from Event 3				0	0	0	7	8	0	0	0	9	0	0	0	10	0	0	0	1
Captured with Tags	0	8	6	0	3	8	9	9	0	0	16	12	0	2	18	11	0	5		2
Captured without Tags	166	76	242	52	59	68	54	35	25	55	87	76	13	23	6	8	100	43		26
Captured	166	84	248	52	62	76	63	44	25	55	103	88	13	25	24	19	100	48	43	28
Released with Tags	166	80	248	51	3	74	63	41	18	54	81	77	13	23	24	17	100	42	43	26
NUMBER OF PARTIALLY RECRUITED BURBOT:																				
Recaptured from Event 1	0	1	0	0	10	3	2	0	0	0	0	0	0	0	0	0	0	0	0	1
Recaptured from Event 2	0	0	1	0	0	1	0	0	0	0	3	1	0	0	1	0	0	0	0	0
Recaptured from Event 3				0	0	0	3	0	0	0	0	3	0	0	0	1	0	0	0	1
Captured with Tags	0	1	1	0	10	4	5	0	0	0	3	4	0	0	1	1	0	0	0	2
Captured without Tags	72	17	7	182	166	65	70	28	35	59	108	76	8	7	3	9	42	12	24	26
Captured	72	18	8	182	176	69	75	28	35	59	111	80	8	7	4	10	42	12	24	28
Released with Tags	72	10	8	152	10	64	70	19	22	47	80	69	4	8	4	9	42	5	24	26

-Continued-

Appendix Table 1. Mark and recapture histories of burbot by sampling event for 16 populations studied from 1982 through 1988 (continued).

	CROSSWIND			SUSITNA					LOUISE					TYONE				
DATE:																		
Year	1987	1987	1988	1986	1986	1987	1987	1988	1986	1986	1987	1987	1988	1986	1986	1987	1987	1988
Beginning	7/23	8/13	7/23	6/27	8/13	7/18	8/21	6/11	6/25	8/19	7/06	8/02	6/11	6/26	8/11	7/29	8/28	6/09
Ending	8/06	8/27	7/26	6/29	8/19	7/31	8/30	6/26	6/28	9/02	7/20	8/19	6/24	6/28	8/13	8/04	9/01	6/11
NUMBER OF FULLY RECRUITED BURBOT:																		
Recaptured from Event 1	0	4	2	0	0	0	2	2	0	8	5	4	5	0	2	2	4	3
Recaptured from Event 2	0	0	2	0	0	1	0	2	0	0	5	5	4	0	0	1	0	2
Recaptured from Event 3	0	0	0	0	0	0	1	2	0	0	0	10	14	0	0	0	3	2
Recaptured from Event 4	0	0	0	0	0	0	0	0	0	0	0	0	12[2]	0	0	0	0	4
Captured with Tags	0	4	4	0	0	1	3	6	0	0	10	19	35	0	2	3	0	11
Captured without Tags	183	105	104	37	47	117	58	284	243	280	303	198	383	111	79	73	7	351
Captured	183	109	108	37	47	118	61	290	243	288	313	217	418	111	81	76	19	362
Released with Tags	165	92	93	34	43	111	58	266	220	258	264	186	368	111	71	75	17	358
NUMBER OF PARTIALLY RECRUITED BURBOT:																		
Recaptured from Event 1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Recaptured from Event 2	0	0	0	0	0	2	0	0	0	0	1	0	0	0	0	1	0	1
Recaptured from Event 3	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0
Recaptured from Event 4	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Captured with Tags	0	0	0	0	0	2	0	1	0	0	2	1	2	0	0	1	0	1
Captured without Tags	64	67	80	43	94	216	165	278	79	82	107	58	126	20	83	96	59	134
Captured	64	67	80	43	94	218	165	279	79	82	109	59	128	20	83	97	59	135
Released with Tags	47	57	36	36	75	200	157	217	38	62	72	54	103	19	70	97	59	134

-Continued-

Appendix Table 1. Mark and recapture histories of burbot by sampling event for 16 populations studied from 1982 through 1988 (continued).

	SEVENMILE						ROUND TANGLE					SHALLOW TANGLE					UPPER TANGLE				
DATE:																					
Year	1986	1986	1987	1987	1988	1988	1986	1986	1987	1987	1988	1986	1986	1987	1987	1988	1986	1986	1987	1987	1988
Beginning	7/22	9/17	6/16	7/31	6/19	7/17	7/21	8/16	7/27	8/22	6/15	7/21	8/16	7/29	8/24	6/13	7/21	8/18	7/31	8/25	6/09
Ending	8/09	9/21	6/20	8/06	6/21	7/19	7/25	8/25	7/30	8/25	6/19	7/25	8/18	8/01	8/30	6/16	7/25	8/20	8/03	8/29	6/22
NUMBER OF BURBOT OF ALL SIZES:																					
Recaptured from Event 1	0	10	5	5	0	1	0	6	4	1	4	0	1	0	0	1	0	0	0	0	1
Recaptured from Event 2	0	0	16	25	4	0	0	0	8	0	3	0	0	0	0	0	0	0	4	1	1
Recaptured from Event 3	0	0	0	8	3	0	0	0	0	5	12	0	0	0	1	2	0	0	0	2	6
Recaptured from Event 4	0	0	0	0	3	3	0	0	0	0	3	0	0	0	0	0	0	0	0	0	4
Recaptured from Event 5	0	0	0	0	0	9															
Captured with Tags	0	10	21	38	10	13	0	6	12	6	22	0	1	0	1	3	0	0	4	3	12
Captured without Tags	116	82	56	102	20	21	155	66	86	51	179	84	31	49	30	44	53	48	41	28	97
Captured	116	92	77	140	30	34	155	72	98	57	201	84	32	49	31	47	53	48	45	31	109
Released with Tags	36	68	59	105	30	34	134	63	95	56	193	52	1	46	20	47	48	35	45	31	108

-Continued-

Appendix Table 1. Mark and recapture histories of burbot by sampling event for 16 populations studied from 1982 through 1988 (continued).

	PAXSON							TOLSONA					
DATE:													
Year	1986	1986	1986	1987	1987	1988	1988	1986	1986	1987	1987	1988	1988
Beginning	7/07	8/04	9/16	7/06	8/06	6/22	7/19	9/23	10/8	6/2	6/23	5/25	8/30
Ending	7/12	8/14	9/20	7/13	8/14	6/30	7/27	9/27	10/10	6/4	6/25	5/27	9/01
NUMBER OF FULLY RECRUITED BURBOT:													
Recaptured from Event 1	0	16	13	32	23	23	3	0	131	68	23	26	12
Recaptured from Event 2	0	0	7	10	9	1	0	0	0	20	12	9	2
Recaptured from Event 3	0	0	0	17	10	9	4	0	0	0	64	57	24
Recaptured from Event 4	0	0	0	0	60	42	21	0	0	0	0	23	8
Recaptured from Event 5	0	0	0	0	0	44	8	0	0	0	0	0	51
Recaptured from Event 6	0	0	0	0	0	0	16	0	0	0	0	0	0
Captured with Tags	0	16	20	59	102	119	52	0	131	88	99	115	97
Captured without Tags	537	338	168	530	249	331	148	531	342	307	71	231	109
Captured	537	354	188	589	351	450	200	531	473	395	170	346	206
Released with Tags	463	111	184	571	335	389	57	531	141	393	167	346	206
NUMBER OF PARTIALLY RECRUITED BURBOT:													
Recaptured from Event 1	0	1	0	1	0	0	1	0	7	11	3	0	0
Recaptured from Event 2	0	0	0	1	0	0	0	0	0	2	0	9	2
Recaptured from Event 3	0	0	0	2	0	0	0	0	0	0	11	9	2
Recaptured from Event 4	0	0	0	0	4	1	7	0	0	0	0	0	1
Recaptured from Event 5	0	0	0	0	0	2	2	0	0	0	0	0	1
Recaptured from Event 6	0	0	0	0	0	0	2	0	0	0	0	0	0
Captured with Tags	0	1	0	4	4	3	12	0	7	13	14	18	6
Captured without Tags	85	81	35	167	136	122	139	163	106	215	27	116	46
Captured	85	82	35	171	140	125	151	163	113	228	41	134	52
Released with Tags	50	17	33	157	108	70	12	153	9	228	40	133	52

-Continued-

Appendix Table 1. Mark and recapture histories of burbot by sampling event for 16 populations studied from 1982 through 1988 (continued).

	FIELDING											
DATE:												
Year	1982	1984	1984	1985	1985	1985	1986	1986	1987	1987	1988	1988
Beginning	9/29	7/20	10/1	7/16	8/19	9/23	7/28	8/21	7/21	8/17	6/29	7/27
Ending	10/1	7/20	10/8	7/20	8/26	9/27	8/01	8/25	7/27	8/22	7/02	7/31
NUMBER OF FULLY RECRUITED BURBOT:												
Recaptured from Event 1	0	0	0	0	0	0	0	0	0	0	0	0
Recaptured from Event 2	0	0	0	0	0	0	1	0	1	0	0	0
Recaptured from Event 3	0	0	0	1	10	2	1	0	1	0	0	0
Recaptured from Event 4	0	0	0	0	9	4	4	2	1	6	0	0
Recaptured from Event 5	0	0	0	0	0	11	11	4	9	1	1	0
Recaptured from Event 6	0	0	0	0	0	0	4	2	6	0	0	0
Recaptured from Event 7	0	0	0	0	0	0	0	13	13	4	2	0
Recaptured from Event 8	0	0	0	0	0	0	0	0	9	4	5	1
Recaptured from Event 9	0	0	0	0	0	0	0	0	0	34	20	5
Recaptured from Event 10	0	0	0	0	0	0	0	0	0	0	19	4
Recaptured from Event 11	0	0	0	0	0	0	0	0	0	0	0	21
Captured with Tags	0	0	0	1	19	17	17	21	40	48	47	31
Captured without Tags	2	2	41	45	78	26	45	28	67	33	94	24
Captured	2	2	41	46	97	43	62	49	107	81	141	55
Released with Tags	1	2	41	47	96	20	59	30	105	55	139	31
NUMBER OF PARTIALLY RECRUITED BURBOT:												
Recaptured from Event 1	0	0	0	0	0	0	0	0	0	0	0	0
Recaptured from Event 2	0	0	0	1	0	0	2	0	0	0	0	0
Recaptured from Event 3	0	0	0	7	10	1	1	3	0	0	0	1
Recaptured from Event 4	0	0	0	0	12	3	5	1	1	3	1	0
Recaptured from Event 5	0	0	0	0	0	16	25	13	7	8	1	1
Recaptured from Event 6	0	0	0	0	0	0	3	3	4	0	1	0
Recaptured from Event 7	0	0	0	0	0	0	0	20	11	9	7	3
Recaptured from Event 8	0	0	0	0	0	0	0	0	8	1	2	1
Recaptured from Event 9	0	0	0	0	0	0	0	0	0	12	15	3
Recaptured from Event 10	0	0	0	0	0	0	0	0	0	0	7	3
Recaptured from Event 11	0	0	0	0	0	0	0	0	0	0	0	10
Captured with Tags	0	0	0	8	22	20	36	40	31	33	34	22
Captured without Tags	5	3	62	104	250	47	176	90	101	117	101	64
Captured	5	3	62	112	272	67	204	130	132	150	135	86
Released with Tags	5	3	62	111	272	21	189	44	131	32	130	22

Appendix Table 2. Mark and recapture history on fully recruited[1] burbot by year for the population in Fielding, Paxson, Susitna, Tyone, Summit, and T Lakes and Lake Louise.

