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Stock Assessment and Biological Characteristics of Burbot in Lakes of Interior Alaska During 1990

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October 1991

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TABLE OF CONTENTS

	Page
LIST OF TABLES	ii
LIST OF FIGURES	iii
LIST OF APPENDICES	iv
ABSTRACT	1
INTRODUCTION	2
METHODS	5
Gear Description	5
Study Design	5
Abundance, Survival Rates, and Recruitment	9
Mean CPUE	11
Length and Weight	12
RESULTS	12
Length Distributions	12
Mean CPUE	18
Mark-Recapture Experiments	18
Survival Rates and Recruitment	24
Length-Weight Relationships	24
Auxiliary Information	24
DISCUSSION	34
ACKNOWLEDGEMENTS	35
LITERATURE CITED	35
APPENDIX A	38
APPENDIX B	42
APPENDIX C	58
APPENDIX D	70

LIST OF TABLES

Table		Page
1.	Numbers of sets and dates of sampling events for the stock assessment of burbot populations in 16 lakes in interior Alaska in 1990	7
2.	Mean lengths (millimeters TL) of burbot measured during sampling events in 16 lakes in interior Alaska in 1990	19
3.	Estimated mean CPUE of fully recruited burbot from stratified and unstratified systematic sampling of populations studied in 1990	21
4.	Estimated mean CPUE of partially recruited burbot from stratified and unstratified systematic sampling of populations studied in 1990	22
5.	Estimated mean CPUE of both partially and fully recruited burbot from unstratified systematic sampling of populations in lakes along the Denali Highway during 1990	23
6.	Estimates of abundance, survival rates, and recruitment for burbot residing in Fielding, George, Harding, Louise, Moose, Paxson, Susitna, T, and Tolsona lakes	25
7.	Estimates of abundance, survival rates, and recruitment for all burbot greater than 300 mm TL residing in Round Tangle, Sevenmile, and Upper Tangle lakes	28
8.	Estimated density of burbot in 15 lakes in interior Alaska during 1990	29

LIST OF FIGURES

Figure		Page
1.	Location of lakes in the Tanana River drainage and near Glennallen that were included in studies of burbot populations in interior Alaska in 1990..........	3
2.	Harvests of burbot in Alaskan sport fisheries, 1977-1989 (A) and percentage of burbot harvested by region (B)..	4
3.	Schematic drawing of hoop traps used to catch burbot in interior Alaska in 1990............................	6
4.	Length-frequency histograms of burbot captured in interior Alaska lakes in 1990......................	13
5.	Plots and estimates (and standard errors) of parameters in the length-weight relationships for burbot sampled in Paxson, Hudson, Tolsona, Moose, Susitna, and Tyone lakes and Lake Louise................................	30

LIST OF APPENDICES

Appendix		Page
A.	Description of lakes sampled in 1990..................	39
B1.	Mark-recapture histories of fully recruited burbot by year (by sampling event in 1990) for the populations in Fielding, Paxson, Tyone, Susitna, Summit, T, George, Tolsona, and Harding lakes, and Lake Louise....	43
B2.	Mark-recapture histories of partially recruited burbot by year (by sampling event in 1990) for the population in Fielding Lake.....................................	47
B3.	Mark-recapture histories of burbot of all sizes by year for the populations in Sevenmile, Landlock Tangle, Round Tangle, and Upper Tangle lakes..................	48
B4.	Mark-recapture histories for fully recruited burbot by year (1987) and by sampling events (1988-90) for the populations in Hudson and Moose lakes where mark-recapture experiments were compromised through tag loss and uncertainty of secondary marks............	50
B5.	Numbers of burbot killed during sampling in 16 lakes in interior Alaska in 1990............................	51
B6.	Estimated mean length-at-age for burbot sampled from Hudson Lake in 1990.............................	52
B7.	Voluntary returns of tagged burbot by sport anglers....	53
B8.	Summary of data archives...............................	55
C.	Frequency of sets by depth and average catch of burbot by depth for interior Alaska lakes sampled in 1990.....	59
D.	Bias and variance of mean CPUE........................	71

ABSTRACT

Abundance and/or indices of abundance were estimated for populations of burbot *Lota lota* in 16 lakes in interior Alaska. Sampling occurred from May through October 1990. Mean catch-per-unit of effort of fully recruited burbot (450 millimeters total length and larger) per 48-hour set ranged from 0.18 (standard error = 0.04) in Summit Lake to 3.83 (standard error = 0.44) in Moose Lake. Abundance of fully recruited burbot estimated with mark-recapture experiments was greatest in Susitna Lake (4,659; standard error = 1,920) and lowest in T Lake (87 fish; standard error = 17). Parameter estimates of allometric length-weight relationships ranged between 6.196 and 8.524 for parameter a, and between 2.701 and 3.377 for parameter b.

KEY WORDS: burbot, *Lota lota*, lakes, abundance, hoop traps, systematic design, random design, stratified design, mean length, length-weight, catch-per-unit of effort, abundance estimates, survival rates, recruitment.

INTRODUCTION

A major sport fishery for burbot *Lota lota* occurs in the lakes of interior Alaska (Figure 1) during the winter months from November to April. The majority of burbot are harvested through the ice using baited setlines or jigging. Harvests of burbot from these lakes increased, on average, 30% annually from 1977 to 1983, with the largest harvest occurring during the years 1984 to 1986 (Mills 1990). The lakes in the Glennallen area (Southcentral Alaska) have historically supported the largest component of this harvest. Harvests from lakes in the Glennallen area were greater than 10,000 burbot annually from 1984-1986, with a peak harvest of over 19,000 burbot occurring during 1985 (Figure 2). The lakes of the Tyone River drainage (consisting of Lake Louise and Susitna and Tyone lakes) have historically supported over half the harvest of burbot in the Glennallen area.

Since the peak harvests in the mid-1980s, harvests of burbot in lakes of interior Alaska have declined. This decline in harvests can be attributed to decreasing abundance of burbot in lakes due to overfishing beyond recruitment and due to more restrictive regulations governing the sport fishery. Emergency regulations adopted in 1987 for many of the lakes reduced the bag and possession limits for burbot to a maximum of five fish and reduced the number of simultaneously fished hooks to a maximum of five. Further reductions were made in several lakes (Lake Louise, Tyone, Susitna, Tolsona, Moose, Summit, Fielding, Harding, and T lakes, and the Tangle Lakes system) where the daily bag and possession limits were further reduced to two fish and anglers were restricted to using two hooks. Also, in 1987, setlines were banned as a legal method of sport fishing in Fielding, T, and Harding lakes as well as throughout the Tangle Lakes system. Since that time, Hudson Lake and Lake Louise have been closed to sport fishing for burbot. Also, setlines were banned in the Tyone River drainage for the last 2 years. A recent (1991) action by the Alaska Board of Fisheries eliminated setlines as a legal manner of sport fishing throughout the Upper Copper-Upper Susitna management area.

In the mid-1980s, staff of the Division of Sport Fish of the Alaska Department of Fish and Game initiated a stock assessment program for burbot populations in the Upper Copper-Upper Susitna basin (Region II) and in the Tanana drainage (Region III). This program has continued since that time as a coordinated, interregional research effort. This document is the fifth in a series of annual reports of the findings from this program and partially fulfills the contract requirements for two Federal Aid projects. The objectives of the program in 1990 were as follows:

<u>Project F-10-6, Job Number R-2-4 (Region II):</u>

1. estimate the abundance of burbot greater than 450 mm total length in Lake Louise and Susitna, Tyone, Moose, Tolsona, Hudson, and Paxson lakes;

2. estimate the length-weight relationships for burbot populations in Susitna, Tolsona, and Hudson lakes; and,

3. estimate recruitment and survival rates for burbot greater than 450 mm total length in each of the study lakes.

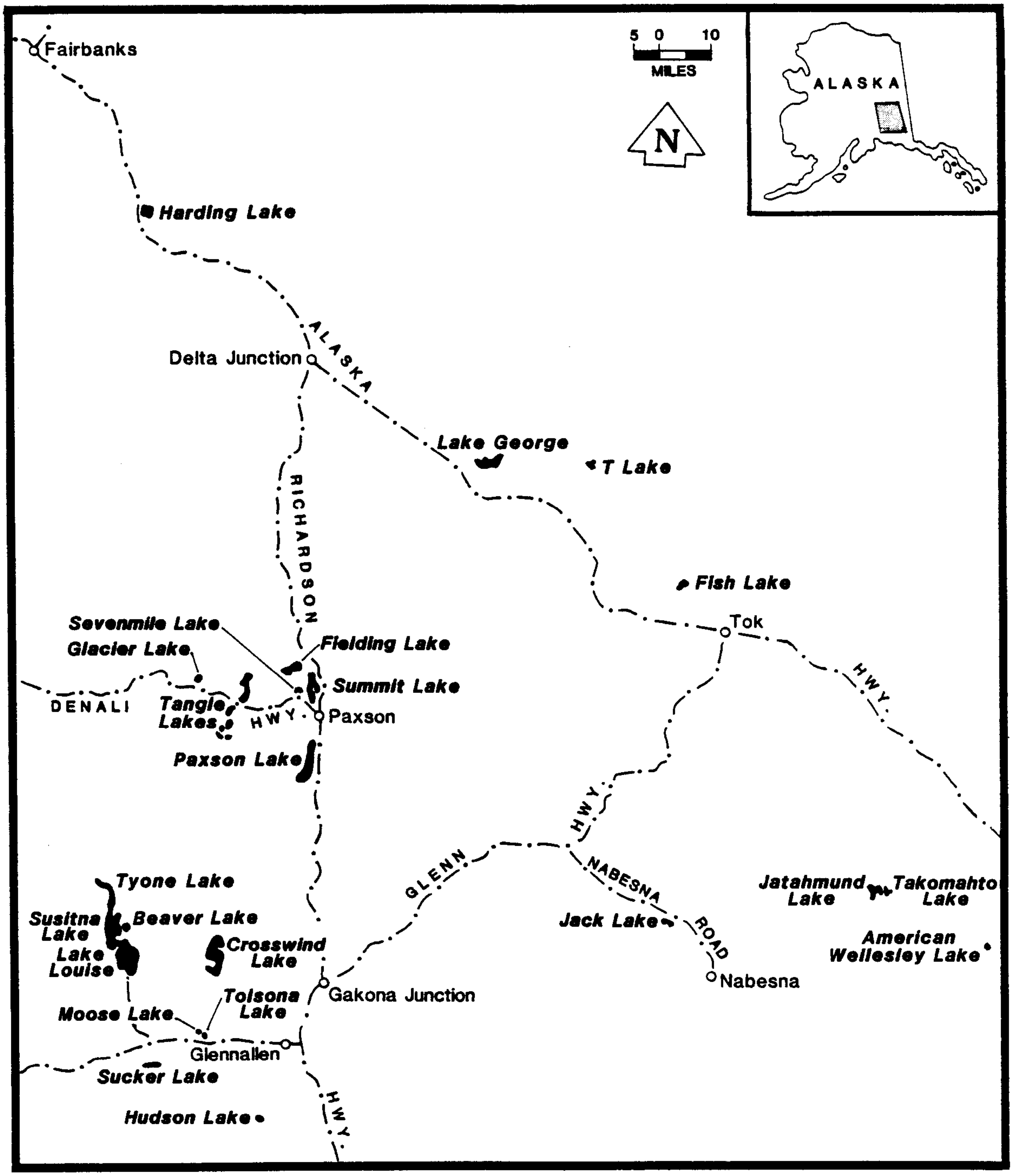
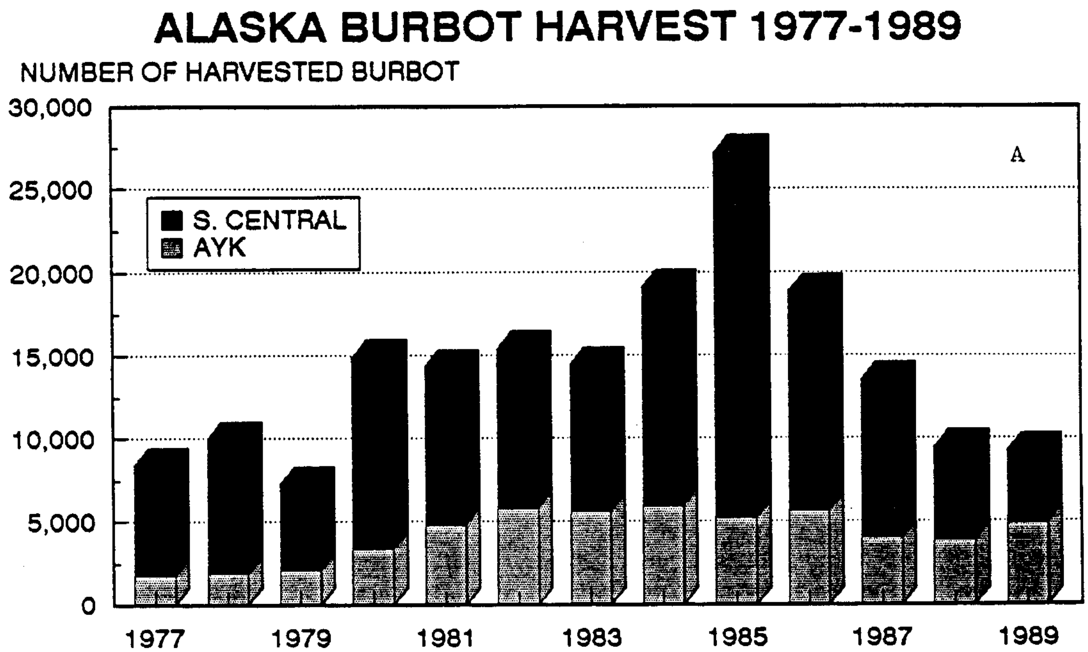


Figure 1. Location of lakes in the Tanana River drainage and near Glennallen that were included in studies of burbot populations in interior Alaska in 1990.



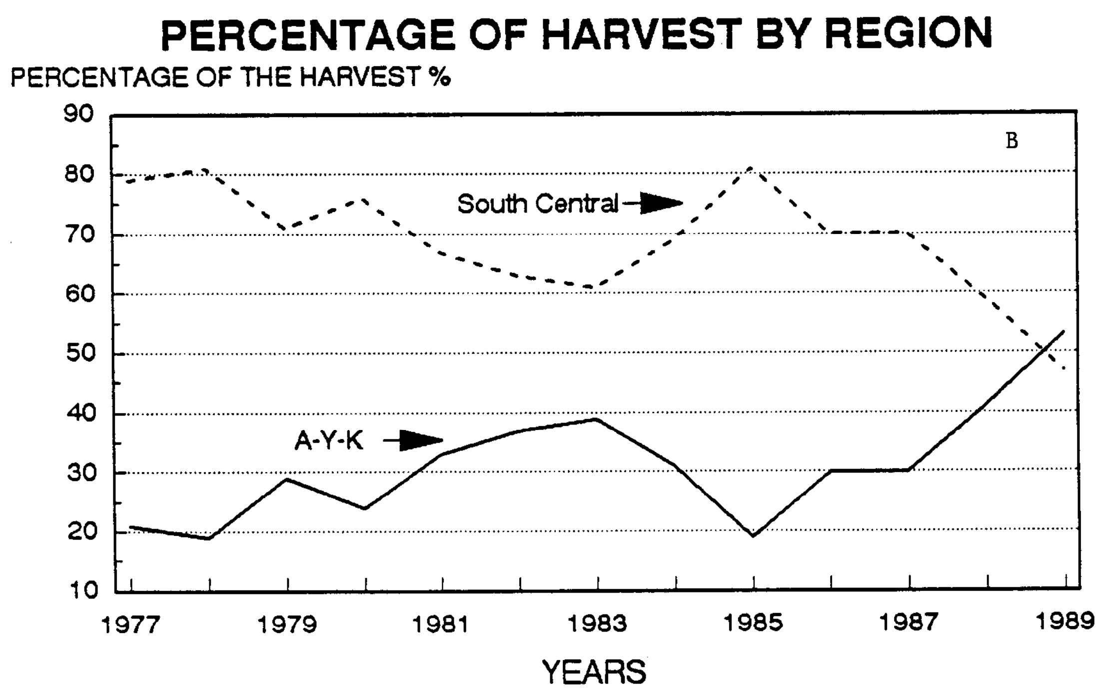


Figure 2. Harvests of burbot in Alaskan sport fisheries, 1977-1989 (A) and percentage of burbot harvested by region (B).

Project F-10-6, Job Number R-3-4a (Region III):

1. estimate the abundance of burbot in Fielding, Landlocked Tangle, Round Tangle, Upper Tangle, Sevenmile, George, and T lakes;

2. index abundance of burbot with mean catch-per-unit-effort statistics in Summit, Fielding, Harding, Landlocked Tangle, Round Tangle, Upper Tangle, Sevenmile, George, and T lakes; and,

3. estimate annual survival rates of those burbot populations for which the Department estimated abundance both during 1989 and 1990.

Each of the populations studied in 1990 has (or had) a popular sport fishery that targeted burbot. Most of these populations resided in lakes that were either geographically isolated or separated by lengthy rivers. The exceptions were the populations in the: (1) Lake Louise Complex (consisting of Lake Louise and Susitna and Tyone lakes); (2) Summit and Paxson lakes; (3) Moose and Tolsona lakes; and (4) the Tangle Lakes Complex (lakes sampled in 1990 in this complex included Landlock, Round, and Upper Tangle lakes). Those lakes are either connected with short rivers, or in the case of Moose and Tolsona lakes, an intermittent stream. Descriptions of each study lake are presented in Appendix A.

METHODS

Gear Description

Burbot were captured in hoop traps 3.05 m in length with seven, 6.35 mm steel hoops (Figure 3). Hoop diameters tapered from 0.61 m at the entrance to 0.46 m at the cod end. Each trap was double throated (tied to the first and third hoop) with throats narrowing to an opening 10 cm in diameter. All netting material was knotted nylon 25 mm bar mesh, held together with No. 15 cotton twine, and treated with an asphaltic compound. Each trap was stretched with two sections of 12 mm galvanized steel conduit which were attached by snap clips to the end hoops of the trap. A numbered buoy was attached to the cod end of the trap with a 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 of the hoop trap. Each hoop trap was soaked for approximately 48 hours (hereafter referred to as a set) to maximize the catch of burbot (Bernard et al. 1991).

