Fishery Data Series No. 98-38

Burbot Research in Rivers of the Tanana River Drainage, 1997

by

Matthew J. Evenson

December 1998

Alaska Department of Fish and Game

Division of Sport Fish

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
hour (spell out for 24-hour clock)	h
minute	min
second	s
Spell out year, month, and week.	

Physics and chemistry

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

General

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

Mathematics, statistics, fisheries

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

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by

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ABSTRACT

As part of an ongoing stock assessment program, burbot *Lota lota* were sampled in two river sections during 1997, one each in the Tanana and Chena rivers, representing the areas where most harvest occurs. These sections have been sampled annually since 1986 and 1988, respectively. A systematic sampling design was used, whereby hoop traps were set and moved daily over an eight-day period. Estimates of mean catch per unit effort, mean length, length distributions, and proportions of catch for three size categories were calculated. Estimates for each were within the range of observed values from previous sampling years.

Catch-age analysis was investigated as a technique to estimate fishing mortality and exploitable abundance of burbot in the Tanana River drainage. However, the current model framework appears to be unstable and is not recommended for generating reliable estimates of abundance for burbot in the Tanana River drainage. The catch-age model results showed a decreasing trend in exploitable abundance from 1987 to 1995 with a slight upward trend in 1996. Fishing mortality estimates for fully recruited burbot were generally low and ranged from 0.04 to 0.17. Improvements in the catch sampling program, a longer time series of data, and more accurate estimates of fishing effort are needed to improve the model estimates. Other models that incorporate length information from the index sampling or catch should be investigated.

Key words: burbot, *Lota lota*, hoop traps, Tanana River, Chena River, catch per unit effort, mean length, catch-age analysis, CAGEAN, exploitable abundance, fishing mortality.

INTRODUCTION

Research concerning burbot *Lota lota* stocks in flowing waters of the Tanana River system has been ongoing since 1983. The objectives of this research program have been to determine biological characteristics such as size, age, and density distributions, identify migratory and reproductive behavior, and determine characteristics of the sport fishery. Results of this research have been published in a number of documents (Hallberg 1984 - 1986; Hallberg et al. 1987; Guinn and Hallberg 1990; Evenson 1988, 1989, 1990a, 1990b, 1991, 1992, 1993a, 1993b, 1994, 1996, 1997, Evenson and Hansen 1991; Evenson and Merritt 1995; Clark et al. 1991; Bernard et al. 1991).

Initially, this research sought to identify individual stocks by identifying movements throughout the system. This was accomplished through a rigorous sampling program that marked and subsequently recaptured burbot in the mainstream Tanana River and in many tributary streams. In 1992 (Evenson 1993b), radio telemetry was used to monitor seasonal movements and identify spawning concentrations in attempts to refine stock definitions. This information indicated that movements were frequent and extensive throughout the system, and that for management purposes, the entire drainage should be considered a single stock (Evenson 1989 and 1990a).

Historical assessment of this stock has been accomplished by estimating abundance through mark-recapture experiments, relative abundance through mean catch per unit effort (CPUE) and length compositions for many river sections throughout the system using a standardized design. These estimates have been obtained annually or semi-annually for various river sections. This assessment has indicated that annual exploitation is low relative to abundance for the entire system. Thus, the stock assessment research has been reduced, and is focused toward those river sections where a substantial harvest occurs.

Catch-age analysis was examined as an alternative method of assessing the population of burbot in the Tanana River beginning in 1994 (Evenson and Merritt 1995). Catch-age analysis uses an age-structured approach to population abundance estimation by combining harvest at age information with auxiliary data (Deriso et al. 1989) to generate abundance estimates by year and age class. Catch-age techniques require a long series of well-sampled catches before meaningful estimates can be generated (Megrey 1989). This analysis includes only ten years of catch samples (1987-1996), and therefore the parameter estimates presented below should not be considered definitive.

The purpose of this investigation was to continue stock monitoring in the Tanana and Chena rivers near Fairbanks. The specific objectives in 1997 were to:

1. estimate length composition (proportion in 25 mm length increments) of all burbot 450-799 mm total length (TL) in one 29 km section each of the Tanana and Chena rivers;
2. estimate abundance of fully recruited burbot to the fished population for years 1987-1996, and,
3. test the hypothesis that the proportion of pre-recruits (ages 4-8) in the fishery collected during periods of ice cover (winter) is equal to those collected during periods of open water (summer).

In addition, mean CPUE of burbot for each of three length categories (small: 300-449 mm TL; medium: 450-799 mm TL; and, large: 800 mm TL and larger) was estimated in each of the two river sections. Other statistics regarding length compositions are presented and compared to previous years' data. A project task for this study was to capture 15 burbot in the Fort Knox Reservoir which were injected with oxytetracycline (OTC) in 1995.

Fort Knox Sampling

Sampling was conducted in the freshwater reservoir of the Fort Knox mining complex located in the Fish Creek drainage (tributary of the Little Chena River) during May 20-22 as part of an age validation study. The objective of the sampling was to capture 15 burbot that were injected with oxytetracycline (OTC) in 1995. Forty-three fish marked with OTC are ultimately needed to estimate the proportion of otoliths with correct ages. These samples should be comprised of approximately equal numbers of burbot that are at large one, two and three years. During this year's sampling, 15 OTC-marked burbot that were at large two years were collected using baited hoop traps. Age analysis will not be conducted until after the final samples are collected in 1998.

METHODS

INDEX SAMPLING

Study Area

The Tanana River is of glacial origin flowing over 900 km and draining 115,255 km^2. The study areas in this investigation included a 29 km section of the Tanana River extending downstream from the confluence of the Chena River, and a 29 km section of the Chena River extending upstream from its confluence with the Tanana River (Figure 1). These same two sections have been sampled annually since 1986 and 1988, respectively, using a similar sampling design.

Gear Description

Burbot were captured in commercially available hoop traps. Two sizes of traps have been used during the past eight years. Small hoop traps were 3.05 m long with seven 6.35 mm steel hoops

3

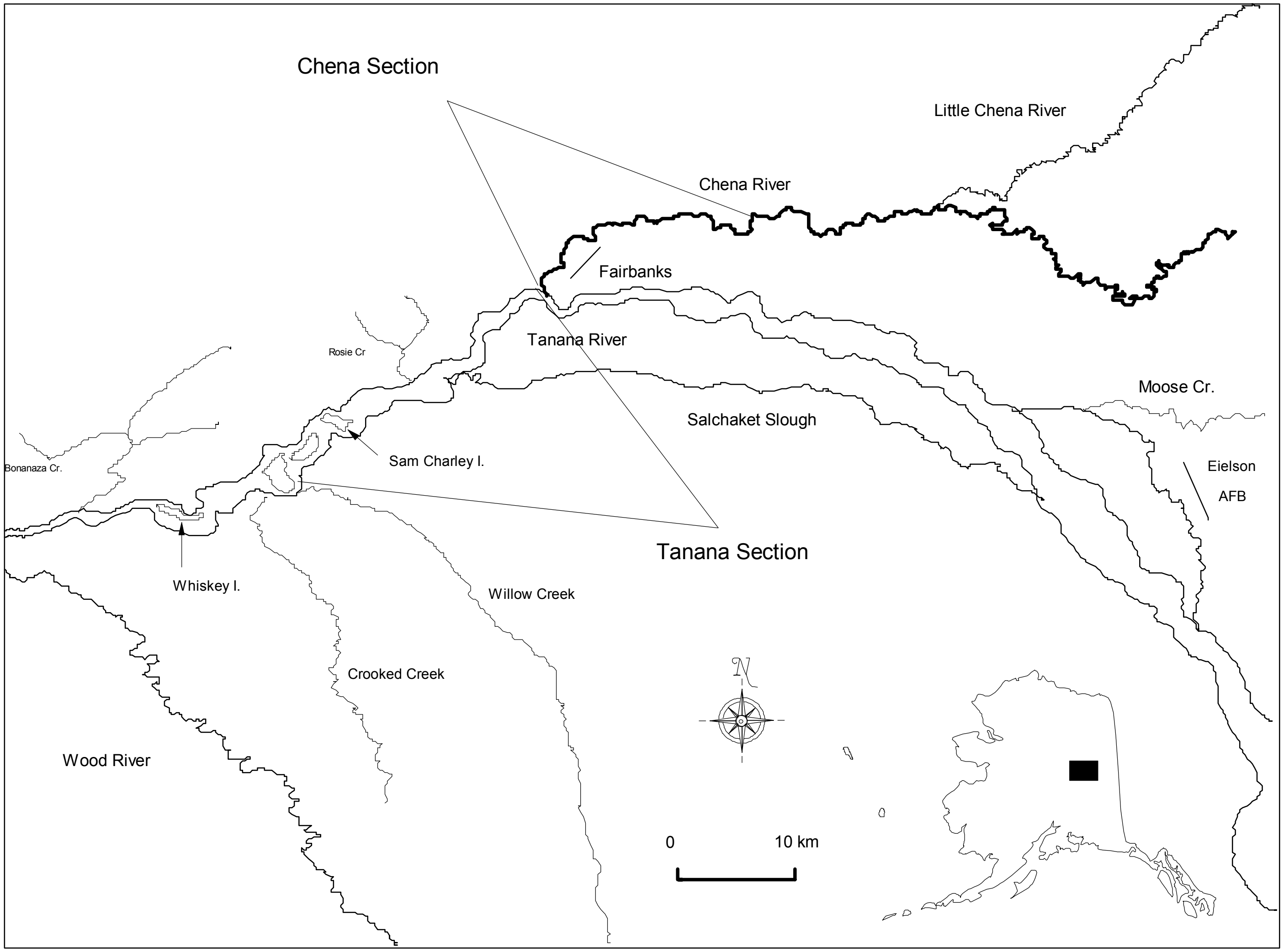

Figure 1.-Map of the Tanana River drainage showing sample sections during 1997.

(Figure 2). Hoop diameters tapered from 0.61 m at the entrance to 0.46 m at the codend. Each trap had a double throat (tied to the second and fourth hoops) which narrowed to an opening 10 cm in diameter. All netting was knotted nylon woven into 25 mm bar mesh, bound with No. 15 cotton twine, and treated with an asphaltic compound. Each trap was kept stretched with two sections of 19 mm polyvinyl chloride (PVC) pipe attached by snap clips to the end hoops.

The larger traps were used prior to 1988, while the smaller traps were used thereafter. Bernard et al. (1991) provides a comprehensive account of the efficacy of both large and small traps. In general, both sizes are effective at catching burbot greater than 300 mm TL, however burbot do not fully recruit to either gear until 450 mm TL. For all lengths 800 mm and larger, large traps are more effective than small traps. Small hoop traps were chosen as a sampling gear beginning in 1988 because they are more easily transported and more traps can be deployed during a sampling day.

Large hoop traps were of similar design, but were 3.66 m long, and had fiberglass hoops with inside diameters tapering from 91 to 69 cm (Figure 2). Throat diameters were 36 cm. Spreader bars made from PVC were also used to keep the traps stretched.

Hoop traps were baited with cut Pacific herring *Clupea harengus* placed in perforated plastic containers. One end of a 5 to 10 m section of polypropylene rope was tied to the cod end of each trap, while the other end was tied off to shore. The traps then fished on the river bottom near shore with the opening facing downstream. An outboard-powered riverboat was used to set, move, and retrieve the traps.

STUDY DESIGN

The sampling design utilized one crew of two persons for a period of two weeks (eight days of sampling). The Tanana River section was sampled during 2-13 June and the Chena River Section was sampled during 25 August – 5 September. A systematic sampling design was used whereby traps were set along both shores at near equal intervals beginning at the most downstream end of the section and progressing to the most upstream end of the section. Traps were set at a density of 1.5 traps per km per day. All traps were fished for approximately 24 h, rebaited, and were moved each day. All trap locations were marked on 1:63,360 USGS maps and were recorded to the nearest km. All burbot captured were measured for total length to the nearest mm, and were tagged using individually numbered Floy internal anchor tags. All fish were released at the capture site.

DATA ANALYSIS

Due to the size selectivity of hoop traps, estimates of mean CPUE and length composition statistics described below are given for three length strata: "small" (≤450 mm TL) "medium" (450-799 mm TL) and "large" (≥800 mm TL).

Catch per Unit Effort

Mean CPUE for each river section and its associated variance were calculated from the number of burbot caught per net-night for all traps set during each sampling period based upon the following equations from Wolter (1984):

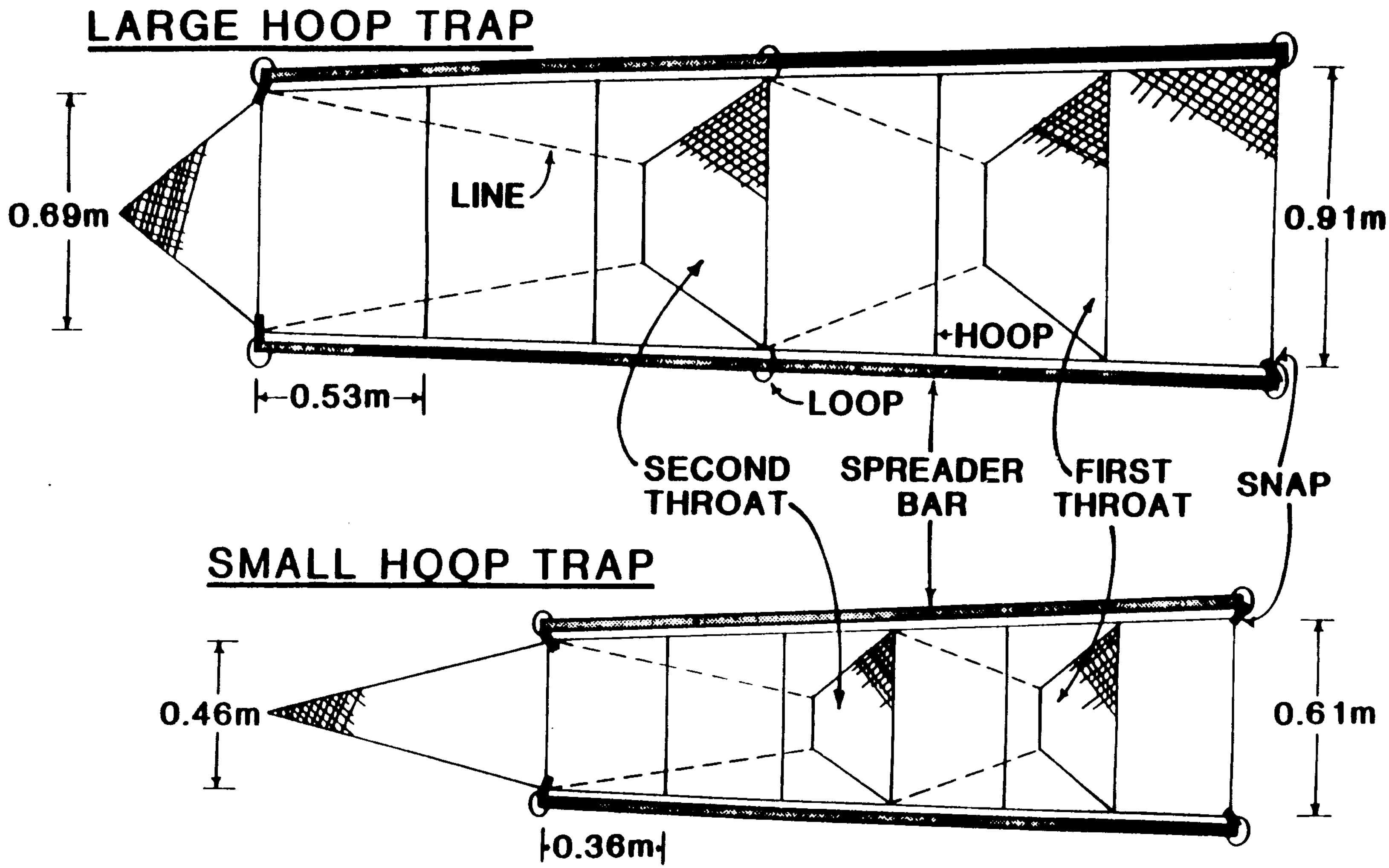

Figure 2.-Diagrams of large and small hoop traps used to catch burbot in flowing waters of the Tanana River drainage.

$$\overline{CPUE}_c = \overline{X}_c = \frac{\sum_{h=1}^{t} X_{ch}}{t} \quad (1)$$

$$V\left[\overline{CPUE}_c\right] = \frac{\sum_{h=2}^{t} \left(X_{ch} - X_{ch-1}\right)^2}{2t(t-1)} \quad (2)$$

where:

X_{ch} = catch of burbot of size class c in hoop trap h (h=1 to t where h=1 the most downstream set and h=t the most upstream); and,

t = the total number of hoop traps in a river section.