FIELDING LAKE					
DATE:					
Year	1984	1985	1986	1987	1988
Beginning	7/20	7/16	7/28	7/21	6/29
Ending	10/8	9/27	8/25	8/22	7/31
NUMBER OF FULLY RECRUITED BURBOT:[1]					
Recaptured from Event 1	0	13	2	2	0
Recaptured from Event 2		0	27	23	1
Recaptured from Event 3			0	30	8
Recaptured from Event 4				0	48
Captured with Tags	0	13	29	55	57
Captured without Tags	43	149	90	93	118
Captured	43	162	119	148	175
Released with Tags	43	138	76	126	149

PAXSON LAKE				
DATE:				
Year	1986	1987	1988	1988
Beginning	7/07	7/06	6/22	7/19
Ending	9/20	8/14	6/30	7/27
NUMBER OF FULLY RECRUITED BURBOT:				
Recaptured from Event 1	0	108	33	7
Recaptured from Event 2		0	86	29
Recaptured from Event 3			0	16
Captured with Tags	0	108	119	52
Captured without Tags	1043	783	331	148
Captured	1043	891	450	200
Released with Tags	721	851	389	57

TYONE LAKE			
DATE:			
Year	1986	1987	1988
Beginning	6/26	7/29	6/09
Ending	8/13	9/05	6/11
NUMBER OF FULLY RECRUITED BURBOT:			
Recaptured from Event 1	0	7	5
Recaptured from Event 2	0	0	6
Captured with Tags	0	7	11
Captured without Tags	190	153	351
Captured	190	160	362
Released with Tags	180	158	358

-Continued-

Appendix Table 2. Mark and recapture history on fully recruited burbot by year for the population in Fielding, Paxson, Susitna, Tyone, Summit, and T Lakes and Lake Louise (continued).

SUSITNA LAKE			
DATE:			
Year	1986	1987	1988
Beginning	6/27	7/18	6/11
Ending	8/19	8/30	6/26
NUMBER OF FULLY RECRUITED BURBOT:			
Recaptured from Event 1	0	3	4
Recaptured from Event 2	0	0	2
Captured with Tags	0	3	6
Captured without Tags	84	175	284
Captured	84	178	290
Released with Tags	77	168	266

SUMMIT LAKE			
DATE:			
Year	1986	1987	1988
Beginning	7/12	7/13	7/06
Ending	9/04	9/20	7/11
NUMBER OF FULLY RECRUITED BURBOT:			
Recaptured from Event 1	0	10	1
Recaptured from Event 2		0	8
Captured with Tags	0	10	9
Captured without Tags	111	122	35
Captured	111	132	44
Released with Tags	51	130	41

T LAKE			
DATE:			
Year	1986	1987	1988
Beginning	6/11	5/26	5/17
Ending	6/19	9/25	5/21
NUMBER OF FULLY RECRUITED BURBOT:			
Recaptured from Event 1	0	6	0
Recaptured from Event 2		0	11
Captured with Tags	0	6	11
Captured without Tags	13	29	8
Captured	13	35	19
Released with Tags	13	33	17

-Continued-

Appendix Table 2. Mark and recapture history on fully recruited burbot by year for the population in Fielding, Paxson, Susitna, Tyone, Summit, and T Lakes and Lake Louise (continued).

LAKE LOUISE			
DATE:			
Year	1986	1987	1988
Beginning	6/25	7/06	6/11
Ending	9/02	8/19	6/24
NUMBER OF FULLY RECRUITED BURBOT:			
Recaptured from Event 1	0	19	9
Recaptured from Event 2	0	0	26
Captured with Tags	0	19	35
Captured without Tags	523	501	383
Captured	523	520	418
Released with Tags	470	440	368

[1] Fully recruited burbot are ≥450 mm TL.

Appendix Table 3. Mark and recapture history on burbot of all sizes[1] by year for the population in Round Tangle, Sevenmile, Shallow Tangle, and Upper Tangle Lakes.

ROUND TANGLE LAKE			
DATE:			
Year	1986	1987	1988
Beginning	7/21	7/27	6/15
Ending	8/25	8/25	6/19
NUMBER OF BURBOT OF ALL SIZES:			
Recaptured from Event 1	0	13	7
Recaptured from Event 2		0	15
Captured with Tags	0	13	22
Captured without Tags	221	137	179
Captured	221	150	201
Released with Tags	191	146	193

SEVENMILE LAKE			
DATE:			
Year	1986	1987	1988
Beginning	7/22	6/16	6/19
Ending	9/21	8/06	7/19
NUMBER OF BURBOT OF ALL SIZES:			
Recaptured from Event 1	0	51	5
Recaptured from Event 2		0	9
Captured with Tags	0	51	14
Captured without Tags	198	158	41
Captured	198	209	55
Released with Tags	94	156	55

-Continued-

Appendix Table 3. Mark and recapture history on burbot of all sizes[1] by year for the population in Round Tangle, Sevenmile, Shallow Tangle, and Upper Tangle Lakes (continued).

SHALLOW TANGLE LAKE			
DATE:			
Year	1986	1987	1988
Beginning	7/21	7/29	6/13
Ending	8/18	8/30	6/16
NUMBER OF BURBOT OF ALL SIZES:			
Recaptured from Event 1	0	0	1
Recaptured from Event 2		0	2
Captured with Tags	0	0	3
Captured without Tags	115	79	44
Captured	115	79	47
Released with Tags	52	65	47

UPPER TANGLE LAKE			
DATE:			
Year	1986	1987	1988
Beginning	7/21	7/31	6/09
Ending	8/18	8/29	6/22
NUMBER OF BURBOT OF ALL SIZES:			
Recaptured from Event 1	0	5	2
Recaptured from Event 2		0	10
Captured with Tags	0	5	12
Captured without Tags	101	69	97
Captured	101	74	109
Released with Tags	83	74	108

[1] Burbot are ≥300 mm TL.

Appendix Table 4. Number of fully (≥450 mm TL) and partially (<450 mm TL) recruited burbot caught (C), number tagged (M), and number recaptured (R) in populations during two sampling events on four lakes in interior Alaska in 1988.

	Fully Recruited				Partially Recruited			
Lake	M_1	C_2	R_2	M_2	M_1	C_2	R_2	M_2
American Wellesley	3				0			
Beaver	63	77	5	72	18	23	1	22
Glacier	0				13			
Jatahmund	67				0			

Appendix Table 5. Mark and recapture histories on fully recruited[1] burbot by year (1987) and by sampling event (1988) for the populations in which mark-recapture experiments were compromised through tag loss and uncertainty on the timing of secondary marks.

MOOSE LAKE			
DATE:			
Year	1987	1988	1988
Beginning	6/01	5/24	9/16
Ending	6/26	5/26	9/18
NUMBER OF FULLY RECRUITED BURBOT:			
Recaptured from Event 1	0	50	40
Recaptured from Event 2		0	31or38
Captured with Tags	0	50	71or78
Captured without Tags	0	124	178or185
Captured	777or778	429	256
Released with Tags	777or778	429	255
HUDSON LAKE			
DATE:			
Year	1987	1988	1988
Beginning	6/15	7/13	9/29
Ending	7/10	7/18	10/03
NUMBER OF FULLY RECRUITED BURBOT:			
Recaptured from Event 1	0	10	12or15
Recaptured from Event 2		0	2or5
Captured with Tags	0	10	17
Captured without Tags	554	127	133
Captured	554	144	150
Released with Tags	550	106	149

[1] For all populations, burbot $\geq$ 450 mm TL were considered fully recruited to the gear while smaller fish were considered to be partially recruited.

Appendix Table 6. Standard errors for estimated mean length at age for burbot sampled in ten lakes in interior Alaska in 1988

	Harding				Jatahmund				Paxson				Round Tangle			
Age	n[1]	M[2]	F[3]	Both	n	M	F	Both	n	M	F	Both	n	M	F	Both
0	0				0				0				0			
1	0				0				0				0			
2	0				0				0				0			
3	3		6	6	0				1				3			18
4	8	7	13	12	0				5	17	16	11	4		10	21
5	1				1				8	21	3	16	3		3	7
6	2	24		24	0				0				1			
7	1				0				2	5		5	0			
8	1				1				1				0			
9	0				4		9	9	4	29	72	33	0			
10	0				1				0				0			
11	0				2	42		42	1				0			
12	0				3		6	5	2			68	0			
13	0				5	19	20	12	0				0			
14	0				0				1				0			
All	16	24	11	21	17	26	20	17	25	31	40	26	11	24	18	14

	Crosswind				Beaver				Louise				Susitna			
Age	n	M	F	Both	n	M	F	Both	n	M	F	Both	n	M	F	Both
0	0				0				0				0			
1	0				0				0				0			
2	0				0				2			2	0			
3	3			6	0				38	15	10	7	3		4	10
4	12	15	19	12	0				40	15	8	7	9		16	13
5	27	8	16	8	0				37	14	7	8	25		14	9
6	5			13	7	14		14	13	13	15	12	22	20	10	7
7	7	13	15	10	2			23	14	13	23	12	9		22	9
8	6	29	53	28	3		10	19	5	31	11	19	2		7	7
9	3		10	10	5		44	44	2		13	13	3			19
10	3	44		44	1				0				0			
11	2		4	4	2	24		24	0				0			
12	0				5	23		23	0				0			
13	0				2			16	0				0			
14	0				1				0				0			
All	69				24				152				73			

-Continued-

Appendix Table 6. Standard errors for estimated mean length at age for burbot sampled in ten lakes in interior Alaska in 1988 (continued).

	Hudson				Jack			
Age	n	M	F	Both	n	M	F	Both
0	0				0			
1	0				0			
2	0				0			
3	0				0			
4	0				2			9
5	3	4		4	2			14
6	3		11	8	7	4	15	15
7	9	10	11	9	5	25	7	12
8	10	30	13	19	4			33
9	6	70	17	45	2		9	9
10	4	5	3	3	2		21	21
11	4	48	35	30	0			
12	2			5	1			
13	1				0			
14	0				1			
15	0				0			
All	42				26			

[1] Sample size.
[2] Males.
[3] Females.