Study Design

Mean CPUE was estimated for 16 lakes with two-stage, systematic surveys (Table 1). First, an overlay with parallel lines was placed across a map of each lake at a randomly chosen position, but with the lines in the overlay perpendicular to the long axis of the lake. Distances between adjacent

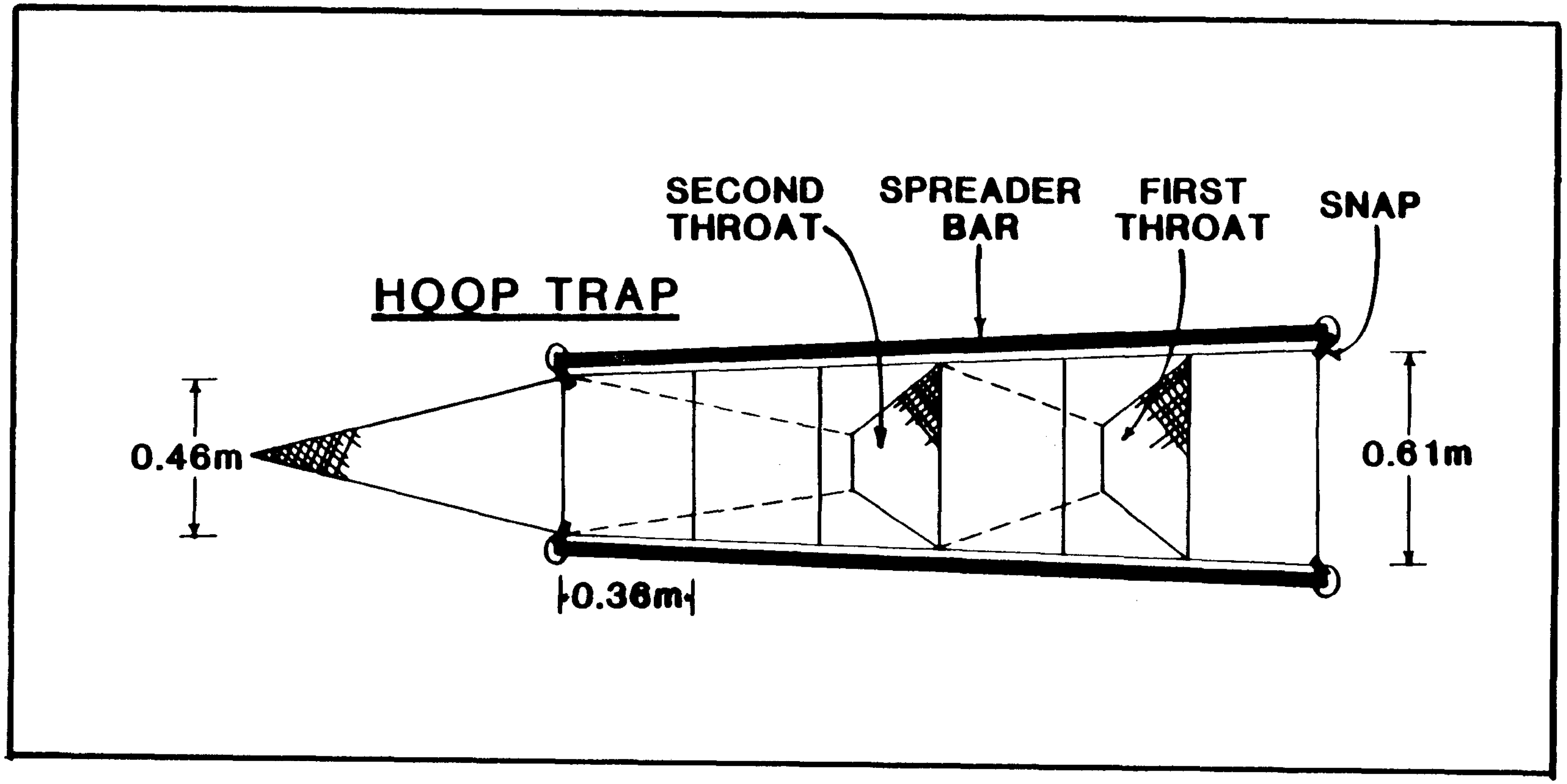


Figure 3. Schematic drawing of hoop traps used to catch burbot in interior Alaska in 1990.

Table 1. Numbers of sets and dates of sampling events for the stock assessment of burbot populations in 16 lakes in interior Alaska in 1990.

Lake	Area (ha)	Sampling: Event	Sampling: Dates	Number of Sets
Fielding	538	1	6/16-20	180
		2	7/19-23	240
		3	8/13-17	180
George	1,863	1	5/25-31	300
Harding	1,000	1	8/18-22	180
		2	9/18-20	122
Landlock Tangle[a]	219	1	7/03-08	218
		2	7/31-8/5	220
Round Tangle	155	1	6/23-26	119
Sevenmile	34	1	6/23-25	40
		2	8/07-09	40
Summit	1,651	1	7/16-20	119
T	162	1	5/18-23	79
Upper Tangle	142	1	7/07-10	119
Hudson	259	1	7/11-17	260
Louise[a]	6,519	1	6/4-19	1,434
Moose	130	1	5/21-23	59
		2	9/04-06	58
Paxson[a]	1,575	1	9/10-26	868
Susitna[a]	3,816	1	6/17-7/2	1,605
Tolsona	130	1	5/22-24	60
		2	9/05-07	60
Tyone	389	1	7/01-05	356
TOTALS			5/18 to 10/6	6,916

[a] Sets were restricted to depths < 15 m.

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. The desired number of sets for each survey in mark-recapture experiments was estimated by dividing an *a priori* estimate of mean CPUE into sample size in numbers of burbot needed for the experiment (see Robson and Regier 1964). The desired number of sets to estimate mean CPUE as an index of abundance was calculated with procedures in Cochran (1977) for determining sample sizes to estimate the mean of a continuous variable. When both parameters (mean CPUE and abundance) were to be estimated, desired sample sizes for both statistics were calculated and the larger was used.

To reduce sampling-induced mortality of burbot resulting from decompression, no traps were set deeper than 15 m in several deep lakes at high altitude (650 m and higher). Parker et al. (1989) determined that fully recruited burbot of high altitude, deep lakes are equally distributed across depths from early spring throughout the summer. This uniform distribution allows restrictive sampling in shallow waters without compromising the accuracy of the mean CPUE as an index of abundance of these burbot. Furthermore, mixing of fully recruited burbot across depths occurs within a few weeks (Lafferty et al. 1990). Selection of sampling locations in these deep lakes followed the same procedure as in other lakes, only a bathymetric map was used, and all locations below 15 m were not considered for sampling. Because partially recruited burbot, < 450 mm total length (TL), are not evenly distributed across depths during summer (Parker et al. 1989), restricting sampling to less than 15 m in depth biased estimates of mean CPUE for that group. For this reason, deep-water sampling in some high altitude lakes occurred when mean CPUE estimates of partially recruited burbot were desired (Summit Lake for example).

Traps were immersed and retrieved during daylight hours beginning on one end of the lake and progressing to the other end. On larger lakes, multiple crews (three members per crew: one person piloted the boat and recorded data while the other two handled traps and measured and tagged captured burbot) immersed and retrieved traps simultaneously. On smaller lakes, a single crew was used to immerse and retrieve traps. Each crew usually immersed and retrieved from 50 to 80 traps in an 8-hour work day. Every new set received fresh bait, and old bait was discarded on shore.

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

Captured fish from each trap were placed into a plastic tank during sampling. Each burbot was measured and those greater than 300 mm TL were doubly marked. Burbot were tagged with an individually numbered Floy tag inserted in the musculature beneath the dorsal fin. Throughout the mark-recapture experiments, Floy tags were deployed in serial order to allow easy recognition of specific locations and sampling events. The second mark, which was used to evaluate loss of Floy tags, was a finclip or a hole punched through the opercle. Recaptures were treated differently for the mark-recapture experiments as compared to the estimation of mean CPUE[2]. Any burbot that was stressed from deep-water removal (usually an expanded gas bladder) or had trap-inflicted injuries was killed and dissected[3]. Otoliths were removed and the sex and maturity of these burbot were recorded. Ages were estimated from whole, polished otoliths by counting annuli according to the methodologies of Beamish and McFarlane (1987) and Chilton and Beamish (1982).

Burbot were separated into two groups for analysis: those fully recruited to the hoop traps ($\geq$ 450 mm TL) and those partially recruited ($<$ 450 mm TL). Bernard et al. (1991) showed that burbot recruited fully to the hoop trap gear between 450 and 500 mm TL in most populations. Determination of sample sizes for surveys and mark-recapture experiments was based solely on fully recruited burbot for most study lakes.

Abundance, Survival Rates, and Recruitment

Abundance of fully recruited burbot was estimated with mark-recapture experiments using one of two estimators: (1) 1-year, two-sample model from Chapman (1951); or (2) the multi-year model of Jolly (1965) and Seber (1965). One-year, two-sample experiments were used in small lakes where sampling costs were low; and Jolly-Seber models were used when a population had been sampled for at least three consecutive events. Because of uncertainty as to the length at full recruitment to sampling gear for burbot in Landlock Tangle, Round Tangle, Upper Tangle, and Sevenmile lakes, a single estimate of abundance was computed for each population (Lafferty et al. 1990). Mark-recapture histories for all populations studied in 1990 are in Appendices B1-B4. The Chapman's modification of the Petersen model (Seber 1982) is:

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

and,

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

[2] Burbot captured "k" times in a single survey were considered captured only once to estimate abundance with mark-recapture experiments, but were considered captured "k" times to estimate mean CPUE.

[3] Burbot with symptoms of decompression were not tagged to promote equal probability of survival and capture of marked and unmarked burbot.

where:

$\hat{N}$ = estimated abundance;

M = number of marked burbot released alive into the population 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.

The open population model of Jolly (1965) and Seber (1965) is:

$$\hat{M}_{i,i+1} = \frac{R_{i,i+2} \; M_{i+1}}{R_{i+1,i+2}} + R_{i,i+1} + D_{i,i+1} \quad (i=2,3,...,s-1) \qquad (3)$$

where:

s = to the sum of sampling events i;

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).

An estimate of the survival rate between sampling events "s" and "t" was calculated as:

$$\hat{S}_{i,i+1} = \frac{\hat{M}_{i,i+1}}{M_i} \quad (i=2,3,...,s-2). \qquad (4)$$

Abundance and recruitment were estimated as follows:

$$\hat{N}_i = \frac{C_i \; \hat{M}_{i-1,i}}{R_{i-1,i}} \quad (i=2,3,...,s-1); \text{ and,} \qquad (5)$$

$$\hat{A}_{i-1,i} = \hat{N}_i - \hat{N}_{i-1} \; \hat{S}_{i-1,i} \quad (i=2,3,...,s-2) \qquad (6)$$

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" that are still living just prior to event "t".

Equations 4 through 6 (and variances) were calculated with the program JOLLY as described in Pollock et al. (1985, 1990).

For those populations that have been in the stock assessment program since 1986 and earlier, a combination of estimation methods (Jolly-Seber and Chapman) was used to extend the range of the estimates according to the approach suggested in Pollock (1982). Gilbert (1973) has demonstrated that statistics using the Jolly-Seber models are unbiased when there are large sample sizes and large numbers of recaptured animals. To maximize sample sizes and numbers of recaptured burbot, sampling events separated by less than 4 weeks were pooled into one event. For those mark-recapture experiments that began in previous years with two sampling events during the first year, the abundance estimated from the Petersen model for that first year was used along with Equation 6 to estimate surviving recruitment between the first 2 years of the experiment. In this case, the variance of the first estimate of recruitment was calculated as follows (Goodman 1960):

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

Mean CPUE

Mean CPUE was estimated for fully (≥ 450 mm TL) and partially (< 450 mm TL) recruited burbot following a two-stage sampling design with transects as first-stage units and sets along transects as second-stage units (Sukhatme et al. 1984). Although all transects had an equal probability of being included in a survey, they were of different sizes (lengths) depending upon the shape of the lake. Under these conditions, an unbiased estimate of mean CPUE is:

$$\overline{CPUE} = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{m_i}\sum_{i=1}^{m_i}\omega_i\, c_{ij} \qquad (8)$$

where:

c_{ij} = catch of burbot from the jth set on the ith transect;

n = number of transects;

m_i = number of sets sampled on the ith transect;

$\omega_i = M_i/\bar{M}$; and

M_i = maximum possible sets on the ith transect.

Although the M_i and $\bar{M}$ are unknown, the m_i and $\bar{m}$ were used as substitutes because both M and m are directly related to the length of transects. Thus $\hat{\omega}_i = m_i/\bar{m}$ was inserted for ω_i. Because few burbot enter traps during daylight (Bernard et al. 1991), catches were not adjusted for the few hours deviation in soak times from the standard 48 hours for most sets. Although the distribution of burbot can be related to depth (Odell 1932; Kennedy 1940; Rawson 1951; Dryer 1966), estimates of mean CPUE were not post-stratified by depth because sampling effort was proportionally (or near proportionally) allocated across depths with the survey design. A two-stage, resampling procedure (Efron 1982, Rao and Wu 1988) was used to generate an empirical distribution of mean CPUE for each survey from which variance of mean CPUE and bias from using $\hat{\omega}$ were estimated (see Appendix D). In resampling procedures, sets were chosen randomly even though the original selection of sets was systematic. Systematically drawn data can be treated as randomly drawn with little concern for bias in the resultant statistics only so long as these data are not autocorrelated nor follow a trend (Wolter 1984).

Length and Weight

Measurements of weight were limited to burbot greater than 600 mm TL to improve the existing length-weight relationships already published for populations in Lake Louise, Susitna, Tyone, Hudson, Tolsona, Moose, and Paxson lakes (Parker et al. 1987, 1988, and 1989). When sample sizes of lengths and weights were large, parameter estimates of allometric length-weight relationships were estimated using the iterative nonlinear least squares technique of Marquardt (1963). This method is similar to performing a series of ridge regressions with an algorithm that is a compromise between Gauss-Newton and steepest descent. 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. Output from these calculations were plotted as an isopleth diagram of the sum of squares of the residuals from each set of initial values. The parameter estimates with the lowest sum of squares were reported.

RESULTS

Length Distributions

Three populations (Landlock Tangle, Moose, and Tolsona lakes) had length distributions that were significantly different between sampling events (Kolmogorov-Smirnov two-sample test, $P < 0.05$; Figure 4) while length distributions of the three sampling events in Fielding Lake were not significantly different from June to July to August. The increase of mean length of fully

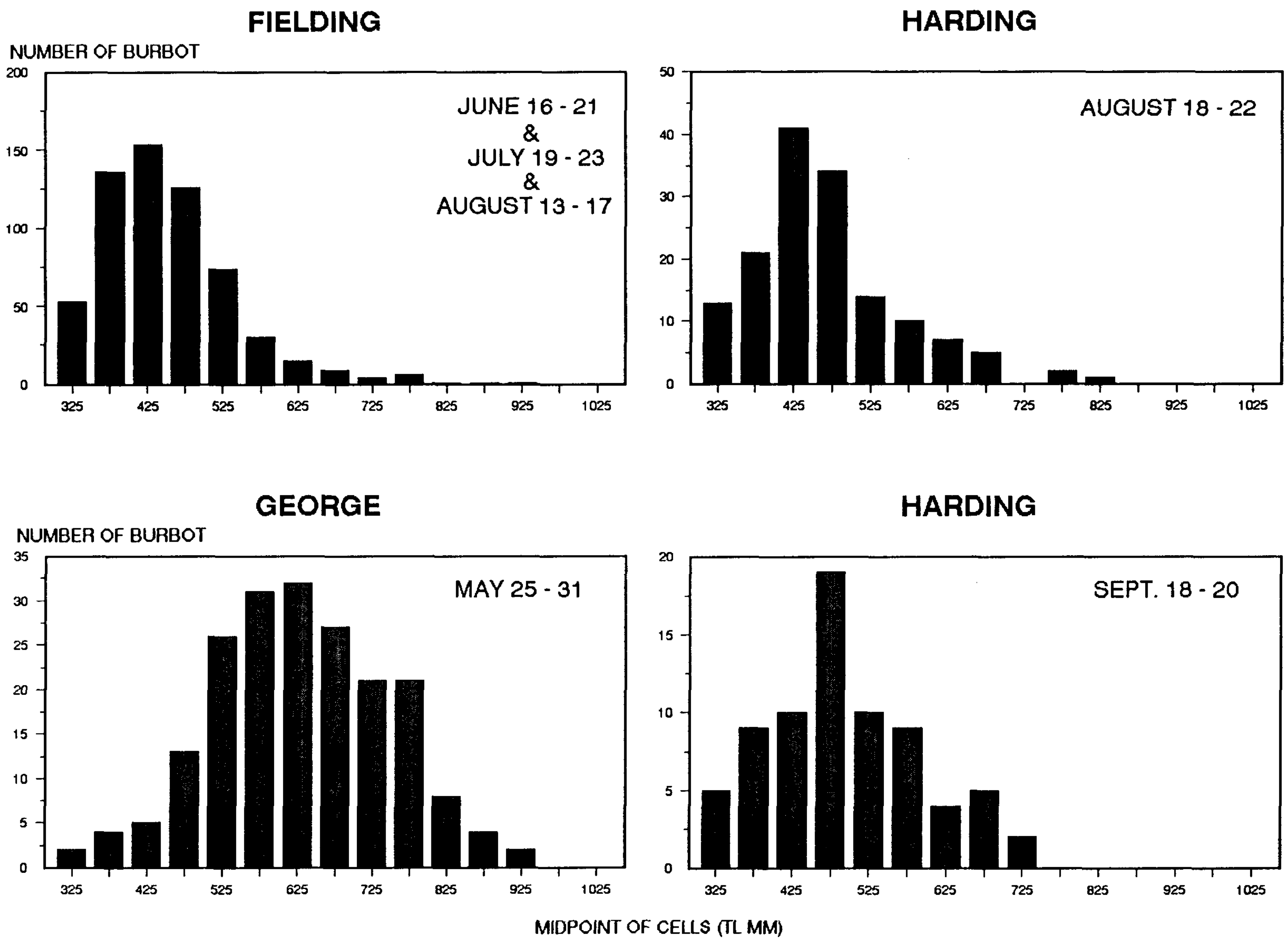

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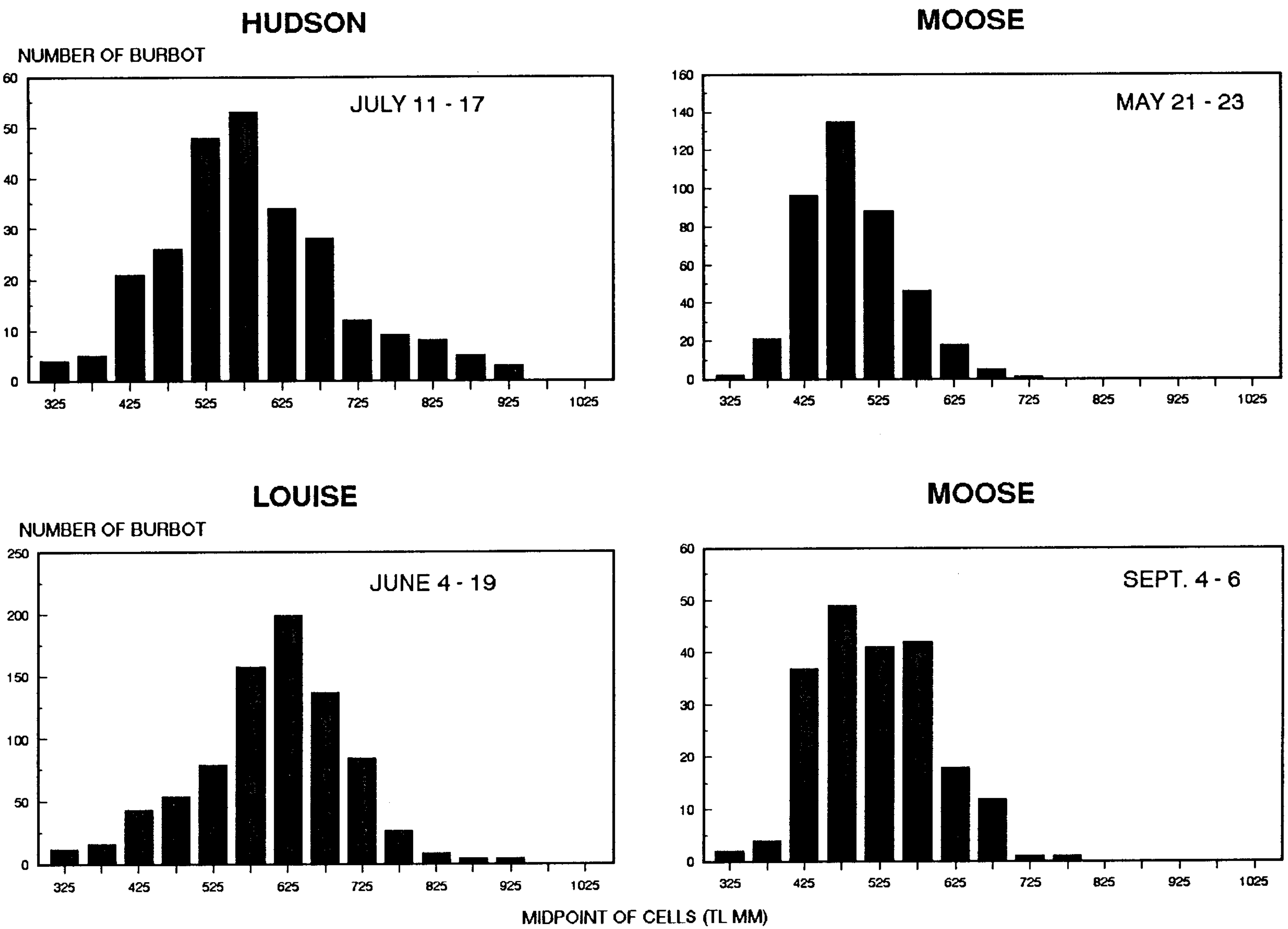
Figure 4. Length-frequency histograms of burbot captured in interior Alaska lakes in 1990.