All estimates of mean CPUE are given in units of number of burbot per net per overnight set, or burbot per net-night (bb/nn).

Length Composition

Lengths of burbot were compared between sections using three methods. Mean lengths and proportions of total catch for each of the three size categories were calculated, and length distributions for various sampling years were plotted and compared.

Mean length and its associated variance was calculated for three length categories as:

$$\bar{l}_a = \sum_{b=1}^{n} \frac{l_{ab}}{n_a} \quad (3)$$

$$V\left[\bar{l}_a\right] = \sum_{b=1}^{n} \frac{\left(l_{ab} - \bar{l}_a\right)^2}{n_a\left(n_a - 1\right)} \quad (4)$$

where:

l_{ab} = length of burbot b in category a; and,
n_a = number of samples in length category a.

All estimates of mean length are expressed to the nearest mm of TL.

Proportions of total catch for each length category and associated variances were calculated as:

$$\hat{P}_a = \frac{n_a}{n} \quad (5)$$

$$V\left[\hat{P}_a\right] = \frac{\hat{P}_a\left(1 - \hat{P}_a\right)}{n-1} \quad (6)$$

$\hat{P}_a$ = the estimated proportion of burbot in category a;

n_a = number of samples in length category a; and,

n = the total number of burbot in the sample.

Data files regarding burbot stock assessment in these two river sections for all sampling done since 1986 are listed in Appendix A.

CATCH-AGE ANALYSIS

Abundance of the Tanana River burbot population by year and age class for years 1987-1996 was estimated using catch-age analysis (Hilborn and Walters 1992). The computer program CAGEAN (Deriso et al. 1985) was used to solve for a non-linear least-squares solution (Marquardt 1963) to parameters related to the population and sport fishery. CAGEAN couples a simulation model of the population dynamics with data generated from various estimation procedures, and compares predicted parameters with observed data. Using a minimization criterion, CAGEAN seeks the set of parameters that minimize differences between predicted and observed values. Standard deviations of calculated parameter estimates are obtained using the Monte Carlo (bootstrap) technique. Two observed data sources were used: 1) total sport harvest estimates for the Tanana River from 1987-1996 (Mills 1988 - 1994 and Howe et al. 1995-1997); and, 2) estimated age composition of the harvest from voluntary angler returns and catch sampling. Auxiliary information in the form of fishing effort was added to stabilize parameter estimation.

Input files for the CAGEAN analysis are given in Appendix B.

Model Assumptions

The assumptions of the catch-age model used in this study are as follows (summarized from Megrey 1989):

1) the age composition of the stock is not constant from year to year;
2) the age composition data are independent of the total catch estimate;
3) there are errors associated with estimating the total catch;
4) all significant components of mortality are accounted for in F (fishing mortality) and M (natural mortality);
5) M does not vary by age, year, or size of the stock and represents all components of mortality not associated with the directed fishery;
6) F does not vary with respect to stock size;
7) F and M operate concurrently and independent of one another;
8) M is known or can be estimated independently;
9) F can vary between years, and within one year it can vary by age;
10) variation in F can be represented as the product of an age and a year factor;
11) exploitation can change between years, but not within a year;
12) catchability (q) of the gear is constant and does not vary by age within a year;
13) there is no gear saturation or competition;

14) the population is closed to immigration and emigration; and,

15) the fishery operates on a single unit stock over its entire geographic range.

These assumptions are tailored to the characteristics of information available for this population and are not necessarily assumed for all catch-age models.

Notation

Notation used to define parameters follows. A caret (^) is used to denote parameter estimates from data (e.g. age composition and harvest) and a tilde (˜) is used to denote parameter estimates from catch-age models.

$\hat{H}_{a,y}$	=	harvest by age in year y as estimated from samples of otoliths and information from the statewide harvest survey;
$\tilde{H}_{a,y}$	=	estimated harvest of fish of age a in year y from the catch-age model;
$\hat{p}_a$	=	observed proportion of age a fish in the sample;
$\hat{L}_a$	=	length at age a;
$\hat{L}_\infty$	=	asymptotic length of burbot;
$\hat{K}$	=	von Bertalanffy growth coefficient;
$\hat{t}_o$	=	theoretical age at length zero;
$\hat{t}_{mb}$	=	0.38 of the maximum observed age;
$\hat{Z}$	=	estimated total mortality;
$\hat{M}$	=	instantaneous natural mortality;
$\tilde{F}$	=	estimated fishing mortality;
$\hat{E}_y$	=	calculated fishing effort in year y for burbot;
$\tilde{s}_a$	=	relative selectivity of sport fishery for age a burbot;
q	=	catchability coefficient;
$\tilde{N}_{a,y}$	=	estimated number of fish in the cohort at age a in year y;
λ	=	effort lambda or weighting factor for effort; and,
μ	=	exploitation fraction or rate.

Population Dynamics

Because the Tanana River burbot fishery occurs essentially year-round, and fishing mortality is continuous, the following equation was used to model abundance of one cohort to the next year:

$$\tilde{N}_{a+1,y+1} = \tilde{N}_{a,y} e^{-Z_{a,y}} \ . \tag{7}$$

Older ages were pooled into a single group (16+) and the abundance of this group was calculated as:

$$\tilde{N}_{16+,y+1} = \tilde{N}_{15,y} e^{-\hat{Z}_{15+,y}} + \tilde{N}_{16+,y} e^{-\hat{Z}_{16+,y}}. \quad (8)$$

Estimated harvest was modeled as a function of:

$$\tilde{H}_{a,y} = \mu_{a,y} \tilde{N}_{a,y} \quad (9)$$

where:

$$\mu_{a,y} = \frac{\tilde{F}_{a,y}}{\hat{Z}_{a,y}} \left[1 - e^{-\hat{Z}_{a,y}}\right]; \text{ and,} \quad (10)$$

$$\tilde{F}_{a,y} = \tilde{F}_y s_a \quad (11)$$

which assumes that fishing mortality and selectivity are separable.

Catch Sampling

Age samples were collected from voluntary returns by sport anglers. Anglers were notified of the study through newspaper advertisements, tag return letters, and notes placed on set-lines. Because the fishery is temporally and spatially dispersed, a formal creel census approach to sampling would be costly and likely would not supplement sample size significantly. Anglers typically use fish bait to capture burbot. Baited hooks are fished both actively (rod and reel) and passively using lines set over night. Regulations require a minimum hook size (distance between point of hook and shank) of 19 mm (3/4 inch). Most samples for this analysis were collected from anglers fishing during the winter using set-lines, and primarily in the middle portion of the Tanana drainage. This area is where the majority (60 - 80%) of the annual harvest occurs (Appendix C), however it is estimated that less than half of the total Tanana drainage harvest of burbot occurs during periods of ice-cover (22% in 1990; Evenson and Hansen 1991). For this analysis, it was assumed that the age proportion from the winter sample is representative of total annual harvests within the Tanana drainage. During 1996 and 1997, efforts were made to collect substantial numbers of carcasses during the open water season as well as during the ice cover season in order to test the assumption of equal catchability within a year (number 12 above). Comparison of the 1996 samples indicated that although the two samples were statistically similar, sample size was small and there likely were differences in age composition among the two seasons (Evenson 1997). This analysis should provide insight into whether past samples are representative of total harvest. Similar testing will occur in years to come to continue to test this assumption.

Age Determination

A pair of otoliths (sagittae bones) was removed from each fish for age analysis. Otoliths were stored dry and then soaked in distilled water for 4 h prior to reading. Otoliths were surface read under a dissecting microscope using reflected light. Magnification varied between 1.0X and 4.0X depending upon the size of the otolith. An aging study conducted previously (Evenson and Merritt 1995) indicated that surface reading techniques provided similar but more precise estimates of age than did break and burn techniques.

Harvest at Age

Total harvests estimated from the statewide harvest survey (Mills 1988-1994 and Howe et al. 1995-1997) were computed by summing harvests from all discrete flowing waters draining into the Tanana River[1]. Harvest at age from 1987-1989 and from 1991-1996 (no catch samples were obtained in 1990) was estimated by multiplying the estimated proportion by age class from angler-returned carcasses and catch sampling (Table 1) and the estimated harvest from the statewide harvest survey (Figure 3; Table 2):

$$\hat{H}_{a,y} = \hat{H}_y \hat{p}_a. \tag{12}$$

where:

$$\hat{p}_a = \frac{n_a}{n}. \tag{13}$$

Gear Selectivity

The range of ages from all samples was 3 - 20. Although not fully recruited to the fishery, burbot of age 5 are present in most harvest samples, and thus was the youngest age considered in this analysis. Bias in determining age increases with age. Therefore, burbot of age 16 and older were pooled into a single 16+ group as recommended by Fournier and Archibald (1982). The age of full vulnerability to the fishery was inferred to be 9 years based on age frequency histograms of the sample.

Catchability

The regulation regime (i.e. gear restrictions, seasons, and bag limits) for this sport fishery was constant during all years of analysis. Additionally, because the fishery is continuous (occurs year round), environmental factors which might influence catchability are minimal compared to discrete fisheries. For these reasons catchability was assumed to be constant among all years.

Instantaneous Natural Mortality

Instantaneous natural mortality is a model input which comes from an independent estimate. No direct measure of natural mortality is available for the Tanana River population. Estimates from lacustrine populations have ranged from 0.41 to 0.50 in the Copper and Tanana River drainages (Parker et al. 1989). A natural mortality rate within this range would seem reasonable for the Tanana River population.

An alternative estimate of instantaneous natural mortality was generated using the von Bertalanffy growth model (von Bertalanffy 1938). This model was used in the estimation of the following life history parameters: K, L_{∞}, and t_0. Estimates of these parameters were obtained using a modified Marquardt non-linear least squares procedure contained in a FORTRAN program. The equation used was:

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1 Areas in the statewide harvest survey which were summed to provide estimates of total harvest were: upper and lower Chena River, lower, middle and upper Tanana River, Nenana River, Salcha River, Shaw Creek, Goodpaster River, Piledriver Slough, Chatanika River, Delta Clearwater River, Minto Flats, and other streams in the Tanana River drainage not specifically listed in the statewide harvest survey.

Table 1.-Proportion at age for the sport harvest of burbot in the Tanana River, 1987-1996.

		Year										
Age	Statistic	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	Total
4	Sample Size	0	3	1	0	0	1	0	0	0	15	20
	Proportion	0.000	0.018	0.008	0.000	0.000	0.002	0.000	0.000	0.000	0.074	0.012
	SE	0.000	0.010	0.008	0.000	0.000	0.002	0.000	0.000	0.000	0.018	0.003
5	Sample Size	4	7	4	0	6	23	0	0	2	20	66
	Proportion	0.059	0.041	0.030	0.000	0.025	0.040	0.000	0.000	0.021	0.099	0.040
	SE	0.029	0.015	0.015	0.000	0.010	0.008	0.000	0.000	0.015	0.021	0.005
6	Sample Size	7	14	7	0	38	88	4	5	5	26	139
	Proportion	0.103	0.082	0.053	0.000	0.105	0.094	0.009	0.000	0.053	0.129	0.084
	SE	0.037	0.021	0.019	0.000	0.020	0.012	0.009	0.000	0.023	0.024	0.007
7	Sample Size	9	25	22	0	38	88	4	5	8	40	239
	Proportion	0.132	0.146	0.165	0.000	0.160	0.154	0.034	0.074	0.085	0.198	0.144
	SE	0.041	0.027	0.032	0.000	0.024	0.015	0.017	0.032	0.029	0.028	0.009
8	Sample Size	4	21	19	0	35	85	4	5	6	33	212
	Proportion	0.059	0.123	0.143	0.000	0.147	0.149	0.034	0.074	0.064	0.163	0.127
	SE	0.029	0.025	0.030	0.000	0.023	0.015	0.017	0.032	0.025	0.026	0.008
9	Sample Size	9	30	14	0	30	73	18	8	9	14	205
	Proportion	0.132	0.175	0.105	0.000	0.126	0.128	0.154	0.118	0.096	0.069	0.123
	SE	0.041	0.029	0.027	0.000	0.022	0.014	0.033	0.039	0.031	0.018	0.008
10	Sample Size	4	22	18	0	32	75	17	8	15	25	216
	Proportion	0.059	0.129	0.135	0.000	0.134	0.131	0.145	0.118	0.160	0.124	0.130
	SE	0.029	0.026	0.030	0.000	0.022	0.014	0.033	0.039	0.038	0.023	0.008
11	Sample Size	6	21	18	0	16	64	24	12	13	14	188
	Proportion	0.088	0.123	0.135	0.000	0.067	0.112	0.205	0.176	0.138	0.069	0.113
	SE	0.035	0.025	0.030	0.000	0.016	0.013	0.037	0.047	0.036	0.018	0.008
12	Sample Size	9	15	11	0	27	43	13	10	11	6	145
	Proportion	0.132	0.088	0.083	0.000	0.113	0.075	0.111	0.147	0.117	0.030	0.087
	SE	0.041	0.022	0.024	0.000	0.021	0.011	0.029	0.043	0.033	0.012	0.007
13	Sample Size	4	4	9	0	18	27	13	6	13	6	100
	Proportion	0.059	0.023	0.068	0.000	0.076	0.047	0.111	0.088	0.138	0.030	0.060
	SE	0.029	0.012	0.022	0.000	0.017	0.009	0.029	0.035	0.036	0.012	0.006
14	Sample Size	4	4	6	0	6	16	6	9	8	1	60
	Proportion	0.059	0.023	0.045	0.000	0.025	0.028	0.051	0.132	0.085	0.005	0.036
	SE	0.029	0.012	0.018	0.000	0.010	0.007	0.020	0.041	0.029	0.005	0.005
15	Sample Size	3	3	3	0	6	16	6	9	2	1	39
	Proportion	0.044	0.018	0.023	0.000	0.017	0.023	0.060	0.044	0.021	0.005	0.023
	SE	0.025	0.010	0.013	0.000	0.008	0.006	0.022	0.025	0.015	0.005	0.009
16+	Sample Size	5	2	1	0	1	10	10	2	2	1	34
	Proportion	0.074	0.012	0.008	0.000	0.004	0.017	0.085	0.029	0.021	0.005	0.020
	SE	0.032	0.008	0.008	0.000	0.004	0.005	0.026	0.021	0.015	0.005	0.003
Total	Sample Size	68	171	133	0	238	572	117	68	94	202	1,663