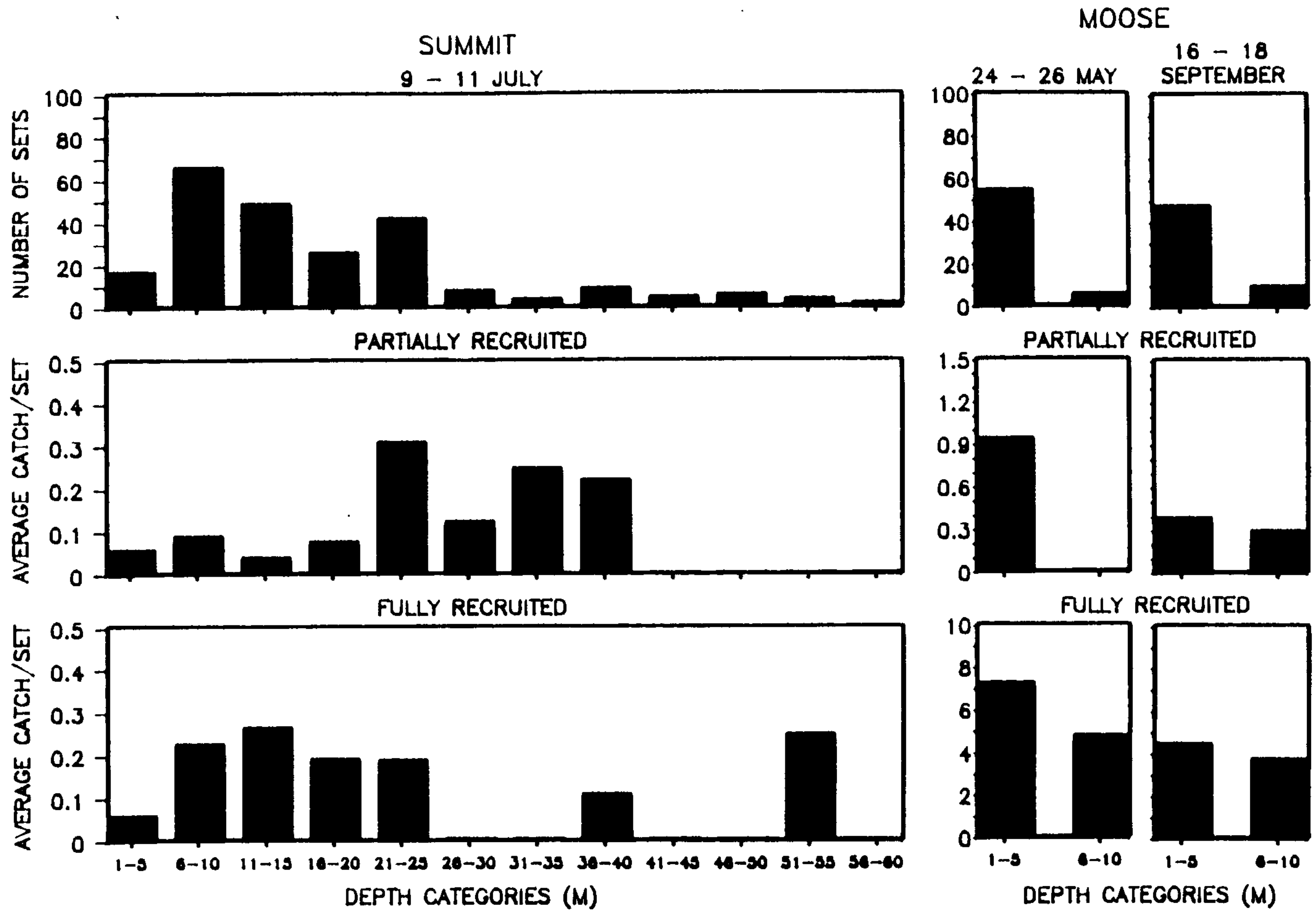
Appendix Table 7. Numbers of burbot killed during sampling in 23 lakes in interior Alaska in 1988.[1]

Lake	Fully Recruited	Partially Recruited	Lake	Fully Recruited	Partially Recruited
American Wellesley	8	0	Moose	3	0
Summit	2	2	Tolsona	0	1
Fielding	2	4	Hudson	42	1
Sevenmile	0	0	Crosswind	25	45
T	2	1	Beaver	19	9
Shallow Tangle	0	0	Sucker	9	3
Upper Tangle	0	1	Jack	17	11
Round Tangle	0	11	Louise	15	25
Paxson	14	9	Susitna	11	63
Glacier	0	1	Tyone	4	0
			George	0	0
			Harding	16	8
			Jatahmund	17	0
TOTAL	28	29		178	166

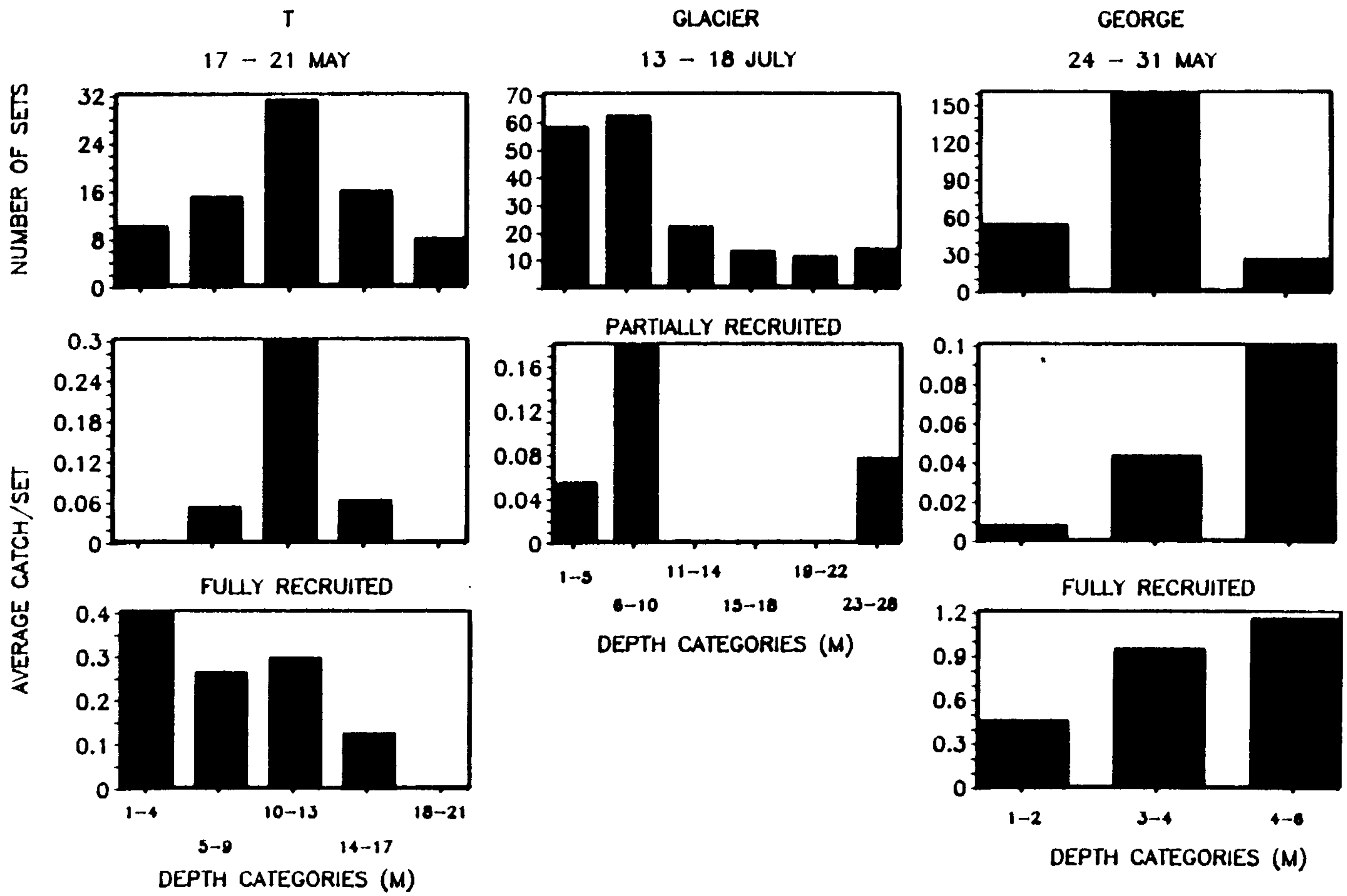
[1] Fully recruited burbot are ≥450 mm TL while partially recruited burbot are smaller.