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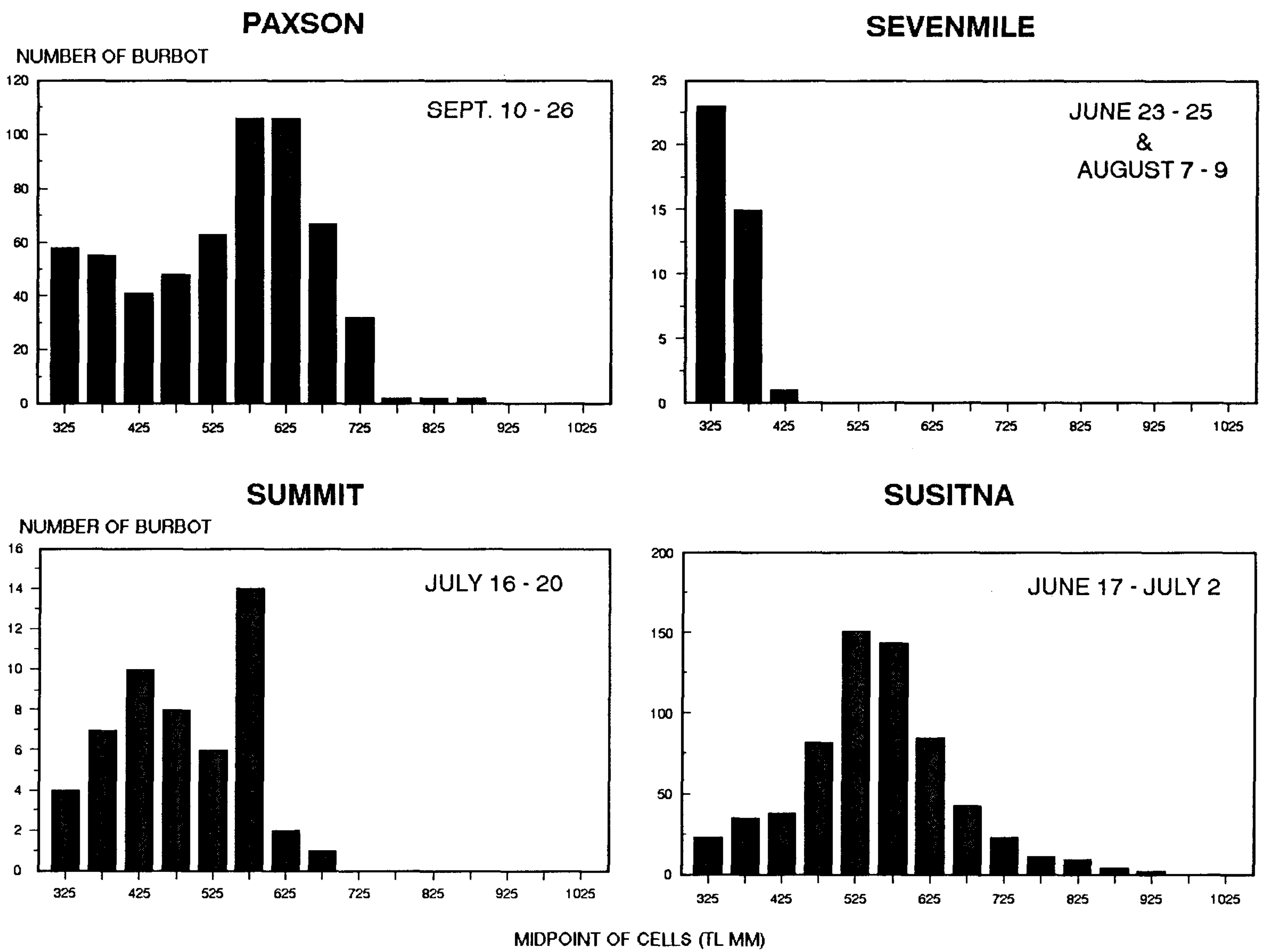

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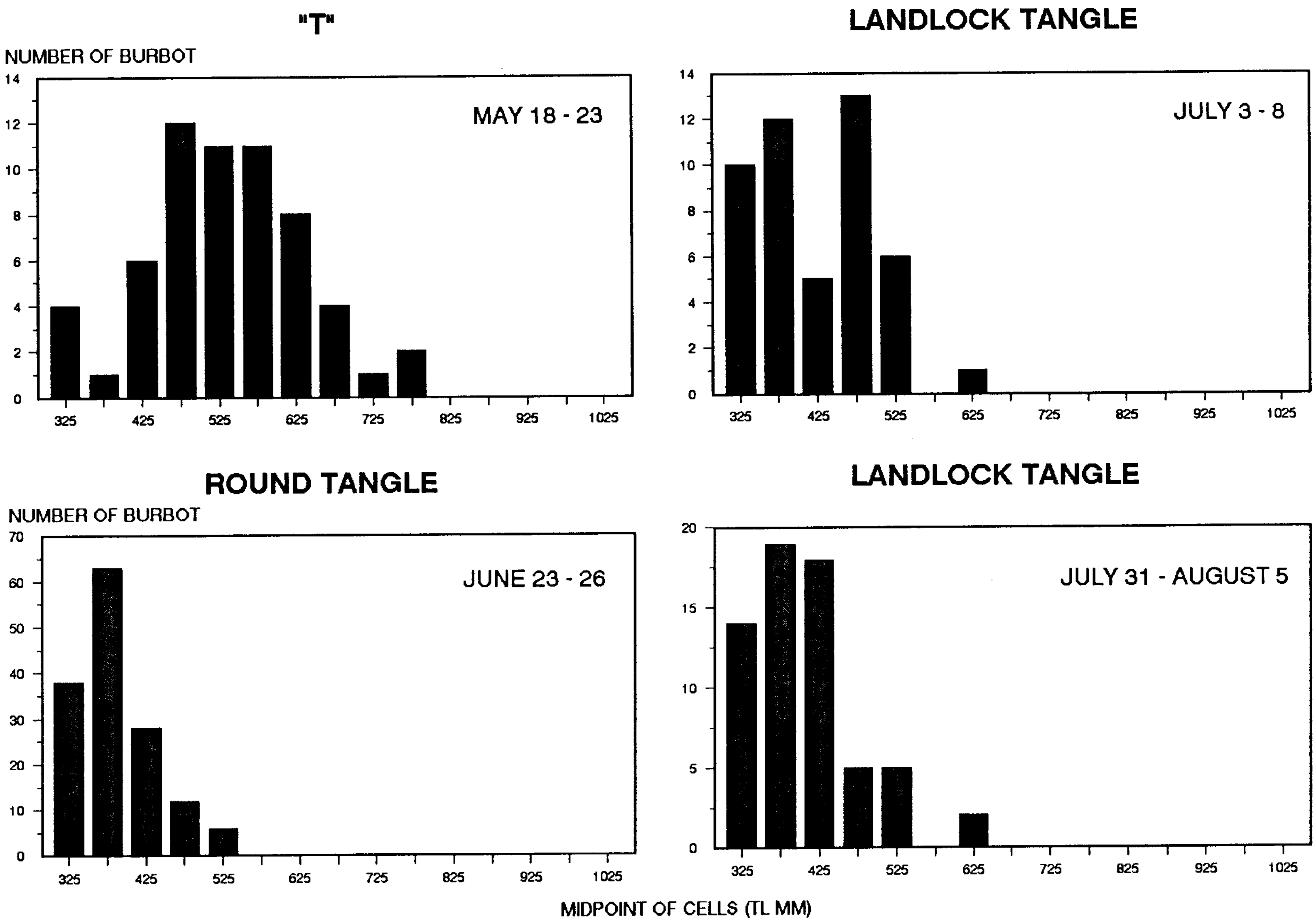

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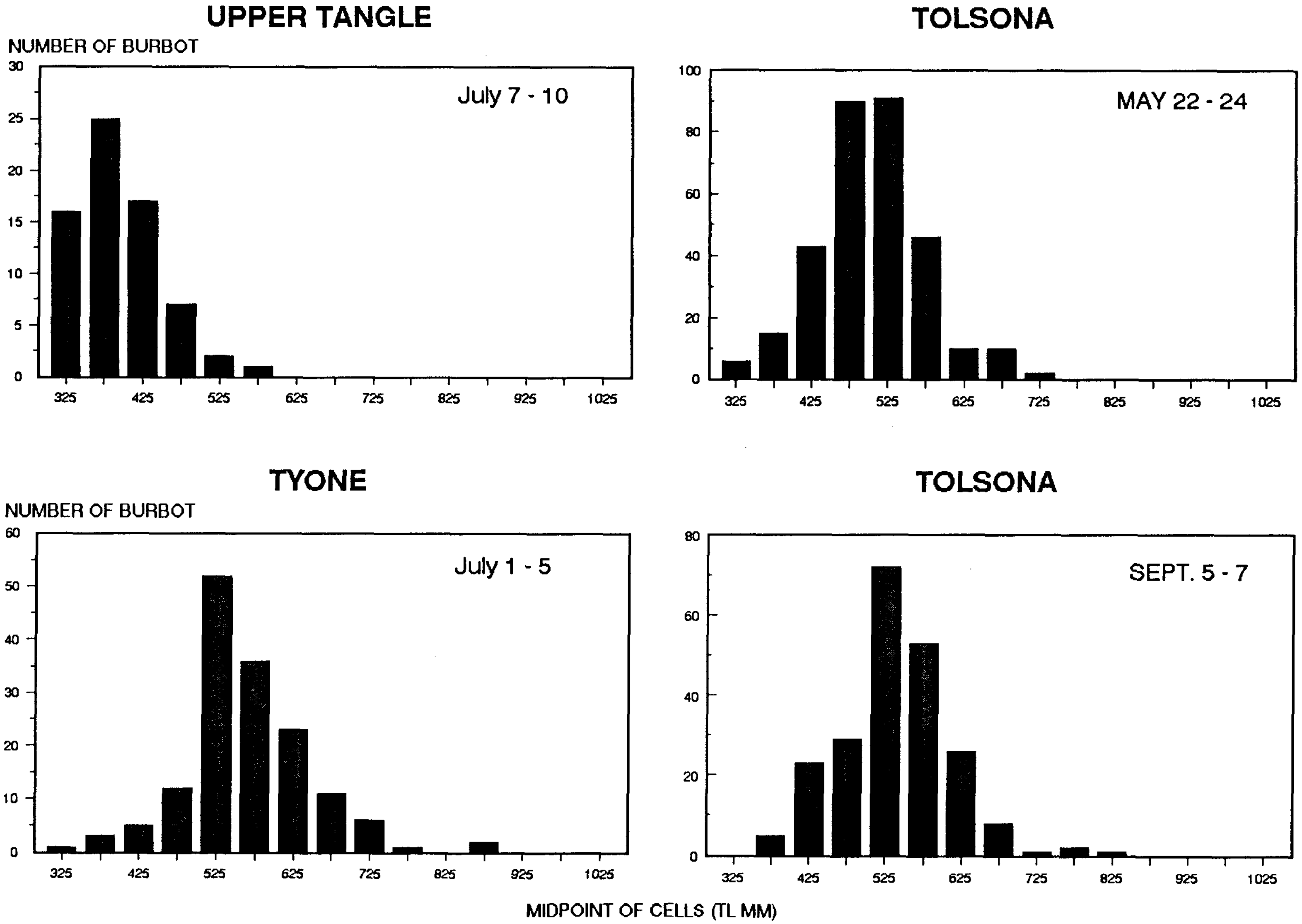

Figure 4. (Page 5 of 5).

recruited burbot in Moose and Tolsona lakes ranged from 24 mm to 34 mm, between the two sampling events (Table 2).

Length distributions from all sampling events had ascending left limbs with modes occurring between 325 mm and 625 mm (Figure 4). Several of these lakes, which are in close geographical proximity to one another, display similar length distributions. For example, the Tangle Lakes and Sevenmile Lake distributions all have modes occurring less than the length at full recruitment for the sampling gear (450 mm TL). These observations are consistent with previous data (Parker et al. 1987, 1988, 1989 and Lafferty et al. 1990).

Mean CPUE

Estimates of bootstrapped mean CPUE of fully recruited burbot in 12 populations during 1990 ranged from 0.18 burbot per set in Summit Lake to 3.83 burbot per set in Moose Lake (Table 3). Mean CPUE of partially recruited burbot (≥ 300 mm but < 450 mm) in the same populations ranged from 0.04 burbot per set in George Lake to 3.15 burbot per set in Moose Lake (Table 4). Estimates of bootstrapped mean CPUE of burbot larger or equal to 300 mm for populations in the Tangle Lakes and Sevenmile Lake ranged from 0.22 burbot per set in Landlocked Tangle Lake to 1.26 burbot per set in Round Tangle Lake (Table 5). Estimated bias in mean CPUE as calculated through bootstrapping was negligible (< 2%)

Mark-Recapture Experiments

Incidence of burbot recaptured in lakes other than the lake in which they were released was negligible within the Lake Louise Complex, relatively common in lakes of the Tangle Lakes Complex, and non-existent elsewhere. Of the 1,004 burbot tagged and released into Tyone Lake since 1986, only one burbot was recaptured in Susitna Lake during 1990 and none in Lake Louise. Of the 1,347 burbot tagged and released in Susitna Lake since 1986, only one was recaptured in Tyone Lake during 1990 and none in Lake Louise. No tagged burbot released into Lake Louise have been caught outside of this lake during the mark-recapture experiment of 1990. However, the historical tag returns from sport anglers (Appendix B7) suggest there is some limited movement of burbot between adjacent lakes within the Lake Louise complex. Of the eight recaptured burbot in Upper Tangle Lake in 1990, five were from adjacent lakes in this complex. Two of the five "strays" were originally marked and released in Round Tangle Lake, one during 1988 and the other during sampling of 1989. The three remaining stray burbot were originally marked and released in Shallow Tangle during the sampling of 1987, 1988, and 1989.

Estimated rates of tag loss for each experiment were not significantly different (t test, $P > 0.05$) than reported estimates in Lafferty et al. (1990). Rates of tag loss between summer sampling events averaged less than 4%. Average rates of tag loss ranged from 5.3% for overwinter experiments to 2.2% for experiments over a period of 3 years. Throughout the duration of the mark-recapture experiments, there was no evidence of regenerated fins on any of the recaptured burbot with tags.

Table 2. Mean lengths (millimeters TL) of burbot measured during sampling events in 16 lakes in interior Alaska in 1990.

Lake	Statistic	First Event Recruitment[a] to the gear			Second Event Recruitment[a] to the gear			Third Event Recruitment[a] to the gear			All Events Fully Recruited[a] to the gear
		Part.	Fully	All	Part.	Fully	All	Part.	Fully	All	
Fielding	Mean	392	533	452	386	523	445	394	525	456	529
	SE	2	7	5	4	11	8	5	11	9	5
	Samples	210	155	365	73	55	128	49	43	92	253
George	Mean	395	645	631							645
	SE	14	8	8							8
	Samples	11	183	194							183
Harding	Mean	395	539	466	388	545	495				541
	SE	4	10	8	8	11	12				7
	Samples	75	72	147	23	50	73				122
Hudson	Mean	388	575	537							575
	SE	6	7	7							7
	Samples	52	204	256							204
Louise	Mean	378	586	557							586
	SE	5	9	4							9
	Samples	113	714	827							714
Moose	Mean	412	510	465	409	530	489				473
	SE	2	3	3	4	5	5				3
	Samples	186	226	412	67	132	199				611
Paxson	Mean	338	580	504							580
	SE	5	4	5							4
	Samples	184	395	579							395
Sevenmile	Mean	349	---	349	347	---	347				---
	SE	5	---	5	6	---	6				---
	Samples	21	0	21	18	0	18				0
Summit	Mean	387	545	485							545
	SE	9	9	13							9
	Samples	20	32	52							32
Susitna	Mean	375	547	505							547
	SE	5	4	4							4
	Samples	157	487	644							487

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Table 2. (Page 2 of 2).

		First Event Recruitment[a] to the gear			Second Event Recruitment[a] to the gear			Third Event Recruitment[a] to the gear			All Events Fully Recruited[a] to the gear
Lake	Statistic	Part.	Fully	All	Part.	Fully	All	Part.	Fully	All	
T	Mean	386	564	534							564
	SE	15	11	13							11
	Samples	10	50	60							50
Upper Tangle	Mean	380	494	396							494
	SE	5	11	7							11
	Samples	59	10	69							10
Round Tangle	Mean	373	487	388							487
	SE	3	7	4							7
	Samples	130	20	150							20
Landlock Tangle	Mean	366	496	421	374	505	394				499
	SE	7	10	11	5	17	8				8
	Samples	27	20	47	49	9	58				29
Tolsona	Mean	401	515	479	405	534	513				493
	SE	4	4	4	4	4	5				3
	Samples	101	215	316	37	184	221				537
Tyone	Mean	392	533	517							533
	SE	11	6	7							6
	Samples	17	133	150							133

[a] Burbot partially recruited to the gear are less than 450 mm TL and fully recruited burbot are greater than or equal to 450 mm TL.

Table 3. Estimated mean CPUE of fully recruited burbot from stratified and unstratified systematic sampling of populations studied in 1990.

Lakes and Dates	Strata	Number of Sets and Transects		Mean CPUE				
				Bootstrapped	Arithmetic	%D	SE	CV
<u>Fielding</u>								
6/16-20	All depths	179	31	0.88	0.87	-0.3%	0.12	13.7%
7/19-23	All depths	239	42	0.23	0.23	-0.1%	0.05	21.9%
8/13-17	All depths	180	32	0.24	0.25	0.3%	0.06	26.2%
<u>George</u>								
5/25-31	All depths	299	36	0.61	0.62	0.1%	0.07	11.0%
<u>Harding</u>								
8/18-22	All depths	180	11	0.41	0.40	-0.6%	0.09	22.2%
9/18-20	All depths	121	8	0.40	0.41	1.3%	0.13	30.6%
<u>Hudson</u>								
7/11-17	All depths	260	33	0.73	0.73	0.4%	0.08	10.8%
<u>Louise</u>								
6/4-19	<15 meters	1,434	85	0.50	0.50	-0.3%	0.04	7.8%
<u>Moose</u>								
5/23	All depths	59	11	3.83	3.81	0.5%	0.44	11.5%
9/06	All depths	58	12	2.26	2.26	-0.1%	0.27	11.8%
<u>Paxson</u>								
9/10-26	<15 meters	868	126	0.50	0.50	-0.3%	0.02	9.2%
<u>Summit</u>								
7/16-20	All depths	175	31	0.18	0.18	0.4%	0.04	24.1%
<u>Susitna</u>								
6/17-7/2	<15 meters	1,603	113	0.30	0.30	-0.4%	0.03	8.8%
<u>T</u>								
5/18-23	All depths	79	10	0.73	0.73	0.3%	0.26	34.9%
<u>Tolsona</u>								
5/22-24	All depths	60	9	3.59	3.58	0.1%	0.43	11.9%
9/05-07	All depths	61	9	2.95	2.95	0.0%	0.33	11.1%
<u>Tyone</u>								
7/01-05	All depths	358	63	0.36	0.36	0.0%	0.06	16.9%

Table 4. Estimated mean CPUE of partially recruited burbot from stratified and unstratified systematic sampling of populations studied in 1990.