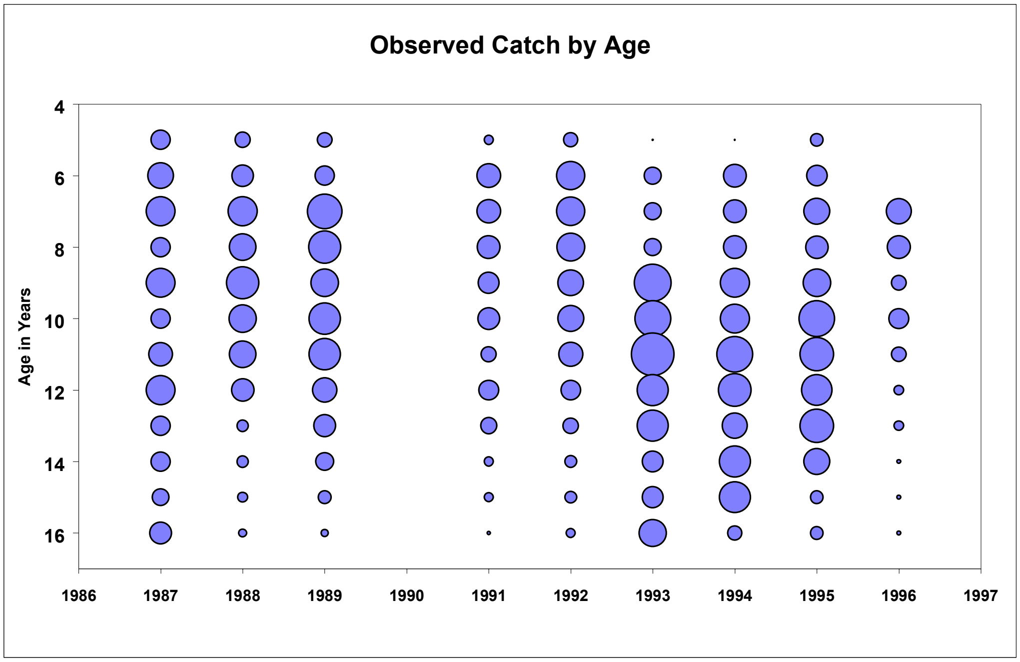

Figure 3. Bubble plot of catch-age data, 1987-1996

Table 2.-Estimated harvest of burbot in flowing waters of the Tanana River drainage from the statewide harvest survey, 1987-1996.

Year	Harvest[a]	SE[Harvest]
1987	3,749	Na[b]
1988	3,406	NA
1989	4,225	NA
1990	3,579	NA
1991	2,187	561
1992	3,231	624
1993	5,181	1,017
1994	4,915	NA
1995	4,668	NA
1996	1,879	NA

[a] Summed from: lower and upper Chena River, lower, middle, and upper Tanana River, Nenana River, Salcha River, Shaw Creek, Goodpaster River, Piledriver Slough, Chatanika River, Delta Clearwater River, Minto Flats, and other flowing waters not specifically listed in the statewide harvest survey.

[b] NA means estimate is not available.

$$\hat{L}_a = \hat{L}_\infty(1 - e^{-\hat{K}(a-\hat{t}_0)}) . \quad (14)$$

The oldest age consistently present in samples was 16, which was used as the maximum age of burbot for purposes of estimating instantaneous natural mortality[2]. Alverson and Carney (1975) have shown that the age at which a cohort reaches its maximum biomass (T_{mb}) is about 0.38 of the maximum age. Alverson and Carney reasoned that because the time at which cohort biomass is maximized is a function of growth and mortality, natural mortality could be estimated by:

$$\hat{M} = \frac{3\hat{K}}{e^{\hat{t}_{mb}\hat{K}} - 1} . \quad (15)$$

Total mortality was estimated as:

$$\hat{Z}_{a,y} = \hat{F}_{a,y} + \hat{M} \ . \quad (16)$$

Equation 9 was used with results from the von Bertalanffy models for the years in which individual age data were available (1987 - 1995). The average of natural mortality for all years was 0.45.

A series of model iterations was run to examine the effect of various natural mortality values on abundance and fishing mortality estimates (Evenson 1997). Changing the natural mortality rate did affect the magnitude of abundance and fishing mortality estimates, but did not affect or change the trends. Ultimately a value of 0.41 was chosen as the instantaneous natural mortality rate because it is the most conservative of the estimates available.

Past catch-age modeling used a ratio of estimated burbot harvest to estimated total harvest in the Tanana River to apportion fishing effort. This indirect measure of fishing effort likely had considerable measurement error and caused much instability in model output (Evenson 1997). A statewide fishery use survey, which may become available in future years, will provide a direct measure of fishing effort. In this analysis, an estimate of effort for any given year was obtained from CPUE estimates from the summer index sampling (described above) in the Tanana River section near Fairbanks along with total harvest estimates from the statewide harvest survey:

$$\hat{E}_y = \hat{H}_y \big/ \overline{CPUE}_y \quad (17)$$

where:

$\overline{CPUE}_y$ = mean CPUE in year y from the Tanana River sample section (equation 1); and,

$\hat{H}_y$ = the total harvest of burbot in the Tanana River in year y.

Fishing effort is used as an auxiliary data source to aid in the estimation of fishing mortality.

Error Structure

A log normal error structure was assumed for harvest at age data. This is similar to other catch-age analyses (Deriso et al. 1985, Doubleday 1976) which assume logarithms of age-specific

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[2] Maximum age should be determined through observation of an unfished population; however Tanana River burbot are not heavily exploited. Thus, relatively little error will be introduced by assuming that maximum age of fish in samples have not been reduced through exploitation.

harvests to be normally distributed. Fishing effort is measured with error, so the relationship between fishing effort and fishing mortality is not exact. The difference between these two terms can be modeled by the log normal distribution:

$$\tilde{\varepsilon}_y = \ln \tilde{F}_y - \ln(q\hat{E}_y) . \qquad (18)$$

Objective Function

A given sum of squares component (SSQ) represents estimation error. The sum of squares which compared differences between observed and estimated log-harvest at age data was computed as:

$$SSQ_{harvest} = \sum_{y,a} [(\ln \tilde{H}_{y,a}) - (\ln \hat{H}_{y,a})]^2 . \qquad (19)$$

The sum of squares which modeled the inexact relationship between fishing effort and fishing mortality was computed as:

$$SSQ_{effort} = \lambda \sum_{y} (\tilde{\varepsilon}_y)^2 \qquad (20)$$

where λ is a weighting term given to the auxiliary effort SSQ.

A value for lambda was derived from sensitivity analysis of model output over a range of values (0.01 to 100). The lambda which exhibited no apparent trends in catch or effort residuals, had a low coefficient of variation, and small bias for estimates of total abundance and exploitable abundance was chosen as the final value for parameter estimation (Appendix D). Ultimately a value of 5 was chosen for use in the model.

The objective was to minimize total prediction error (O_{total}) which was computed in the program algorithm by adding each of the error components:

$$O_{total} = SSQ_{harvest} + SSQ_{effort}. \qquad (21)$$

RESULTS

INDEX SAMPLING

In the Tanana River section during 1997, a total of 517 burbot were caught with 310 net-nights of effort. Estimates of mean CPUE were 0.65 bb/nn (SE = 0.06) for small burbot, 1.01 bb/nn (SE = 0.07) for medium burbot, and 0.01 bb/nn (SE = 0.01) for large burbot (Table 3). The mean CPUE estimates from 1997 in the Tanana River section for medium burbot was greater than the 1996 estimate, but was within the range of estimates from previous years. The mean CPUE estimate for small burbot was among the highest on record. Mean CPUE estimates for large burbot are typically low compared to those of medium and small burbot, but the 1997 estimate was at the lower end of observed values.

In the Chena River section, a total of 216 burbot were caught with 239 net-nights of effort. Estimates of mean CPUE were 0.15 bb/nn (SE = 0.03) for small burbot, 0.73 bb/nn (SE = 0.10) for medium burbot, and 0.03 (SE = 0.01) for large burbot (Table 4). The mean CPUE estimate

Table 3.-Catch per unit effort (CPUE) estimates of burbot sampled in the Tanana River section, 1986-1997.

River					Small			Medium			Large			Medium + Large		
Sampling		km	Trap	Net	(300-449 mm TL)			(450-799 mm TL)			(≥800 mm TL)			(≥450 mm TL)		
Dates	Year	Sampled	Size	Nigh	Catch	CPUE	SE	Catch	CPUE	SE	Catch	CPUE	SE	Catch	CPUE	SE
07/29-08/02	1986[a]	334-352	Large	99	51	0.52	NA[b]	94	0.95	NA	7	0.07	NA	101	1.02	NA
08/11-08/15	1986[a]	334-352	Large	128	42	0.33	NA	57	0.45	NA	3	0.02	NA	60	0.47	NA
07/22-07/25	1987[a]	339-354	Large	77	22	0.29	0.02	41	0.53	NA	6	0.08	NA	47	0.61	0.09
07/28-07/31	1987[a]	339-354	Large	106	70	0.66	0.10	73	0.69	NA	6	0.06	NA	79	0.75	0.09
08/04-08/07	1987[a]	339-354	Large	79	24	0.30	0.08	45	0.57	NA	2	0.03	NA	47	0.59	0.10
08/18-08/21	1987[a]	339-354	Large	183	46	0.25	0.05	178	0.97	NA	14	0.08	NA	192	1.05	0.11
07/06-07/09	1988	312-376	Small	268	159	0.59	0.05	144	0.54	NA	1	<0.01	NA	145	0.54	0.05
06/13-06/16	1989	317-374	Small	237	137	0.58	0.06	125	0.53	NA	6	0.03	NA	131	0.55	0.05
08/14-08/16	1990	344-376	Small	90	44	0.49	0.10	96	1.07	NA	4	0.04	NA	100	1.11	0.12
07/11-07/17	1991	336-360	Small	310	97	0.31	0.04	247	0.80	0.07	3	0.01	0.01	250	0.81	0.07
08/24-08/28	1992	336-360	Small	277	57	0.21	0.03	266	0.96	0.08	16	0.06	0.01	282	1.02	0.08
06/08-06/11	1993	336-360	Small	257	85	0.32	0.04	175	0.67	0.05	6	0.02	<0.01	181	0.70	0.05
06/07-06/17	1994	336-360	Small	317	157	0.50	0.05	173	0.55	0.05	4	0.01	0.01	177	0.56	0.05
06/13-06/23	1995	330-360	Small	303	184	0.61	0.07	195	0.64	0.06	4	0.01	0.01	199	0.66	0.06
06/04-06/14	1996	336-360	Small	316	193	0.61	0.06	224	0.71	0.06	8	0.03	0.01	232	0.73	0.06
06/03-06/13	1997	339-361	Small	310	201	0.65	0.06	312	1.01	0.07	4	0.01	0.01	316	1.02	0.07

[a] Data used as part of a mark-recapture experiment to estimate abundance.

[b] Data is not available for this estimate.

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Table 4.-Catch per unit effort (CPUE) estimates of burbot sampled in the Chena River section, 1988-1997.

River					Small			Medium			Large			Medium + Large		
Sampling		km	Trap	Net	(300-449 mm TL)			(450-799 mm TL)			(≥800 mm TL)			(≥450 mm TL)		
Dates	Year	Sample	Size	Night	Catch	CPUE	SE	Catch	CPUE	SE	Catch	CPUE	SE	Catch	CPU	SE
09/07-09/09	1988	0-24	Small	88	23	0.32	0.08	65	0.90	0.13	0	0	0	65	0.90	0.13
06/12-06/15	1990[a]	0-24	Small	232	14	0.06	0.02	16	0.07	NA[b]	0	0	0	16	0.07	0.02
08/21-08/24	1990[a]	0-24	Small	204	41	0.20	0.04	82	0.40	NA	1	<0.01	NA	83	0.41	0.06
08/27-08/31	1990[a]	0-24	Small	203	59	0.29	0.04	204	1.00	NA	1	<0.01	NA	205	1.01	0.11
09/06-09/07	1990[a]	0-24	Small	73	26	0.36	0.03	90	1.23	NA	0	0	0	90	1.23	0.09
09/27-09/28	1990[a]	0-24	Small	80	9	0.11	0.03	66	0.83	NA	2	0.03	NA	68	0.85	0.05
08/27-08/30	1991[a]	0-24	Small	268	35	0.13	0.03	218	0.81	0.09	0	0	0	218	0.81	0.09
09/04-09/07	1991[a]	0-24	Small	248	28	0.11	0.03	171	0.69	0.08	3	0.01	<0.01	174	0.70	0.08
08/31-09/04	1992	0-24	Small	272	19	0.07	0.02	111	0.41	0.05	1	<0.01	<0.01	112	0.41	0.05
08/17-08/20	1993	0-24	Small	257	23	0.08	0.01	127	0.49	0.09	0	0	0	127	0.49	0.09
08/31-09/09	1994	0-27	Small	200	38	0.19	0.03	137	0.69	0.08	4	0.02	0.01	141	0.71	0.08
08/29-09/08	1995	0-27	Small	273	77	0.28	0.04	249	0.91	0.08	8	0.03	0.01	257	0.94	0.08
08/27-09/06	1996	0-29	Small	274	57	0.21	0.03	161	0.59	0.07	2	0.01	<0.01	163	0.59	0.07
08/26-09/05	1997	0-29	Small	239	36	0.15	0.03	174	0.73	0.10	6	0.03	0.01	180	0.75	0.10

[a] Data used as part of a mark-recapture experiment to estimate abundance.

[b] Data is not available for this estimate.

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for medium burbot in the Chena River in 1997 was within the observed range of estimates from previous years, and was greater than the previous years' estimate. The mean CPUE estimate for small burbot was at the lower end of the observed range, while the mean CPUE estimate for large burbot was at the upper end of the observed range.

Lengths of burbot sampled in the Tanana River section ranged from 269-899 mm TL. Estimates of mean length were 385 mm TL (SE = 3) for small burbot, 534 mm TL (SE = 4) for medium burbot, and 861 mm TL (SE = 20) for large burbot (Table 5).

Lengths of burbot sampled in the Chena River section ranged from 298-936 mm TL. Estimates of mean length were 401 mm TL (SE = 8) for small burbot, 559 mm TL (SE = 6) for medium burbot, and 855 (SE = 25) for large burbot (Table 6).

Due to size selectivity of the hoop traps, proportions of total catch attributed to each of the three size categories do not represent true population proportions, but do provide a means of comparison among years. Large burbot are caught in low proportions in both sections (less than 5% using small hoop traps), but are slightly more predominant in the Tanana River section than in the Chena River section (Tables 7-8). In the Tanana River section, the proportion of medium burbot has ranged from 0.47 to 0.78 since 1986. The 1997 estimate of 0.60 (SE = 0.03) is in the middle of this range. Correspondingly, the proportion of small burbot in the 1997 sample (0.39; SE = 0.03) was also in the middle of the observed range, which may be indicative of moderate recruitment.

