Fishery Data Series No. 97-34

Burbot Research in Rivers of the Tanana River Drainage, 1996

by

Matthew J. Evenson

November 1997

Alaska Department of Fish and Game Division of Sport Fish

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used in Division of Sport Fish Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications without definition. All others must be defined in the text at first mention, as well as in the titles or footnotes of tables and in figures or figure captions.

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

FISHERY DATA SERIES NO. 97-34

BURBOT RESEARCH IN RIVERS OF THE TANANA RIVER DRAINAGE, 1996

by

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ABSTRACT

As part of an ongoing stock assessment program, burbot were sampled in two river sections (approximately 25 km in length), one each in the Tanana and Chena rivers, representing the area 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 used to combine harvest estimates from the statewide harvest survey and age composition from catch sampling with auxiliary information in the form of angler effort to estimate exploitable abundance of burbot in the Tanana River drainage. The CAGEAN model results showed a decreasing trend in exploitable abundance from 1987 to 1995, which corresponds to a trend in increased fishing mortality during that time. Catch-age analysis appears to be a promising method for estimating trend in abundance for burbot in the Tanana River drainage, but 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.

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, examine spawning characteristics, monitor harvests, 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, 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 which marked and subsequently recaptured burbot in the mainstream Tanana River and in many tributary streams. More recently (Evenson 1993b), radio telemetry was used to monitor seasonal movements and identify spawning concentrations in attempt 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).

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 important river sections (areas of large harvest such as the Chena and Tanana rivers near the city of Fairbanks). 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. The purpose of this investigation was to continue stock monitoring in the Tanana and Chena rivers near Fairbanks. The specific objectives were to:

1. estimate the length composition)proportion in 25 mm length increments) of all burbot 450-799 mm TL in one 24 km section of the Tanana River and in one 24 km section of the Chena River.
2. estimate abundance of fully recruited burbot to the fished population using catch-age analysis; and,
3. test the hypothesis that the proportion of pre-recruits (ages 4-8) in the fishery during ice-cover (winter) is equal to that in the fishery during periods of open water (summer).

A task of the project was to:

1. estimate mean CPUE of burbot for each of three length categories (small:300-449 mm total length (TL); medium: 456-799 mm TL; and, large 800 mm TL and larger in one 24 km section of the Tanana River and in one 24 km section of the Chena River.

In addition, other statistics regarding length compositions are presented and compared to previous years data.

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. 1985, 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 1985). This analysis includes nine years of catch samples (1987-1995), and therefore the parameter estimates presented below should not be considered definitive. The purpose of this analysis is to present the development of the CAGEAN model for these data and to identify bias and problems with the model so that it can be improved and fine tuned with additional years data. The specific objectives were to estimate abundance of fully recruited burbot to the fished population for years 1987-1995, and to 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).

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 it's 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.

METHODS: INDEX SAMPLING

GEAR DESCRIPTION

Burbot were captured in commercially available hoop traps. Two sizes of traps have been used during the past eight years. The larger of the two traps were used during all years prior to 1988,

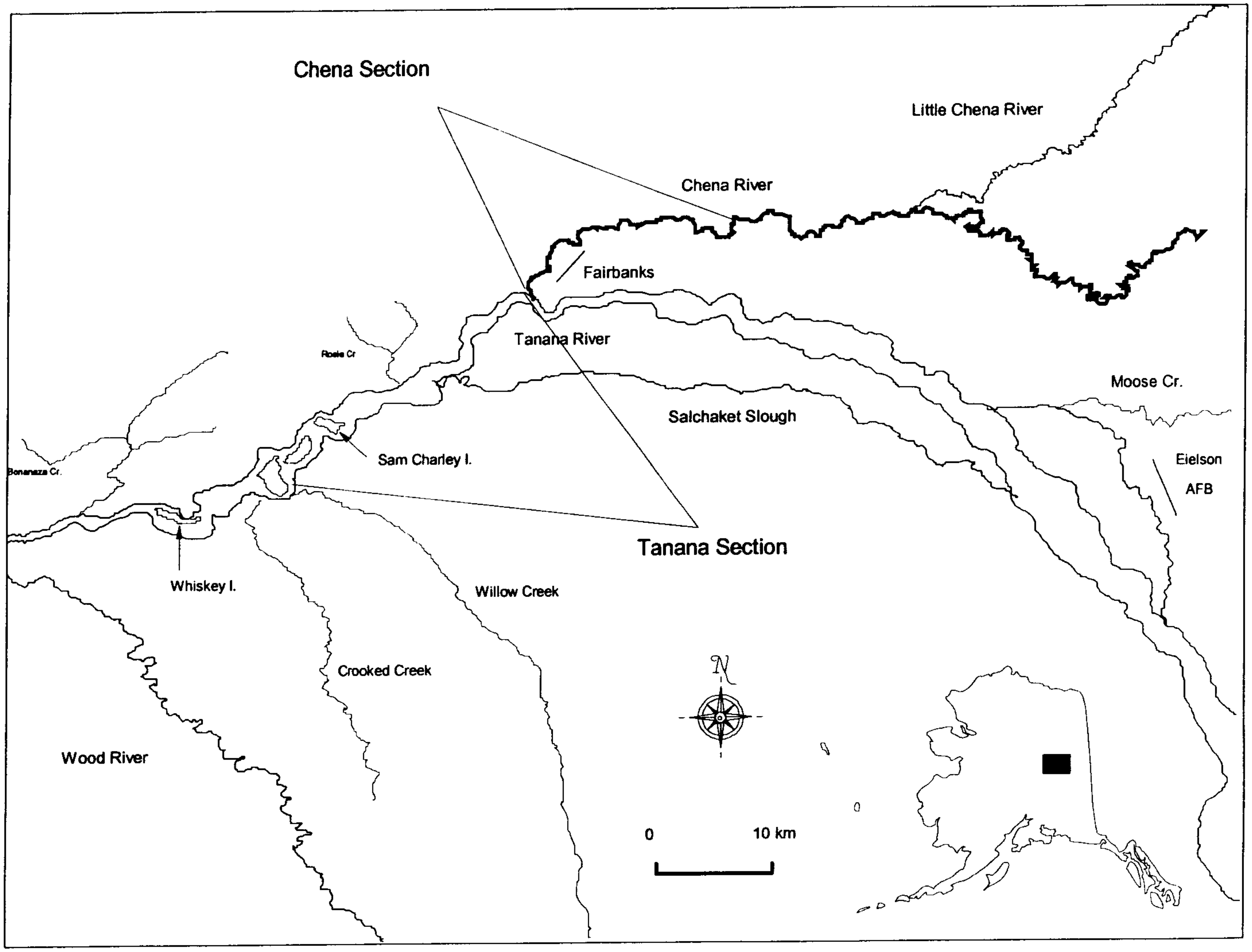

Figure 1.-Map of the Tanana River drainage showing sample sections during 1996.

while the smaller traps were used in following years. 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 total length (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.

Small hoop traps were 3.05 m long with seven 6.35 mm steel hoops (Figure 2). Hoop diameters tapered from 0.61 m at the entrance to 0.46 m at the cod end. Each trap had a double throat (tied to the second and fourth hoops) which narrows 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.

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* and placed in perforated plastic containers. One end of a five 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 over a period of two weeks (eight days of sampling). 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, were 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 (TL) 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 described above, 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):