Lakes and Dates	Strata	Number of Sets and Transects		Mean CPUE Bootstrapped	Mean CPUE Arithmetic	%D	SE	CV
Fielding								
6/16-20	All depths	179	31	1.17	1.16	-0.4%	0.21	18.2%
7/19-23	All depths	239	42	0.30	0.31	0.2%	0.05	16.8%
8/13-17	All depths	180	32	0.28	0.28	-0.2%	0.06	23.2%
George								
5/25-31	All depths	299	36	0.04	0.04	1.7%	0.02	41.6%
Harding								
8/18-22	All depths	180	11	0.42	0.41	-1.2%	0.10	25.3%
9/18-20	All depths	122	8	0.19	0.19	-1.0%	0.06	31.0%
Hudson								
7/11-17	All depths	260	33	0.19	0.19	-0.0%	0.04	22.4%
Louise								
6/4-19	<15 meters	1,434	85	0.08	0.08	-0.1%	0.01	16.4%
Moose								
5/23	All depths	11	59	3.15	3.13	-0.9%	0.67	21.5%
9/06	All depths	12	58	1.17	1.16	1.6%	0.34	29.2%
Paxson								
9/10-26	<15 meters	868	126	0.25	0.25	-0.3%	0.03	9.2%
Summit								
7/16-20	All depths	219	31	0.10	0.10	0.4%	0.04	35.4%
Susitna								
6/17-7/2	<15 meters	1,603	113	0.10	0.10	0.3%	0.01	12.4%
T								
5/18-23	All depths	79	10	0.13	0.13	-0.2%	0.05	40.2%
Tolsona								
5/24	All depths	60	9	1.68	1.68	0.7%	0.31	18.5%
9/07	All depths	61	9	0.64	0.64	-0.7%	0.16	24.7%
Tyone								
7/1-5	All depths	358	63	0.05	0.05	1.1%	0.02	31.6%

Table 5. Estimated mean CPUE of both partially and fully recruited burbot from unstratified systematic sampling of populations in lakes along the Denali Highway during 1990.

Lakes and Dates	Strata	Number of Sets and Transects		Mean CPUE Bootstrapped	Mean CPUE Arithmetic	%D	SE	CV
<u>Landlock</u> <u>Tangle</u>								
7/3-8	< 15 m	217	31	0.22	0.22	1.0%	0.05	24.2%
7/31-8/5	< 15 m	219	31	0.26	0.26	0.1%	0.05	19.3%
<u>Round</u> <u>Tangle</u>								
6/23-26	All depths	119	16	1.26	1.26	-0.4%	0.18	14.7%
<u>Sevenmile</u>								
6/23-25	All depths	40	7	0.52	0.52	-0.6%	0.17	33.2%
8/07-09	All depths	40	7	0.45	0.46	1.6%	0.20	44.0%
<u>Upper</u> <u>Tangle</u>								
7/07-10	All depths	118	26	0.58	0.58	-1.4%	0.14	24.8%

Abundance of fully recruited (≥ 450 mm) burbot in Fielding, George, Harding[4], Hudson, Moose, Paxson, Susitna, T, and Tolsona lakes and Lake Louise ranged from 87 fish in T Lake to 4,659 fish in Susitna Lake (Table 6). Estimates of abundance across the last two annual sampling events for all experiments, except T Lake, were not significantly different (*t* test, $\alpha = 0.05$). Abundance of burbot 300 mm and larger in Round Tangle, Sevenmile, and Upper Tangle lakes ranged from 121 fish in Sevenmile Lake to 1,403 fish in Round Tangle Lake (Table 7). None of the 1990 abundance estimates are significantly different (*t* test, $\alpha = 0.05$) than the 1989 abundance estimates. Estimates for both Sevenmile and Landlock Tangle lakes could not be calculated due to insufficient numbers of recaptured burbot between the two sampling events.

Density of fully recruited burbot ranged from 0.25 fish per hectare in Harding Lake to 12.23 fish per hectare in Tolsona Lake (Table 8). Density of burbot 300 mm and larger in the Tangle Lakes and Sevenmile Lake ranged from 4.41 fish per hectare in Sevenmile Lake to 9.05 fish per hectare in Round Tangle Lake (Table 8). In general, deeper and larger lakes contained less dense populations of burbot.

Survival Rates and Recruitment

Annual survival rates ranged from 49.2% to over 100% for fully recruited burbot between the last two sampling events (Table 6). Annual survival rate of burbot greater than 300 mm TL in Round Tangle, Upper Tangle, and Sevenmile lakes ranged between 52.7 to 59.3% (Table 7). Recruitment of burbot greater than 450 mm TL ranged from 14 in Harding Lake to 2,391 in Moose Lake (Table 6). Due to insufficient numbers of recaptures, an estimate of the annual survival rate of burbot in Landlock Tangle Lake was not estimated. Recruitment of burbot greater than 300 mm TL in the Tangle Lakes and Sevenmile Lake ranged from 85 in Sevenmile to 1,029 in Round Tangle Lake (Table 7).

Length-Weight Relationships

Parameters of the allometric length-weight relationships for populations in Hudson, Moose, Paxson, Susitna, Tolsona, and Tyone lakes and in Lake Louise ranged between 6.196 and 8.524 for a and between 2.701 and 3.377 for b (Figure 5).

Auxiliary Information

Several additional Appendices (B5-B8 and C) provide continuity between previous annual reports or summarize information that could be useful to the reader. A summary of sampling mortalities during 1990 is located in Appendix B5. Since the sample size of mortalities was greater than 20 burbot in Hudson Lake, the age composition is presented in Appendix B6. Historical voluntary tag returns from sport anglers is provided in Appendix B7. Appendix B8 is a listing of the data for each specific study lake and the

[4] An estimate of the abundance of fully recruited burbot in Harding Lake could be estimated even though it was not included in the objectives of Project F-10-6, Job Number R-3-4a.

Table 6. Estimates of abundance, survival rates, and recruitment for burbot residing in Fielding, George, Harding, Louise, Moose, Paxson, Susitna, T, and Tolsona lakes.

Lake	Date	Days between events	Abundance Est.	Abundance (SE)	Abundance CV %	Survival Rate % Est.	Survival Rate % (SE)	Recruitment Est.	Recruitment (SE)
Fielding	10/05/84		N/A						
		355				66.1	(14.2)	N/A	
	9/25/85		331	(87)	26.3				
		332				54.7	(7.3)	168	(73)
	9/02/86		336	(57)	17.0				
		325				63.2	(7.2)	36	(34)
	7/24/87		221	(22)	10.0				
		341				81.1	(8.4)	218	(39)
	7/15/88		380	(47)	12.4				
		345				72.6	(9.4)	173	(45)
	6/11/89		430	(59)	13.7				
		356				84.8	(17.8)	252	(81)
	6/18/90		612	(134)	21.9				
		33				62.7	(25.6)	24	(64)
	7/02/90		407	(164)	40.3				
George	6/15/87		1,773[b]	(599)	31.0				
		346				52.5	(22.1)	N/A	
	5/27/88		3,658	(2,077)	56.8				
		375				51.9	(25.0)	909	(1,210)
	6/6/89		2,778	(1,433)	51.6				
Harding	9/11/86		N/A						
		324				68.1	(20.4)	N/A	
	6/18/87		255	(87)	34.1				
		468				64.6	(22.2)	313	(156)
	9/28/88		464	(185)	39.9				
		357				49.2	(20.0)	14	(81)
	9/20/89		237	(98)	41.1				
Louise	6/22/86		6,990[a]	(2,131)	30.5				
		381				40.6	(8.7)	1,864	(2,032)
	7/13/87		4,973	(1,478)	29.7				
		330				51.7	(9.2)	860	(889)
	6/16/88		3,391	(750)	22.1				
		357				71.6	(13.3)	1,689	(676)
	6/08/89		4,106	(816)	19.9				

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Table 6. (Page 2 of 3).

Lake	Date	Days between events	Abundance Est.	Abundance (SE)	Abundance CV %	Survival Rate % Est.	Survival Rate % (SE)	Recruitment Est.	Recruitment (SE)
Moose	5/26/88		2,884[b]	(403)	14.0				
		113				59.9	(7.0)	-312	(203)
	9/01/88		1,497	(253)	16.9				
		247				60.4	(6.8)	227	(148)
	5/21/89		1,132	(127)	11.2				
		61				83.4	(12.4)	301	(146)
	7/10/89		1,245	(210)	16.9				
		67				76.1	(15.4)	128	(124)
	9/09/89		1,076	(195)	18.1				
		19				62.9	(15.1)	259	(118)
	10/08/89		934	(206)	22.1				
		231				114.0	(42.3)	2,391	(913)
	5/24/90		3,453	(1,236)	35.8				
Paxson	7/10/86		9,111[a]	(1,996)	21.6				
		365				62.3	(7.0)	1,787	(1,392)
	7/10/87		4,485	(624)	13.9				
		339				80.4	(14.1)	-361	(449)
	6/10/88		3,244	(592)	18.3				
		439				79.5	(29.5)	1,547	(691)
	9/20/89		4,114	(1,478)	35.9				
Susitna	8/16/86		N/A						
		355				N/A		N/A	
	8/24/87		3,471	(1,954)	56.3				
		323				19.2	(9.2)	1,433	(1,539)
	6/19/88		2,929	(1,554)	53.6				
		355				96.6	(36.7)	1,852	(2,423)
	6/24/89		4,659	(1,950)	41.8				
T	6/15/86		N/A						
		406				98.9	(34.9)	N/A	
	7/26/87		92	(38)	41.3				
		346				44.1	(13.7)	199	(224)
	5/19/88		239	(226)	94.6				
		411				74.5	(17.5)	87	(163)
	7/04/89		87	(17)	19.5				

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Table 6. (Page 3 of 3).

Lake	Date	Days between events	Abundance Est.	(SE)	CV %	Survival Rate % Est.	(SE)	Recruitment Est.	(SE)
Tolsona	10/26/86		1,901[a]	(120)	21.6				
		237				60.4	(4.7)	138	(209)
	6/03/87		1,300	(121)	9.3				
		336				73.0	(6.5)	599	(133)
	5/26/88		1,545	(162)	10.5				
		96				77.2	(8.9)	22	(118)
	9/01/88		1,214	(148)	12.2				
		267				79.2	(10.4)	629	(139)
	5/24/89		1,590	(191)	12.0				
		112				91.3	(16.6)	85	(146)
	9/14/89		1,535	(276)	18.0				
		241				66.3	(17.7)	1,067	(323)
	5/25/90		2,085	(512)	24.6				

[a] Estimate obtained from Parker et al. (1987).

[b] Estimate obtained from Parker et al. (1988).

Table 7. Estimates of abundance, survival rates, and recruitment for all burbot greater than 300 mm TL residing in Round Tangle, Sevenmile, and Upper Tangle lakes.

Lake	Date	Days between events	Abundance			Survival Rate %		Recruitment	
			Est.	(SE)	CV %	Est.	(SE)	Est.	(SE)
Round Tangle	8/07/86		N/A						
		369				36.1	(12.1)	N/A	
	8/11/87		744	(295)	39.7				
		310				35.5	(12.1)	375	(178)
	6/17/88		638	(221)	34.6				
		389				59.3	(29.7)	1,029	(573)
	7/11/89		1,403	(728)	51.6				
Sevenmile	7/25/86		N/A						
		351				1.5	(45.6)	N/A	
	7/10/87		576	(185)	32.1				
		360				12.8	(4.9)	55	(29)
	7/05/88		121	(43)	35.5				
		376				52.7	(35.3)	85	(64)
	7/16/89		150	(100)	66.7				
Upper Tangle	8/04/86		N/A						
		375				24.1	(11.6)	N/A	
	8/14/87		250	(140)	56.0				
		311				89.2	(45.5)	455	(312)
	6/21/88		678	(376)	55.5				
		397				56.2	(72.4)	537	(738)
	7/23/89		917	(1,186)	129.3				

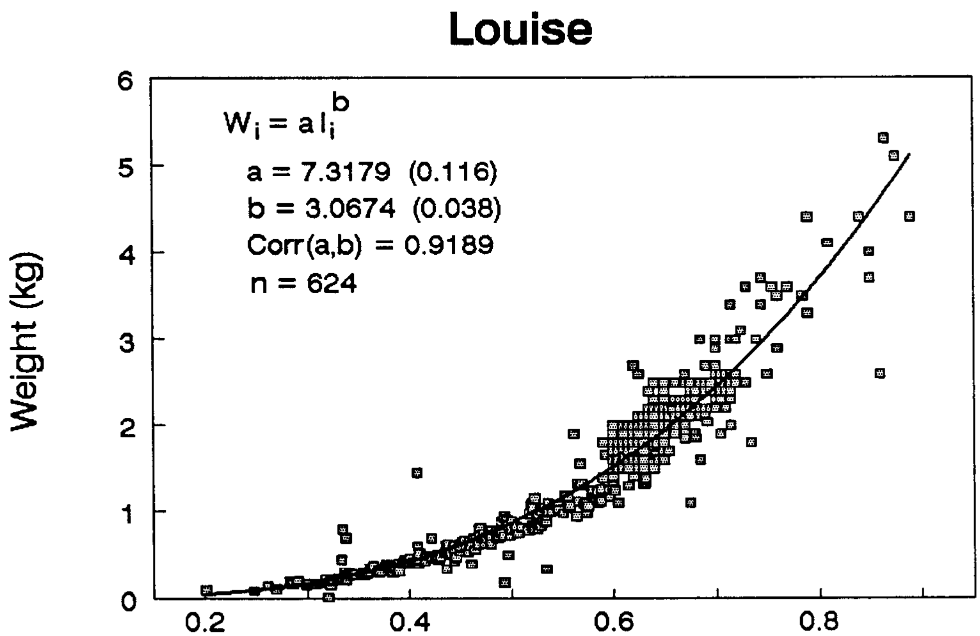
Table 8. Estimated density of burbot in 15 lakes in interior Alaska during 1990.

Lake	Size of Burbot	Estimated Abundance	SE	Area of Lake (ha)	Estimated Density[c]	SE
Fielding	≥ 450	612	134	538	1.14	0.25
George	≥ 450	2,778	1,433	1,863	1.49	0.77
Harding	≥ 450	250	106	1,000	0.25	0.11
Hudson	≥ 450	3,118	1,302	259	12.04	5.03
Landlocked Tangle	≥ 450	975[a]	408	219	4.45	1.86
Louise	≥ 450	4,106	816	6,519	0.63	0.13
Moose	≥ 450	1,132	127	130	8.71	0.98
Paxson	≥ 450	4,114	1,478	1,575	2.61	0.94
Round Tangle	≥ 300	1,403	728	155	9.05	4.67
Sevenmile	≥ 300	150	100	34	4.41	2.94
Susitna	≥ 450	4,659	1,950	3,816	1.22	0.51
T	≥ 450	87	17	162	0.54	0.10
Tolsona	≥ 450	1,590	191	130	12.23	1.47
Tyone	≥ 450	2,426[b]	1,653	389	6.24	4.25
Upper Tangle	≥ 300	917	1,186	142	6.46	8.35

[a] From Lafferty et al. (1990); estimate applies to 1988.

[b] From Parker et al. (1989); estimate applies to 1987.

[c] Number of burbot per hectare.



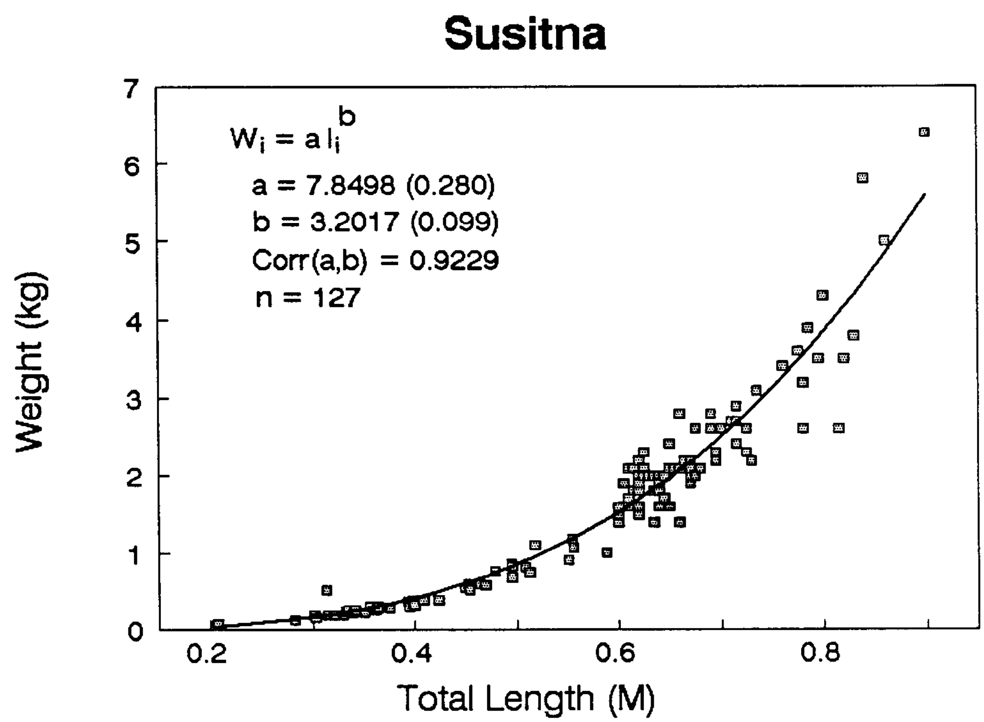


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Figure 5. Plots and estimates (and standard errors) of parameters in the length-weight relationships for burbot sampled in Paxson, Hudson, Tolsona, Moose, Susitna, and Tyone lakes and Lake Louise.

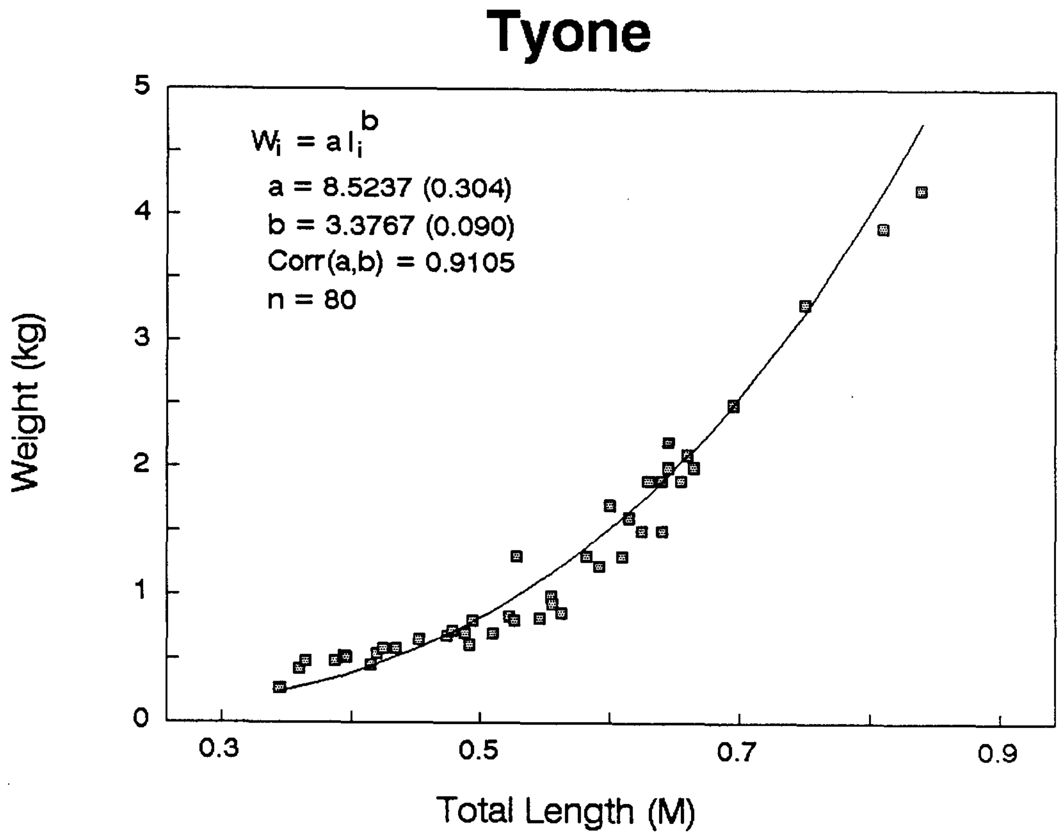

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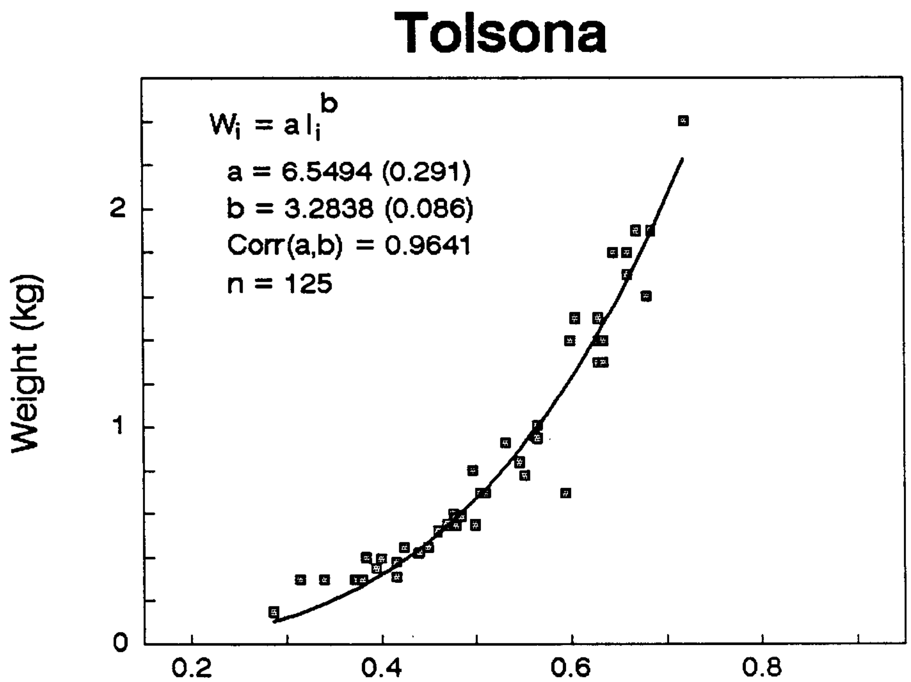
Figure 5. (Page 2 of 4).