APPENDIX D

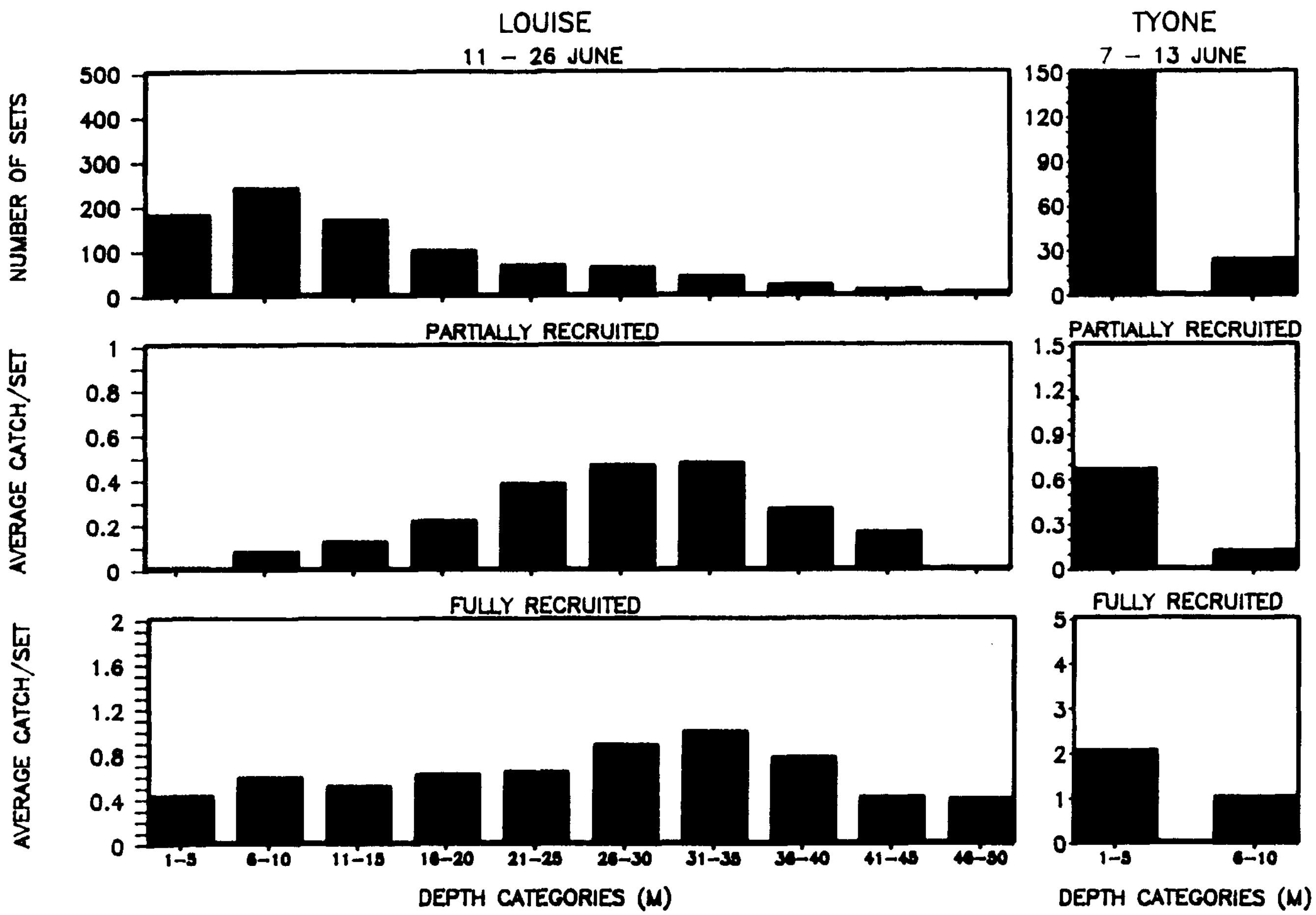
Figures



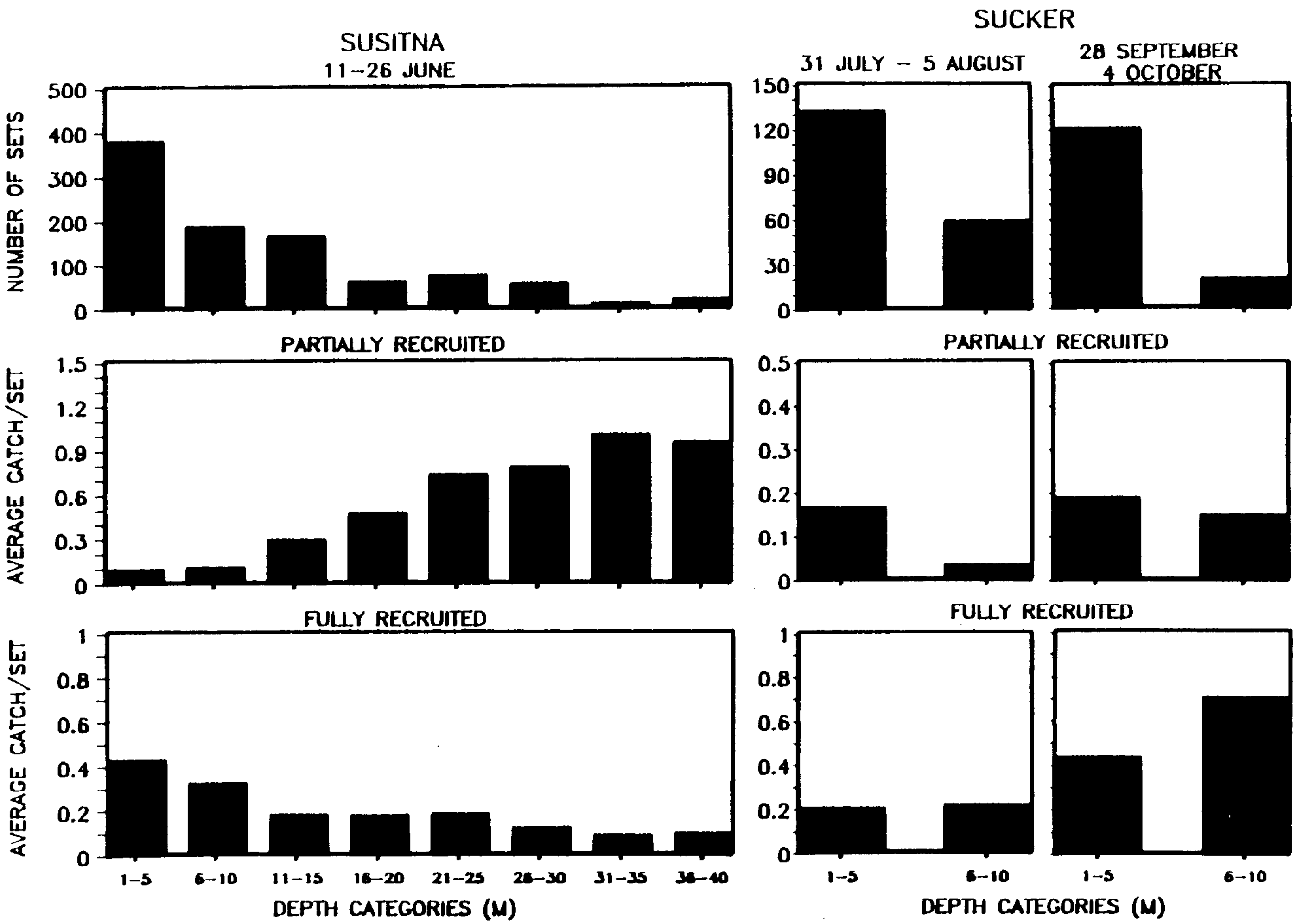
Appendix Figure 1. Frequency of sets by depth and average catch by depth of fully (≥450 mm TL) and partially recruited (<450 mm TL) burbot for the sampling events in Summit and Moose Lakes in 1988.



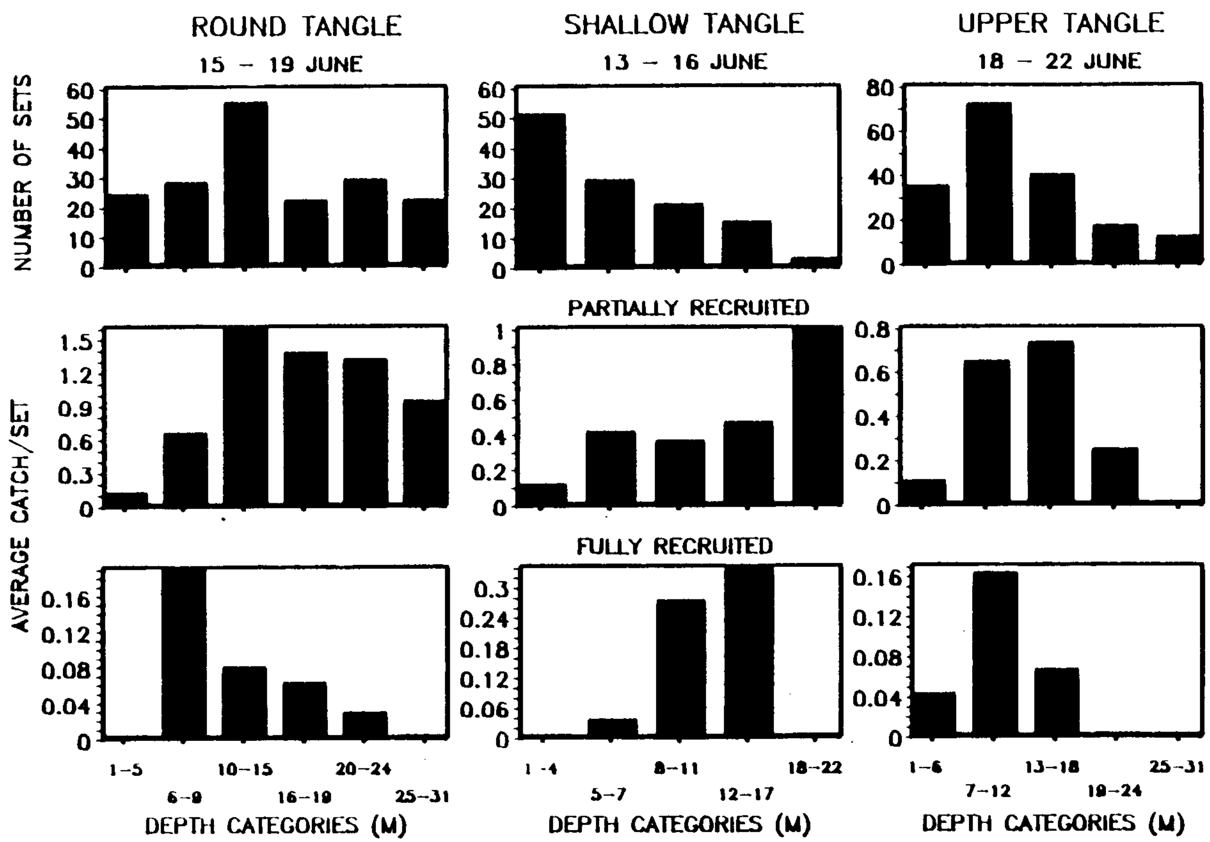
Appendix Figure 2. Frequency of sets by depth and average catch by depth of fully (≥450 mm TL) and partially recruited (<450 mm TL) burbot for the sampling events in T, Glacier, and George Lakes in 1988.