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

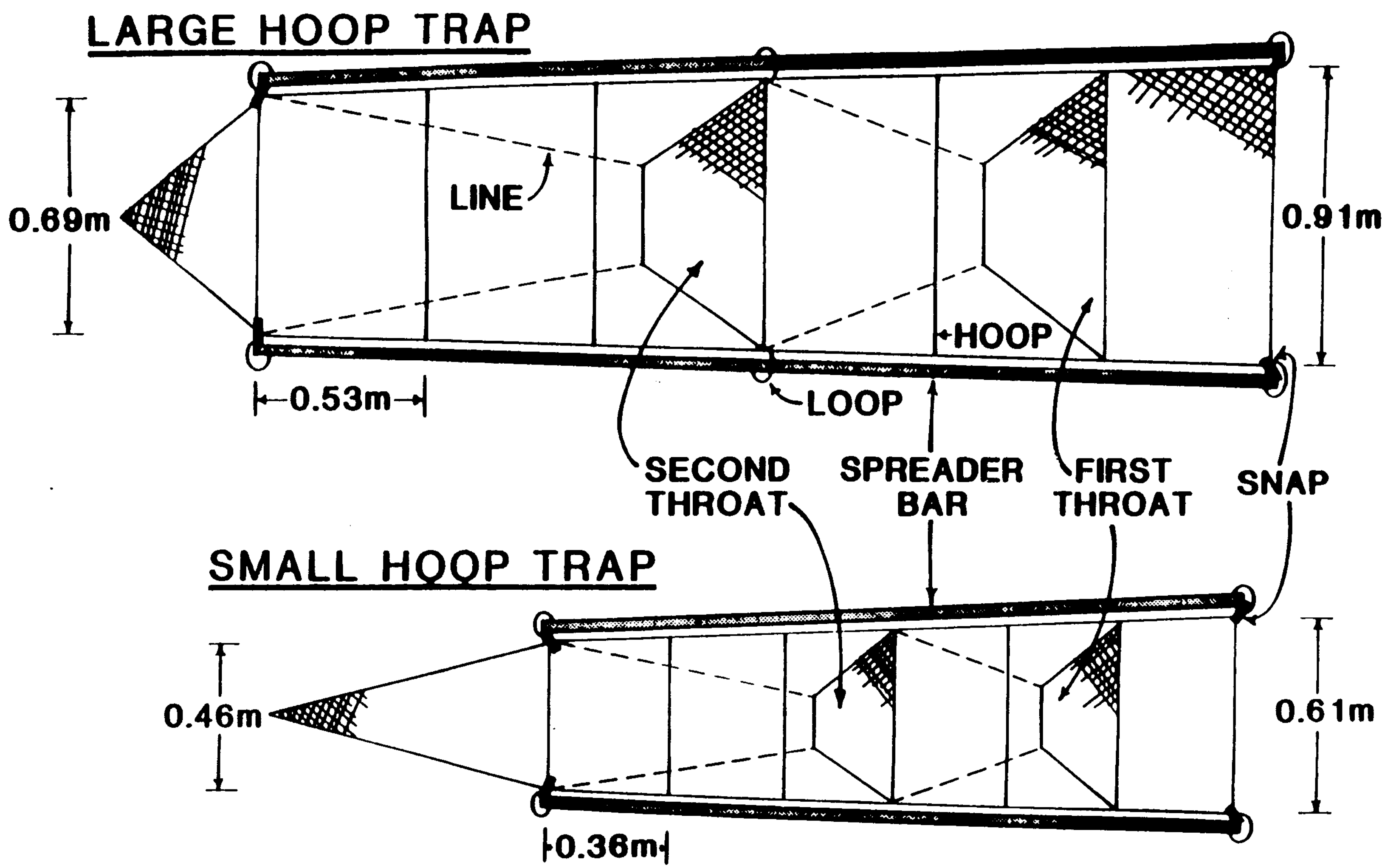

Figure 2.-Diagrams of large and small hoop traps used to catch burbot in flowing waters of the Tanana River drainage.

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

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

Length compositions of burbot sampled in these two sections were examined using three methods. Mean lengths and proportions of total catch for each of the three size categories were calculated. In addition, length distributions for various sampling years were plotted and compared.

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

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

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

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 total length (TL).

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

$$\hat{P}_z = \frac{n_z}{n} \tag{5}$$

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

$\hat{P}_z$ = the estimated proportion of burbot in category z;
n_z = number of samples in length category z; 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.

METHODS: CATCH-AGE ANALYSIS

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: total sport harvest estimates for the Tanana River from 1987-1995[1] (Mills 1988 - 1994 and Howe et al. 1995 - 1996); and estimated age composition of the harvest (ages 4 - 16+) determined from surface aging of otoliths collected from the fishery. Auxiliary information in the form of fishing effort (angler days; Mills 1988 - 1994 and Howe et al. 1995 - 1996) was introduced to stabilize parameter estimation. Initial values generated by CAGEAN were used for initial parameter estimates. Input files for the CAGEAN analysis are given in Appendix B.

MODEL ASSUMPTIONS

The assumptions of the CAGEAN model 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.

Collection of otoliths for aging has historically been confined to samples from the winter fishery, and primarily in the middle portion of the Tanana drainage. This is where the majority (60 -

[1] No harvest samples were collected for 1990 so harvest at age information is missing for that year.

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; see Evenson and Hansen 1991). For this analysis, it has been assumed that the age proportion from the winter sample in the middle Tanana River drainage is representative of total annual harvests within the Tanana drainage. Because movements of burbot are frequent and extensive throughout this system (Evenson 1989 and 1990a), and because most of the harvest occurs in the middle Tanana River drainage, it is also assumed that assumption 15 is valid. Therefore, the geographic area of the stock is defined as the entire Tanana River and its tributaries. During 1996, 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). Although the 1996 harvest sample was not used as part of the CAGEAN analysis, it 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.

NOTATION

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

$\hat{H}_{a,y}$ = 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;

$\hat{F}$ = estimated fishing mortality;

$\hat{E}_y$ = calculated fishing effort in year y for burbot;

$\widehat{AD}$ = estimated angler days from the statewide harvest survey;

$\tilde{\varepsilon}_y$ = error in relationship between fishing mortality and fishing effort in year y;

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.

HARVEST AT AGE

Total harvests estimated from the statewide harvest survey (Mills 1988-1994 and Howe et al. 1995-1996) were computed by summing harvests from all discrete flowing waters draining into the Tanana River[2] (see Figure 3). Harvest at age from 1987-1989 and from 1991-1995 (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 (Table 2):

$$\hat{H}_{a,y} = \hat{H}_y \hat{p}_a. \tag{7}$$

AGE DETERMINATION

A pair of otoliths (sagittae bones) were removed from each fish for age analysis. Otoliths were stored dry and were 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.

GEAR DESCRIPTION AND VULNERABILITY

Anglers typically use fish bait to capture burbot. Baited hooks are fished both actively (rod and reel) or 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.

The range of ages from all samples was 4 - 20. Although not fully recruited to the fishery, burbot of age 5 are present in most years harvest samples, and thus this 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 determined to be 9 from initial CAGEAN model output (Figure 4). Iterations of the model were conducted with ages of full vulnerability ranging from ages 7 to 10 to examine the effect on abundance and fishing mortality estimates (Appendix D1).

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[2] 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.

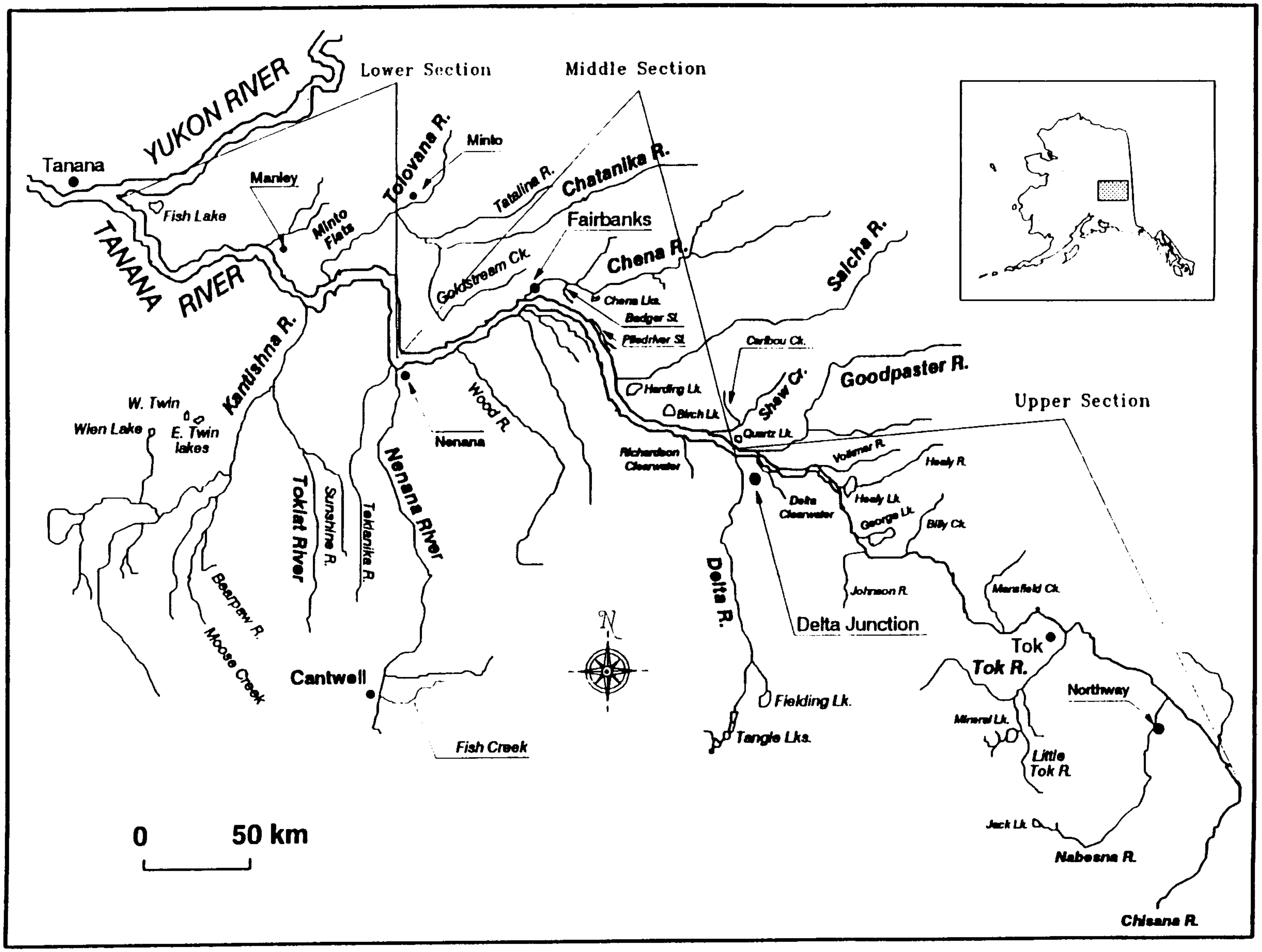

Figure 3.-Map of the Tanana River drainage, with the lower, middle and upper sections of the Tanana River demarcated.