Estimates of the proportions of medium burbot in the Chena River section are generally higher than those in the Tanana River section, and have ranged from 0.53 to 0.86 since 1988. The 1997 estimate was 0.81 (SE = 0.03), which is in the upper end of this range. The proportion of small burbot in the 1997 catch was 0.17 (SE = 0.06), which is also in the lower end of the observed range, and may indicate below average recruitment.

Statistical comparisons among cumulative length frequency distributions for sample years 1988-1993 indicated that distributions were not homogenous in either river section, but no distinct increasing or decreasing trend was apparent (Evenson 1994). Plotted length frequencies indicate that distributions are more variable in the Tanana River section than in the Chena River section (Figures 4 and 5). This is likely attributed to the more variable times of sampling in the Tanana River section (See Tables 3-4 for dates of sampling).

CATCH-AGE ANALYSIS

Parameter Estimates

The catch-age model estimated values for 36 parameters (Table 9). The remaining estimates of abundance and fishing mortality were derived from these estimates. Full vulnerability (selectivity) to the gear was assigned at age 9. Vulnerability to the gear was predicted by the model for ages 5 through 8 (Figure 6).

Estimated Abundance

Both total absolute abundance and exploitable abundance (the number of fish that are potentially vulnerable to the fishery) showed decreasing trends from 1987 to 1995, but estimates from 1996 indicated a reversal of this trend (Table 10 and Figure 7). As expected, the coefficients of

Table 5.-Mean length estimates of burbot sampled in the Tanana River section, 1986-1997.

Sampling Dates	Year	River km Sampled	Hoop Trap Size	Length Range (mm TL)	Small (300-449 mm TL) Catch	Mean	SE	Medium (450-799 mm TL) Catch	Mean	SE	Large (>800 mm TL) Catch	Mean	SE	Medium + Large (>450 mm TL) Catch	Mean	SE
07/29-08/02	1986	334-352	Large	260-863	51	382	6	94	552	8	7	839	9	101	572	10
08/11-08/15	1986	334-352	Large	266-905	42	379	7	57	556	14	3	846	29	60	570	13
07/22-07/25	1987	339-354	Large	315-1,025	22	400	7	41	544	12	6	888	41	47	588	21
07/28-07/31	1987	339-354	Large	304-1,079	70	396	5	73	552	9	6	885	45	79	578	13
08/04-08/07	1987	339-354	Large	308-1,028	24	399	7	45	569	12	2	937	92	47	584	16
08/18-08/21	1987	339-354	Large	311-1,000	46	411	4	178	570	7	14	882	17	192	593	9
07/06-07/09	1988	312-376	Small	235-855	159	388	3	144	520	5	1	855	ID[a]	145	523	5
06/13-06/16	1989	317-374	Small	278-895	137	381	4	125	535	6	6	849	13	131	549	8
08/14-08/16	1990	344-376	Small	300-900	44	393	6	96	540	8	4	856	23	100	553	8
07/11-07/17	1991	336-360	Small	238-922	97	386	5	247	530	4	3	893	19	250	534	4
08/24-08/28	1992	336-360	Small	277-1,040	57	398	6	266	557	5	16	864	16	282	574	6
06/08-06/11	1993	336-360	Small	280-902	86	375	5	174	552	6	6	841	14	180	562	7
06/07-06/17	1994	336-360	Small	265-915	158	382	4	169	529	6	4	864	23	173	537	7
06/13-06/23	1995	330-360	Small	259-937	184	375	4	195	534	5	4	849	30	199	540	6
06/04-06/14	1996	336-360	Small	245-990	192	379	3	224	535	5	8	853	22	232	546	6
06/03-06/13	1997	339-361	Small	269-899	201	385	3	312	534	4	4	861	20	316	538	4

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Table 6.-Mean length estimates of burbot sampled in Chena River section, 1988-1997.

			Hoop	Length	Small (300-449 mm TL)			Medium (450-799 mm TL)			Large (>800 mm TL)			Medium + Large (>450 mm TL)		
Sampling Dates	Year	River km Sampled	Trap Size	Range (mm TL)	Catch	Mean	SE	Catch	Mean	SE	Catch	Mean	SE	Catch	Mean	SE
09/07-09/09	1988	0-24	Small	306-754	23	394	8	65	557	8	0	ID	ID	65	557	8
06/27-06/30	1989	0-40	Small	295-802	30	366	6	74	568	10	1	802	ID	75	571	10
06/12-06/15	1990	0-24	Small	265-600	14	375	14	16	510	12	0	ID	ID	16	510	12
08/21-08/24	1990	0-24	Small	302-873	41	400	7	82	540	8	1	873	ID	83	544	8
08/27-08/31	1990	0-24	Small	294-852	59	409	5	204	555	5	1	852	ID	205	556	5
09/06-09/07	1990	0-24	Small	316-762	26	391	9	90	554	7	0	ID	ID	90	554	7
09/27-09/28	1990	0-24	Small	315-905	9	381	18	66	554	9	2	888	18	68	564	9
08/27-08/30	1991	0-24	Small	288-785	35	385	8	218	562	5	0	ID	ID	218	562	5
09/04-09/07	1991	0-24	Small	295-895	28	382	9	171	565	5	3	850	27	174	569	5
08/31-09/04	1992	0-24	Small	307-843	19	388	10	111	575	7	1	843	ID	112	577	7
08/17-08/20	1993	0-24	Small	295-760	23	371	11	126	565	7	0	ID	ID	126	565	7
08/31-09/09	1994	0-27	Small	303-910	38	395	7	136	573	6	4	839	28	140	581	7
08/29-09/08	1995	0-27	Small	275-897	77	385	5	249	563	5	8	836	13	257	571	6
08/27-09/06	1996	0-29	Small	255-816	57	383	6	161	572	6	2	808	8	163	575	7
08/26-09/05	1997	0-29	Small	298-936	36	401	8	174	559	6	6	855	25	180	569	7

[a] Insufficient data.

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Table 7.-Estimates of proportions of small, medium, and large burbot sampled in the Tanana River section, 1986-1997.

Sampling Date	Year	River km Sampled	Hoop Trap Size	Catch Total	Catch Small	Proportion	SE	Catch Medium	Proportion	SE	Catch Large	Proportion	SE
Tanana River													
07/29-08/02	1986	334-352	Large	152	51	0.34	0.04	94	0.62	0.04	7	0.05	0.02
08/11-08/15	1986	334-352	Large	102	42	0.41	0.05	57	0.56	0.05	3	0.03	0.02
07/22-07/25	1987	339-354	Large	69	22	0.32	0.06	41	0.59	0.06	6	0.09	0.03
07/28-07/31	1987	339-354	Large	149	70	0.47	0.04	73	0.49	0.04	6	0.04	0.02
08/04-08/07	1987	339-354	Large	71	24	0.34	0.06	45	0.63	0.06	2	0.03	0.02
08/18-08/21	1987	339-354	Large	238	46	0.19	0.03	178	0.75	0.03	14	0.06	0.02
07/06-07/09	1988	312-376	Small	304	159	0.52	0.03	144	0.47	0.03	1	0	0
06/13-06/16	1989	317-374	Small	268	137	0.51	0.03	125	0.47	0.03	6	0.02	0.01
08/14-08/16	1990	344-376	Small	144	44	0.31	0.04	96	0.67	0.04	4	0.03	0.01
07/11-07/17	1991	336-360	Small	347	97	0.28	0.02	247	0.71	0.02	3	0.01	0
08/24-08/28	1992	336-360	Small	339	57	0.17	0.02	266	0.78	0.02	16	0.05	0.01
06/08-06/11	1993	336-360	Small	266	86	0.32	0.03	174	0.65	0.03	6	0.02	0.01
06/07-06/17	1994	336-360	Small	331	158	0.48	0.03	169	0.51	0.03	4	0.01	0.01
06/13-06/23	1995	330-360	Small	383	184	0.48	0.03	195	0.51	0.03	4	0.01	0.01
06/04-06/14	1996	336-360	Small	424	192	0.45	0.02	224	0.53	0.02	8	0.02	0.02
06/03-06/13	1997	339-361	Small	517	201	0.39	0.03	312	0.60	0.03	4	0.01	0.01

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Table 8.-Estimates of proportions of small, medium, and large burbot sampled in the Chena River section, 1988-1997.

Sampling Date	Year	River km Sampled	Hoop Trap Size	Catch Total	Small	Catch Proportion	SE	Medium	Catch Proportion	SE	Large	Catch Proportion	SE
09/07-09/09	1988	0-24	Small	88	23	0.26	0.05	65	0.74	0.05	0	0	0
06/27-06/30	1989	0-24	Small	105	30	0.29	0.04	74	0.70	0.04	1	0.01	0.01
06/12-06/15	1990	0-24	Small	30	14	0.47	0.09	16	0.53	0.09	0	0	0
08/21-08/24	1990	0-24	Small	124	41	0.33	0.04	82	0.66	0.04	1	0.01	0.01
08/27-08/31	1990	0-24	Small	264	59	0.22	0.03	204	0.77	0.03	1	0	0
09/06-09/07	1990	0-24	Small	116	26	0.22	0.04	90	0.78	0.04	0	0	0
09/27-09/28	1990	0-24	Small	77	9	0.12	0.04	66	0.86	0.04	2	0.03	0.02
08/27-08/30	1991	0-24	Small	253	35	0.14	0.02	218	0.86	0.02	0	0	0
09/04-09/07	1991	0-24	Small	202	28	0.14	0.02	171	0.85	0.03	3	0.01	0.01
08/31-09/04	1992	0-24	Small	131	19	0.15	0.03	111	0.85	0.03	1	0.01	0.01
08/17-08/20	1993	0-24	Small	149	23	0.15	0.03	126	0.85	0.03	0	0	0
08/31-09/09	1994	0-27	Small	178	38	0.21	0.03	136	0.76	0.03	4	0.02	0.01
08/29-09/08	1995	0-27	Small	334	77	0.23	0.02	249	0.75	0.02	8	0.02	0.01
08/27-09/06	1996	0-29	Small	220	57	0.26	0.03	161	0.73	0.03	2	0.01	0.01
08/26-09/05	1997	0-29	Small	216	36	0.17	0.06	174	0.81	0.03	6	0.03	0.01

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TANANA RIVER

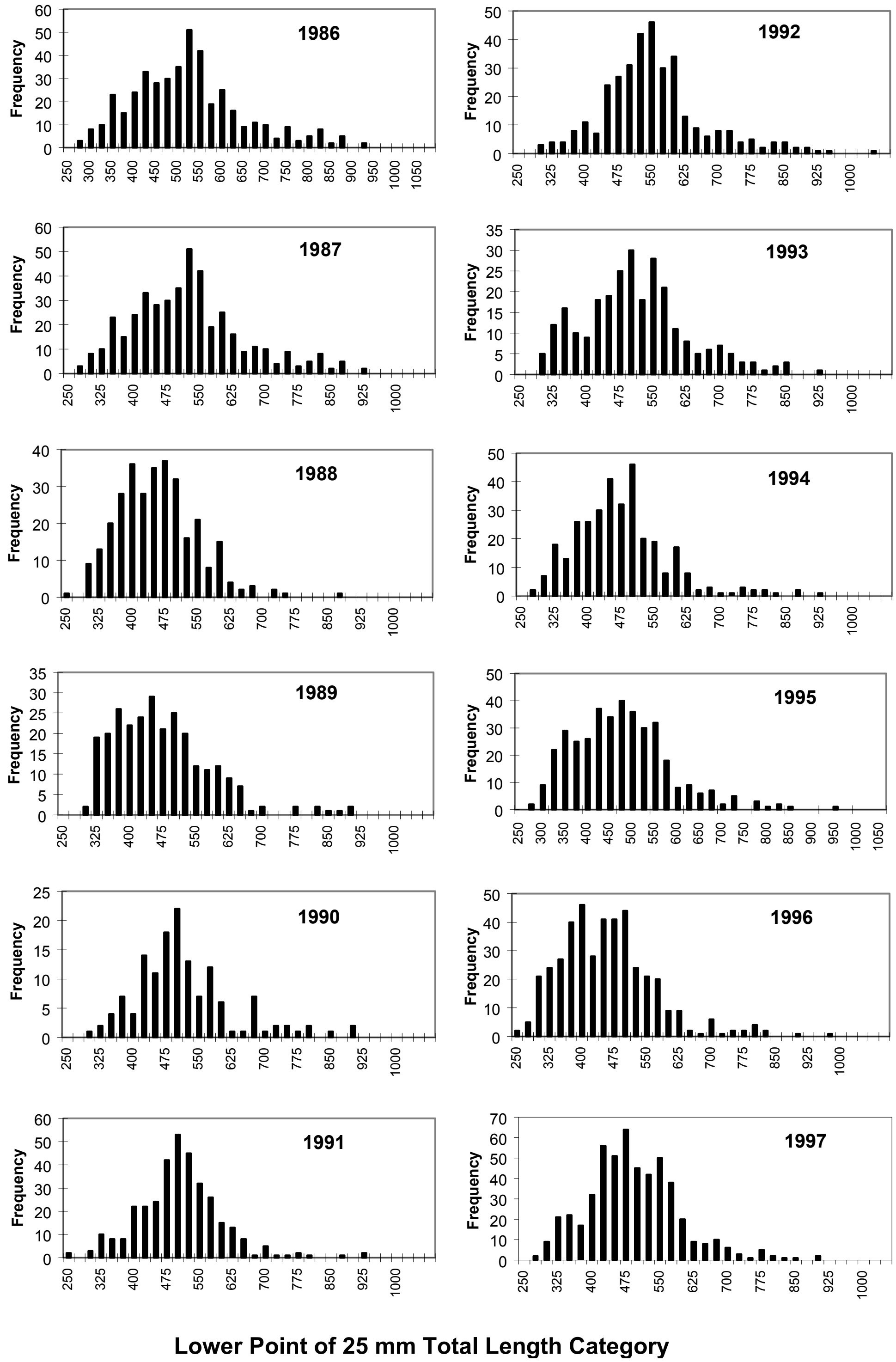

Figure 4.-Length frequency distributions of burbot sampled with hoop traps in the Tanana River, 1986-1997.