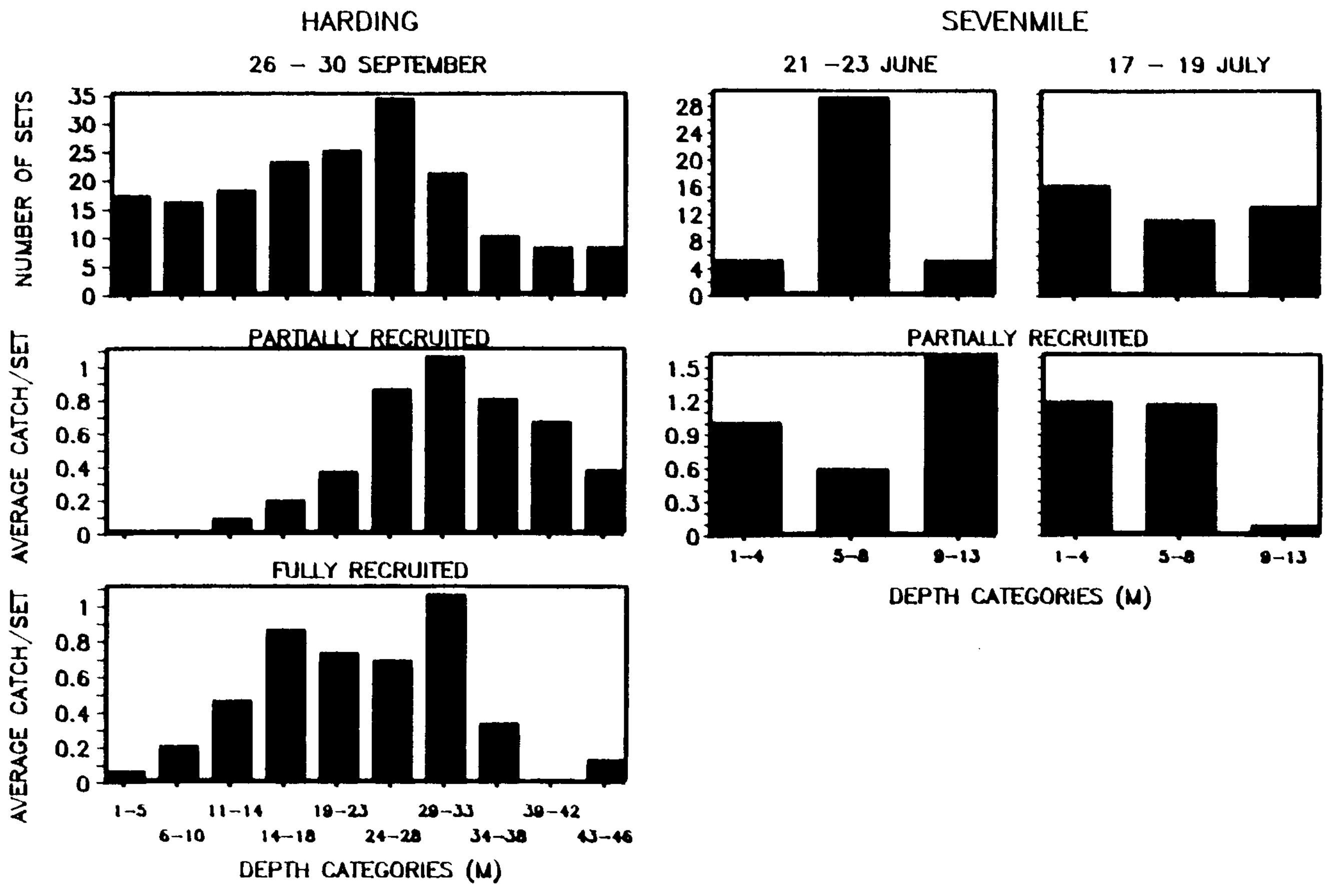
Appendix Figure 3. Frequency of sets by depth and average catch by depth of fully (≥450 mm TL) and partially recruited (<450 mm TL) burbot for the sampling events in Lake Louise and Tyone Lake in 1988.



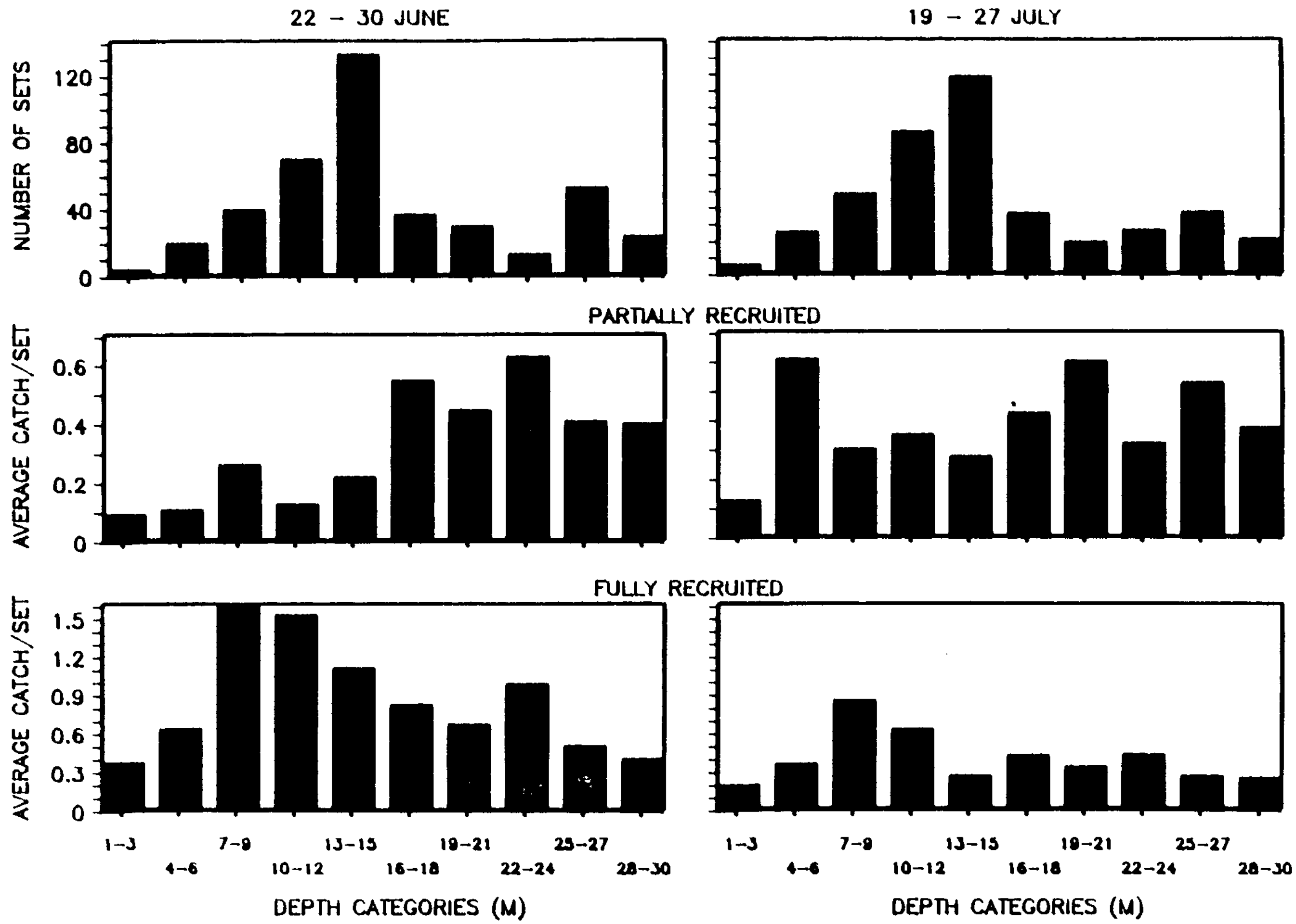
Appendix Figure 4. Frequency of sets by depth and average catch by depth of fully (≥450 mm TL) and partially recruited (<450 mm TL) burbot for the sampling events in Susitna and Sucker Lakes in 1988.



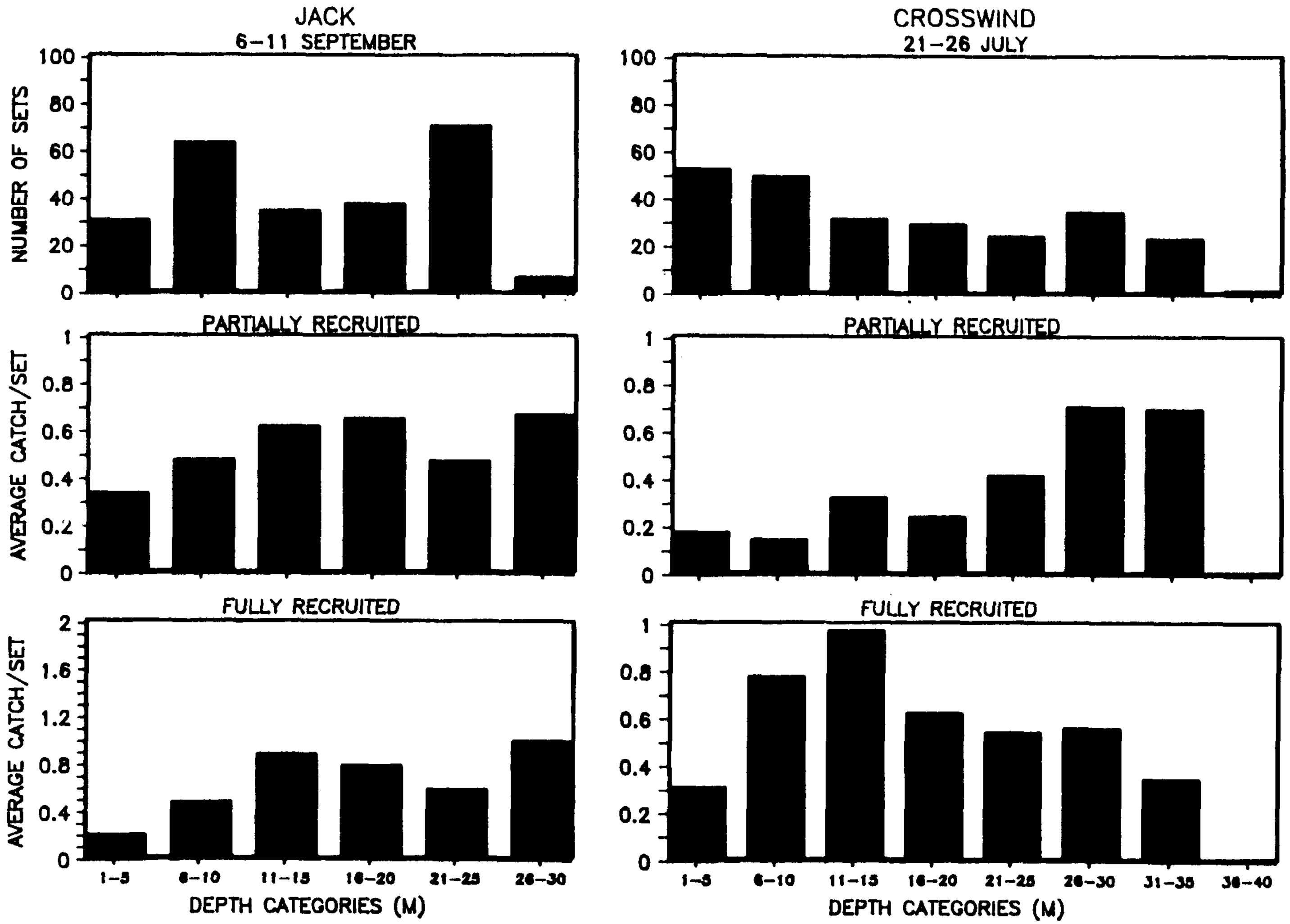
Appendix Figure 5. Frequency of sets by depth and average catch by depth of fully ($\geq$450 mm TL) and partially recruited (<450 mm TL) burbot for the sampling events in Round Tangle, Shallow Tangle, and Upper Tangle Lakes in 1988.