Table 1.-Proportion at age of burbot in the Tanana River, estimated from carcasses collected during the winter sport harvest, for the years 1987-1995.

		Year									
Age	Statistic	1987	1988	1989	1990	1991	1992	1993	1994	1995	Total
4	Sample Size	0	3	1	0	0	1	0	0	0	5
	Proportion	0.000	0.018	0.008	0.000	0.000	0.002	0.000	0.000	0.000	0.003
	SE	0.000	0.010	0.008	0.000	0.000	0.002	0.000	0.000	0.000	0.002
	CV	0	57	100	0	0	100	0	0	0	45
5	Sample Size	4	7	4	0	6	23	0	0	2	46
	Proportion	0.059	0.041	0.030	0.000	0.025	0.040	0.000	0.000	0.210	0.031
	SE	0.029	0.015	0.015	0.000	0.010	0.008	0.000	0.000	0.150	0.005
	CV	49	37	49	0	40	20	0	0	70	15
6	Sample Size	7	14	7	0	38	88	4	5	5	113
	Proportion	0.103	0.082	0.053	0.000	0.105	0.094	0.009	0.000	0.053	0.077
	SE	0.037	0.021	0.019	0.000	0.020	0.012	0.009	0.000	0.023	0.007
	CV	36	26	37	0	19	13	100	0	44	9
7	Sample Size	9	25	22	0	38	88	4	5	8	199
	Proportion	0.132	0.146	0.165	0.000	0.160	0.154	0.034	0.074	0.085	0.136
	SE	0.041	0.027	0.032	0.000	0.024	0.015	0.017	0.032	0.029	0.009
	CV	31	19	20	0	15	10	49	43	34	7
8	Sample Size	4	21	19	0	35	85	4	5	6	179
	Proportion	0.059	0.123	0.143	0.000	0.147	0.149	0.034	0.074	0.064	0.123
	SE	0.029	0.025	0.030	0.000	0.023	0.015	0.017	0.032	0.025	0.009
	CV	49	20	21	0	16	10	49	43	40	7
9	Sample Size	9	30	14	0	30	73	18	8	9	191
	Proportion	0.132	0.175	0.105	0.000	0.126	0.128	0.154	0.118	0.096	0.131
	SE	0.041	0.029	0.027	0.000	0.022	0.014	0.033	0.039	0.031	0.009
	CV	31	17	25	0	17	11	22	33	32	7
10	Sample Size	4	22	18	0	32	75	17	8	15	191
	Proportion	0.059	0.129	0.135	0.000	0.134	0.131	0.145	0.118	0.160	0.131
	SE	0.029	0.026	0.030	0.000	0.022	0.014	0.033	0.039	0.038	0.009
	CV	49	20	22	0	16	11	23	33	24	7
11	Sample Size	6	21	18	0	16	64	24	12	13	174
	Proportion	0.088	0.123	0.135	0.000	0.067	0.112	0.205	0.176	0.138	0.119
	SE	0.035	0.025	0.030	0.000	0.016	0.013	0.037	0.047	0.036	0.008
	CV	39	20	22	0	24	12	18	26	26	7
12	Sample Size	9	15	11	0	27	43	13	10	11	139
	Proportion	0.132	0.088	0.083	0.000	0.113	0.075	0.111	0.147	0.117	0.095
	SE	0.041	0.022	0.024	0.000	0.021	0.011	0.029	0.043	0.033	0.008
	CV	31	25	29	0	18	15	26	29	28	8
13	Sample Size	4	4	9	0	18	27	13	6	13	94
	Proportion	0.059	0.023	0.068	0.000	0.076	0.047	0.111	0.088	0.138	0.064
	SE	0.029	0.012	0.022	0.000	0.017	0.009	0.029	0.035	0.036	0.006
	CV	49	50	32	0	23	19	26	39	26	10
14	Sample Size	4	4	6	0	6	16	6	9	8	59
	Proportion	0.059	0.023	0.045	0.000	0.025	0.028	0.051	0.132	0.085	0.040
	SE	0.029	0.012	0.018	0.000	0.010	0.007	0.020	0.041	0.029	0.005
	CV	49	50	40	0	40	25	40	31	34	13
15	Sample Size	3	3	3	0	6	16	6	9	2	38
	Proportion	0.044	0.018	0.023	0.000	0.017	0.023	0.060	0.044	0.021	0.026
	SE	0.025	0.010	0.013	0.000	0.008	0.006	0.022	0.025	0.015	0.004
	CV	57	57	57	0	50	27	37	57	70	16
16	Sample Size	5	2	1	0	1	10	10	2	2	33
	Proportion	0.074	0.012	0.008	0.000	0.004	0.017	0.085	0.029	0.021	0.023
	SE	0.032	0.008	0.008	0.000	0.004	0.005	0.026	0.021	0.015	0.004
	CV	43	71	100	0	100	31	30	70	70	17
Total	Sample Size	68	171	133	0	238	572	117	68	94	1,461

Table 2.-Estimated harvest of burbot and angler days of fishing effort in flowing waters of the Tanana River drainage from the statewide harvest survey, 1987-1995.

Year	Harvest[a]	SE[Harvest]	Effort[b]
1987	3,749	NA[c]	3,026
1988	3,406	NA	1,666
1989	4,225	NA	2,421
1990	3,579	NA	3,225
1991	2,187	561	2,748
1992	3,231	624	1,721
1993	5,181	1,017	4,329
1994	4,915	NA	2,968
1995	4,668	NA	5,732

[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] Specific estimates of effort towards burbot in the Tanana River are not available. Effort was calculated as the product of the proportion of burbot harvest to total harvest and total angler days of effort in the Tanana River drainage from the statewide harvest survey.

[c] NA means estimate is not available.

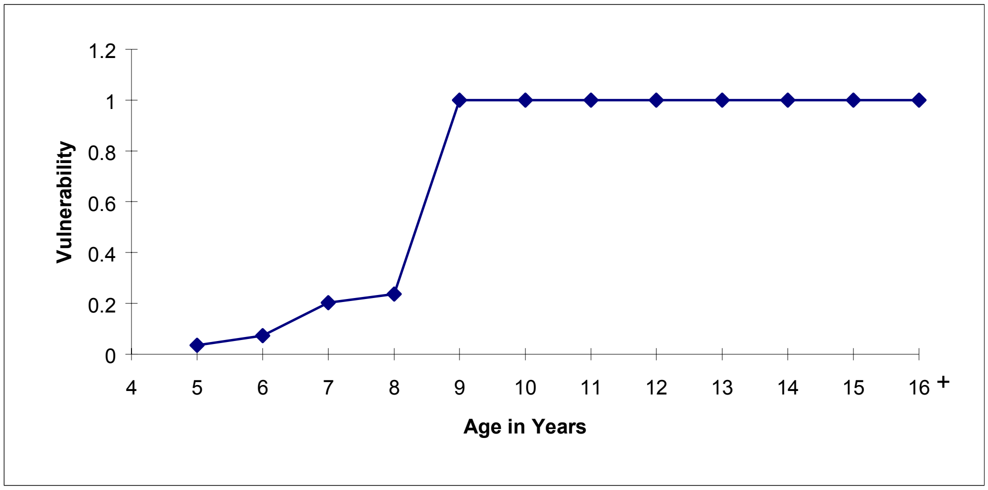

Figure 4.-Estimated gear vulnerability at age for the burbot sport fishery in the Tanana River.

CATCHABILITY

The regulation regime (i.e. gear restrictions, seasons, and bag limits) for this sport fishery was constant during all years of analysis (1987-1995). 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 an input into the model which comes from an independent estimate. No direct measure of natural mortality is available for the Tanana River population. Estimates obtained from mark-recapture experiments in interior Alaska 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_o. Estimates of these parameters were obtained using a modified Marquardt non-linear least squares procedure contained in a FORTRAN program. The equation used was:

$$\hat{L}_a = \hat{L}_{\infty}(1 - e^{-\hat{K}(a-\hat{t}_0)}). \tag{8}$$

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[3]. 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:

$$\hat{M} = \frac{3\hat{K}}{e^{\hat{t}_{mb}\hat{K}} - 1}. \tag{9}$$

Equation 8 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.

Total mortality was estimated as:

$$\hat{Z}_{a,y} = \hat{F}_{a,y} + \hat{M}_{a,y}. \tag{10}$$

The oldest sample ever aged was 20 years. Using the above formulae with this as the maximum age yielded a instantaneous natural mortality rate of 0.35. A series of model iterations was run to examine the effect of various natural mortality values on abundance and fishing mortality estimates (Appendix D2). Ultimately a value of 0.41 was chosen as the instantaneous natural mortality rate.

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[3] 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.