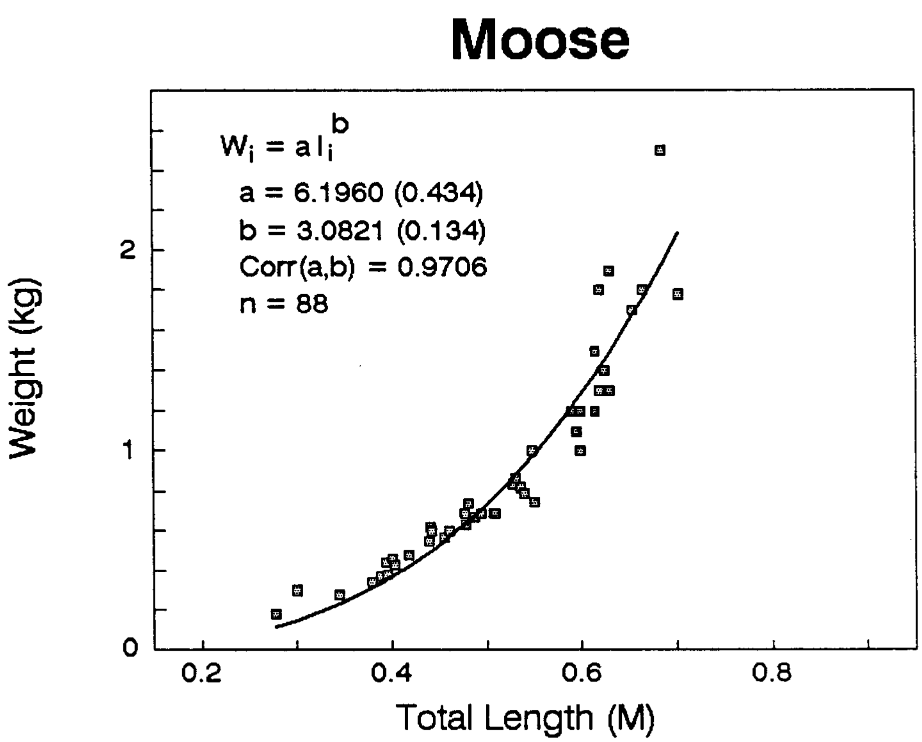


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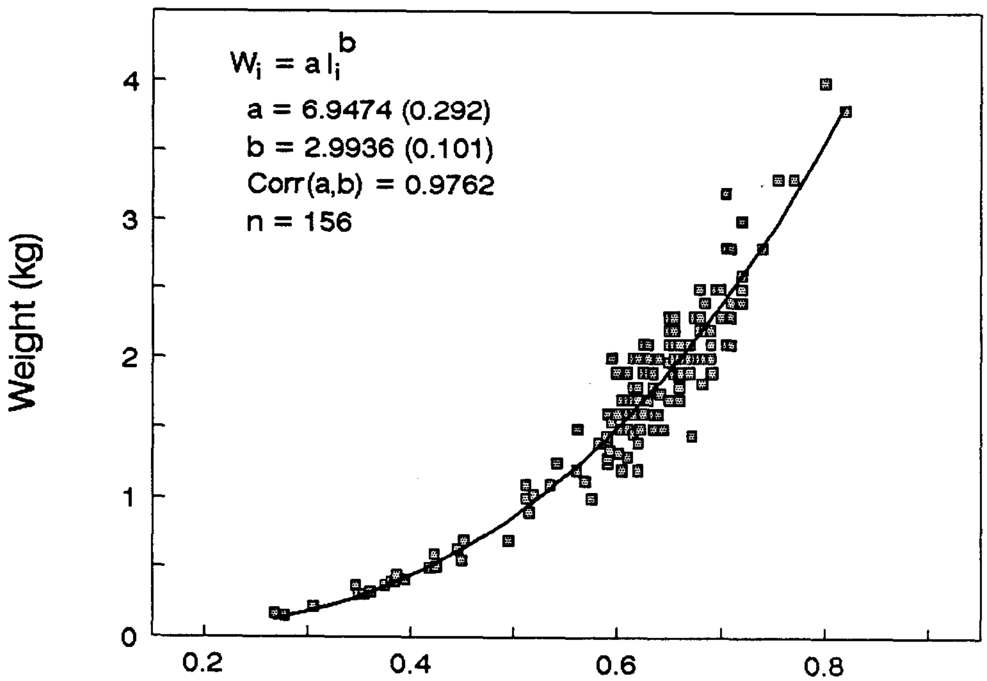
Figure 5. (Page 3 of 4).

PAXSON



HUDSON

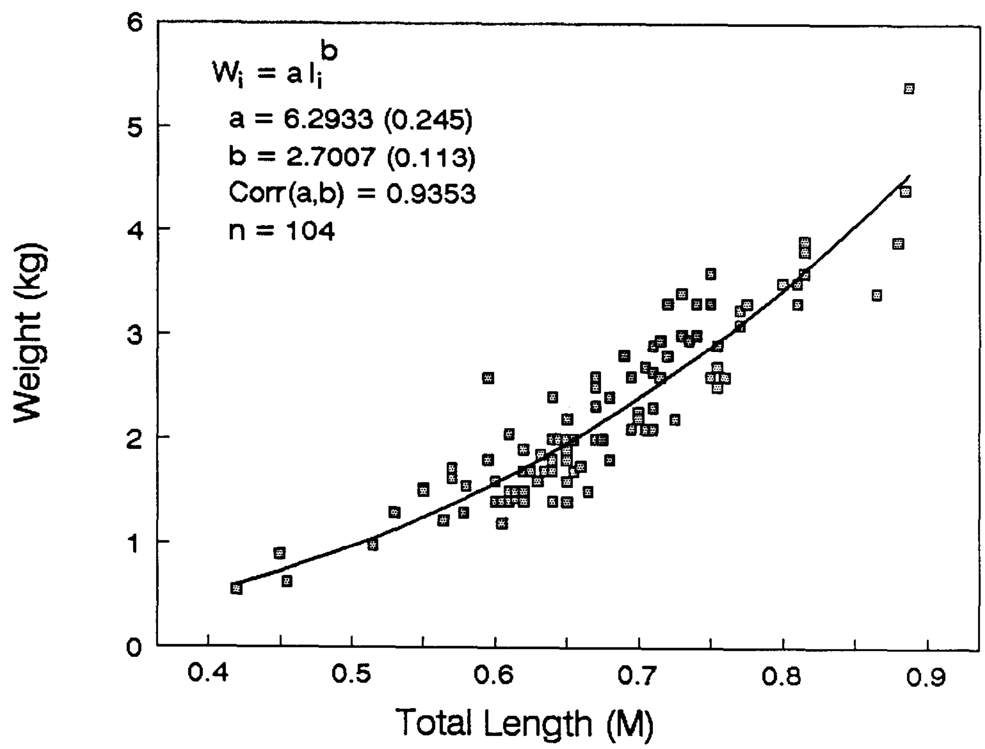


Figure 5. (Page 4 of 4).

custodian. Finally, Appendix C provides a graphic presentation of the catch by depth for partially and fully recruited burbot.

DISCUSSION

Several of the populations studied since 1986 have exhibited declines in the abundance of fully recruited burbot with Lake Louise and Paxson Lake having the most dramatic declines. Lake Louise supported an expanding burbot fishery from 1977 through 1986, with a peak harvest (3,200) occurring during 1986 (Mills 1990). The abundance of fully recruited burbot during 1986 was estimated to be about 7,000 burbot. By 1988, the estimated abundance of burbot had fallen to 3,400, almost equal to the estimated harvest of burbot during 1986. The abundance of fully recruited burbot also declined dramatically in Paxson Lake, from about 9,000 burbot in 1986 to only 3,244 in 1988. The estimates of mean CPUE for fully recruited burbot for both Paxson Lake and Lake Louise have also decreased from 1986 to 1989. Recent abundance estimates of burbot in these lakes indicate that the burbot populations are stabilizing. Abundance estimates for 1989 are not significantly different ($P > 0.05$) than previous abundance estimates of 1988. Corresponding to the change in burbot abundance, estimates of mean CPUE have also increased slightly for these lakes. However, the mean length of both partially and fully recruited burbot have not changed for the populations in Lake Louise and Paxson Lake, indicating that little recruitment is occurring in the fully recruited populations. These three independent methods of burbot stock assessment indicate that burbot stocks in Lake Louise and Paxson Lake are stabilizing.

The Fielding Lake population was depressed and at its lowest abundance in 1987 with 221 fully recruited burbot. Since 1984, dramatic decreases in harvest due to closure of the setline fishery and season restrictions have increased abundance of fully recruited burbot to 430 in 1989. In 1990, abundance increased to 612 fully recruited burbot. This increase in the estimates of fully recruited burbot is mirrored in the CPUE data: estimated CPUE increased from 0.49 in 1988 to 0.88 in 1990. During this period, the CPUE of partially recruited burbot also increased from 0.56 in 1988 to 1.17 in 1990. Most of the recruitment occurred in 1988 as evidenced by a decrease in mean length of fully recruited burbot during that year.

Sevenmile Lake is the highest in altitude of all sampled lakes and has a stunted population of burbot that does not exceed 450 mm in length. Between 1987 and 1988, the population decreased from 576 to 121 burbot. Correspondingly, the mean CPUE decreased from 1.66 to 0.76. During 1989 and 1990, CPUE has stabilized at 0.52. Environmental conditions, rather than fishing mortality, is thought to be the contributing factor to the collapse of this population.

Failure to anticipate historical declines in abundance has made our estimates of abundance less precise than planned for. By the catch equation ($C = qfN$), the fraction of the population caught (C/N) with a given sampling effort (f as number of sets) is always the same regardless of the size of the population (N) so long as catchability (as expressed through q) is the same. By not anticipating the reduction in abundance from harvest by sport fisheries, our *a priori* estimates of N used in planning were generally too high. In mark-recapture experiments, there is an inverse relationship between abundance and the fraction of the population that must be sampled to obtain an estimate with a particular precision: the lower the abundance, the higher the fraction to be sampled (Robson and Regier 1964). When our *a priori* estimates were too high, our sampling effort (number of sets) was too low. The anticipated fraction of the population was caught, it was just that the fraction was too low. Fortunately, this leverage works in reverse as well. If the population increases, precision of the mark-recapture experiments will increase with the present sampling design.

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APPENDIX A

DESCRIPTION OF LAKES SAMPLED IN 1990

FIELDING LAKE (63°10′ N, 145°42′ W) is accessible by road 3 km southwest of the Richardson Highway. Fielding Lake is 538 hectare 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, and 15 to 20 recreational cabins are located along the south shore. Fielding Lake contains Arctic grayling *Thymallus arcticus*, burbot *Lota lota*, lake trout *Salvelinus namaycush*, and round whitefish *Prosopium cylindraceum*.

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 hectare with a maximum depth of 11 m and an 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 *Esox lucius* 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 Arctic grayling, burbot, humpback whitefish *Coregonus pidschian*, least cisco *Coregonus sardinella*, longnose suckers *Catostomus catostomus*, and round whitefish.

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 hectare 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. Indigenous species in Harding Lake are burbot, least cisco, northern pike, and slimy sculpin *Cottus cognatus*. Transplanted species include Arctic char *Salvelinus alpinus*, Arctic grayling, coho salmon *Oncorhynchus kisutch*, lake trout, rainbow trout *Oncorhynchus mykiss*, sheefish *Stenodus leucicthys*, and sockeye salmon *Oncorhynchus nerka*.

HUDSON LAKE (61°53′ N, 145°40′ W) is a remote lake 19 km southwest of Copper Center. Hudson Lake is 259 hectare 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 was a large winter ice fishery for burbot. Hudson Lake contains Arctic grayling, burbot, longnose suckers, rainbow trout, and round whitefish.

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 hectare 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 has supported year-round fishing for Arctic grayling, burbot, lake trout, and round whitefish.

LANDLOCK TANGLE LAKE (63°00′ N, 146°03′ W) is located south of Upper Tangle Lake and is accessible by foot over a 1 km portage. Landlock Tangle Lake is 219 hectare with maximum depth of 36 m and an elevation of 875 m. Landlock Tangle Lake has Arctic grayling, burbot, lake trout, longnose suckers, and round whitefish.

MOOSE LAKE (62°07′ N, 146°05′ W) is accessible from Tolsona Lake by a 1 km trail from the north end of Tolsona Lake. Moose Lake is 130 hectare 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 hectare 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 Arctic grayling, burbot, lake trout, sockeye salmon, 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 hectare 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, burbot, lake trout, longnose suckers, and round whitefish.

SEVENMILE Lake (63°06′ N, 145°38′ W) is located 1 km by road from the Denali Highway. Sevenmile Lake is 34 hectare 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 burbot and lake trout populations. No other species are known to exist in the lake.

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 hectare with a maximum depth of 72 m and an elevation of 979 m. Public facilities are available for launching boats. There is one lodge and a private recreational campground along the lake. Summit Lake contains burbot, lake trout, round whitefish, and sockeye salmon.

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 hectare 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 burbot, lake trout, 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 hectare 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 burbot, humpback whitefish, least cisco, and northern pike.

TOLSONA LAKE (62°06′ N, 146°04′ W) is accessible from the Glenn Highway. Tolsona Lake is 130 hectare 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 Arctic grayling, burbot, longnose suckers, stocked rainbow trout, 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 hectare with a maximum depth of 9 m and an elevation of 720 m. There are 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 hectare with a maximum depth of 30 m and an elevation of 868 m. A boat launch and campground facilities are available at the mouth of this lake. Upper Tangle Lake has Arctic grayling, lake trout, round whitefish, burbot, and longnose suckers.

APPENDIX B

Appendix B1. Mark-recapture histories of fully recruited[a] burbot by year (by sampling event in 1990) for the populations in Fielding, Paxson, Tyone, Susitna, Summit, T, George, Tolsona, and Harding lakes, and Lake Louise.

FIELDING LAKE									
Date: Year	1984	1985	1986	1987	1988	1989	1990	1990	1990
Beginning	7/20	7/16	7/28	7/21	6/29	6/26	6/16	7/19	8/13
Ending	10/8	9/27	8/25	8/22	7/31	8/04	6/20	7/23	8/17
NUMBER OF FULLY RECRUITED BURBOT:									
Recaptured from Event 1	0	13	2	2	0	2	0	0	0
Recaptured from Event 2		0	27	23	1	1	0	1	0
Recaptured from Event 3			0	30	8	2	0	0	1
Recaptured from Event 4				0	48	18	2	1	2
Recaptured from Event 5					0	43	14	2	3
Recaptured from Event 6						0	35	10	7
Recaptured from Event 7							0	14	8
Recaptured from Event 8								0	6
Captured with Tags	0	13	29	55	57	66	51	28	27
Captured without Tags	43	149	90	93	118	115	103	28	16
Captured	43	162	119	148	175	181	154	56	43
Released with Tags	43	138	76	126	149	177	152	56	43

GEORGE LAKE				
DATE: Year	1987	1988	1989	1990
Beginning	6/01	5/24	6/01	5/21
Ending	6/30	5/31	6/11	5/31
NUMBER OF FULLY RECRUITED BURBOT:				
Recaptured from Event 1	0	6	5	2
Recaptured from Event 2		0	13	4
Recaptured from Event 3			0	10
Captured with Tags	0	6	18	16
Captured without Tags	200	242	276	167
Captured	200	248	294	183
Released with Tags	196	248	294	183

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HARDING LAKE						
DATE: Year	1986	1987	1988	1989	1990	1990
Beginning	7/06	6/11	9/26	9/18	8/18	9/18
Ending	8/19	6/24	9/30	9/22	8/22	9/22
NUMBER OF FULLY RECRUITED BURBOT:						
Recaptured from Event 1	0	14	3	2	0	0
Recaptured from Event 2		0	9	4	3	1
Recaptured from Event 3			0	8	3	2
Recaptured from Event 4				0	6	2
Recaptured from Event 5					0	2
Captured with Tags	0	14	12	14	12	7
Captured without Tags	55	87	76	38	59	44
Captured	55	103	88	52	71	51
Released with Tags	54	81	77	52	66	51

LAKE LOUISE					
DATE: Year	1986	1987	1988	1989	1990
Beginning	6/25	7/06	6/11	6/01	6/04
Ending	9/02	8/19	6/24	6/16	6/19
NUMBER OF FULLY RECRUITED BURBOT:					
Recaptured from Event 1	0	19	9	12	2
Recaptured from Event 2		0	26	17	15
Recaptured from Event 3			0	36	23
Recaptured from Event 4				0	62
Captured with Tags	0	19	35	65	102
Captured without Tags	523	501	348	577	619
Captured	523	520	383	642	721
Released with Tags	470	440	368	635	717

PAXSON LAKE					
DATE: Year	1986	1987	1988	1989	1990
Beginning	7/07	7/06	6/22	9/15	9/10
Ending	9/20	8/14	7/27	9/25	9/26
NUMBER OF FULLY RECRUITED BURBOT:					
Recaptured from Event 1	0	95	34	21	9
Recaptured from Event 2		0	110	22	15
Recaptured from Event 3			0	23	12
Recaptured from Event 4				0	9
Captured with Tags	0	95	144	72	45
Captured without Tags	759	814	309	206	360
Captured	759	909	453	278	405
Released with Tags	759	909	439	278	396

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SUMMIT LAKE					
DATE: Year	1986	1987	1988	1989	1990
Beginning	7/12	7/13	7/06	7/14	7/16
Ending	9/04	9/20	7/11	7/17	7/20
NUMBER OF FULLY RECRUITED BURBOT:					
Recaptured from Event 1	0	10	1	2	0
Recaptured from Event 2		0	8	3	6
Recaptured from Event 3			0	2	3
Recaptured from Event 4				0	2
Captured with Tags	0	10	9	7	11
Captured without Tags	111	122	35	20	21
Captured	111	132	44	27	32
Released with Tags	51	130	41	27	29
SUSITNA LAKE					
DATE: Year	1986	1987	1988	1989	1990
Beginning	6/27	7/18	6/11	6/16	6/17
Ending	8/19	8/30	6/26	7/01	7/02
NUMBER OF FULLY RECRUITED BURBOT:					
Recaptured from Event 1	0	3	3	4	0
Recaptured from Event 2		0	3	2	1
Recaptured from Event 3			0	17	11
Recaptured from Event 4				0	13
Captured with Tags	0	3	6	23	25
Captured without Tags	84	176	284	324	463
Captured	84	179	290	347	488
Released with Tags	77	169	266	347	488
T LAKE					
DATE: Year	1986	1987	1988	1989	1990
Beginning	6/11	5/26	5/17	5/17	5/18
Ending	6/19	9/25	5/21	5/22	5/23
NUMBER OF FULLY RECRUITED BURBOT:					
Recaptured from Event 1	0	6	0	2	0
Recaptured from Event 2		0	1	11	1
Recaptured from Event 3			0	8	2
Recaptured from Event 4				0	20
Captured with Tags	0	6	1	21	23
Captured without Tags	13	43	18	42	27
Captured	13	49	19	63	50
Released with Tags	13	47	17	62	48

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Appendix B1. (Page 4 of 4).