CHENA RIVER

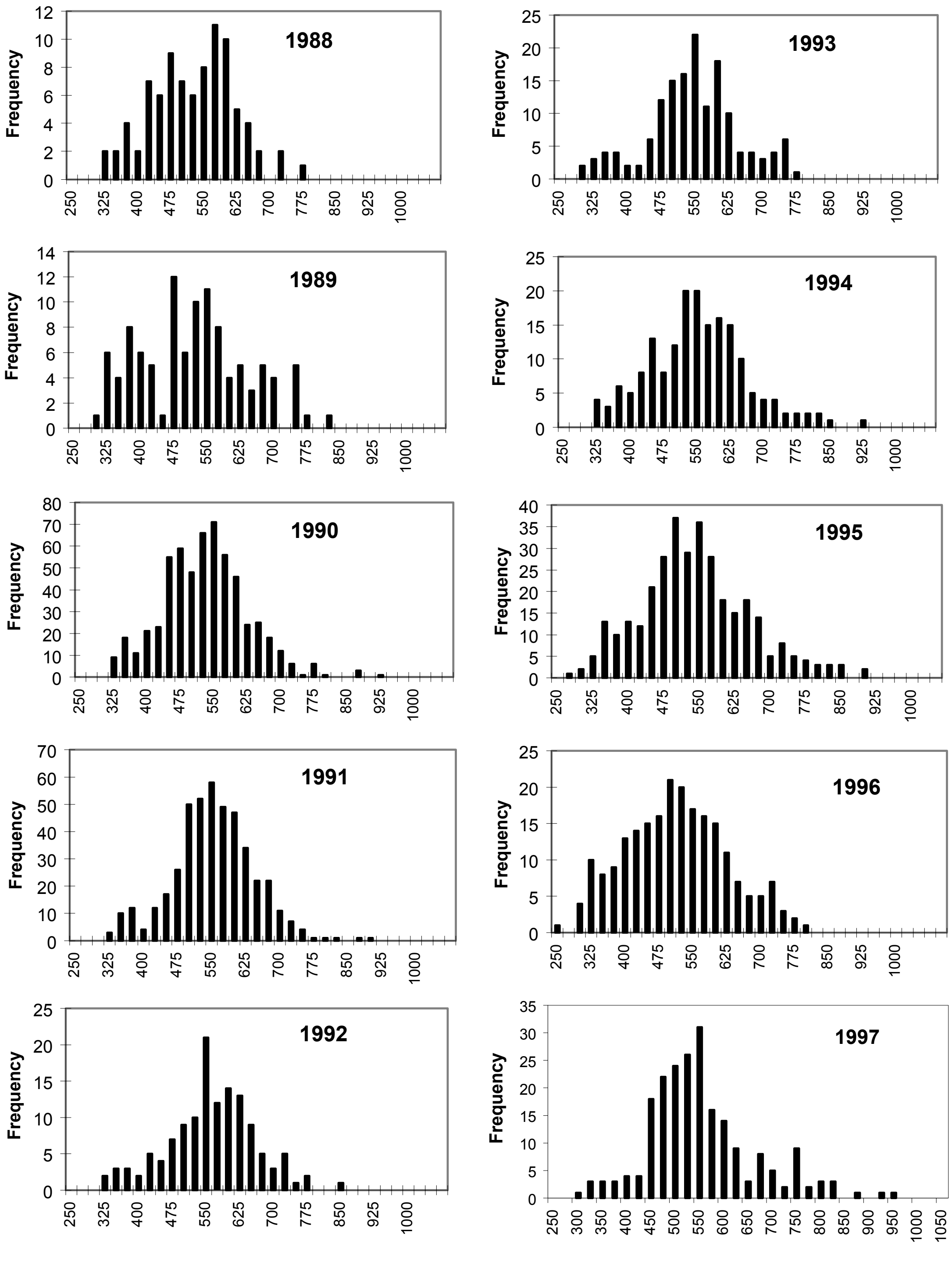

Figure 5.-Length frequency distributions of burbot sampled with hoop traps in the Chena River, 1988-1997.

Table 9.-Parameter estimates for the catch-age model based on data from 1987-1996.

Number	Parameter	Estimate	ln Estimate	Description
1	P16,87	2,158	7.677	Abundance of Age 16 in 1987
2	P15,87	818	6.707	Abundance of Age 15 in 1987
3	P14,87	1,855	7.526	Abundance of Age 14 in 1987
4	P13,87	2,064	7.633	Abundance of Age 13 in 1987
5	P12,87	3,670	8.208	Abundance of Age 12 in 1987
6	P11,87	8,455	9.043	Abundance of Age 11 in 1987
7	P10,87	9,850	9.195	Abundance of Age 10 in 1987
8	P 9,87	18,716	9.837	Abundance of Age 9 in 1987
9	P 8,87	23,377	10.060	Abundance of Age 8 in 1987
10	P 7,87	40,100	10.599	Abundance of Age 7 in 1987
11	P 6,87	64,533	11.075	Abundance of Age 6 in 1987
12	P 5,87	84,754	11.348	Abundance of Age 5 in 1987
13	P 5,88	76,310	11.243	Abundance of Age 5 in 1988
14	P 5,89	64,640	11.077	Abundance of Age 5 in 1989
15	P 5,90	54,166	10.900	Abundance of Age 5 in 1990
16	P 5,91	40,261	10.603	Abundance of Age 5 in 1991
17	P 5,92	25,475	10.145	Abundance of Age 5 in 1992
18	P 5,93	70,362	11.161	Abundance of Age 5 in 1993
19	P 5,94	70,435	11.162	Abundance of Age 5 in 1994
20	P 5,95	60,181	11.005	Abundance of Age 5 in 1995
21	P 5,96	187,139	12.140	Abundance of Age 5 in 1996
22	F87, 1	0.082	-2.501	Terminal Fishing Mortality in 1987
23	F88, 1	0.070	-2.658	Terminal Fishing Mortality in 1988
24	F89, 1	0.093	-2.380	Terminal Fishing Mortality in 1989
25	F90, 1	0.051	-2.978	Terminal Fishing Mortality in 1990
26	F91, 1	0.043	-3.153	Terminal Fishing Mortality in 1991
27	F92, 1	0.070	-2.658	Terminal Fishing Mortality in 1992
28	F93, 1	0.131	-2.033	Terminal Fishing Mortality in 1993
29	F94, 1	0.171	-1.765	Terminal Fishing Mortality in 1994
30	F95, 1	0.139	-1.976	Terminal Fishing Mortality in 1995
31	F96, 1	0.037	-3.289	Terminal Fishing Mortality in 1996
32	S 1, 5, 1	0.034	-3.376	Selectivity for Age 5
33	S 1, 6, 1	0.089	-2.418	Selectivity for Age 6
34	S 1, 7, 1	0.223	-1.502	Selectivity for Age 7
35	S 1, 8, 1	0.282	-1.267	Selectivity for Age 8
36	Q 1, 1	0.0000165	-11.014	Catchability Coefficient

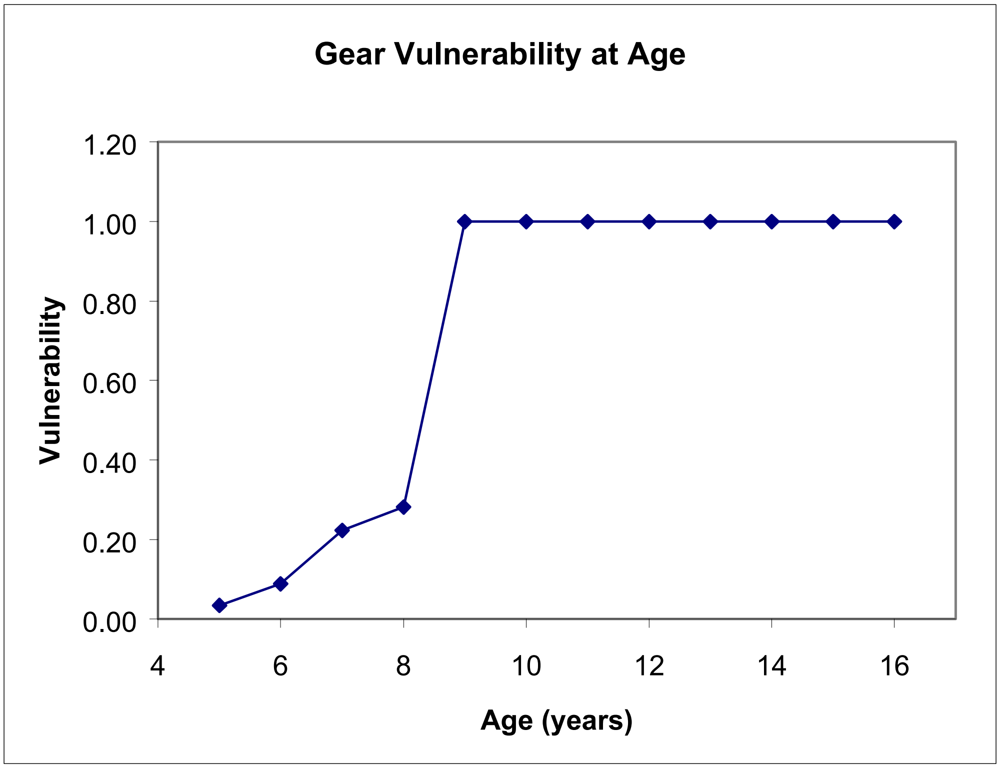

Figure 6.-Catch-age estimates of gear vulnerability at age for the burbot sport fishery in the Tanana River based on data from 1987-1996.

Table 10.-Catch-age estimates of total absolute abundance, mean exploitable abundance, and mean bootstrap estimates for Tanana River burbot, 1987-1996.

	Total Absolute Abundance					Total Exploitable Abundance				
Year	Estimated	Mean	Stand. Dev.	cv	Bias	Estimated	Mean	Stand. Dev.	cv	Bias
1987	260,349	263,963	50,894	0.193	0.014	71,741	75,447	16,087	0.213	0.052
1988	245,301	249,936	51,555	0.206	0.019	68,683	71,216	15,253	0.214	0.037
1989	224,318	228,828	52,464	0.229	0.020	67,152	68,903	13,897	0.202	0.026
1990	199,045	206,961	52,589	0.254	0.040	64,649	66,523	14,652	0.220	0.029
1991	170,215	175,365	45,304	0.258	0.030	61,004	62,096	14,061	0.226	0.018
1992	136,737	140,927	38,362	0.272	0.031	56,044	57,265	13,324	0.233	0.022
1993	158,573	175,192	68,504	0.391	0.105	50,436	51,999	12,971	0.249	0.031
1994	171,511	185,338	86,254	0.465	0.081	44,387	46,575	12,869	0.276	0.049
1995	169,273	184,208	85,627	0.465	0.088	40,120	42,181	13,014	0.309	0.051
1996	295,954	362,401	268,906	0.742	0.225	41,274	44,035	15,729	0.357	0.067

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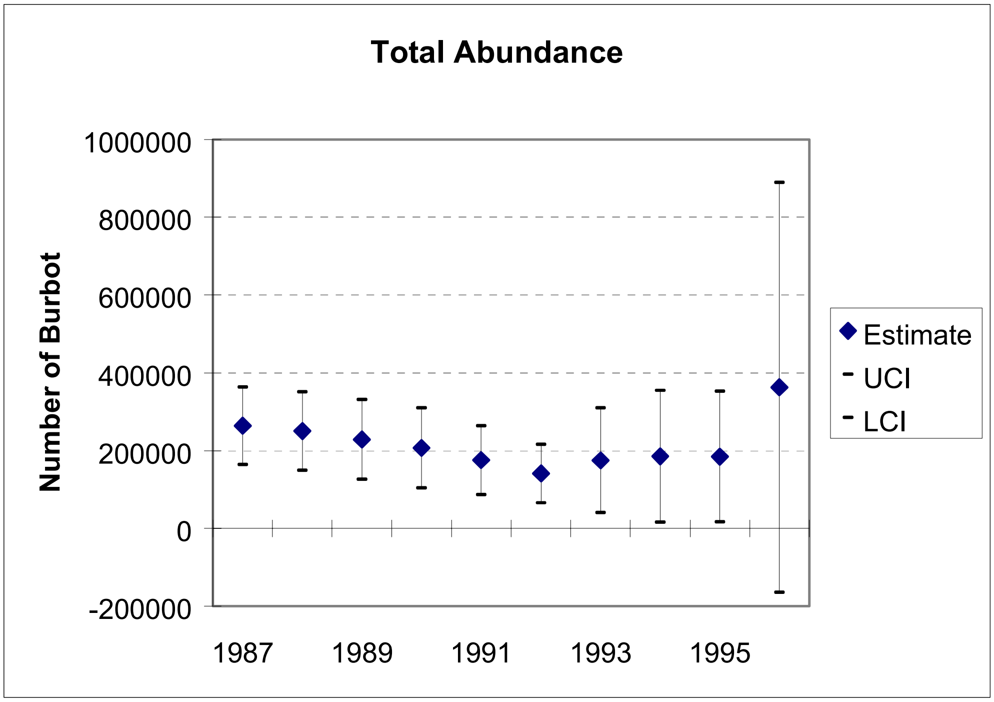

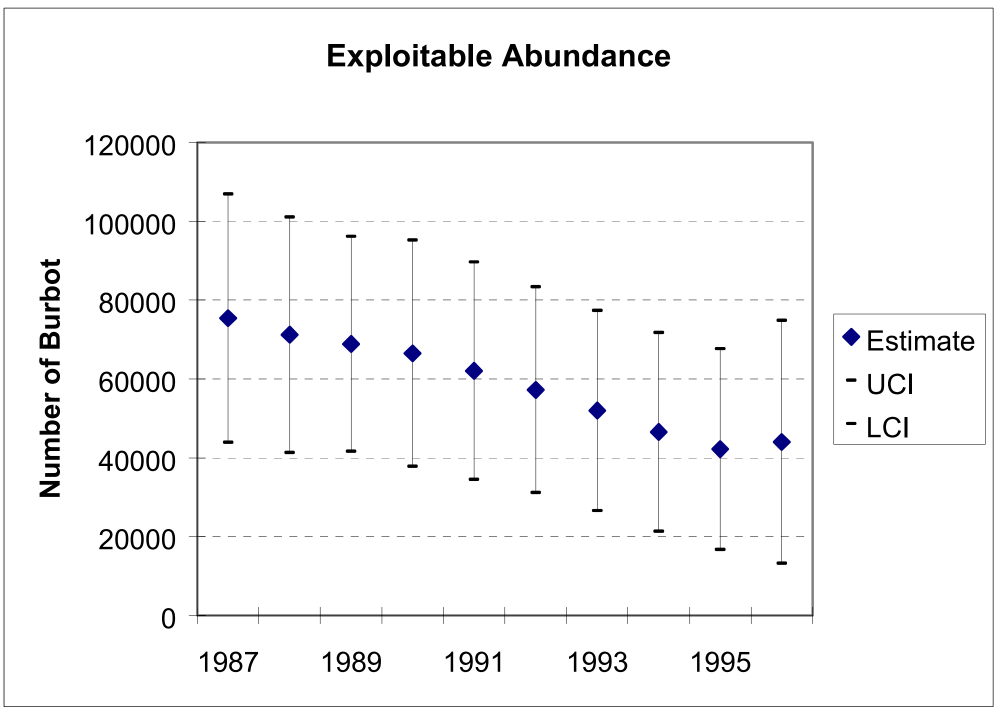

Figure 7.-Catch-age estimates of total and exploitable abundance of burbot in the Tanana River, 1987-1996.

variation for the most recent estimates were high compared to prior years because cohort information is not complete.

Total absolute abundance is defined as fish at large prior to harvest, without consideration of the gear selectivity adjustment. Total absolute abundance estimates decreased markedly from 1987 to 1995 for young, partially-recruited fish (Table 11). Whereas, abundance of older fish (ages 12+) did not vary to the same extent during this time frame. Thus, the decreasing trend in total exploitable abundance may be more attributable to decreased numbers of young, partially-recruited fish than to a substantial depletion of older, large fish. The estimate for age 5 burbot in 1996 indicated a surge of new recruits.

Estimated Fishing Mortality

Estimated fishing mortality for partially recruited burbot was relatively low overall. Estimated fishing mortality of fully recruited burbot ranged from 0.07 to 0.17, and was highest in years 1993-1995 (Table 12).

Model Bias

Predictions of harvest and effort from the catch-age model track well with observed values (Figure 8). Harvest and effort predictions showed no consistent pattern of either over or under estimating fishing effort.