Fishing Effort Source File, Effort Lambda

Estimated total angler days from the statewide harvest survey could not be used as a direct measure of fishing effort because data are collected by waterbody, not by species targeted. To obtain an estimate of fishing effort it was assumed that the fraction of burbot harvested from the mainstem Tanana River relative to total fish harvested is proportional to the fraction of angler days expended for burbot, relative to total angler days:

$$\hat{E}_y = \frac{\hat{H}_{burbot,y}}{\hat{H}_{total,y}} x \hat{AD}_y . \tag{11}$$

Fishing effort in terms of angler days was used as an auxiliary data source to aid in the estimation of fishing mortality.

An effort lambda (λ) of 50 was derived by running CAGEAN models over a range of lambda's (0.01 to 1,000). This lambda value produced effort residuals (Appendix D3 and D4) and catch residuals (Appendix D5 and D6) with no apparent trends when compared to the residuals produced by other lambda values. This lambda value also yielded coefficient of variations (cv) for estimates of total absolute abundance and exploitable abundance which were low relative to other lambda values (Appendix D7). Lambda values of 100 and 1,000 actually produced lower cv's than did the lambda equal to 50, however, because these data were estimated indirectly, it was felt that these extreme weighting values were not prudent. The choice of a lambda value can have profound impacts on estimates of total absolute and exploitable abundance (Appendix D8).

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 harvest age compositions to be normally distributed. Angler days (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:

$$\tilde{\varepsilon}_y = \ln \hat{F}_y - \ln(q\hat{E}_y) . \tag{12}$$

Population Dynamic Models

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:

$$\tilde{N}_{a+1,y+1} = \tilde{N}_{a,y} e^{-Z_{a,y}} . \tag{13}$$

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

$$\tilde{N}_{16+,y+1} = \tilde{N}_{15,y} + \tilde{N}_{16+,y} e^{-Z_{16+},y} . \tag{14}$$

Estimated harvest was modeled as a function of:

$$\tilde{H}_{a,y} = \mu_{a,y} \tilde{N}_{a,y} \tag{15}$$

which assumes that exploitation and vulnerability are separable.

STATISTICAL MODELS

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:

$$SSQ_{harvest} = \sum_{y,a} [(\ln \tilde{H}_{y,a}) - (\ln \hat{H}_{y,a})]^2 . \qquad (16)$$

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

$$SSQ_{effort} = \lambda \sum_{y} (\tilde{\varepsilon}_y)^2 . \qquad (17)$$

OBJECTIVE FUNCTION

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

$$O_{total} = SSQ_{harvest} + SSQ_{effort}. \qquad (18)$$

The value of the objective function is to measure how well the model fits observed data. A smaller objective function signifies a better fit.

RESULTS: INDEX SAMPLING

In the Tanana River section during 1996, a total of 424 burbot were caught with 316 net-nights of effort. Estimates of mean CPUE were 0.61 bb/nn (SE = 0.06) for small burbot, 0.71 bb/nn (SE = 0.06) for medium burbot, and 0.03 bb/nn (SE = 0.01) for large burbot (Table 3). The mean CPUE estimates from 1996 in the Tanana River section for medium burbot was greater than the 1995 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, and the 1995 estimate was at about the midpoint of observed values.

In the Chena River section, a total of 334 burbot were caught with 273 net-nights of effort. Estimates of mean CPUE were 0.21 bb/nn (SE = 0.03) for small burbot, 0.59 bb/nn (SE = 0.07) for medium burbot, and 0.01 (SE < 0.01) for large burbot (Table 4). Mean CPUE estimate for medium burbot in the Chena River in 1996 was within the observed range of estimates from previous years, but was lower than the previous two years' estimates.

Estimates of mean length for burbot sampled from the Tanana River section were 379 mm TL (SE = 3) for small burbot, 535 mm TL (SE = 5) for medium burbot, and 853 mm TL (SE = 22) for large burbot (Table 5). Estimates of mean length for burbot sampled from the Chena River section were 383 mm TL (SE = 6) for small burbot, 572 mm TL (SE = 6) for medium burbot, and 808 (SE = 8) 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

Table 3.-Catch per unit effort (CPUE) estimates of burbot sampled in the Tanana River section, 1986-1996.

River Sampling Dates	Year	km Sampled	Trap Size	Net Night	Small (300-449 mm TL) Catch	CPUE	SE	Medium (450-799 mm TL) Catch	CPUE	SE	Large (≥800 mm TL) Catch	CPUE	SE	Medium + Large (≥450 mm TL) 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

[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, 1988-1996.

River Sampling Dates	Year	Km Sampled	Trap Size	Net Nights	Small (300-449 mm TL) Catch	Small CPUE	Small SE	Medium (450-799 mm TL) Catch	Medium CPUE	Medium SE	Large (≥800 mm TL) Catch	Large CPUE	Large SE	Medium + Large (≥450 mm TL) Catch	Medium + Large CPUE	Medium + Large 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

[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 5.-Mean length estimates of burbot sampled in the Tanana River section, 1986-1996.

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

[a] Insufficient data.

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Table 6.-Mean length estimates of burbot sampled in Chena River section, 1988-1996.

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
09/07-09/09	1988	0-24	Small	306-754	23	394	8	65	557	8	0	ID[a]	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

[a] Insufficient data.

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Table 7.-Estimates of proportions of small, medium, and large burbot sampled in the Tanana River section, 1986-1996.

Sampling Date	Year	River km Sampled	Hoop Trap Size	Catch Total	Small	Catch Proportion	SE	Medium	Catch Proportion	SE	Large	Catch 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

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Table 8.-Estimates of proportions of small, medium, and large burbot sampled in the Chena River section, 1988-1996.

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

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burbot has ranged from 0.47 to 0.78 since 1986. The 1996 estimate of 0.53 (SE = 0.02) is at the lower end of this range. Correspondingly, the proportion of small burbot in the 1996 sample was at the upper end of the observed range, which may be indicative of strong 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 1996 estimate was 0.73 (SE = 0.03), which is slightly above the midpoint of this range. The proportion of small burbot in the 1996 catch was 0.26 (SE = 0.03), which is also slightly above the midpoint of the observed range. 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 5 and 6). This is likely attributed to the more variable times of sampling in the Tanana River section (See Tables 1-2 for dates of sampling).

RESULTS: CATCH-AGE ANALYSIS

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 (Table 9 and Figure 7). As expected, the coefficient of variation for the most recent estimates were high compared to prior years because cohort information for CAGEAN estimation 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 at age estimates decreased markedly from 1987 to 1995 for young, partially-recruited fish (Table 10). 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.

ESTIMATED FISHING MORTALITY

Estimated fishing mortality for partially recruited burbot is in general relatively low. However, estimated fishing mortality of all ages increased markedly beginning in 1992 (Table 11). Thisincrease in fishing mortality corresponds to a decline in exploitable abundance and steady harvest rate. The highest estimated fishing mortality rate was 20% during 1995 for fully recruited burbot. Fishing mortality of pre-recruits (ages 4-8) has remained low (below 4%) for all ages and years.

MODEL BIAS

Predictions of harvest from the CAGEAN model track well with observed values, while the predictions of effort show considerable disparity from observed values (Figure 8). 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 higher for recent years than for earlier estimates (Table 9). This is similar in trend to the estimates of variance for the abundance estimates.