TOLSONA LAKE								
DATE: Year	1986	1987	1988	1988	1989	1989	1990	1990
Beginning	09/23	6/02	5/25	8/30	5/23	9/12	5/22	9/05
Ending	10/10	6/04	5/27	9/01	5/25	9/14	5/24	9/07
NUMBER OF FULLY RECRUITED BURBOT:								
Recaptured from Event 1	0	123	35	14	5	3	5	9
Recaptured from Event 2		0	79	32	33	18	11	5
Recaptured from Event 3			0	51	36	13	11	8
Recaptured from Event 4				0	45	13	4	5
Recaptured from Event 5					0	63	14	8
Recaptured from Event 6						0	22	9
Recaptured from Event 7							0	21
Captured with Tags	0	123	114	97	119	110	67	65
Captured without Tags	531	379	235	109	229	129	182	130
Captured	531	502	349	206	349	239	249	195
Released with Tags	531	497	349	206	348	239	249	195

TYONE LAKE					
DATE: Year	1986	1987	1988	1989	1990
Beginning	6/26	7/29	6/09	6/30	7/01
Ending	8/13	9/05	6/11	7/03	7/05
NUMBER OF FULLY RECRUITED BURBOT:					
Recaptured from Event 1	0	6	5	4	1
Recaptured from Event 2		0	4	0	0
Recaptured from Event 3			0	5	3
Recaptured from Event 4				0	4
Captured with Tags	0	6	9	9	8
Captured without Tags	182	157	351	156	131
Captured	182	163	360	165	139
Released with Tags	182	163	356	165	138

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

Appendix B2. Mark-recapture histories of partially recruited[a] burbot by year (by sampling event in 1990) for the population in Fielding Lake.

Date:	Year	1984	1985	1986	1987	1988	1989	1990	1990	1990
	Beginning	7/20	7/16	7/28	7/21	6/29	6/26	6/16	7/19	8/13
	Ending	10/8	9/27	8/25	8/22	7/31	8/04	6/20	7/23	8/17
NUMBER OF PARTIALLY RECRUITED BURBOT:										
Recaptured from Event 1		0	19	6	0	1	0	0	0	0
Recaptured from Event 2			0	50	23	4	4	0	0	0
Recaptured from Event 3				0	29	13	2	0	0	0
Recaptured from Event 4					0	28	5	2	0	0
Recaptured from Event 5						0	31	4	1	0
Recaptured from Event 6							0	20	12	6
Recaptured from Event 7								0	8	3
Recaptured from Event 8									0	1
Captured with Tags		0	19	56	52	46	42	26	21	10
Captured without Tags		65	432	278	230	175	244	185	51	38
Captured		65	451	334	282	221	286	211	72	48
Released with Tags		65	404	233	163	152	279	201	71	48

[a] Burbot between 300 and 449 mm TL.

Appendix B3. Mark-recapture histories of burbot of all sizes[a] by year for the populations in Sevenmile, Landlock Tangle, Round Tangle, and Upper Tangle lakes.

SEVENMILE LAKE

Date: Year	1986	1987	1988	1989	1990
Beginning	7/22	6/16	6/19	6/29	6/23
Ending	9/21	8/06	7/19	8/05	8/09
NUMBER OF BURBOT OF ALL SIZES:					
Recaptured from Event 1	0	51	5	2	0
Recaptured from Event 2		0	9	2	0
Recaptured from Event 3			0	9	2
Recaptured from Event 4				0	3
Captured with Tags	0	51	14	13	5
Captured without Tags	198	158	41	39	33
Captured	198	209	55	52	38
Released with Tags	94	156	55	52	38

LANDLOCK TANGLE LAKE

DATE: Year	1986	1987	1989	1990
Beginning	7/20	6/30	7/09	7/03
Ending	7/24	8/07	8/11	8/05
NUMBER OF BURBOT OF ALL SIZES:				
Recaptured from Event 1	0	5	0	0
Recaptured from Event 2		0	7	5
Recaptured from Event 3			0	12
Captured with Tags	0	5	7	17
Captured without Tags	50	222	146	88
Captured	50	227	153	105
Released with Tags	54	211	122	103

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Appendix B3. (Page 2 of 2).

ROUND TANGLE LAKE

		1986	1987	1988	1989	1990
DATE:	Year	1986	1987	1988	1989	1990
	Beginning	7/21	7/27	6/15	6/24	6/23
	Ending	8/25	8/25	6/19	7/28	6/26
NUMBER OF BURBOT OF ALL SIZES:						
Recaptured from Event 1		0	13	7	1	0
Recaptured from Event 2			0	15	5	0
Recaptured from Event 3				0	17	5
Recaptured from Event 4					0	8
Captured with Tags		0	13	22	23	13
Captured without Tags		221	137	179	207	138
Captured		221	150	201	230	151
Released with Tags		191	146	193	220	150

UPPER TANGLE LAKE

		1986	1987	1988	1989	1990
DATE:	Year	1986	1987	1988	1989	1990
	Beginning	7/21	7/31	6/09	7/07	7/07
	Ending	8/18	8/29	6/22	8/08	7/10
NUMBER OF BURBOT OF ALL SIZES:						
Recaptured from Event 1		0	5	2	1	0
Recaptured from Event 2			0	10	4	0
Recaptured from Event 3				0	5	2
Recaptured from Event 4					0	1
Captured with Tags		0	5	12	10	3
Captured without Tags		101	69	97	86	67
Captured		101	74	109	96	70
Released with Tags		83	74	108	93	68

a Burbot are ≥ 300 mm TL.

Appendix B4. Mark-recapture histories for fully recruited[a] burbot by year (1987) and by sampling events (1988-90) for the populations in Hudson and Moose lakes where mark-recapture experiments were compromised through tag loss and uncertainty of secondary marks.

HUDSON LAKE

DATE:	1987	1988	1988	1989	1990
Year	1987	1988	1988	1989	1990
Beginning	6/15	7/13	9/29	7/11	7/11
Ending	7/10	7/18	10/03	7/16	7/17
Recaptured from Event 1	0	21	6or9	6	7
Recaptured from Event 2		0	10or13	6	11
Recaptured from Event 3			0	8	5
Recaptured from Event 4				0	9
Captured with Tags	0	21	16or21	20	32
Captured without Tags	337	214	168or163	163	194
Captured	337	235	184	183	226
Released with Tags	337	231	142	145	202

MOOSE LAKE

DATE:	1988	1988	1989	1989	1989	1989	1990	1990
Year	1988	1988	1989	1989	1989	1989	1990	1990
Beginning	5/24	9/16	5/24	7/07	9/07	10/6	5/21	9/04
Ending	5/26	9/18	5/26	7/09	9/09	10/8	5/23	9/06
Recaptured from Event 1	0	35or42	35or39	13	6	2	11	1
Recaptured from Event 2	0	0	66	6	7	2	3	0
Recaptured from Event 3			0	45	34	16	23	4
Recaptured from Event 3				0	28	8	0	3
Recaptured from Event 4					0	29	2	1
Recaptured from Event 5						0	15	8
Recaptured from Event 6							0	12
Captured with Tags	58	75or82	118or122	72	86	68	54	29
Captured without Tags	371	176or169	307or303	88	90	82	306	135
Captured	429	251	425	160	176	150	360	164
Released with Tags	426	251	425	160	174	150	360	164

[a] Burbot ≥ 450 mm TL were considered fully recruited to the gear.

Appendix B5. Numbers of burbot killed during sampling in 16 lakes in interior Alaska in 1990.

Lake	Fully Recruited[a]	Partially Recruited
Fielding	2	11
George	0	0
Harding	5	11
Hudson	23	1
Louise	3	4
Moose	3	0
Paxson	0	0
Sevenmile	0	0
Summit	3	1
Susitna	0	1
T	2	0
Landlock Tangle	0	1
Round Tangle	0	1
Upper Tangle	0	2
Tolsona	0	0
Tyone	0	0
TOTAL	41	33

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

Appendix B6. Estimated mean length-at-age for burbot sampled from Hudson Lake in 1990.

Hudson Lake		Age														
Sex	Statistic	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Male	Sample Size	0	0	0	0	2	1	2	3	1	0	0	1	0	0	0
	Mean Length					430	490	583	640	720			740			
	S.E.					20	0	13	4	0			0			
Female	Sample Size	0	0	0	0	0	1	1	7	2	0	0	0	1	1	0
	Mean Length						500	555	653	683				755	810	
	S.E.						0	0	22	33				0	0	
Combined																
	Sample Size	0	0	0	0	2	2	3	10	3	0	0	1	1	1	0
	Mean Length					430	495	573	652	695			740	755	810	
	S.E.					20	5	12	15	23			0	0	0	

Appendix B7. Voluntary returns of tagged burbot by sport anglers.

Lake	Date Tagged	Tag Number	Date Caught	Recapture Location
Beaver	9/22/88	43749	03/17/89	Beaver
	6/27/88	43510	03/17/89	Beaver
	6/27/88	45123	04/09/89	Beaver
	6/12/88	44545	04/09/89	Susitna
	6/12/88	45167	05/05/89	Beaver
	9/24/88	43835	05/04/89	Beaver
Crosswind	7/23/88	45354	02/26/90	Crosswind
Fielding	7/24/90	70931	09/07/90	Lower Tangle River
	8/20/85	31845	11/24/90	Fielding
George	6/11/89	10380	03/19/90	George
	7/09/90	10380	03/19/90	George Creek
Lake Louise	6/15/88	43214	03/24/89	Lake Louise
	6/15/88	44634	03/01/89	Susitna
	6/20/88	43329	03/18/89	Lake Louise
	7/24/87	40487	03/31/89	Susitna
	6/20/88	43354	03/17/89	Lake Louise
	6/23/88	43461	03/18/89	Lake Louise
	6/11/89	43061	03/18/89	Lake Louise
	8/14/87	41118	07/02/89	Lake Louise
	7/22/87	40411	11/20/88	Susitna
	8/19/87	41180	07/04/89	Lake Louise
Moose	5/26/88	41903	12/27/89	Moose
Paxson	8/14/86	37305	06/10/89	Paxson
	6/25/88	63282	04/16/89	Paxson
	6/24/88	63247	04/16/89	Paxson
	7/10/87	24424	04/16/89	Paxson
	7/12/86	30633	09/20/89	Paxson
	6/29/88	63475	07/14/89	Paxson
Sucker	6/12/87	3655	02/27/89	Sucker
	9/30/87	43977	02/17/89	Sucker
	6/12/87	3692	02/17/89	Sucker
	6/12/87	3707	02/17/89	Sucker

-continued-

Appendix B7. (Page 2 of 2).

Lake	Date Tagged	Tag Number	Date Caught	Recapture Location
Susitna	7/26/87	40570	03/01/89	Susitna
	6/09/88	44166	03/01/89	Tyone
	9/22/88	43763	03/09/89	Beaver
	6/20/88	44863	04/18/89	Susitna
	6/14/88	44581	04/19/89	Susitna
Tolsona	5/27/88	42968	01/03/89	Tolsona
	9/25/86	38749	04/02/89	Tolsona
	9/25/86	38980	04/02/89	Tolsona
	9/24/86	38572	03/18/89	Tolsona
	6/04/87	88075	03/18/89	Tolsona
	9/02/88	45650	03/18/89	Tolsona
	8/05/86	37706	03/18/89	Tolsona
	6/04/87	39866	03/18/89	Tolsona
	6/04/87	39547	04/10/89	Tolsona
	6/04/87	39638	04/10/89	Tolsona
	6/04/87	39985	04/10/89	Tolsona
	5/24/89	46858	11/27/89	Tolsona
	9/02/88	45790	11/27/89	Tolsona
	9/02/88	45788	03/10/90	Tolsona
	6/04/87	39031	01/07/90	Tolsona
	6/04/87	39072	01/21/90	Tolsona
	9/24/86	38878	02/12/90	Tolsona
	6/04/87	39966	02/18/90	Tolsona
	6/04/87	39995	02/18/90	Tolsona
	5/27/88	41639	02/18/90	Tolsona
	5/27/88	42926	02/18/90	Tolsona
	5/24/89	45773	02/18/90	Tolsona
	5/24/89	46895	02/18/90	Tolsona
	9/02/88	45669	02/18/90	Tolsona
	9/12/89	143420	02/18/90	Tolsona
	6/04/87	39591	02/18/90	Tolsona
Tyone	6/10/88	44395	02/10/89	Tyone
	9/01/87	41473	06/17/89	Tyone
	8/22/87	41251	08/27/89	Susitna

Appendix B8. Summary of data archives.

Location	Project Leader	Storage Softwear and version
Region II Anchorage	R. Lafferty 267-2225	Comma delimited ASCII files Standard RTS Archive format[a]

Lake	Data Map File Name	 Data Format	 Softwear
Fielding	U0130ha9.dta	Tagging Length	RTS-ASCII
	U0130hb0.dta	Hoopnet	RTS-ASCII
	U0130hc0.dta	Hoopnet	RTS-ASCII
	Fie90th.dbf	Tag History	DBASE
George	U0110HA0.dta	Hoopnet	RTS-ASCII
	Geo90th.dbf	Tag History	DBASE
Harding	U1890HA0.dta	Hoopnet	RTS-ASCII
	U1890hb0.dta	Hoopnet	RTS-ASCII
	Hard90th.dbf	Tag History	DBASE
Hudson	I0090h-0.dta	Hoopnet	RTS-ASCII
	Hud90th .dbf	Tag History	Dbase
Louise	I0100h-0.dta	Hoopnet	RTS-ASCII
	Lou90th .dbf	Tag History	Dbase
Moose	I2270h-0.dta	Hoopnet	RTS-ASCII
	Moo90thb.dbf	Tag History	Dbase
Paxson	I0130h-0.dta	Hoopnet	RTS-ASCII
	Pax90th .dbf	Tag History	Dbase
Susitna	I0110h-0.dta	Hoopnet	RTS-ASCII
	Sus90th .dbf	Tag History	Dbase
Tolsona	I2860h-0.dta	Hoopnet	RTS-ASCII
	Tol90thb.dbf	Tag History	Dbase
Tyone	I0120h-0.dta	Hoopnet	RTS-ASCII
	Tyo90th .dbf	Tag History	Dbase

-continued-

Location	Project Leader	Storage Softwear and version
Region III Delta Jct.	F. Parker 895-4632	Comma delimited ASCII files Standard RTS Archive format[a]

Lake	Data Map		
	File Name	Data Format	Softwear
Landlock Tangle	U015eha0.dta	Hoopnet	RTS-ASCII
	U015ehb0.dta	Hoopnet	RTS-ASCII
	Llt90th.dbf	Tag History	Dbase
Round Tangle	U015cha0.dta	Hoopnet	RTS-ASCII
	Rdt90th.dbf	Tag History	Dbase
Upper Tangle	U015dha0.dta	Hoopnet	RTS-ASCII
	Upt90th.dbf	Tag History	Dbase
Sevenmile	U3060ha0.dta	Hoopnet	RTS-ASCII
	U3060hb0.dta	Hoopnet	RTS-ASCII
	Sev90th.dbf	Tag History	Dbase
Summit	I0140ha0.dta	Hoopnet	RTS-ASCII
	Sum90th.dbf	Tag History	Dbase
T	U3370ha0.dta	Hoopnet	RTS-ASCII
	Tee90th.dbf	Tag History	Dbase

-continued-

Appendix B8. (Page 3 of 3).

Location	Project Leader	Storage Softwear and version
Region III Delta Jct.	F. Parker 895-4632	Comma delimited ASCII files Standard RTS Archive format[a]

Lake	Data Map		
	File Name	Data Format	Softwear
T	U33701a9.dta	Tagging Length	RTS-ASCII
	U33701b9.dta	Tagging Length	RTS-ASCII
	Tee89M .wk!	Trap net CPUE	Lotus (sqz)
	Tee89R .wk!	Trap net CPUE	Lotus (sqz)
	Tee89th .wk!	Tag History	Lotus (sqz)

Definitions of Data Formats:

Hoopnet: a mark-sense form developed by Alaska Department of Fish and Game, Division of Sport Fish-Research and Technical Services (RTS) for the recording of trap, catch, and tagging information.

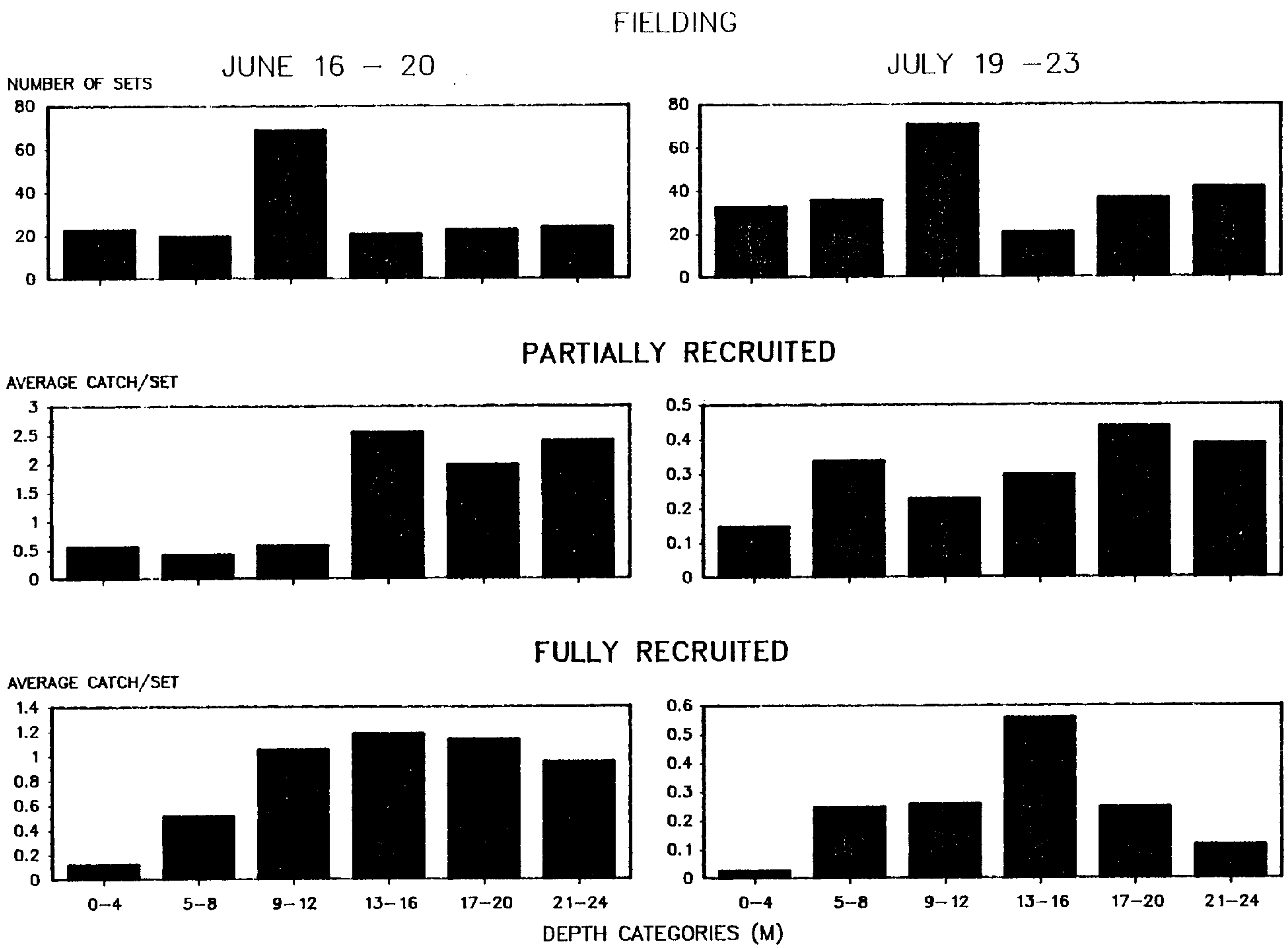
Tag History: a Dbase file that contains lake specific historical tagging information by individual tags and recaptures by sampling events.