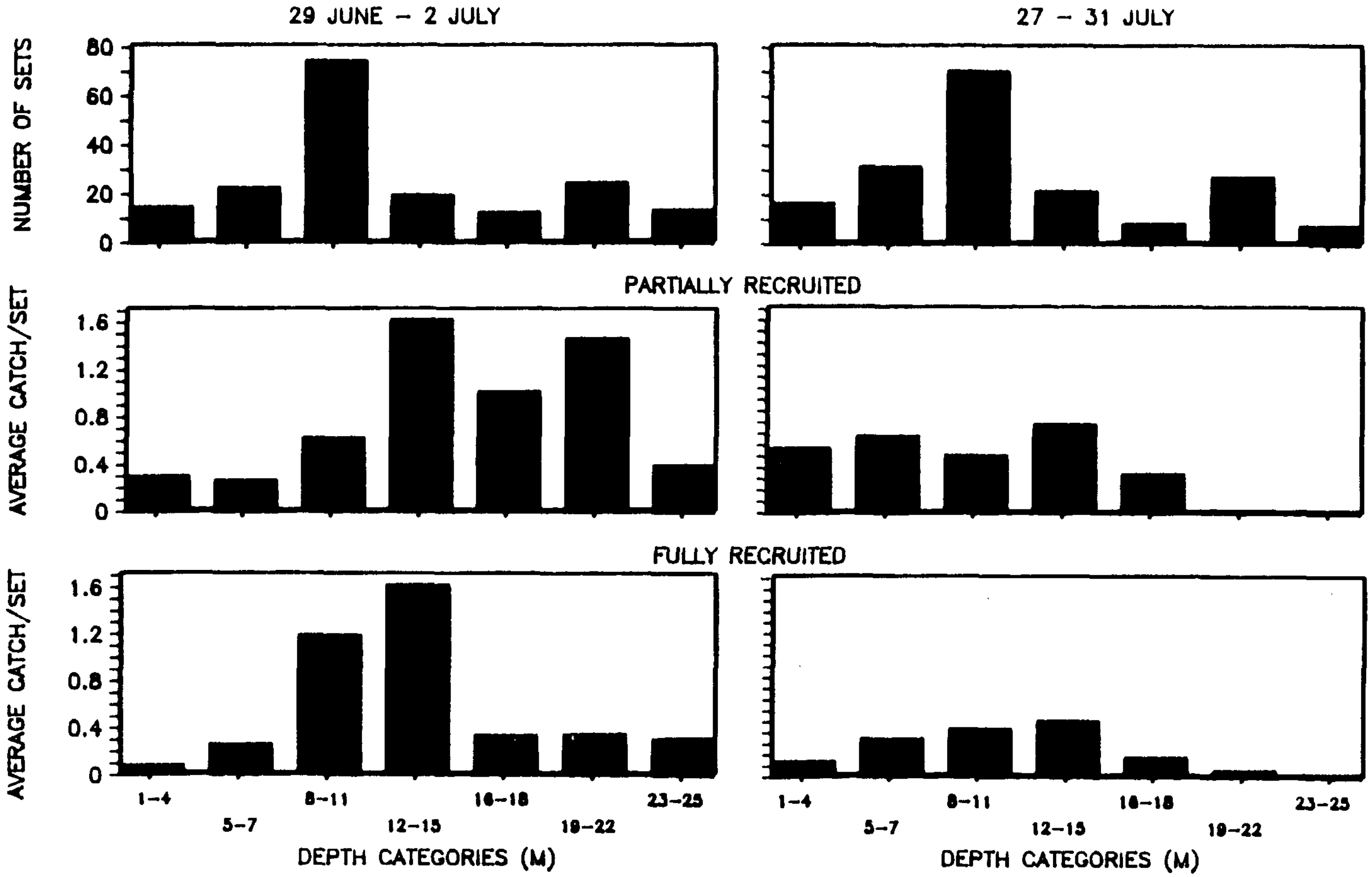
Appendix Figure 6. Frequency of sets by depth and average catch by depth of fully (≥450 mm TL) and partially recruited (<450 mm TL) burbot for the sampling events in Harding and Sevenmile Lakes in 1988.



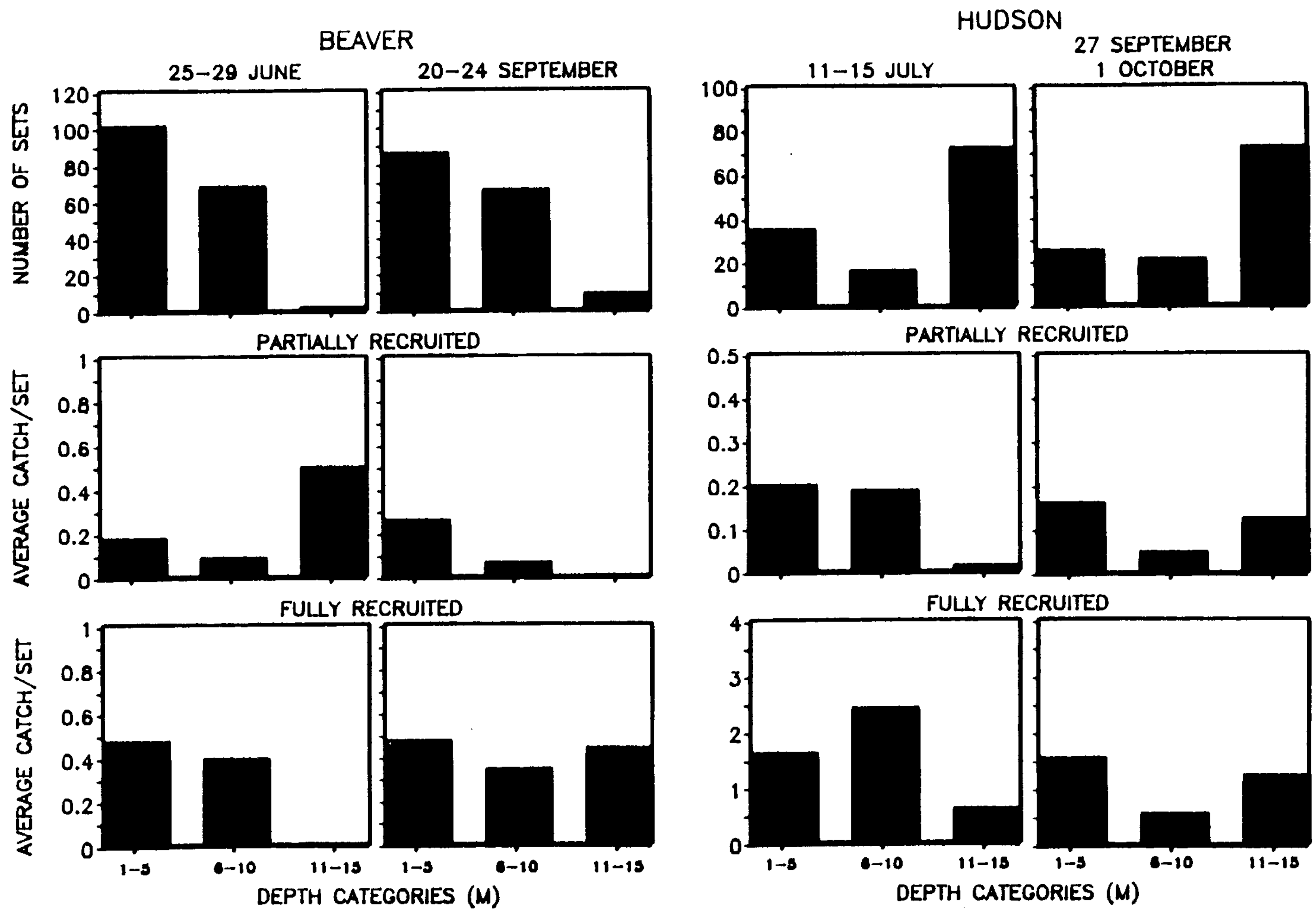
Appendix Figure 7. Frequency of sets by depth and average catch by depth of fully ($\geq$450 mm TL) and partially recruited (<450 mm TL) burbot for the sampling events in Paxson Lake in 1988.



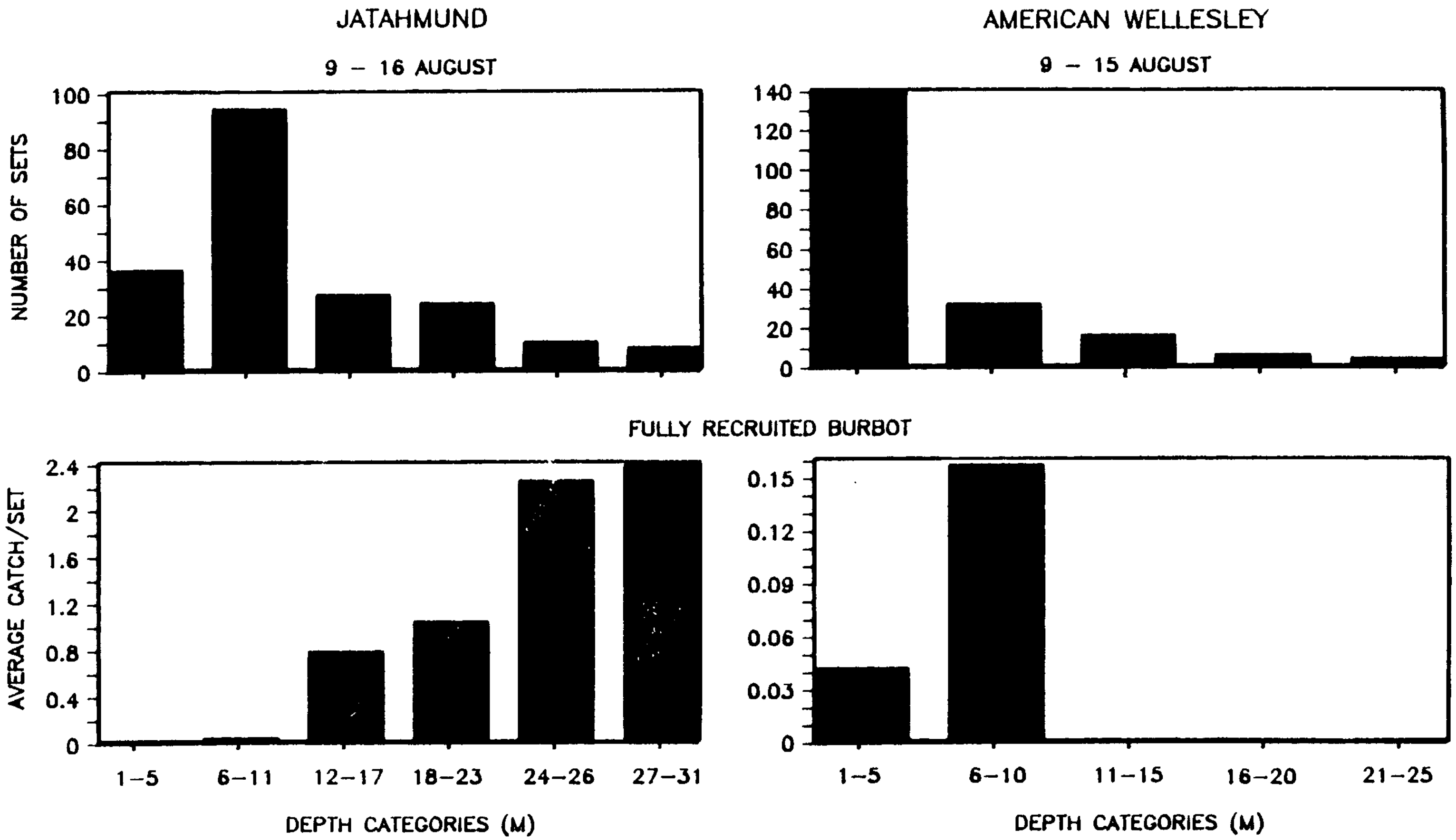
Appendix Figure 8. Frequency of sets by depth and average catch by depth of fully (≥450 mm TL) and partially recruited (<450 mm TL) burbot for the sampling events in Jack and Crosswind Lakes in 1988.