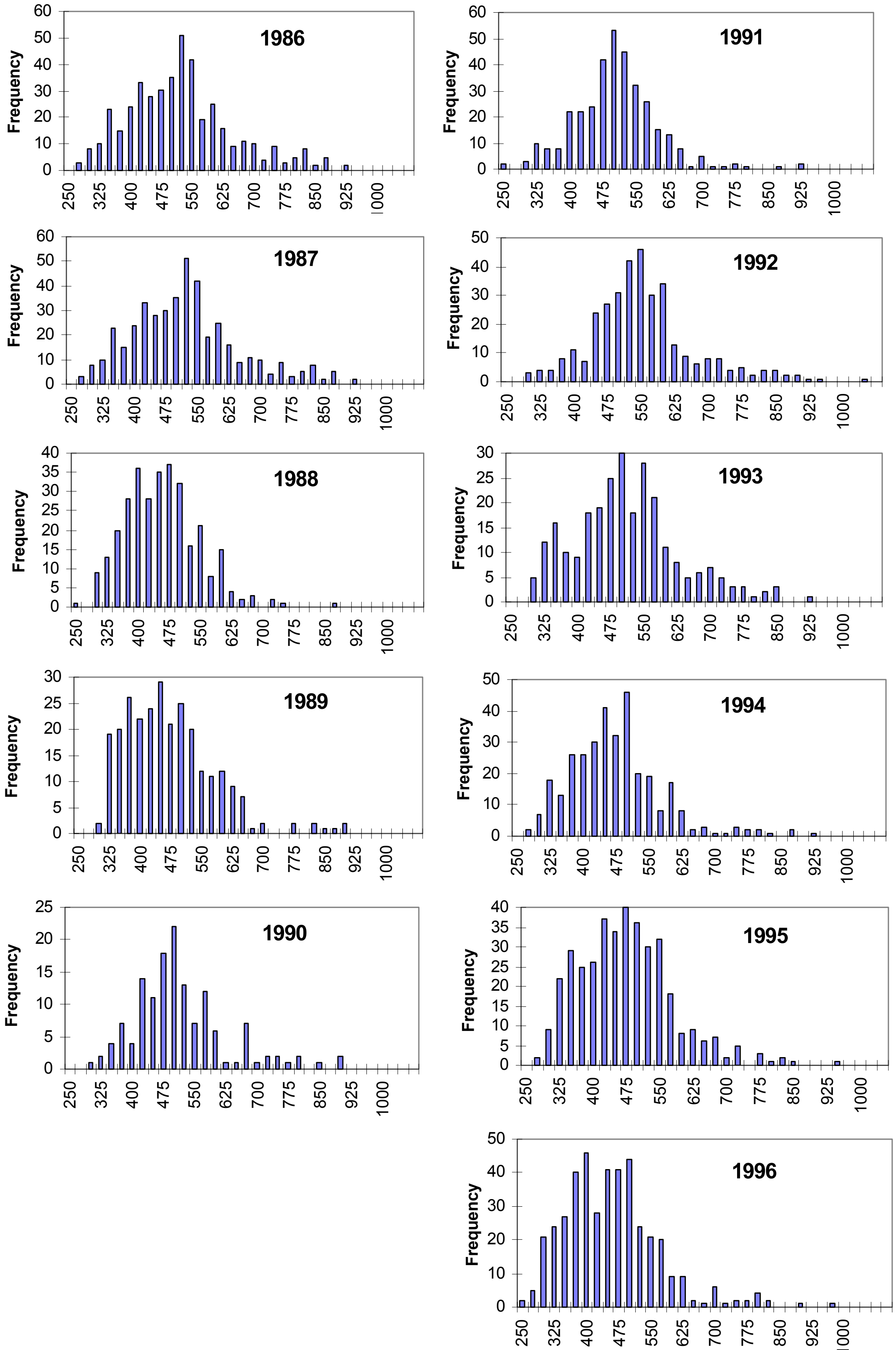

Figure 5.-Length frequency distributions of burbot sampled in the Tanana River, 1986-1996.

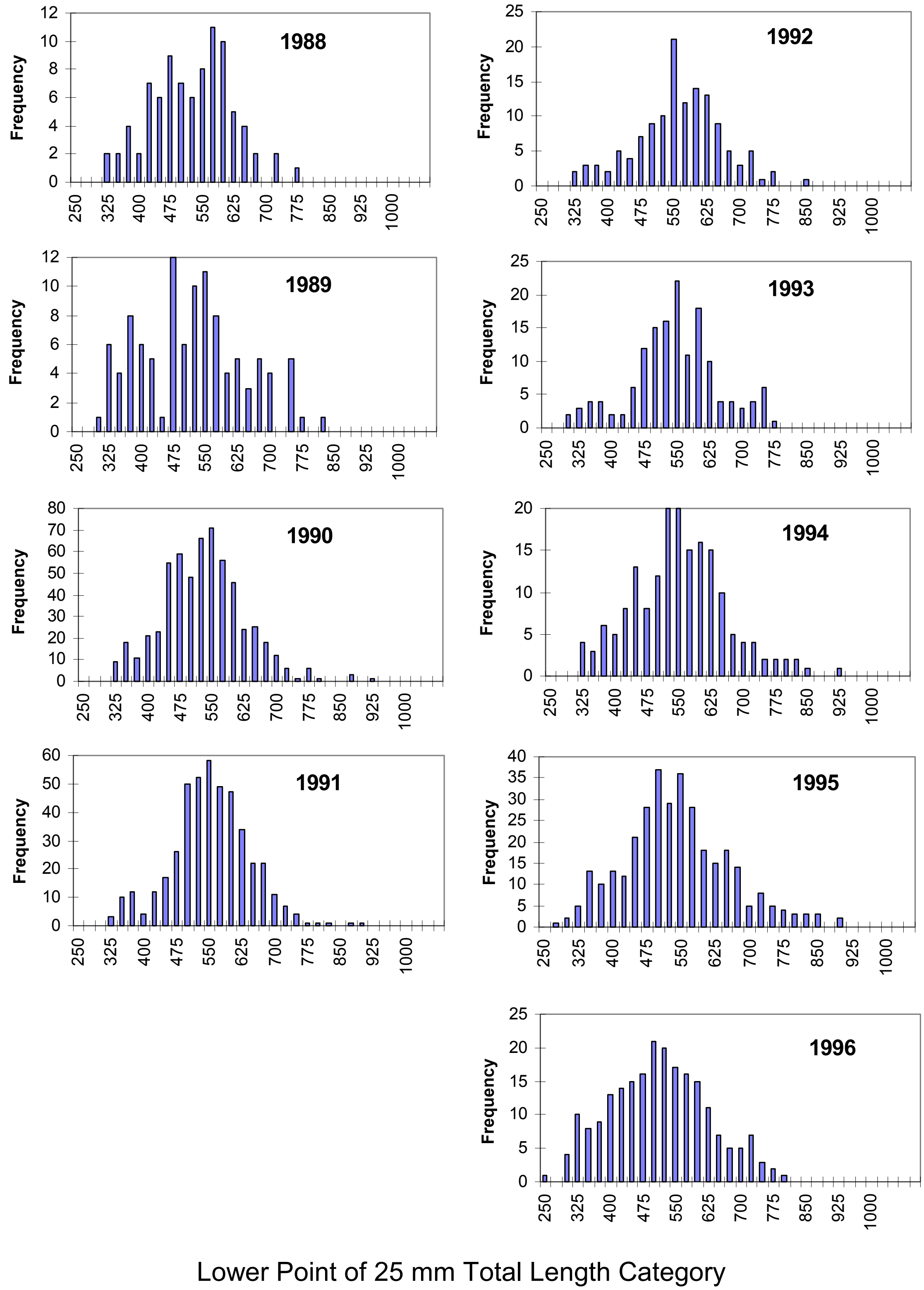

Figure 6.-Length frequency distributions of burbot sampled in the Chena River, 1988-1996.

Table 9.-Estimated total absolute abundance, mean exploitable abundance, and mean bootstrap estimates from the CAGEAN model, Tanana River burbot, 1987-1995.

	Total Absolute Abundance					Total Exploitable Abundance				
Year	Estimated	Mean	Stand. Dev.	cv	Bias	Estimated	Mean	Stand. Dev.	cv	Bias
1987	277,645	293,143	52,364	0.18	0.05	68,320	73,899	10,529	0.14	0.08
1988	251,277	269,167	43,855	0.16	0.07	67,098	71,756	8,698	0.12	0.06
1989	224,352	238,927	38,962	0.16	0.06	66,561	70,846	9,080	0.13	0.06
1990	191,139	205,710	35,919	0.17	0.07	65,107	69,360	9,831	0.14	0.06
1991	154,515	168,468	31,377	0.19	0.08	59,079	62,343	9,459	0.15	0.05
1992	126,352	141,326	30,543	0.22	0.11	51,654	55,372	8,230	0.15	0.07
1993	108,186	130,123	39,277	0.30	0.17	44,915	48,495	7,402	0.15	0.07
1994	97,445	129,353	53,608	0.41	0.25	36,239	40,187	6,723	0.17	0.10
1995	78,540	106,674	44,163	0.41	0.26	29,430	33,604	6,121	0.18	0.12