Specific codes and organization of columns for each data format are available on request from RTS.

[a] Alaska Department of Fish and Game-Division of Sport Fish-Research and Technical Services (RTS).

[b] Lotus squeezed file - (wk!) - Turner Hall Publishing 1986, version 1.5.

APPENDIX C



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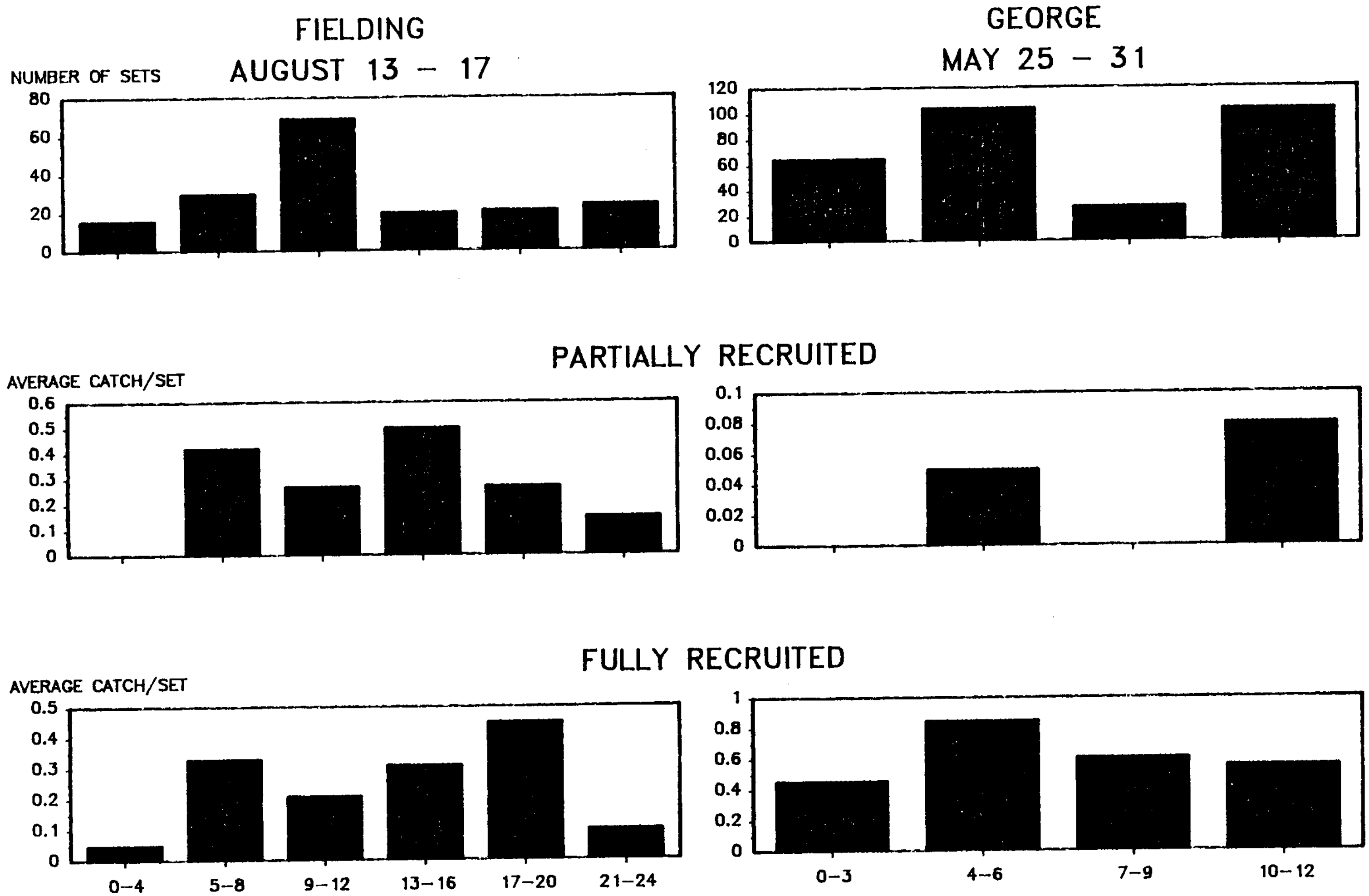
Appendix C. Frequency of sets by depth and average catch of burbot by depth for interior Alaska lakes sampled in 1990.



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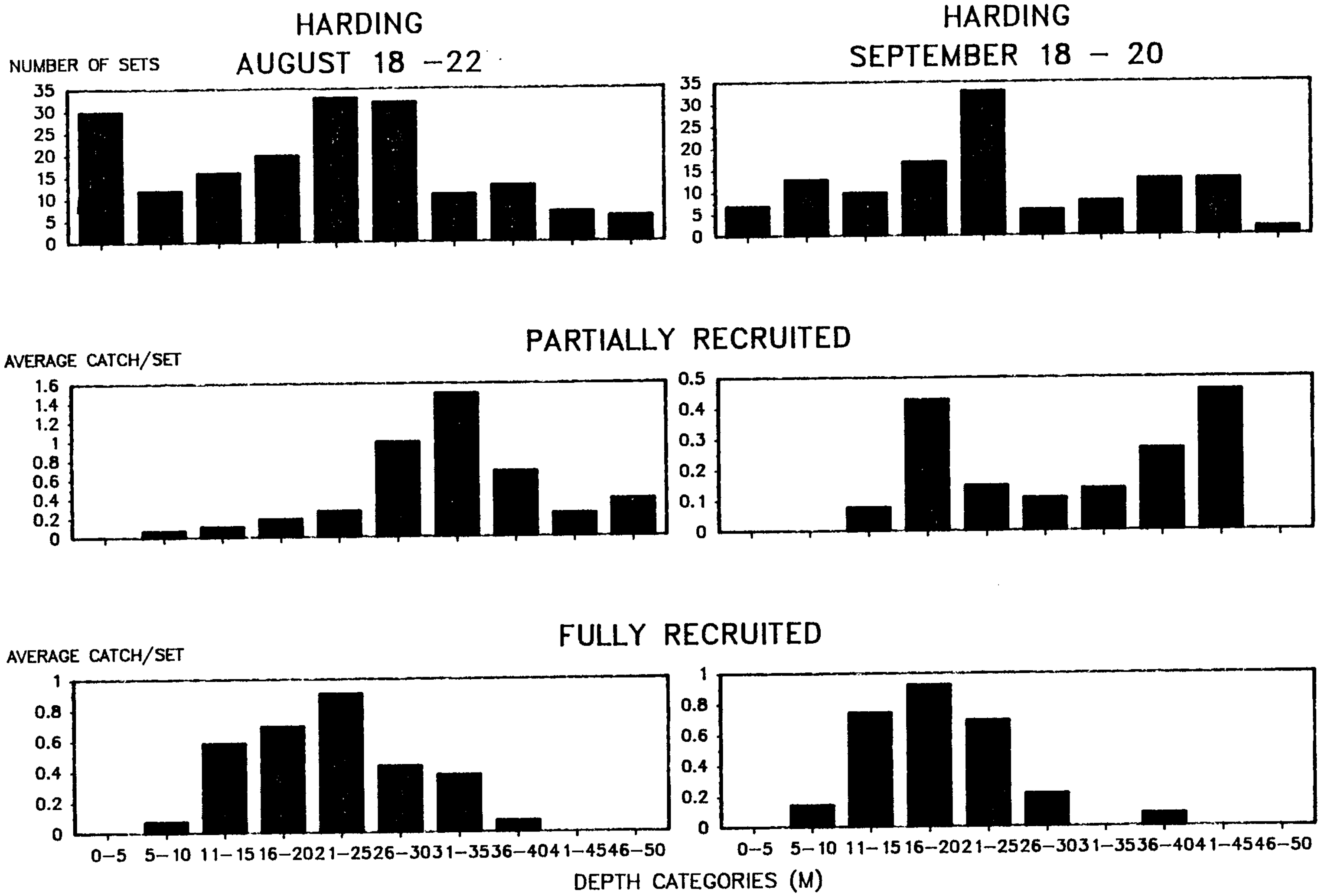
Appendix C. (Page 2 of 11).



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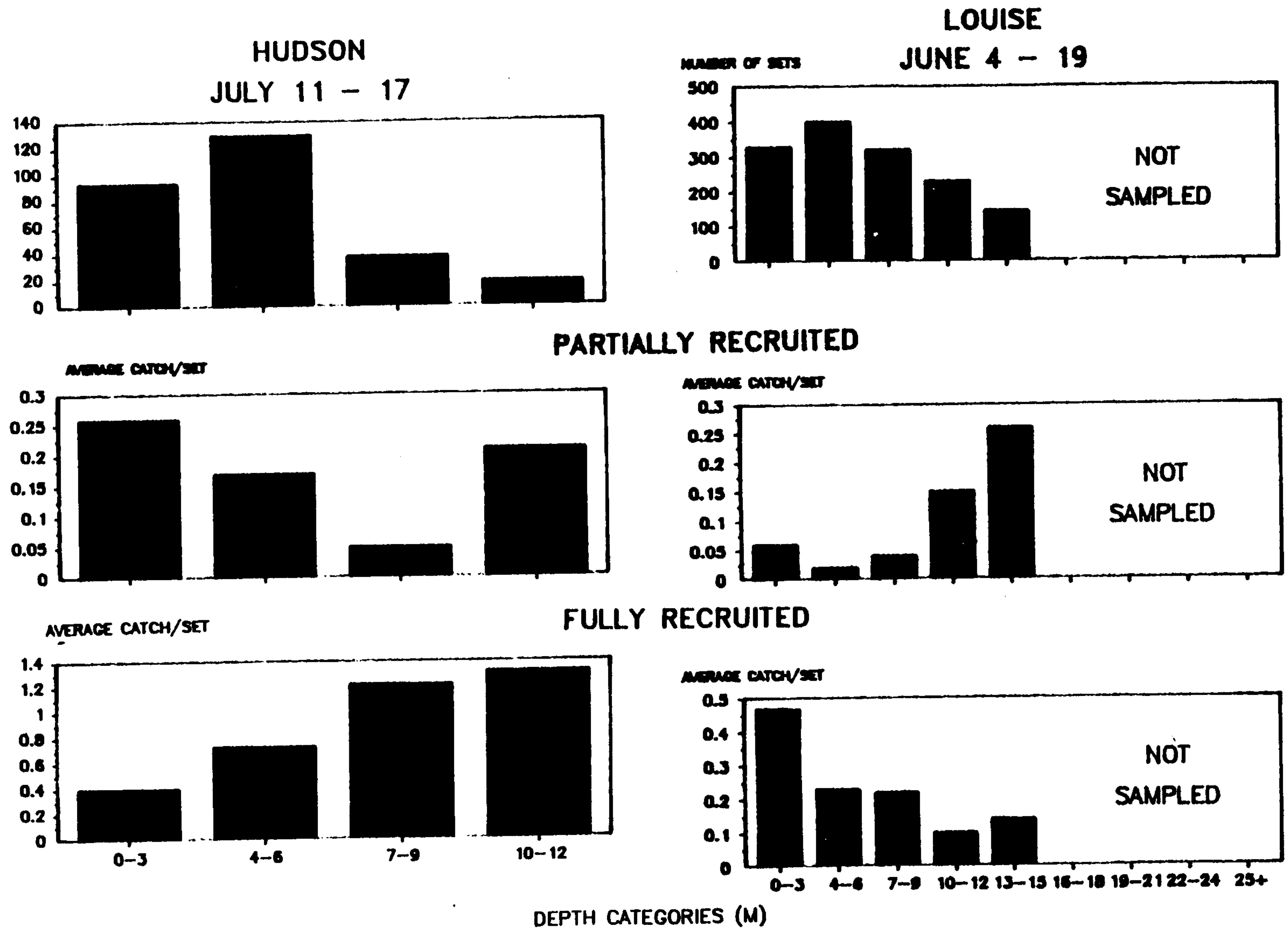
Appendix C. (Page 3 of 11).



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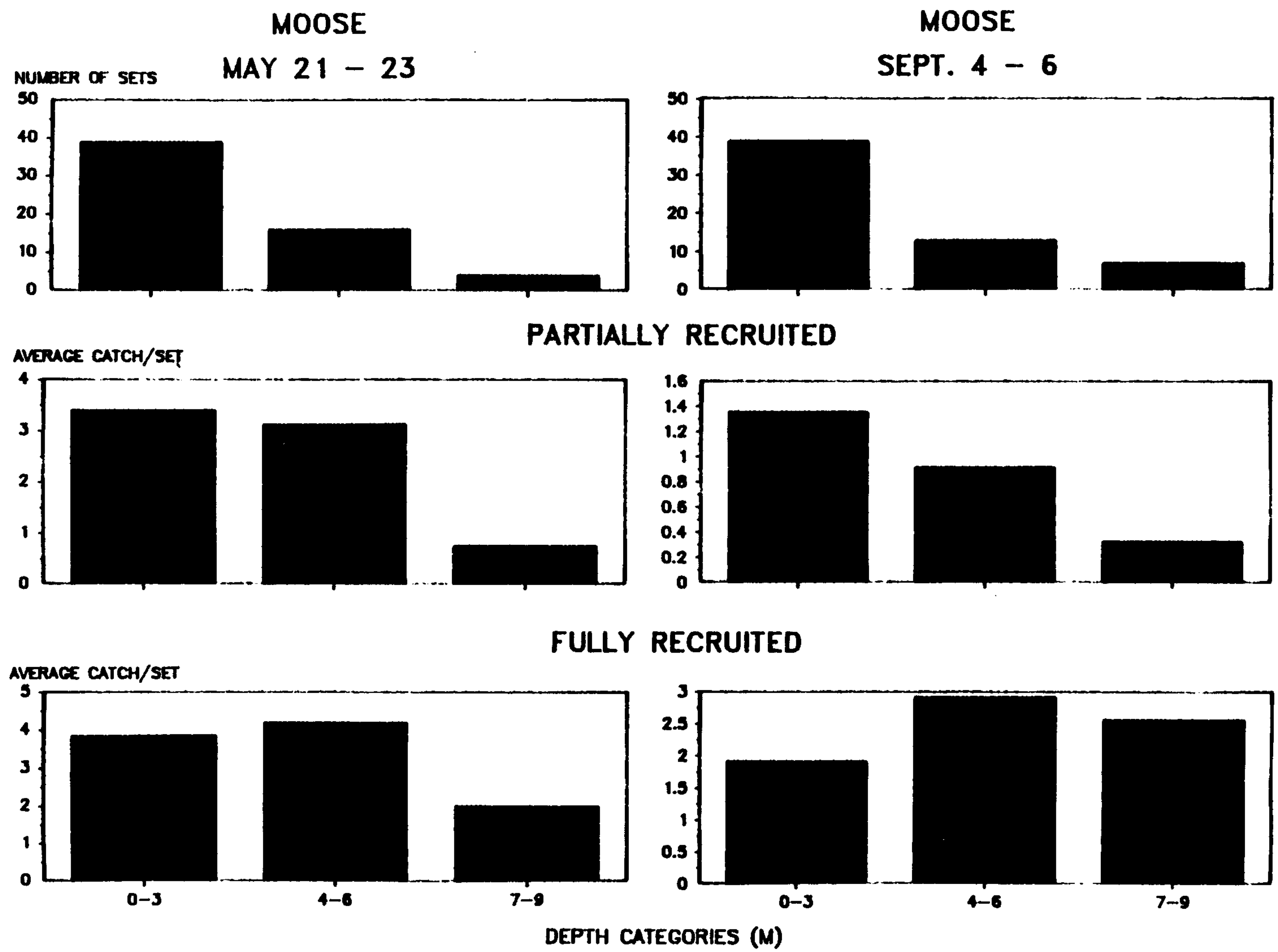
Appendix C. (Page 4 of 11).



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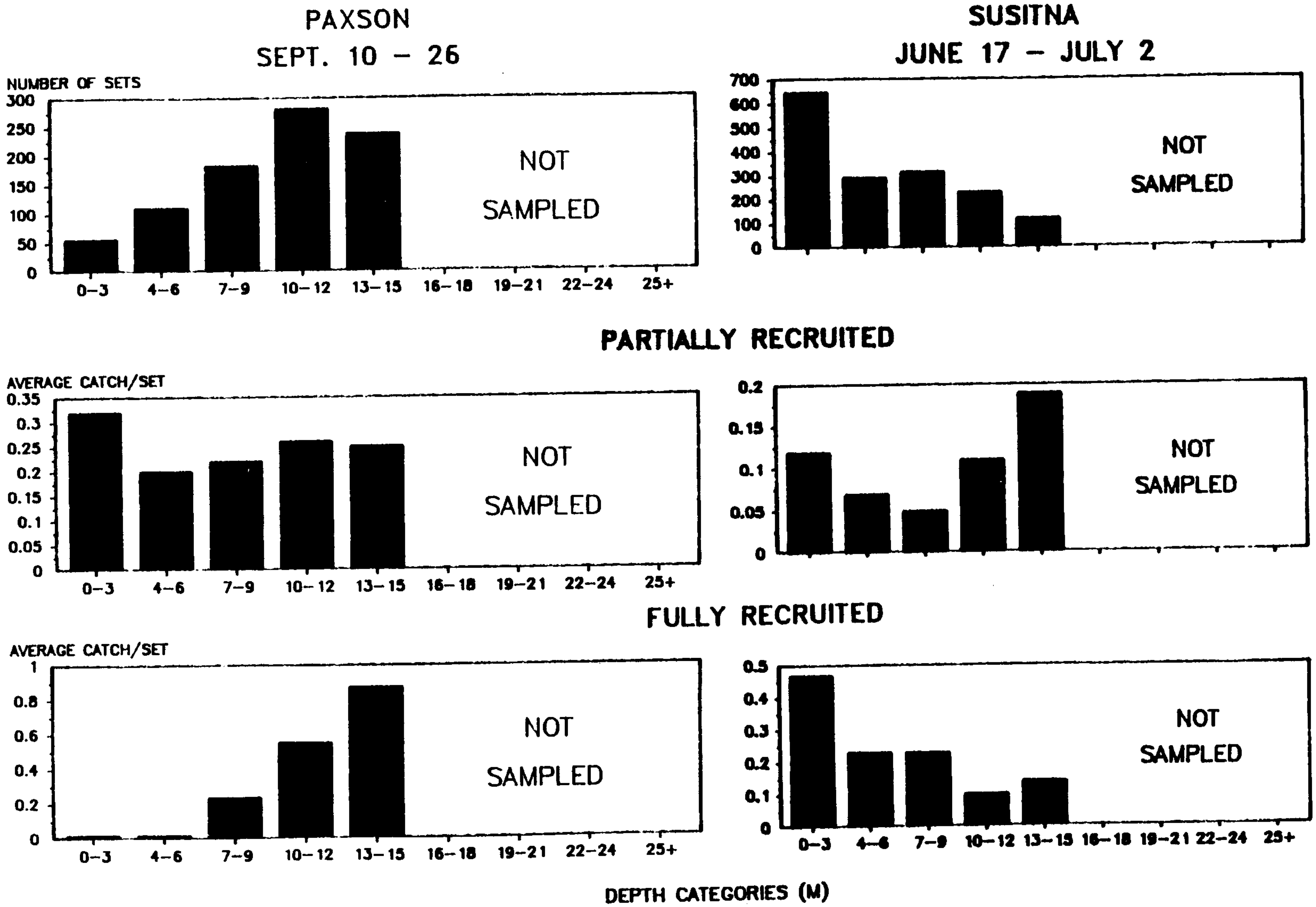
Appendix C. (Page 5 of 11).