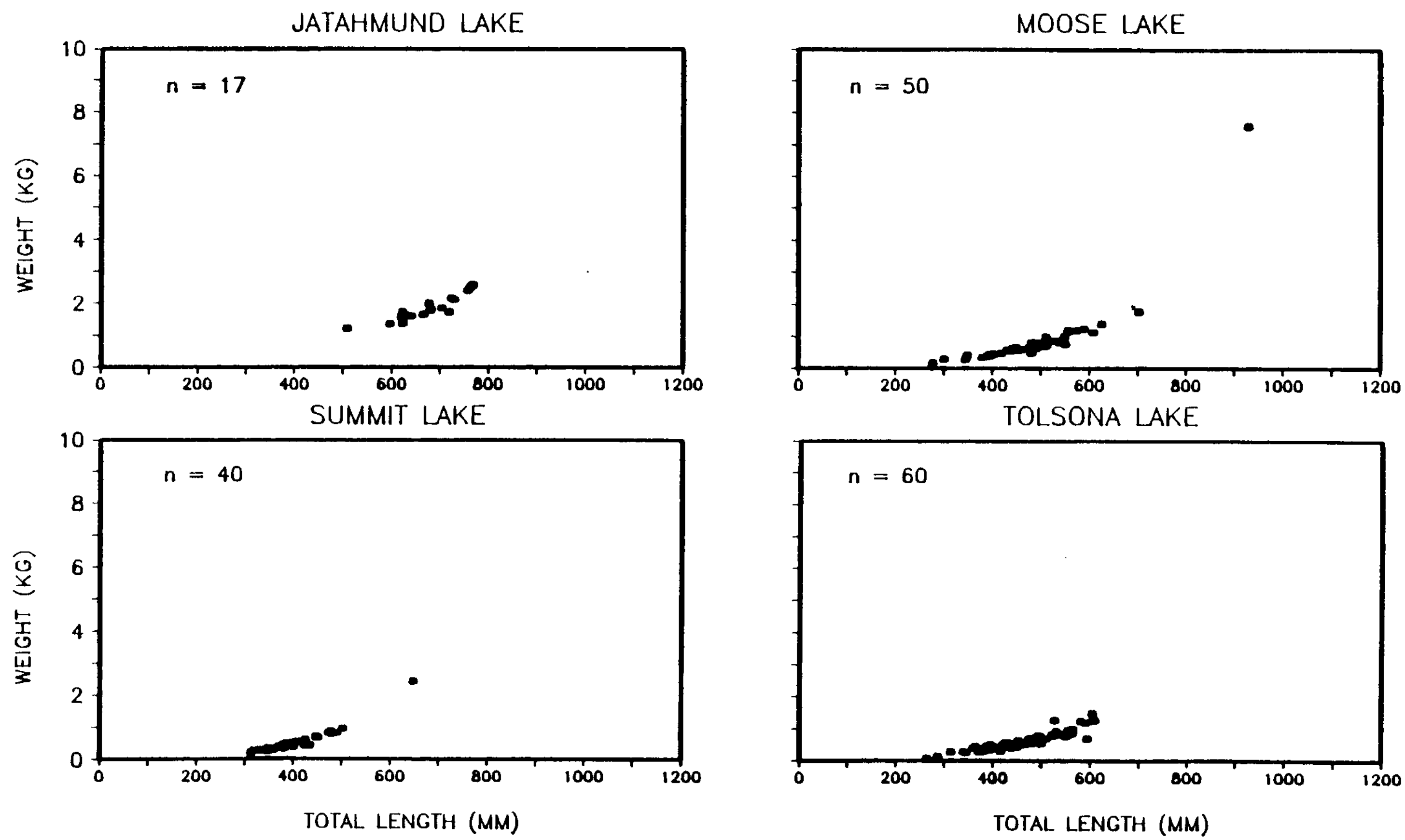
Appendix Figure 9. Frequency of sets by depth and average catch by depth of fully (≥450 mm TL) and partially recruited (<450 mm TL) burbot for the sampling events in Fielding Lake in 1988.



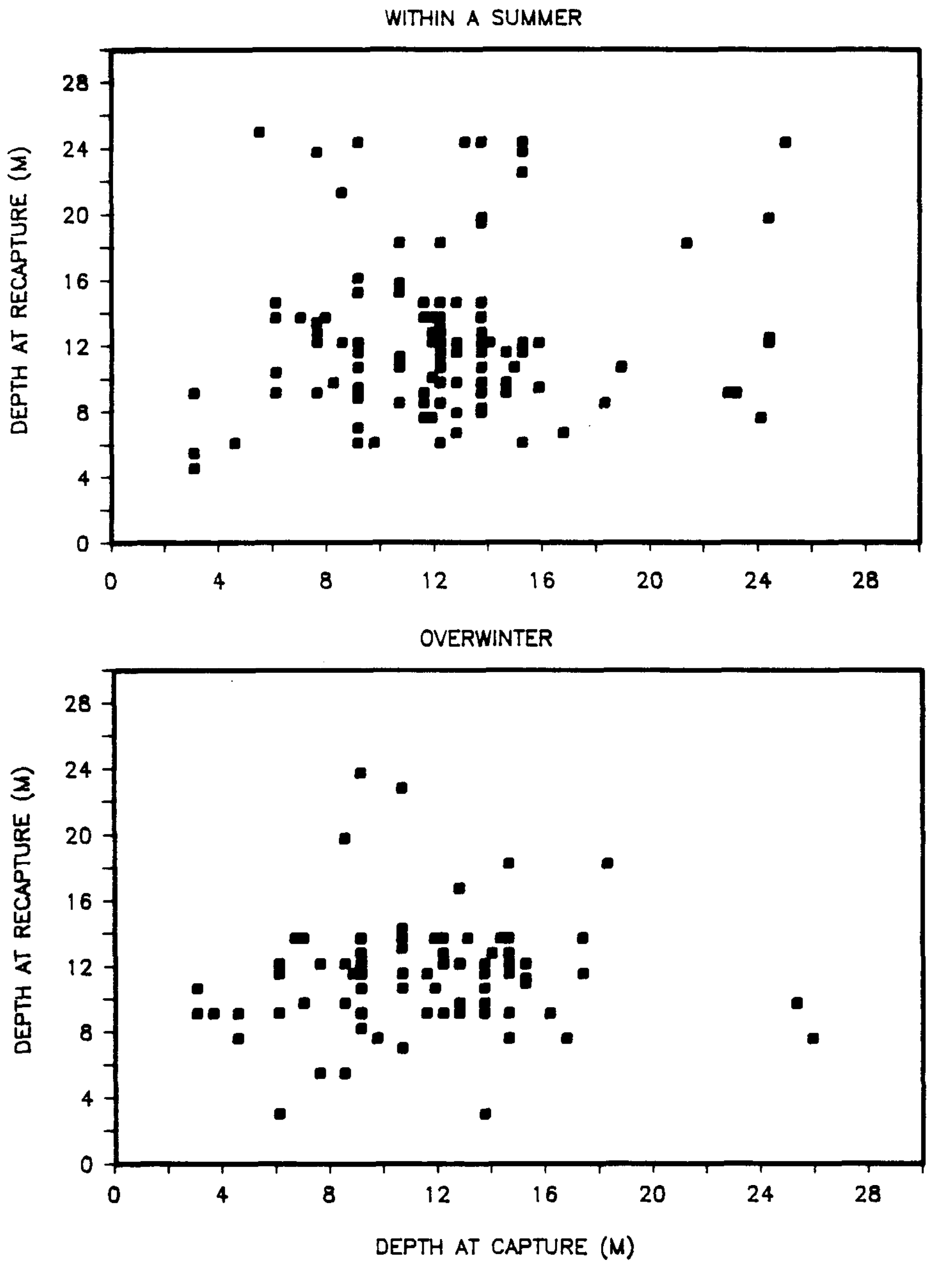
Appendix Figure 10. Frequency of sets by depth and average catch by depth of fully (≥450 mm TL) and partially recruited (<450 mm TL) burbot for the sampling events in Beaver and Hudson Lakes in 1988.