The statistical bias (difference between the model estimate and the mean bootstrap estimate) associated with the model estimates of abundance was generally small, but was higher for recent years than for earlier estimates (Figure 9). This is similar in trend to the estimates of variance for the abundance estimates.

Retrospective Analysis

A retrospective analysis from data collected through 1994, 1995 and 1996, respectively, was conducted using identical model inputs for natural mortality, age at full recruitment, and effort lambda. This analysis revealed considerable differences in estimates of terminal fishing mortality and abundance (Figure 10) for most years. Trends for both estimates were similar in early years, but became more divergent in recent years.

Test for Equal Catchability Among Seasons

Comparison of the age distribution of samples collected during open-water periods and ice-cover periods during 1997 revealed that the two distributions overall were statistically similar (χ^2=15.52; df=12; P=0.21: Figure 11). However, proportions of pre-recruited (ages 4-8) and fully recruited burbot (ages 9 and older) were less similar (χ^2=3.94; df=1; P=0.05). This sample was more homogenous than the sample collected in 1996, which showed significant differences between proportions of recruits and pre-recruits.

Table 11.-Catch-age estimates of total abundance at age for burbot in the Tanana River, 1987-1996.

	Age											
Year	5	6	7	8	9	10	11	12	13	14	15	16+
1987	84,754	64,533	40,100	23,377	18,716	9,850	8,455	3,670	2,064	1,855	818	2,158
1988	76,310	56,089	42,516	26,131	15,160	11,443	6,022	5,170	2,244	1,262	1,134	1,820
1989	64,640	50,522	36,992	27,779	17,003	9,380	7,080	3,726	3,199	1,388	781	1,828
1990	54,166	42,763	33,254	24,049	17,961	10,286	5,675	4,284	2,254	1,935	840	1,578
1991	40,261	35,885	28,251	21,820	15,733	11,328	6,488	3,579	2,702	1,422	1,220	1,525
1992	25,475	26,680	23,724	18,571	14,308	10,005	7,204	4,126	2,276	1,718	904	1,746
1993	70,362	16,866	17,596	15,501	12,084	8,852	6,190	4,457	2,553	1,408	1,063	1,640
1994	70,435	46,488	11,064	11,342	9,915	7,035	5,154	3,604	2,595	1,486	820	1,573
1995	60,181	46,471	30,384	7,068	7,173	5,544	3,934	2,882	2,015	1,451	831	1,338
1996	187,139	39,750	30,462	19,551	4,511	4,144	3,203	2,273	1,665	1,164	838	1,253

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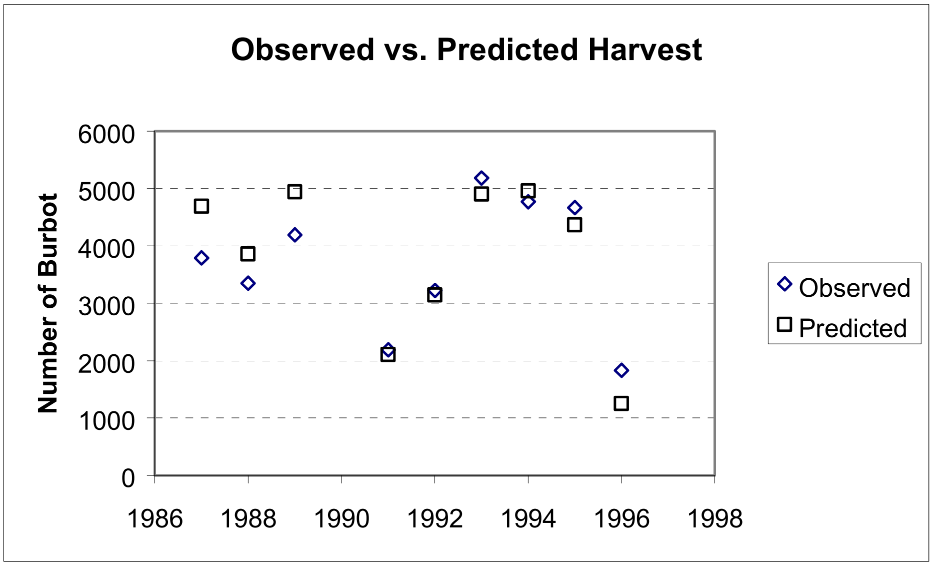
Table 12.-Catch-age estimates of fishing mortality at age for burbot in the Tanana River, 1987-1996.

	Age				
Year	5	6	7	8	9+
1987	0.003	0.007	0.018	0.023	0.082
1988	0.002	0.006	0.016	0.020	0.070
1989	0.003	0.008	0.021	0.026	0.093
1990	0.002	0.005	0.011	0.014	0.051
1991	0.001	0.004	0.010	0.012	0.043
1992	0.002	0.006	0.016	0.020	0.070
1993	0.004	0.012	0.029	0.037	0.131
1994	0.006	0.015	0.038	0.048	0.171
1995	0.005	0.012	0.031	0.039	0.139
1996	0.001	0.003	0.008	0.011	0.037



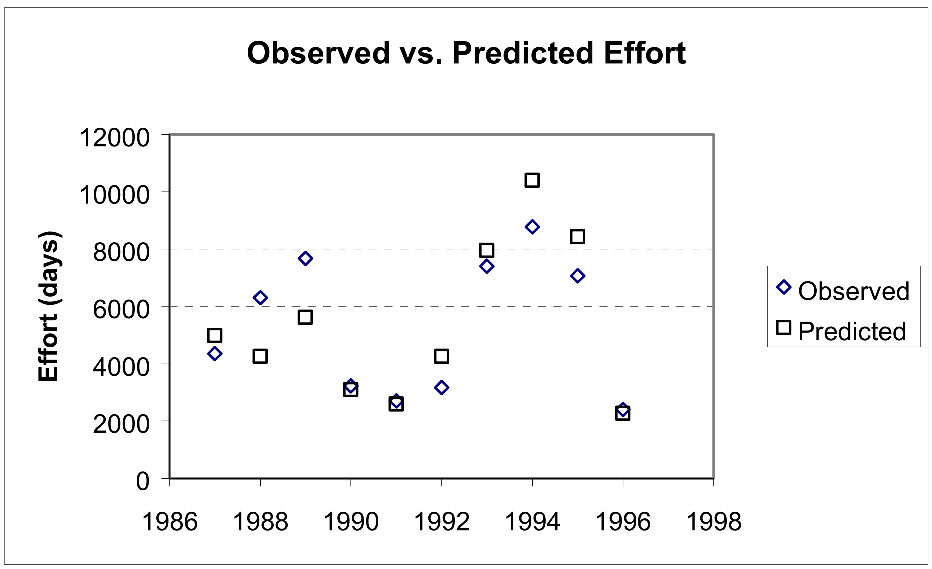
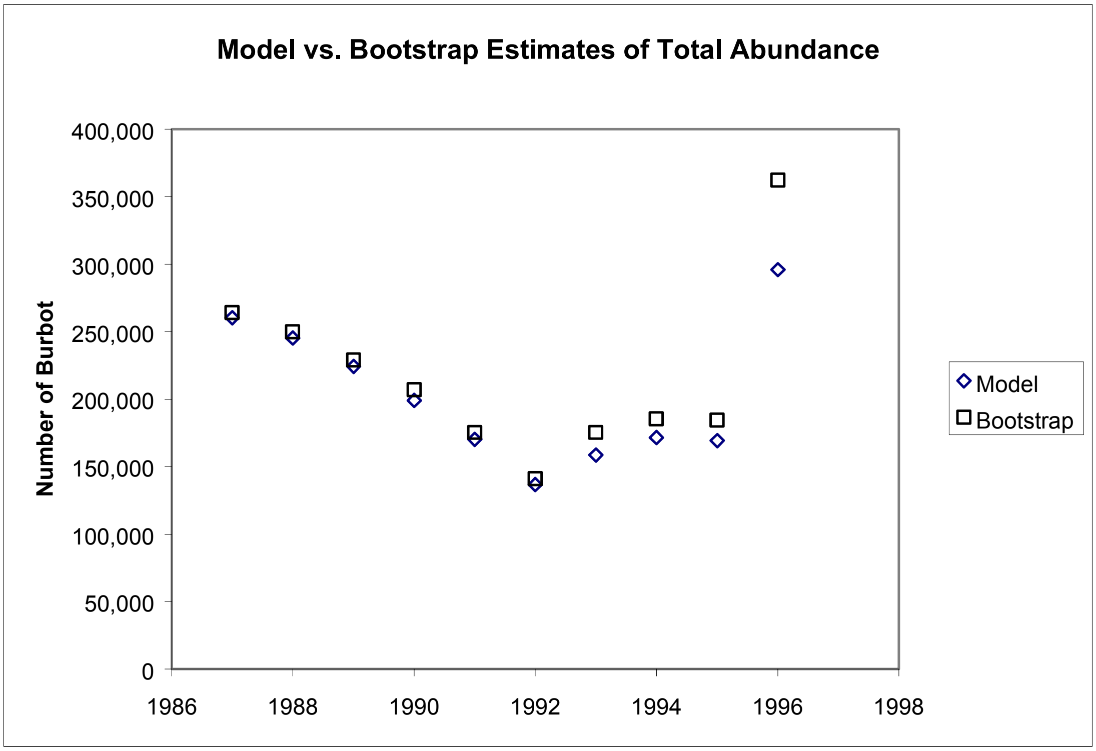


Figure 8.-Comparison of observed harvest and effort with estimates predicted from the catch-age model, Tanana River, 1987-1996.



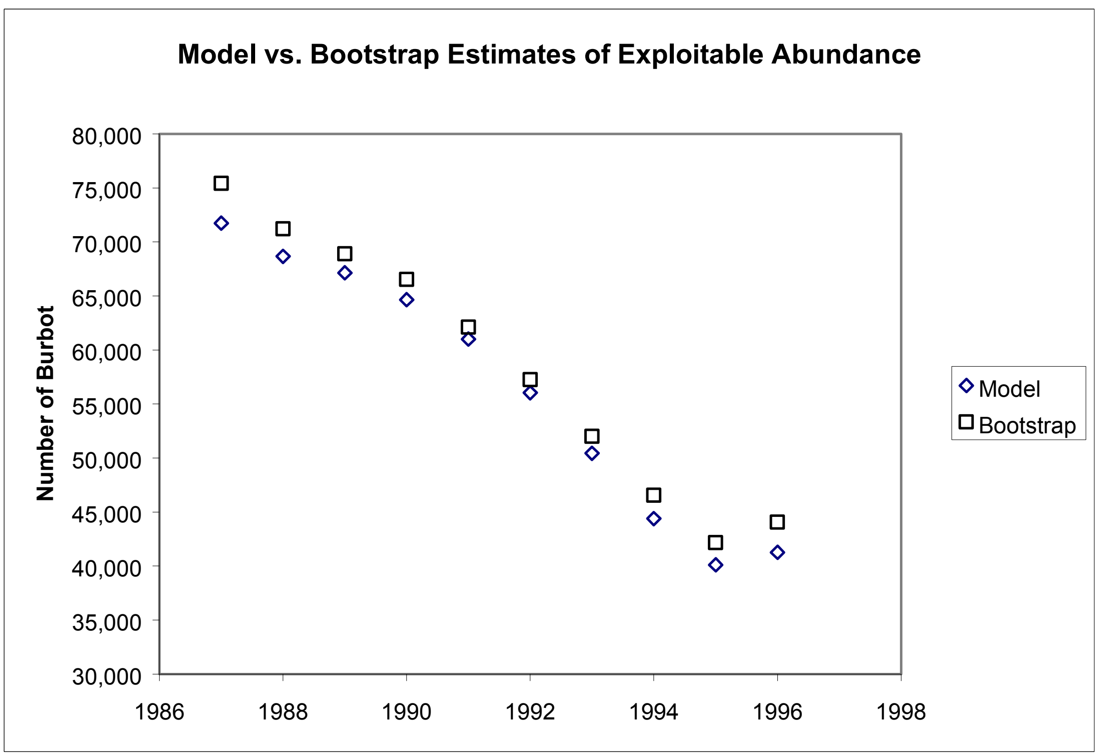


Figure 9.-Plots of model bias by year for estimates of total abundance and exploitable abundance.

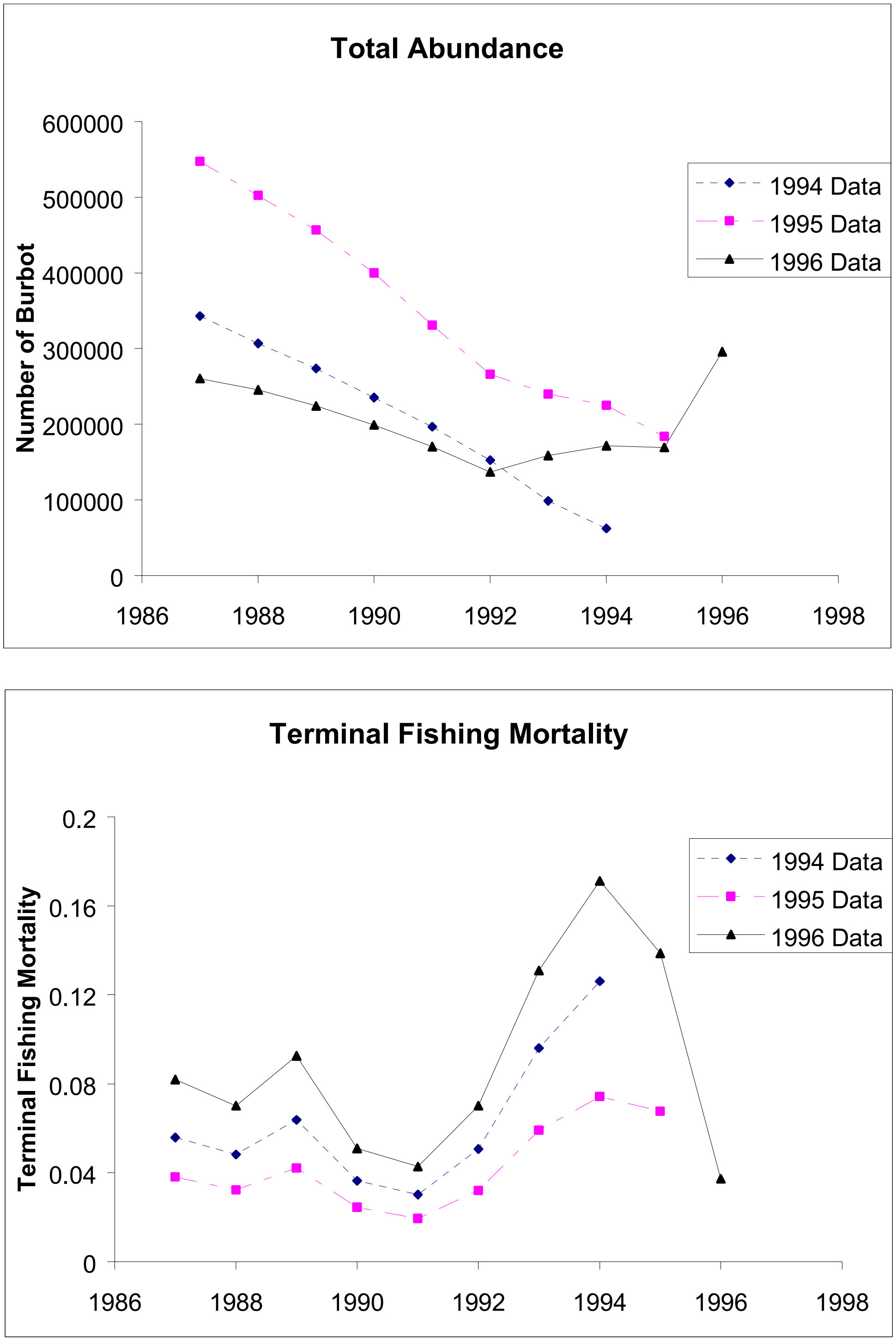


Figure 10.-A retrospective catch-age analysis of total abundance and terminal fishing mortality estimates from data collected through 1994, 1995, and 1996, respectively.