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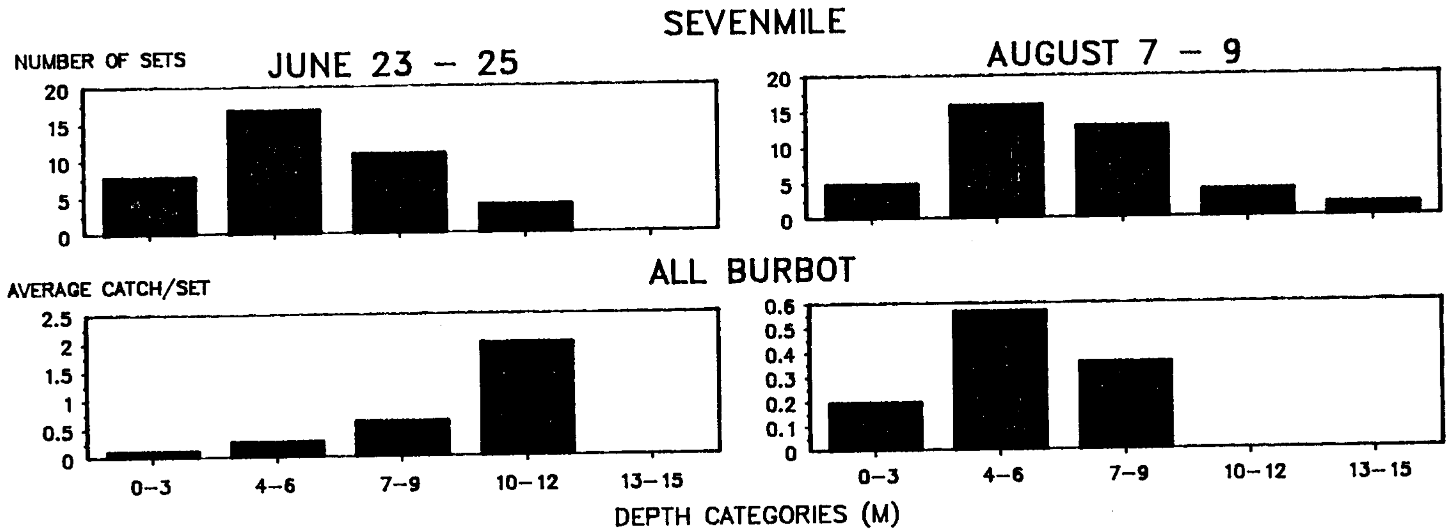
Appendix C. (Page 6 of 11).



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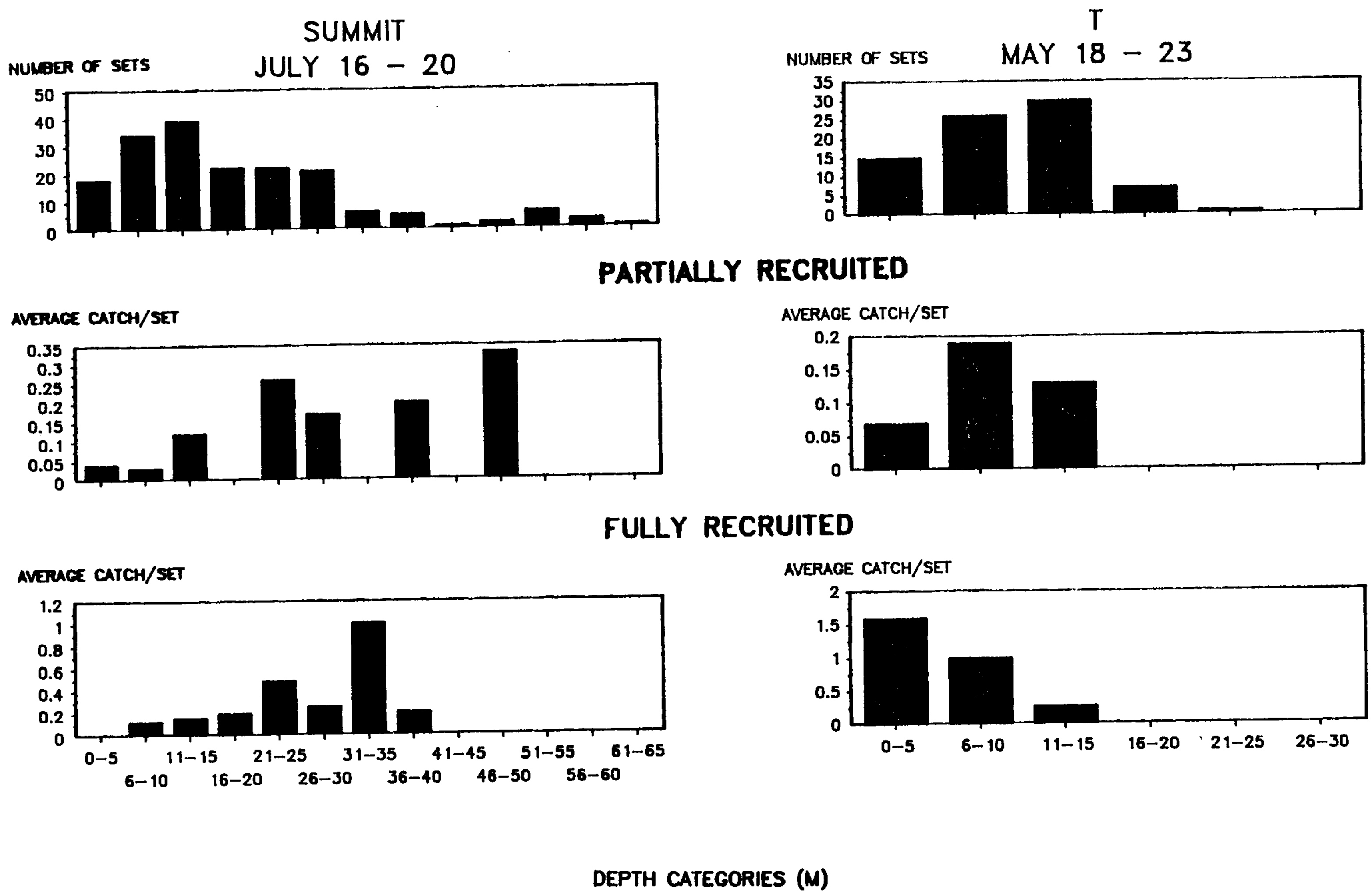
Appendix C. (Page 7 of 11).



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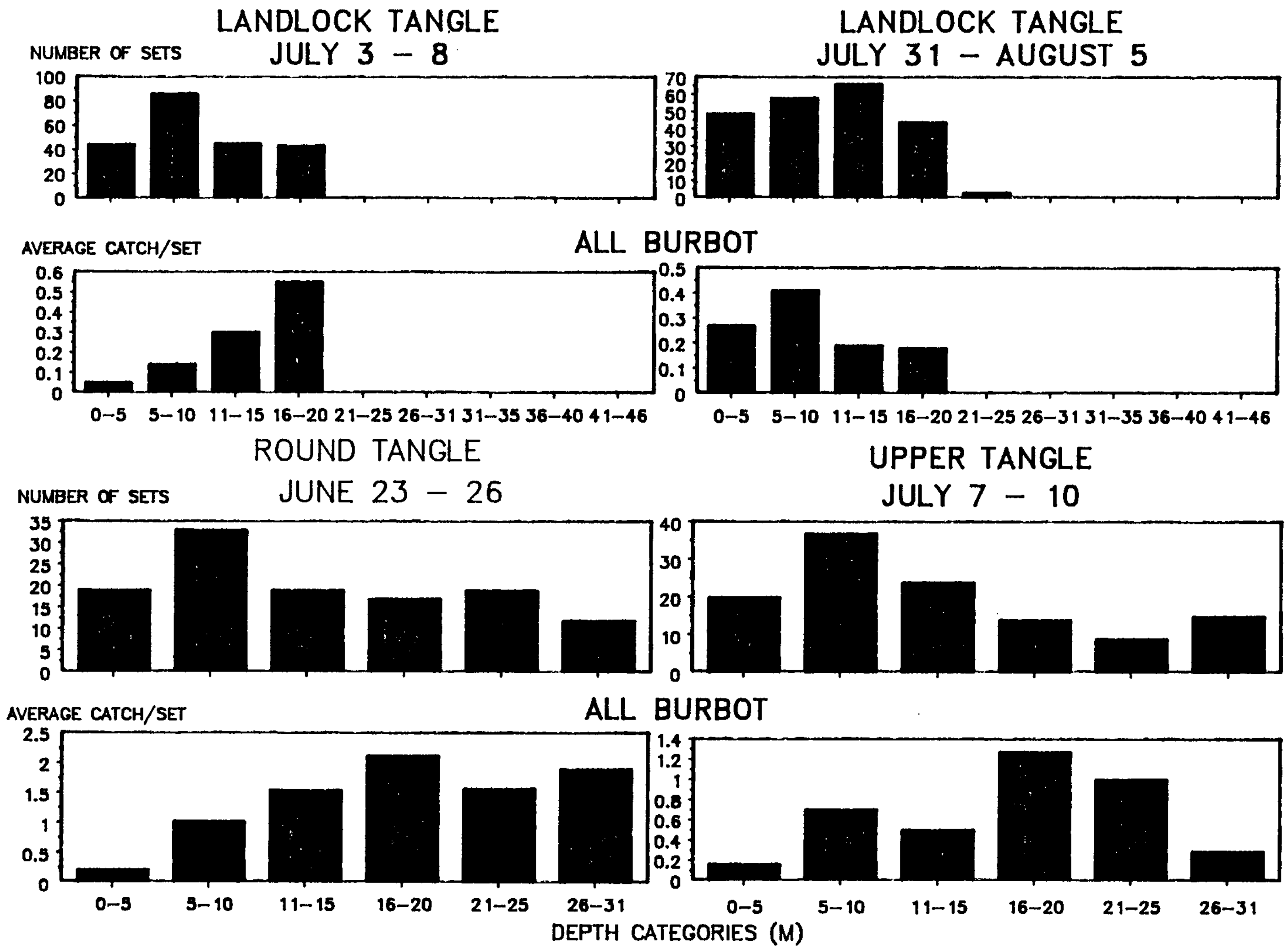
Appendix C. (Page 8 of 11).



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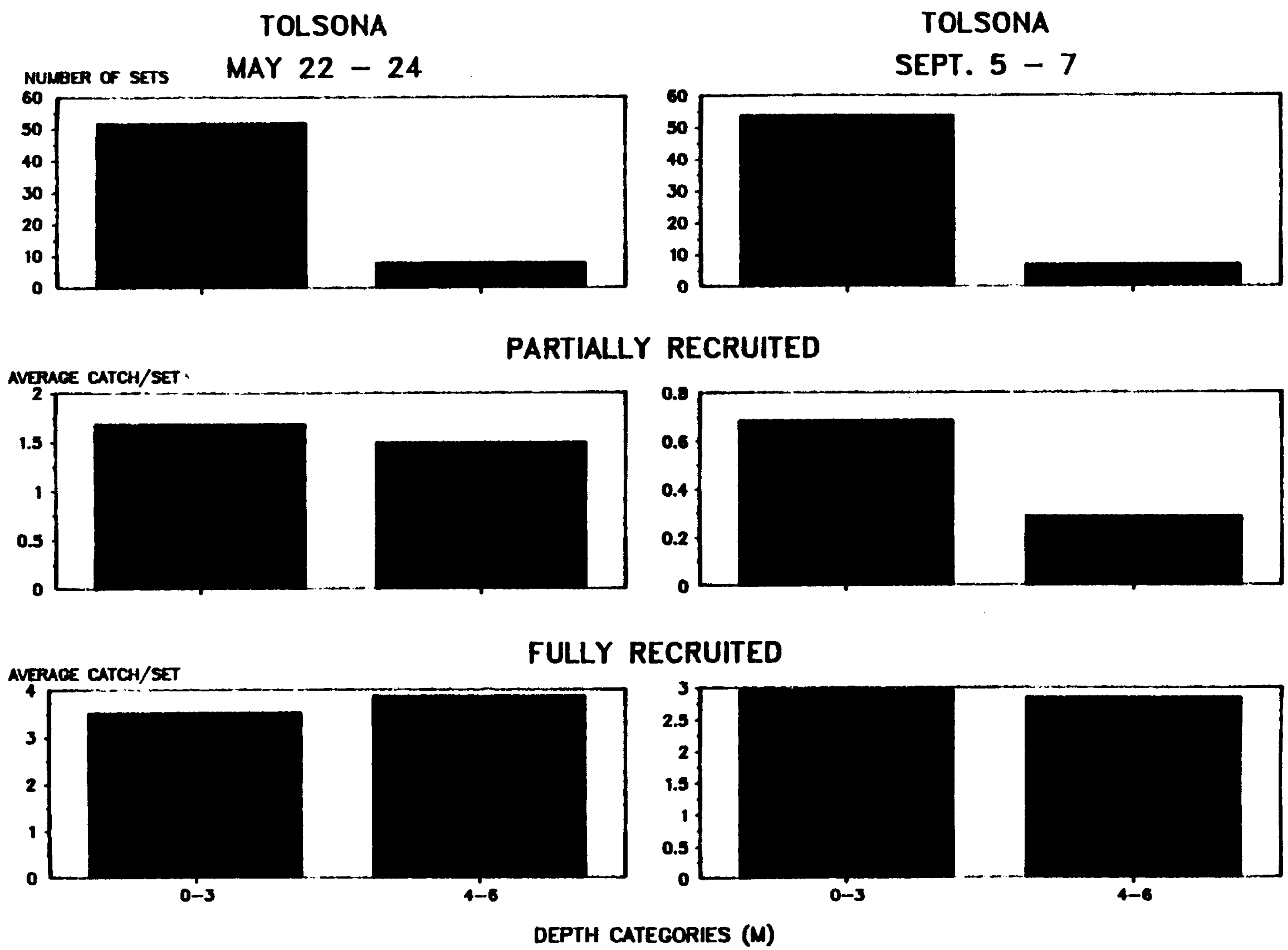
Appendix C. (Page 9 of 11).



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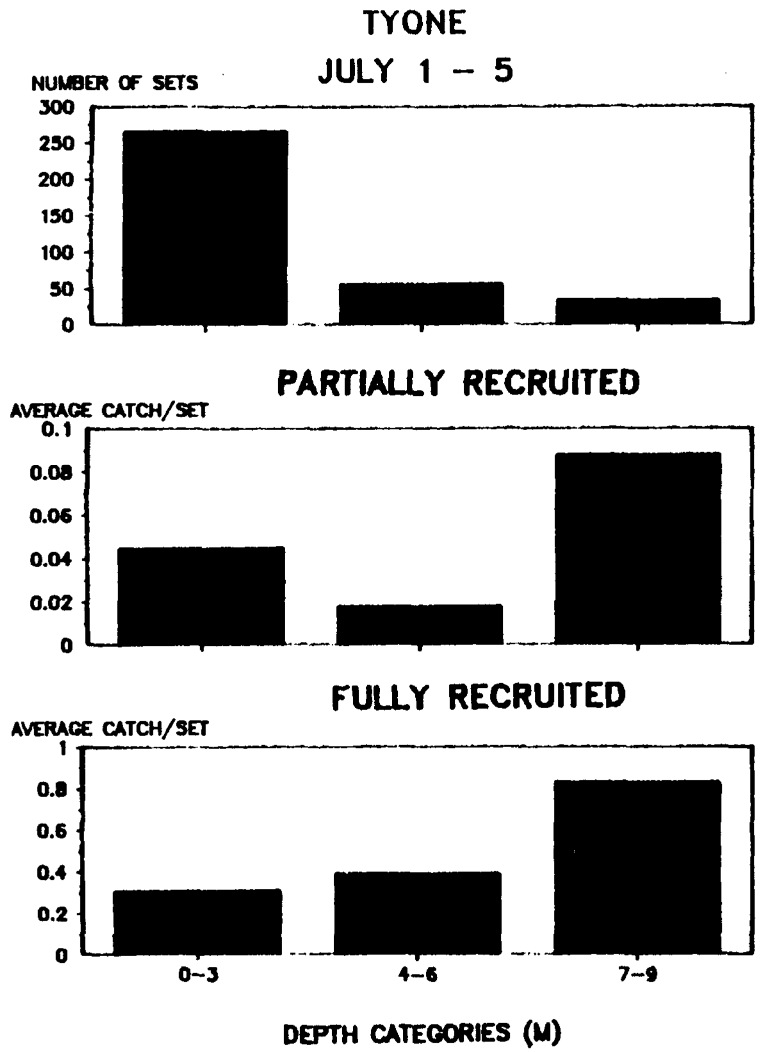
Appendix C. (Page 10 of 11).



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Appendix C. (Page 11 of 11).

APPENDIX D

BIAS AND VARIANCE OF MEAN CPUE

Variance of mean CPUE, its empirical distribution, and its bias were estimated for each survey with the resampling techniques of Efron (1982). Each survey produced data $\{c_{ij}\}$ in which c_{ij} is the catch of burbot in set j on transect i of the survey where $i=1,n$ and $j=1,m_i$. One thousand bootstrap samples (B=1000) were drawn by resampling these original data with replacement. For each bootstrap sample, n transects were randomly chosen with replacement from the n transects in each survey, then from each chosen transect, m_i catches were randomly drawn from the m_i sets on that transect. Although sets were selected systematically on each transect to produce the original data, catches were presumed to be independently distributed along each transect, a situation for which random selection of catches would be unbiased (Wolter 1984). Each bootstrap sample can be expressed as $\{c^*_{ij}\}_b$ in which c^*_{ij} is the catch of burbot in set j on transect i of the survey where $i=1,n$ and $j=1,m^*_i$ and $b=1,B$. Since transects were chosen during the resampling with equal probability even though they were of different sizes, the $\{c^*_{ij}\}$ were scaled appropriately with the technique suggested by Rao and Wu (1988):

$$\tilde{c}_{ij} = \overline{CPUE} + \left[\frac{n}{n-1}\right]^{1/2} (\hat{\omega}^*_i \bar{c}^*_i - \overline{CPUE}) + \hat{\omega}^*_i \left[\frac{m^*_i}{m^*_i - 1}\right]^{1/2} (c^*_{ij} - \bar{c}^*_i) \quad (D.1)$$

where $\hat{\omega}^*_i = m^*_i/\bar{m}^*$, $\overline{CPUE}$ = mean CPUE from the original data (from Equation 1), and $\{\tilde{c}_{ij}\}$ = appropriately weighted, resampled catch statistics. The estimate of mean CPUE from the bootstrap estimate is calculated as:

$$\overline{CPUE}^* = \frac{1}{n} \sum_{i=1}^{n} \frac{1}{m^*_i} \sum_{i=1}^{m_i} \tilde{c}_{ij} \quad (D.2)$$

The B bootstrap estimates of mean CPUE comprise the empirical distribution F(mean $CPUE^*_1$,....mean $CPUE^*_B$) for the original estimate mean CPUE from Equation 1 as obtained through resampling. Variance of mean CPUE from the original data can be estimated as the population variances of the bootstrap samples:

$$V[\overline{CPUE}] = \frac{\sum_{b=1}^{B} (\overline{CPUE}^*_b - \overline{\overline{CPUE}}^*)^2}{B - 1} \quad (D.3)$$

where:

$$\overline{\overline{CPUE}}^{*} = \frac{\sum_{b=1}^{B} \overline{CPUE}_b^{*}}{B} \qquad (D.4)$$

The difference between $\overline{\overline{CPUE}}^{*}$ and the original statistic $\overline{CPUE}$ is an estimate of bias in the original statistic.

The $\{c_{ij}\}$ were resampled with a computer program based on Microsoft™ Fortran that included subroutines from IMSL, Inc. of Houston, Texas for the generation of uniformly distributed random numbers.