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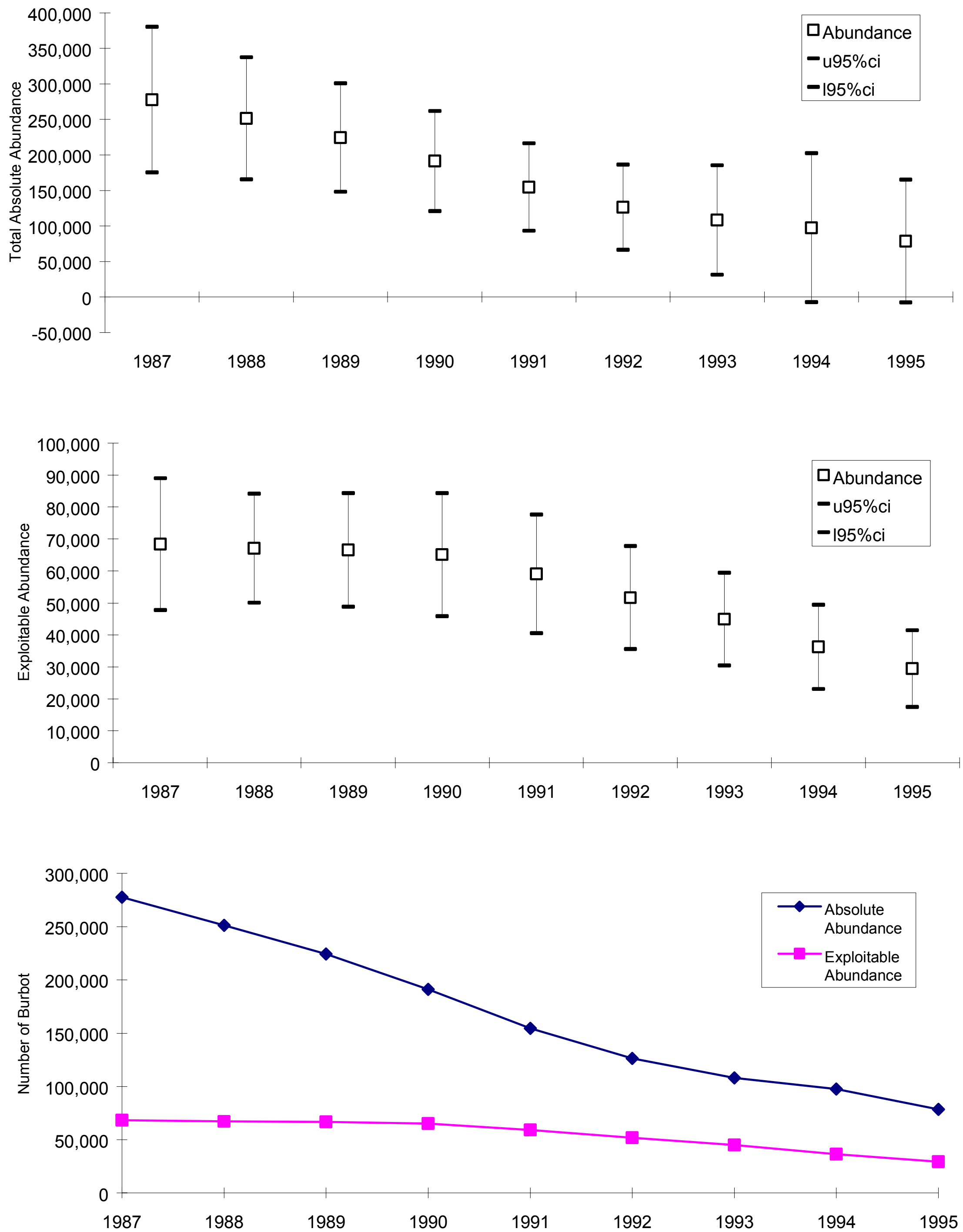

Figure 7.-Total estimated absolute and exploitable abundance of burbot in the Tanana River, 1987-1995.

Table 10.-Estimated total absolute abundance at age for burbot in the Tanana River, 1987-1995.

	Age											
Year	5	6	7	8	9	10	11	12	13	14	15	16+
1987	93,256	72,195	41,664	25,913	17,426	9,656	7,451	3,596	1,858	1,831	761	2,037
1988	71,560	61,659	47,538	27,054	16,779	10,424	5,776	4,457	2,151	1,111	1,095	1,673
1989	60,201	47,389	40,735	31,154	17,701	10,489	6,516	3,611	2,786	1,345	695	1,731
1990	45,925	39,829	31,246	26,551	20,259	10,781	6,388	3,968	2,199	1,697	819	1,477
1991	32,396	30,353	26,205	20,244	17,149	11,991	6,381	3,781	2,349	1,302	1,004	1,359
1992	27,010	21,434	20,016	17,085	13,169	10,459	7,314	3,892	2,306	1,433	794	1,441
1993	26,517	17,883	14,155	13,102	11,164	8,186	6,502	4,546	2,419	1,434	891	1,389
1994	29,891	17,502	11,733	9,099	8,388	6,367	4,668	3,708	2,593	1,380	817	1,300
1995	16,553	19,754	11,513	7,597	5,873	4,952	3,758	2,756	2,189	1,530	814	1,250

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Table 11.-Estimated fishing mortality at age for burbot in the Tanana River, 1987-1995.

	Age				
Year	5	6	7	8	9+
1987	0.004	0.008	0.022	0.025	0.104
1988	0.002	0.005	0.013	0.014	0.060
1989	0.003	0.006	0.018	0.020	0.086
1990	0.004	0.009	0.024	0.027	0.114
1991	0.003	0.006	0.018	0.020	0.084
1992	0.002	0.005	0.014	0.016	0.065
1993	0.005	0.011	0.032	0.036	0.152
1994	0.004	0.009	0.025	0.028	0.117
1995	0.007	0.015	0.043	0.048	0.204

Retrospective Analysis

A retrospective analysis from data collected through 1993, 1994 and 1995, 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 9) for most years. Estimates of terminal fishing mortality were lower in magnitude with each additional year of data added and were more divergent in recent years than in early years. Conversely, estimates of total absolute abundance were higher in magnitude with each additional year of data added and were more divergent in early years than in recent years.

Test for Equal Catchability Among Seasons

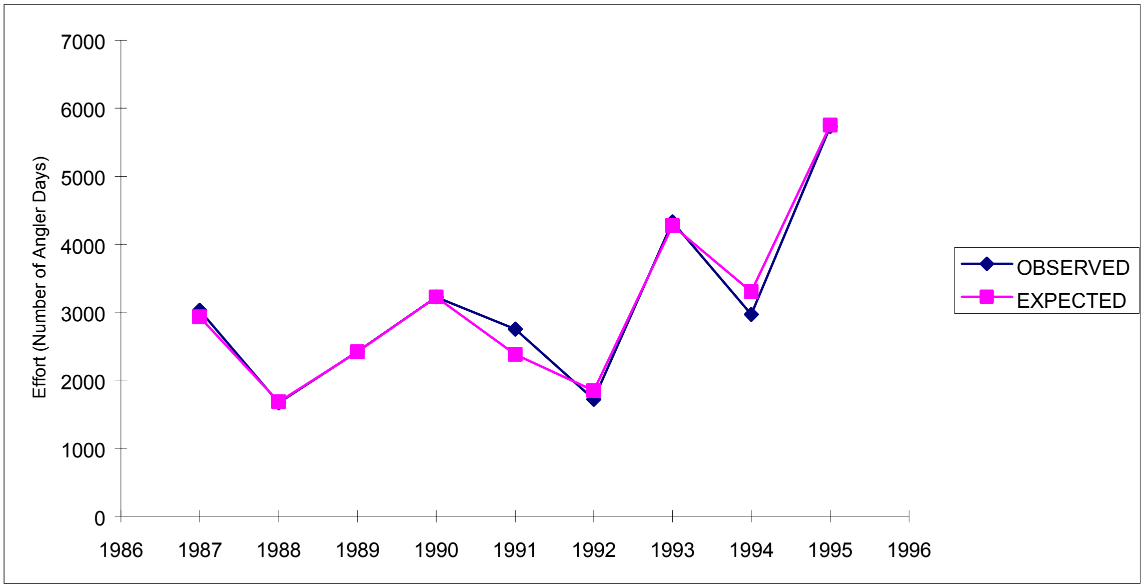
Comparison of the age distribution of samples collected during open-water periods and ice-cover periods of 1996 revealed that the two distributions overall were statistically similar (χ^2=22.0; df=13; P=0.06: Figure 10). However, proportions of pre-recruited (ages 4-8) and fully recruited burbot (ages 9 and older) were dissimilar (χ^2=12.2; df=1; P<0.001) with a higher proportion of fully recruited burbot (48%) caught during ice cover periods than during ice-free periods (24%).

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. Although harvests have remained relatively stable since 1981, the current regulations could potentially cause a much greater harvest given increased angler participation.

Accurate stock assessment of burbot in this system is difficult for a number of reasons. Because it 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 which 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 1996 estimates were similar to those obtained in previous years. 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 which 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