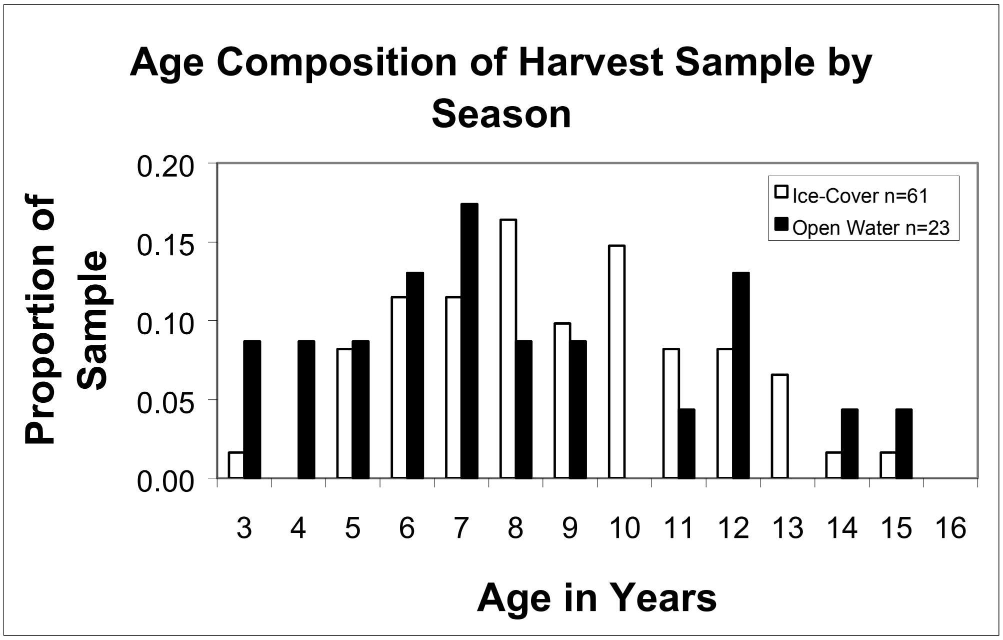


Figure 11.-Age distributions of burbot harvested in the Tanana River from samples collected during open water and ice-cover periods in 1997.

DISCUSSION

The ultimate goal of this ongoing stock assessment is to determine what level of harvest is sustainable for this population, and what regulation regime is required to ensure sustainable yield, while at the same time maximizing angler opportunity and satisfaction. The current regulation regime is extremely liberal (15 fish per day bag and possession limit; open year-round; set-lines allowed). Thus, it is unlikely that further liberalization of the regulations would provide additional opportunity or satisfaction to anglers. Annual harvests have, for the most part, remained relatively stable since 1981, but did drop substantially in 1996. The current regulations could potentially cause a much greater harvest given an increase in angler participation.

Accurate stock assessment of burbot in this system is difficult for a number of reasons. Because the system is so large, only a small portion can be sampled during the open water period. Information from tag recoveries and from radio telemetry investigations have indicated that there is substantial interchange among burbot in river sections over the span of one year or more (Evenson 1990a, 1993b). Thus, stock structure (size composition and density) can vary annually as well as seasonally within a small section as a result of movements into and out of the section. Also, there are seasonal fluctuations in both catch rates and in size composition of sampled catches that can be attributed to changes in catchability. Similar fluctuations occur in lacustrine systems as well (Bernard et al. 1991) where immigration and emigration are unlikely.

To alleviate problems associated with seasonal fluctuations in catch rates, sampling was modified (beginning in 1994) to cover a two week period instead of a one week period as was the case in years prior to 1994. Standard errors of 1997 estimates were similar to those obtained prior to 1994. It is believed that this slightly longer sampling period will reduce some of the seasonal variation in catchability and will provide CPUE and length composition estimates that are more comparable among years. In addition, a standard sampling time was established for each section. In the Tanana River section sampling times varied from early June to late August from 1986-1992. Beginning in 1993, a standard sampling time of early to mid June was established. In the Chena River section, sampling times have been more consistent. With the exception of one sampling event in 1990, all sampling has taken place between late August and late September. These same time frames should be used in future years.

Obtaining estimates of abundance in index sections, while a more accurate method of stock assessment than CPUE indices, has met with limited success in past investigations. Due to the low probability of capture using hoop traps, abundance estimates require substantial effort (twice as much as is needed to estimate mean CPUE) and in the past have been marginally precise (relative precision of seven estimates has ranged between 58% to 87%; Evenson, 1993a).

The catch-age analyses conducted to date (Evenson and Merritt 1995; and Evenson 1996-1997 and this study) indicate that the estimates of abundance and fishing mortality are likely biased and that the current model structure is not appropriate. The results of the retrospective analysis indicate there is instability in the model. This instability may be a result of small sample sizes, incomplete cohort information, or poor auxiliary data. If the instability is a result of incomplete cohort information (short time series), similar analyses in future years should show more stable estimates. Future modeling efforts should investigate incorporating length information from catch samples or index sampling and age-based models with fewer parameters (combine age classes).

The catch-age model yielded estimates of abundance that appeared reasonable (within an order of magnitude) compared to expansions of mark-recapture estimates of small index areas throughout the drainage (Evenson 1993a). The precision of the estimates is adequate for management purposes (typically ±25% of the true abundance is the regional goal for abundance estimates). The relatively small statistical bias associated with the abundance estimates indicates that the model fits the data reasonably well.

The model portrays a dramatic, decreasing trend in total exploitable abundance from 1987 to 1995, especially with ages 5-9. This decline may be attributed to one or more causes. The first cause may be an actual decline in the number of young partially recruited fish. Neither length frequency distributions nor CPUE estimates corroborate this steady decline. Instead, they show a more cyclic pattern in relative abundance of small burbot (less than 450 mm TL) with low numbers from 1986-1987, high numbers from 1988-1989, low numbers again from 1990-1992, and high numbers again from 1993-1996 (Table 3; Figure 3). Another explanation for the downward trend in abundance may be an artifice of the model. In a retrospective catch-age analysis of Pacific halibut *Hippoglossus stenolepus*, Parma (1992) found that estimates of stock abundance tended to be auto-correlated, with the stock consistently being overestimated or underestimated for a series of consecutive years. The model in this study indicated a surge of recruits in 1996, whereas the CPUE data showed large catch rates of pre-recruit sized fish beginning in 1995 (Table 3). This lag may be attributed to auto-correlated error. Hightower (1996) noted a similar auto-correlation of errors in estimated stock size of widow rockfish *Sebastes entomelas,* and indicated that these errors were large in early years, but decreased considerably once 12-15 years of data were available. Such errors could be stock-specific, so it is unknown whether these errors exist in this analysis. However, because this study was comprised of only ten years of data, and because age-structured models generally require a long term data set, the estimates and trends given in this report should not be considered definitive.

In addition to the possibility of auto-correlation in errors and a short time series of data, the catch-age analysis used in this study was constrained in other respects. Foremost is the tenuous quality of the catch sampling data that is used to generate harvest at age information. This data suffers from two major shortfalls. The first is imprecise estimates of age composition due to small sample sizes. Sample sizes have ranged from 68 to 572 burbot per calendar year (no samples were collected in 1990). The larger sample was supplemented extensively with additional catch sampling (non-sport harvest) to examine burbot reproductive characteristics. Coefficient of variations (CV) for many of the proportions of harvest by age estimates were quite large (see Table 1). The second shortfall is that the harvest samples have been temporally and spatially discrete. Future catch sampling should attempt to increase overall sample sizes and include samples from both open-water and ice-cover seasons.

Another constraint of the catch-age model is the indirect measure of effort. A more direct measure of fishing effort for burbot in the Tanana River is needed to increase the precision of parameter estimates.

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Dave Stoller, and Lisa Stuby expertly assisted with collecting data. Local sport fishermen voluntarily contributed samples for age analysis. Lisa Stuby assisted with aging otoliths. Margaret Merritt and Steve Fleischman provided technical review. Terrance Quinn provided insightful suggestions for improving the model. Sara Case finalized the document for publication.

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APPENDIX A

Appendix A.-Data files regarding burbot stock assessment in sections of the Tanana and Chena rivers archived by the Research and Technical Services of the Alaska Department of Fish and Game-Sport Fish Division[a].

Year	Data File	River (River Kilometer)
1986	U0275ETA.DTA	Tanana River (334-352)
1986	U0275ETB.DTA	Tanana River (334-352)
1986	U0275ETC.DTA	Tanana River (334-352)
1987	U0275CBA.DTA	Tanana River (339-354)
1987	U0275DBA.DTA	Tanana River (339-354)
1987	U0275EBA.DTA	Tanana River (339-354)
1987	U0275EBB.DTA	Tanana River (339-354)
1987	U0275EBC.DTA	Tanana River (339-354)
1988	U275CLA8.DTA	Tanana River (312-376)
1988	U0020LA8.DTA	Chena River (0-24)
1989	U275BLA9.DTA	Tanana River (317-374)
1989	U0020LA1.DTA	Chena River (0-40)
1990	U2750HA0.DTA	Tanana River (344-376)
1990	U0020HA0.DTA	Chena River (0-24)
1990	U0020HB0.DTA	Chena River (0-24)
1990	U0020HC0.DTA	Chena River (0-24)
1990	U0020HD0.DTA	Chena River (0-24)
1990	U0020HE0.DTA	Chena River (0-24)
1991	U2750HA1.DTA	Tanana River (336-360)
1991	U0020HA1.DTA	Chena River (0-24)
1992	U2750HA2.DTA	Tanana River (336-360)
1992	U0020HA2.DTA	Chena River (0-24)
1993	U2750HA3.DTA	Tanana River (336-360)
1993	U0210HA3.DTA	Chena River (0-24)
1994	U2750HA4.DTA	Tanana River (336-360)
1994	U0020HA4.DTA	Chena River (0-24)
1995	U2750LA5.DTA	Tanana River (336-360)
1995	U0020LA5.DTA	Chena River (0-24)
1996	U2750HA6.DTA	Tanana River (336-360)
1996	U0020HA6.DTA	Chena River (0-29)
1997	U2750HAA.DTA	Tanana River (336-360)
1997	U0020LAA.DTA	Chena River (0-29)

[a] Files for other river sections sampled since 1986 are given in Evenson and Merritt (1995).

APPENDIX B
COMMAND AND DATA FILES USED TO RUN CAGEAN

Appendix B1.-Command File: to generate initial values (CAGINIT.DAT), 1997.

TANANA BURBOT 1987-1996

cagfrst.out	(Name of output file)
1987 1996	(Range of years for analysis)
5 16	(Range of ages for analysis)
1	(Number of gear types)
1	(Code number for gear type 1)
1	(Number of selectivity groups)
1987 1996	(Range of years of first selectivity group)
9 16	(Range of ages of full selectivity first group)
1	(Number of catchability groups)
1987 1995	(First and last years of catchability group 1)
100	(Number of bootstrap samples)
0.41000	(Instantaneous Natural Mortality)
0.0	(To stop natural mortalities)
OK	(OK to parameters)
Y	(To full listing)
0	(No fixing of variables - fix catchability)
1	(Pooling of data (1=YES))
catch.dat	(Name of catch input file)
weight.dat	(Name of weight input file)
effort.dat	(Name of effort input file)
5	(Effort or catchability Lambda for gear type 1)
NONE	(Name of Fecundity input file)
COHORT	(Code word to generate initial values)
0.5	(Specification of Terminal Fishing Mortality)
NONE	(Spawner recruit Lambda)
kboot.out	(Name of Bootstrap Output file)
Y	(Print labeled residuals)
Y	(print sorted residuals)

-continued-

Appendix B2.-Command File: final run for parameter estimates (CAGFINAL.OUT), 1997.

TANANA BURBOT 1987-1996	
cagfrst.out	(Name of output file)
1987 1996	(Range of years for analysis)
5 16	(Range of ages for analysis)
1	(Number of gear types)
1	(Code number for gear type 1)
1	(Number of selectivity groups)
1987 1996	(Range of years of first selectivity group)
9 16	(Range of ages of full selectivity first group)
1	(Number of catchability groups)
1987 1996	(First and last years of catchability group 1)
100	(Number of bootstrap samples)
0.41000	(Instantaneous Natural Mortality)
0.0	(To stop natural mortalities)
OK	(OK to parameters)
Y	(To full listing)
0	(No fixing of variables - fix catchability)
1	(Pooling of data (1=YES))
catch.dat	(Name of catch input file)
weight.dat	(Name of weight input file)
effort.dat	(Name of effort input file)
5	(Effort or catchability Lambda for gear type 1)
NONE	(Name of Fecundity input file)
inits.dat	(file name containing initial values)
0.5	(Specification of Terminal Fishing Mortality)
NONE	(Spawner recruit Lambda)
kboot.out	(Name of Bootstrap Output file)
Y	(Print labeled residuals)
Y	(print sorted residuals)

Appendix B3.-Effort file (EFFORT.DAT), 1997.

1987	1	4,359
1988	1	6,307
1989	1	7,682
1990	1	3,224
1991	1	2,700
1992	1	3,168
1993	1	7,401
1994	1	8,777
1995	1	7,072
1996	1	2,427

Appendix B4.-Harvest file (CATCH.DAT), 1997.