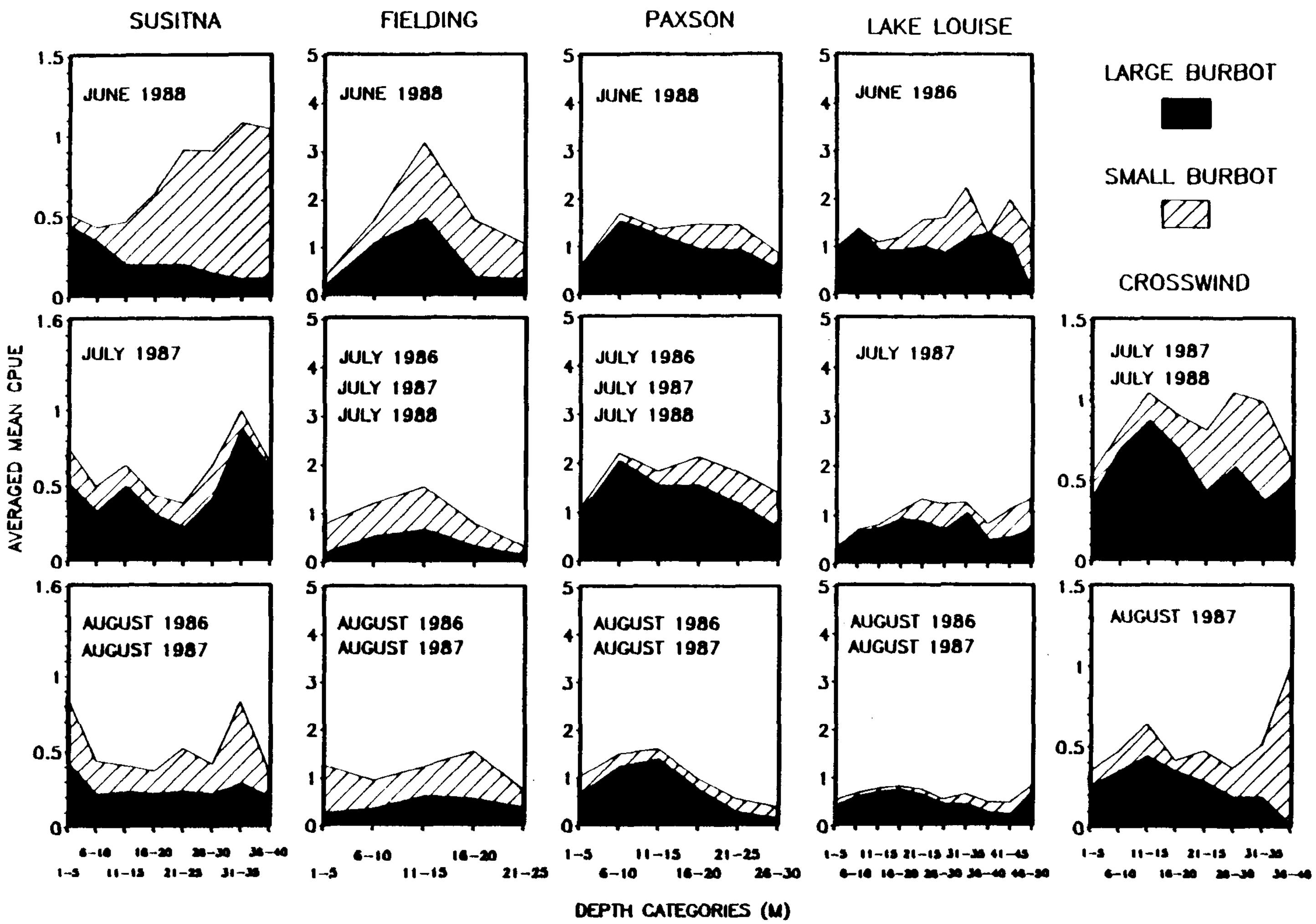
Appendix Figure 11. Frequency of sets by depth and average catch by depth of fully recruited (≥450 mm TL) burbot for the sampling events in Jatahmund and American Wellesley Lakes in 1988.



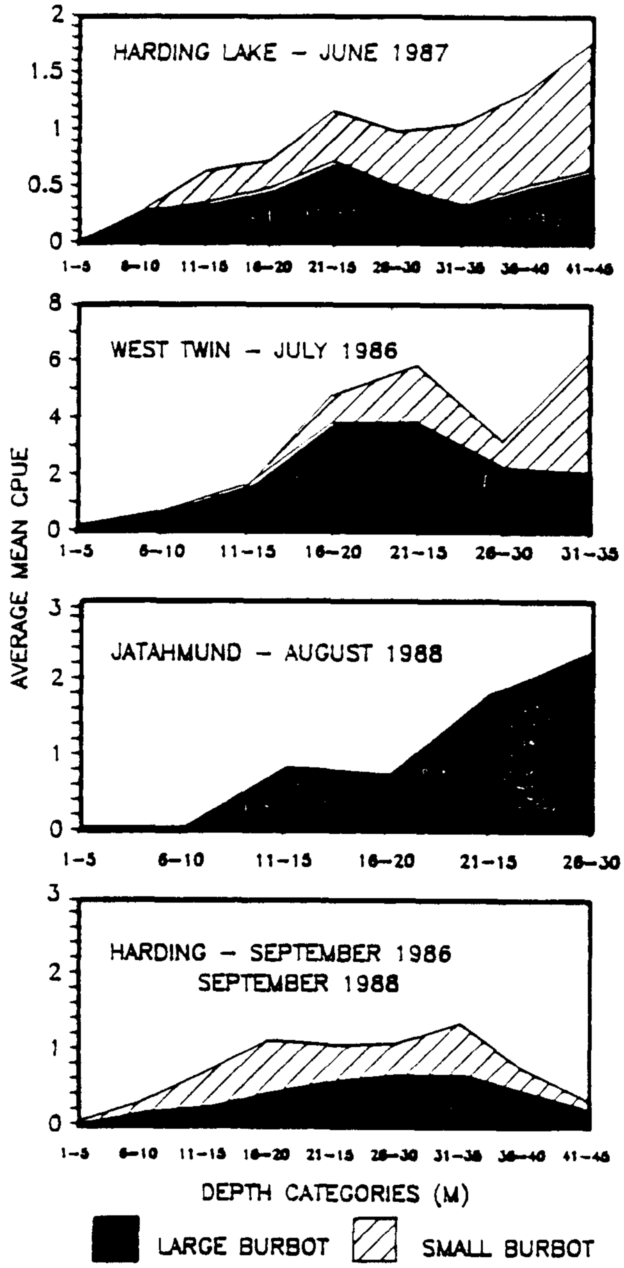
Appendix Figure 12. Length and weight data for burbot in Tolsona, Moose, Summit, and Jatahmund Lakes. Data were collected during 1986-1988 from the first three populations and during 1988 from the population in Jatahmund Lake.



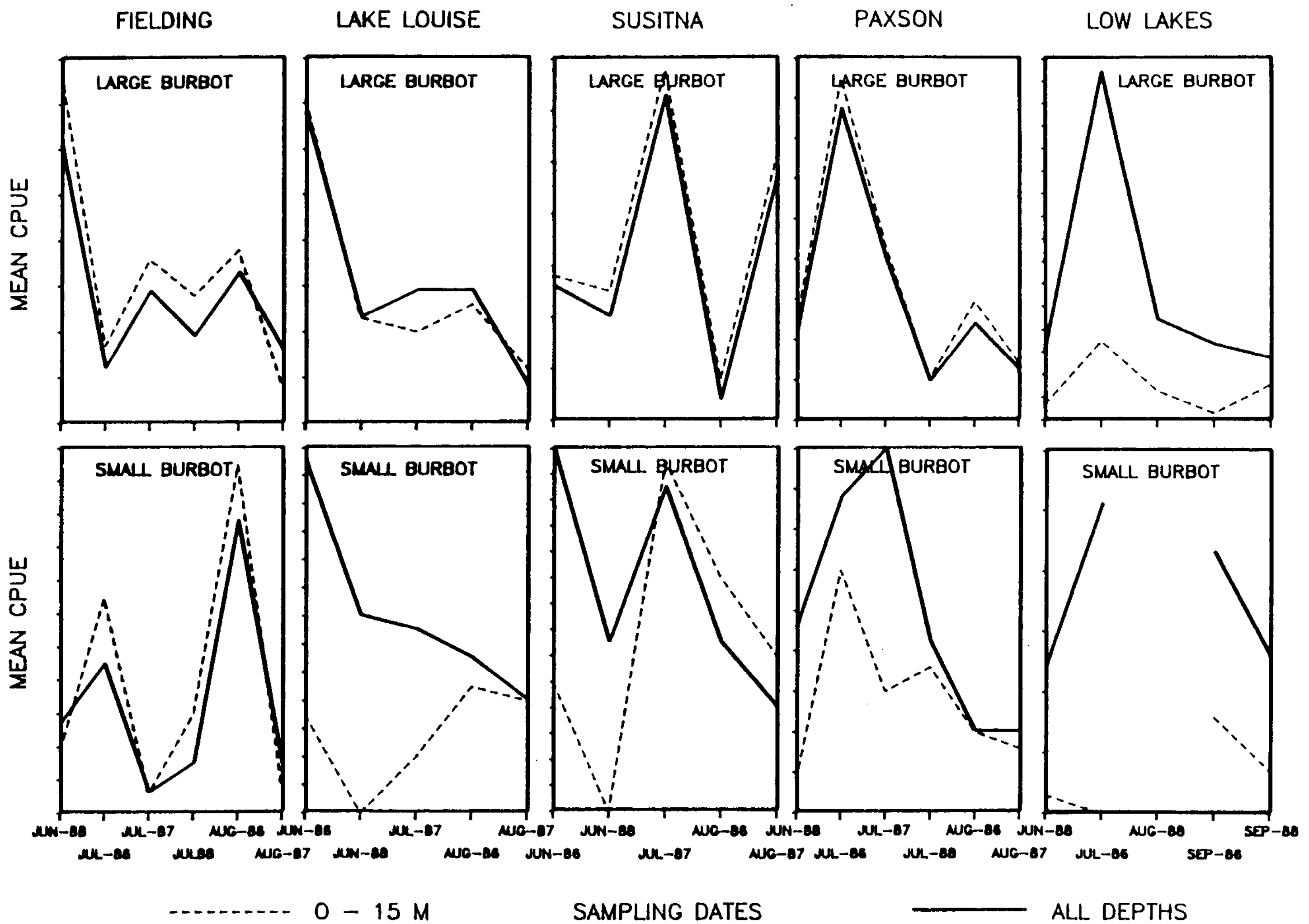
Appendix Figure 13. Relationship between depth of capture and depth of recapture of burbot ≥300 mm TL free in Paxson Lake between sampling events within a summer and free between sampling events in different years (overwinter). Data were collected in 1986-1988.



Appendix Figure 14. Area polygons of mean CPUE by depth, by season, and by size of burbot for populations in high-elevation lakes (>600 m). Mean CPUE are arithmetic averages from data collected during 1986-1988. Large burbot are ≥450 mm TL; small burbot are <450 mm TL.



Appendix Figure 15. Area polygons of mean CPUE by depth, by season, and by size of burbot for populations in low-elevation lakes (<600 m). Mean CPUE are arithmetic averages from data collected during 1986-1988. Large burbot are ≥450 mm TL; small burbot are <450 mm TL.



Appendix Figure 16. Comparison of mean CPUE calculated from all sets and from shallow sets by season in lakes at elevations higher than 600 m (Fielding, Louise, Susitna, and Paxson Lakes) and in lakes at lower elevation. Mean CPUE are arithmetic averages from data collected during 1986-1988. Large burbot are ≥450 mm TL; small burbot are <450 mm TL.