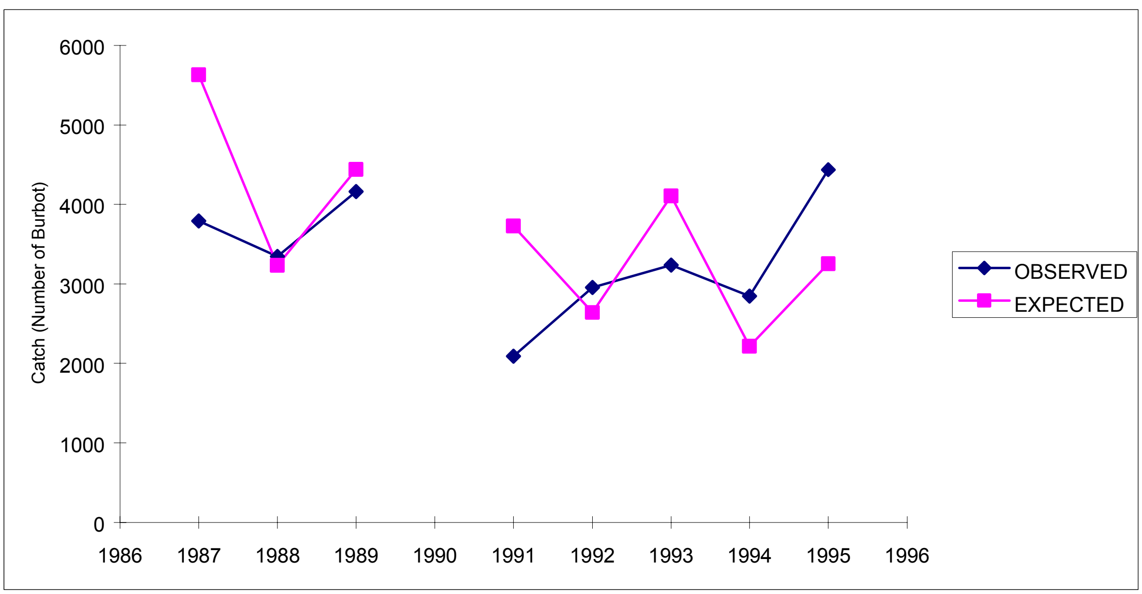
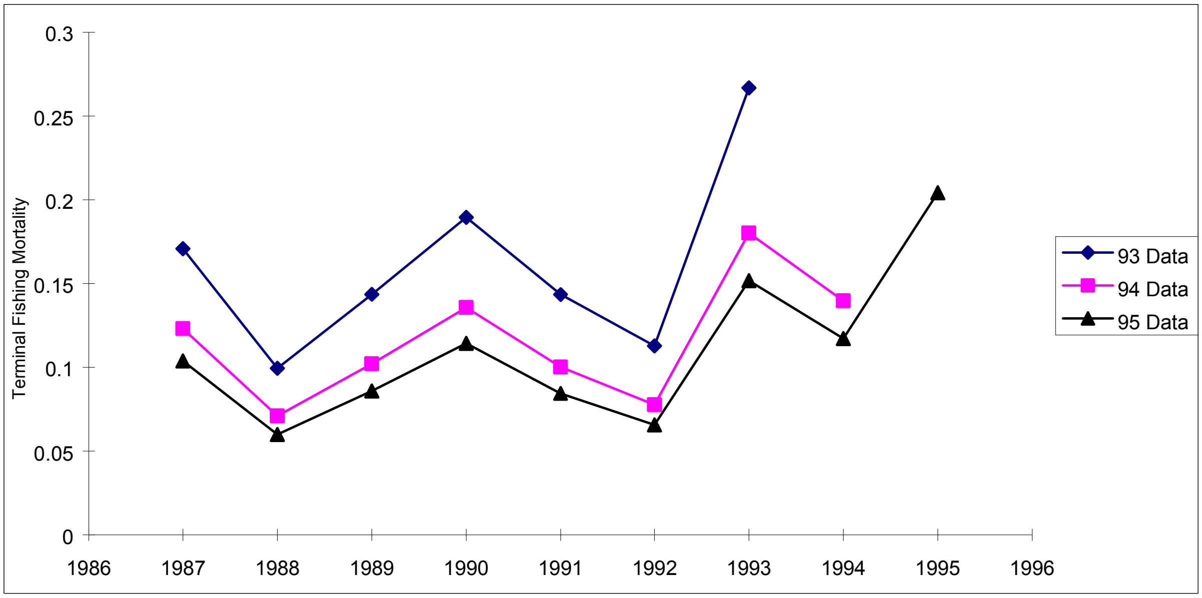


Figure 8.-Comparison of observed effort and catch with estimates predicted from the CAGEAN model, Tanana River, 1987-1995.



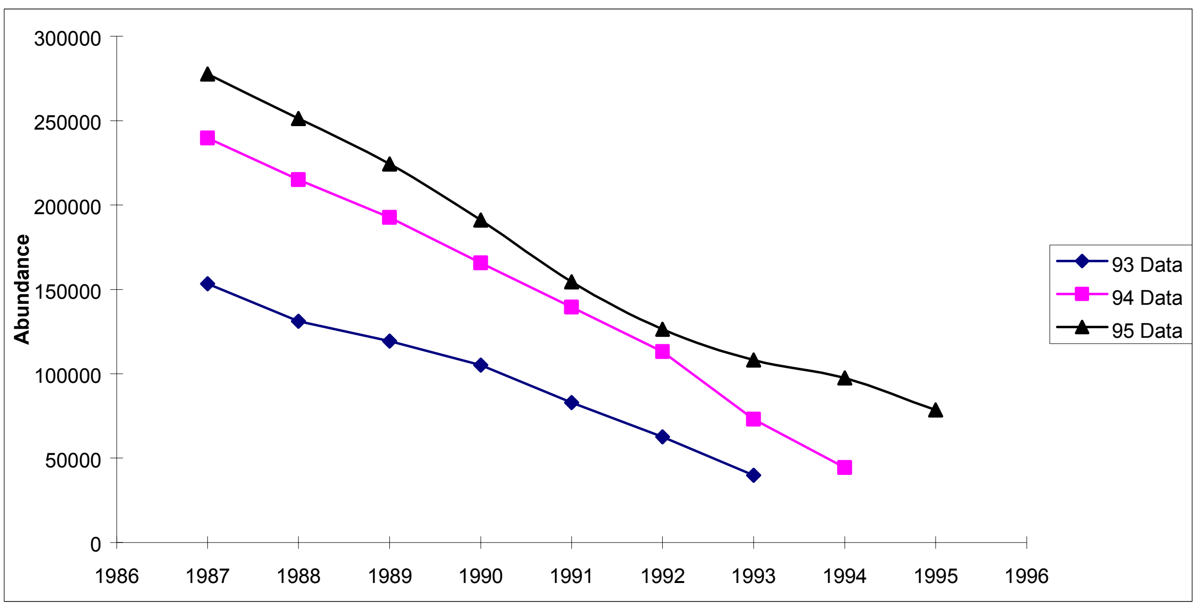


Figure 9.-A retrospective catch-age analysis of terminal fishing mortality and abundance estimates from the CAGEAN model from data collected through 1993, 1994, and 1995, respectively.

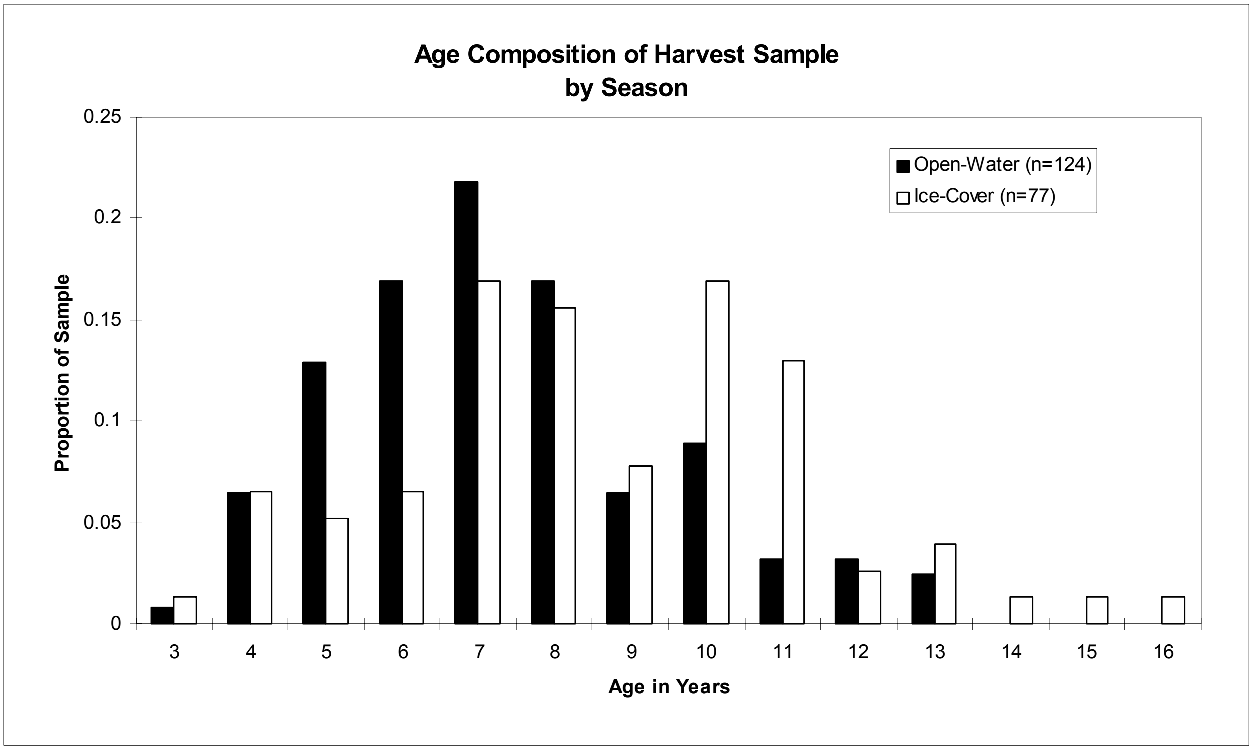


Figure 10.-Age distributions of burbot harvested in the Tanana River from samples collected during open water and ice-cover periods in 1996.

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, 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).

Catch-age analysis appears to be a promising method for estimating trends in abundance and fishing mortality for burbot in Tanana River drainage. The estimates of abundance appear reasonable (within an order of magnitude) compared to expansions of mark-recapture estimates of small index areas throughout the drainage (Evenson 1993a), and 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 6). Future modeling efforts should investigate models which incorporate length composition and CPUE information. Another explanation for the downward trend in abundance may be an artifice of CAGEAN. In a retrospective catch-age analysis of Pacific halibut *Hippoglossus stenolepus*, Parma (1993) found that estimates of stock abundance tended to be autocorrelated, with the stock consistently being overestimated or underestimated for a series of consecutive years. Hightower (1996) noted a similar autocorrelation 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 nine 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. The inadequacy of the length of the time series is also corroborated by the results of the retrospective analysis. The magnitude of changes in fishing mortality and abundance estimates with each additional years data indicates that information is incomplete for many cohorts.