5	1987	1	5.4066
6	1987	1	5.9663
7	1987	1	6.2176
8	1987	1	5.4066
9	1987	1	6.2176
10	1987	1	5.4066
11	1987	1	5.8121
12	1987	1	6.2176
13	1987	1	5.4066
14	1987	1	5.4066
15	1987	1	5.1190
16	1987	1	5.6298
5	1988	1	4.9375
6	1988	1	5.6307
7	1988	1	6.2105
8	1988	1	6.0362
9	1988	1	6.3928
10	1988	1	6.0827
11	1988	1	6.0362
12	1988	1	5.6997
13	1988	1	4.3779
14	1988	1	4.3779
15	1988	1	4.0902
16	1988	1	3.6848
5	1989	1	4.8447
6	1989	1	5.4043
7	1989	1	6.5495
8	1989	1	6.4029

-continued-

9	1989	1	6.0975
10	1989	1	6.3488
11	1989	1	6.3488
12	1989	1	5.8563
13	1989	1	5.6556
14	1989	1	5.2502
15	1989	1	4.5570
16	1989	1	3.4584
5	1990	1	0.0
6	1990	1	0.0
7	1990	1	0.0
8	1990	1	0.0
9	1990	1	0.0
10	1990	1	0.0
11	1990	1	0.0
12	1990	1	0.0
13	1990	1	0.0
14	1990	1	0.0
15	1990	1	0.0
16	1990	1	0.0
5	1991	1	4.0098
6	1991	1	5.4369
7	1991	1	5.8556
8	1991	1	5.7734
9	1991	1	5.6192
10	1991	1	5.6838
11	1991	1	4.9906
12	1991	1	5.5139
13	1991	1	5.1084

-continued-

14	1991	1	4.0098

15	1991	1	3.6043
16	1991	1	2.2180
5	1992	1	4.8669
6	1992	1	5.7204
7	1992	1	6.2087
8	1992	1	6.1741
9	1992	1	6.0219
10	1992	1	6.0489
11	1992	1	5.8903
12	1992	1	5.4926
13	1992	1	5.0272
14	1992	1	4.5040
15	1992	1	4.2964
16	1992	1	4.0340
5	1993	1	0.0
6	1993	1	3.7906
7	1993	1	5.1769
8	1993	1	5.1769
9	1993	1	6.6810
10	1993	1	6.6238
11	1993	1	6.9686
12	1993	1	6.3555
13	1993	1	6.3555
14	1993	1	5.5823
15	1993	1	5.7365
16	1993	1	6.0932

-continued-

5	1994	1	0.0
6	1994	1	0.0

7	1994	1	5.86
8	1994	1	5.86
9	1994	1	6.33
10	1994	1	6.33
11	1994	1	6.7355
12	1994	1	6.5532
13	1994	1	6.0424
14	1994	1	6.4478
15	1994	1	5.3492
16	1994	1	4.9437
5	1995	1	4.5983
6	1995	1	5.5146
7	1995	1	5.9846
8	1995	1	5.6970
9	1995	1	6.1024
10	1995	1	6.6132
11	1995	1	6.4701
12	1995	1	6.3031
13	1995	1	6.4701
14	1995	1	5.9846
15	1995	1	4.5983
16	1995	1	4.5983

-continued-

5	1996	1	5.1673
6	1996	1	5.4297
7	1996	1	5.8605
8	1996	1	5.6681
9	1996	1	4.8107
10	1996	1	5.3905
11	1996	1	4.8107
12	1996	1	3.9634
13	1996	1	3.9634
14	1996	1	2.1716
15	1996	1	2.1716
16	1996	1	2.1716

Appendix B5.-Weight file (WEIGHT.DAT), 1997.

5	1987	1	1
6	1987	1	1
7	1987	1	1
8	1987	1	1
9	1987	1	1
10	1987	1	1
11	1987	1	1
12	1987	1	1
13	1987	1	1
14	1987	1	1
15	1987	1	1
16	1987	1	1

This Format was repeated for all years 1989-1996.

APPENDIX C

Appendix C.-Tanana River burbot harvest by river section, 1977-1996.

Annual Harvest[a] River	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Mainstem Tanana River																				
Lower Tanana R.[b]	0	0	0	0	0	0	0	0	0	0	40	218	130	236	113	93	11	180	172	53
Middle Tanana R.[b]	0	0	0	0	0	0	0	0	0	0	1,873	1,692	1,764	912	834	1,286	2,460	2,191	2,292	734
Upper Tanana R.[b]	0	0	0	0	0	0	0	0	0	0	409	509	411	641	654	338	685	823	838	232
Total Tanana R.[cd]	0	0	0	0	0	0	0	1,921	1,365	2,948	2,322	2,419	2,325	1,789	1,602	1,717	3,156	3,194	3,302	1,019
Lower Tanana River Tributaries																				
Chatanika R.	34	18	9	50	5	42	21	13	175	40	13	55	10	17	0	8	0	0	91	9
Nenana R.[d]	0	0	0	0	0	0	0	0	0	0	53	0	60	68	11	76	11	0	0	44
Minto Flats	37	72	45	9	32	21	0	39	105	32	132	0	20	0	56	0	0	208	161	18
Middle Tanana River Tributaries																				
Chena R.	642	389	807	1,127	1,317	1,457	1,055	1,233	2,065	889	149	386	1,322	304	225	1,032	1,135	737	597	441
Salcha R.	0	0	0	0	0	0	0	0	35	296	0	18	0	203	23	25	64	21	23	9
Piledriver Sl.[d]	0	0	0	0	0	0	0	84	0	0	79	55	100	456	203	195	568	73	299	80
Shaw Cr.[d]	0	0	0	0	0	0	0	415	175	120	607	0	170	354	45	161	161	93	138	27
Upper Tanana River Tributaries																				
Delta Clearwater R	0	0	0	29	0	0	0	13	0	0	26	0	0	0	0	0	0	0	0	0
Goodpaster R.[d]	0	0	0	0	0	0	0	221	350	88	13	109	120	0	0	17	86	0	23	18
Other Areas[e]	829	832	966	1,285	2,257	1,866	3,146	935	245	441	355	364	100	388	23	93	289	589	34	107
% Total											9.5	10.7	2.4	10.8	1.1	2.8	5.3	12.0	0.7	5.7
Total Lower River											238	273	220	321	180	177	22	388	424	124
% Total											6.3	8.0	5.2	9.0	8.2	5.3	0.4	7.9	9.1	6.6
Total Middle											2,708	2,151	3,356	2,229	1,330	2,695	4,388	3,115	3,349	1,291
% Total											72.2	63.2	79.4	62.3	60.8	81.2	80.2	63.4	71.7	68.7
Total Upper River											448	618	531	641	654	355	771	823	861	357
% Total											11.9	18.1	12.6	17.9	30.0	10.7	14.1	16.7	18.4	19.0
Total All Areas	1,542	1,311	1,827	2,500	3,611	3,386	4,306	4,790	4,515	4,854	3,749	3,406	4,225	3,579	2,187	3,320	5,470	4,915	4,668	1,879

[a] Data from Alaska statewide harvest survey (Mills 1978-1994, and Howe et al. 1995-1997)
[b] River sections were not described as specific areas on the survey form until 1987.
[c] Includes harvests from upper, middle, lower, and unspecified sections.
[d] was not described as a specific area until 1984. Any harvest that may have occurred in this area would have been listed in the "Other this Areas" category.
[e] Was described as "Other Waters" on the survey form until 1984, and may have included harvests from lakes and ponds. Beginning in 1984, this category is listed as "Other Streams" on the survey form.

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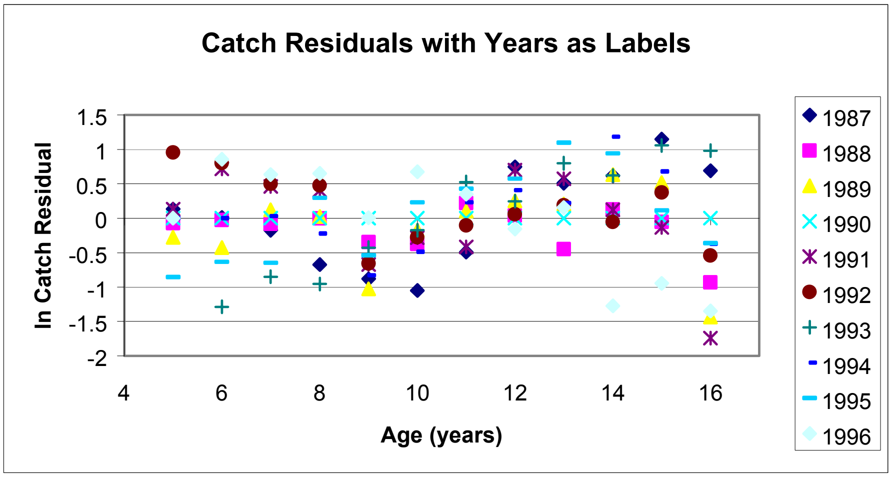
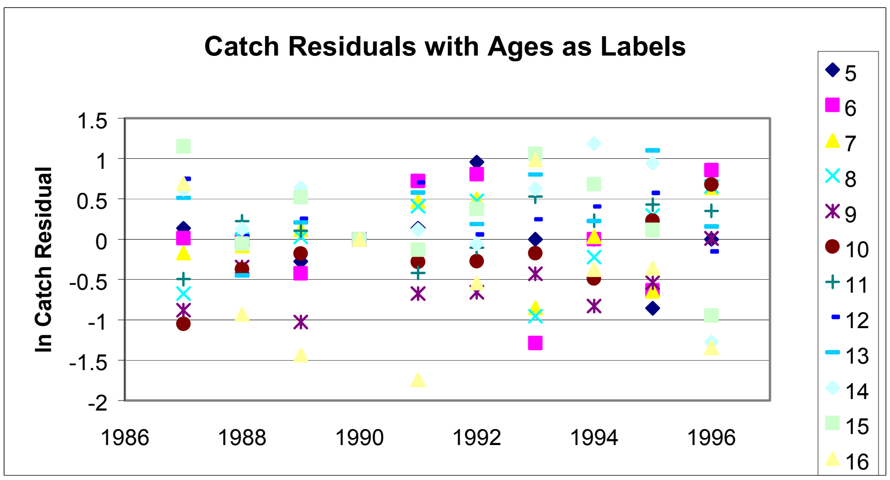
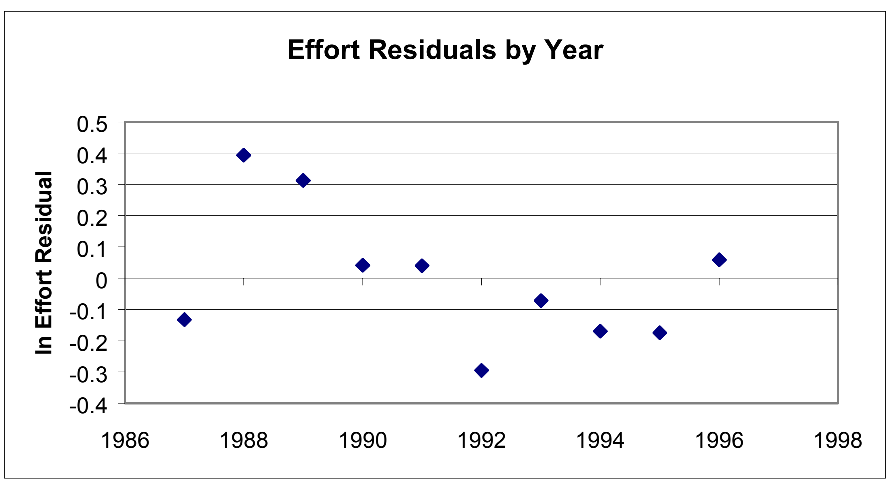
APPENDIX D
Iterations of the catch-age model used to examine the affects of various lambda values on model performance.

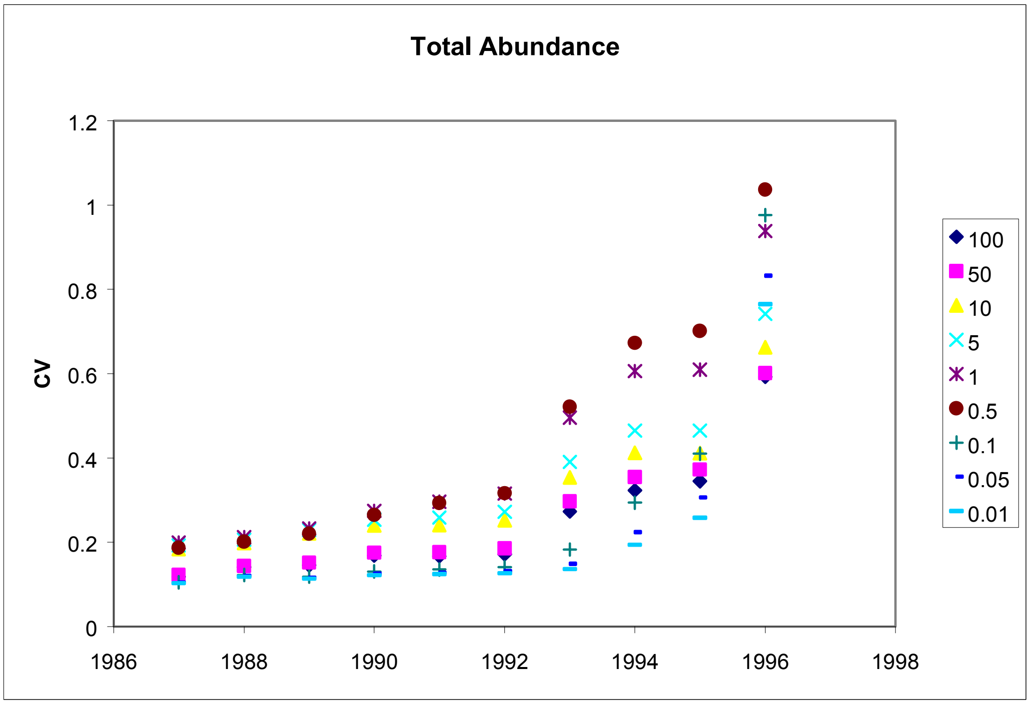
Appendix D1.-Plots of catch residuals by age with years as labels and by year with ages as labels and plots of effort residuals by year for lambda = 5.

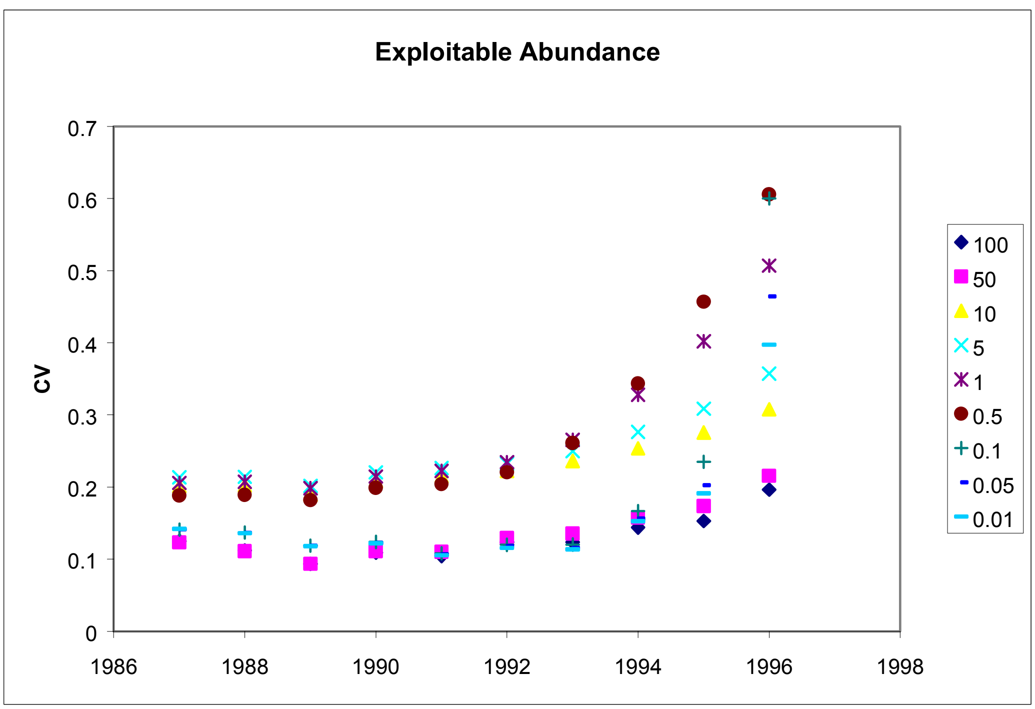






Appendix D2.-Plots of coefficient of variation by year for estimates of total abundance and exploitable abundance for various lambda values.





Appendix D3.-Plots of model bias by year for estimates of total abundance and exploitable abundance for various lambda values.