In addition to the possibility of autocorrelation 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 which 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. Coefficients of

Variation (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. Comparison of age distributions from open-water and ice-cover samples from 1996 indicated differences in length compositions. Future catch sampling should attempt to increase overall sample sizes and include samples from both seasons.

Another constraint of the CAGEAN 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.

ACKNOWLEDGMENTS

Dave Stoller, James Savereide, and Lisa Stuby expertly assisted with collecting data. Local sport fishermen voluntarily contributed samples for age analysis. Lisa Stuby assisted with aging otoliths and running iterations of the CAGEAN program. Mike Wallendorf provided biometric support and technical reviews. 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)

[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).

TANANA BURBOT 1987-1995

cagfrst.out	(Name of output file)
1987 1995	(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 1995	(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)
50	(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)

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

TANANA BURBOT 1987-1995	
cagfrst.out	(Name of output file)
1987 1995	(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 1995	(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)
50	(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).

1987	1	3026
1988	1	1666
1989	1	2421
1990	1	3225
1991	1	2748
1992	1	1721
1993	1	4329
1994	1	2968
1995	1	5732

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

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

-continued-

12	1991	1	5.5139
13	1991	1	5.1084
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

-continued-

Appendix B4.-Page 4 of 4.

15	1993	1	5.7365
16	1993	1	6.0932
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

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

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 1989-1995.

APPENDIX C.

Appendix C.-Tanana River burbot harvest 1977-1995, by river section.

Annual Harvest[a] River	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
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
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
Upper Tanana R.[b]	0	0	0	0	0	0	0	0	0	0	409	509	411	641	654	338	685	823	838
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
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
Nenana R.[d]	0	0	0	0	0	0	0	0	0	0	53	0	60	68	11	76	11	0	0
Minto Flats	37	72	45	9	32	21	0	39	105	32	132	0	20	0	56	0	0	208	161
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
Salcha R.	0	0	0	0	0	0	0	0	35	296	0	18	0	203	23	25	64	21	23
Piledriver Sl.[d]	0	0	0	0	0	0	0	84	0	0	79	55	100	456	203	195	568	73	299
Shaw Cr.[d]	0	0	0	0	0	0	0	415	175	120	607	0	170	354	45	161	161	93	138
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
Goodpaster R.[d]	0	0	0	0	0	0	0	221	350	88	13	109	120	0	0	17	86	0	23
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
% Total											9.5	10.7	2.4	10.8	1.1	2.8	5.3	12.0	0.7
Total Lower River											238	273	220	321	180	177	22	388	424
% Total											6.3	8.0	5.2	9.0	8.2	5.3	0.4	7.9	9.1
Total Middle											2,708	2,151	3,356	2,229	1,330	2,695	4,388	3,115	3,349
% Total											72.2	63.2	79.4	62.3	60.8	81.2	80.2	63.4	71.7
Total Upper River											448	618	531	641	654	355	771	823	861
% Total											11.9	18.1	12.6	17.9	30.0	10.7	14.1	16.7	18.4
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

[a] Data from Alaska statewide harvest survey (Mills 1978-1994, and Howe et al. 1995-1996)

[b] River sections were not described as specific areas on the survey form until 1987.

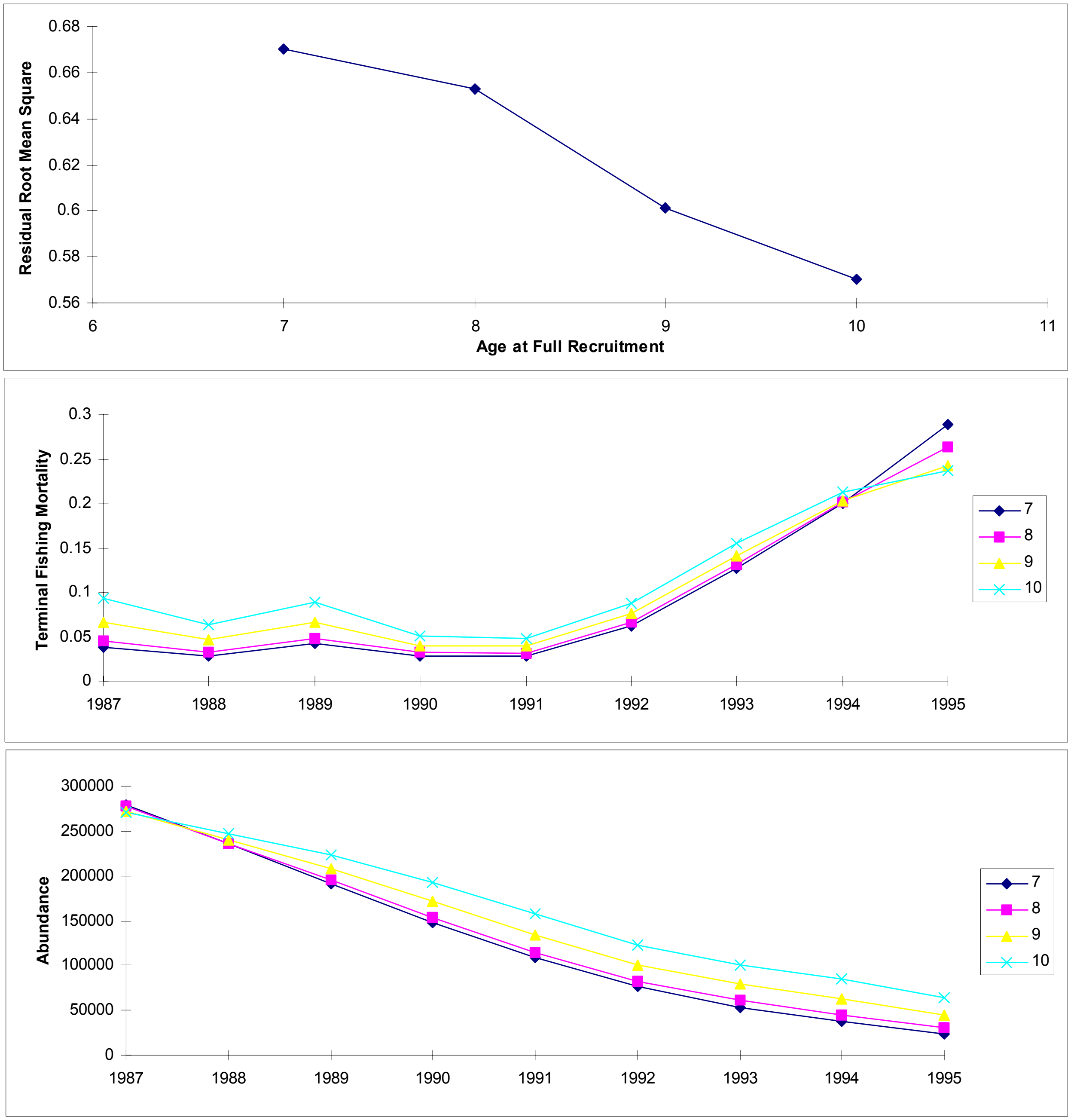
[c] Includes harvests from upper, middle, lower, and unspecified sections.

[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.

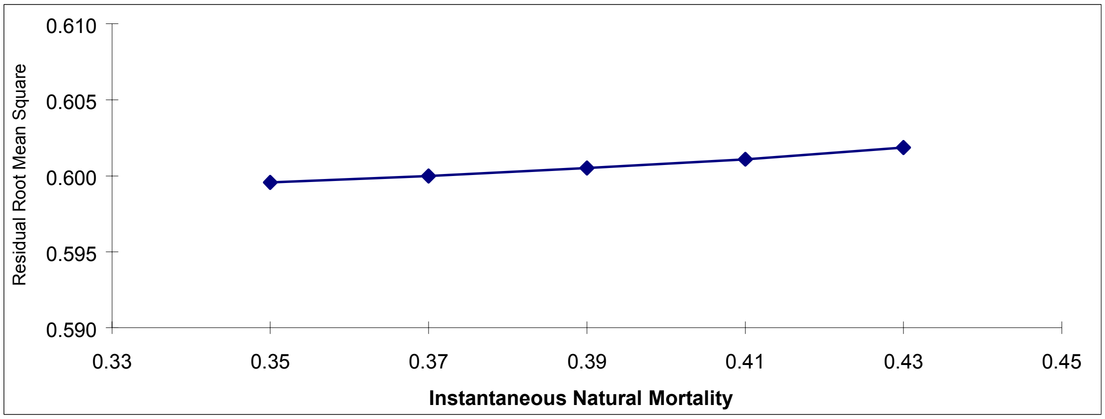
[e] Was described as “Other Waters” on the survey form until 1984, and may have included harvests from lakes and ponds. Beginning in 1984, this category is listed as “Other Streams” on the survey form.

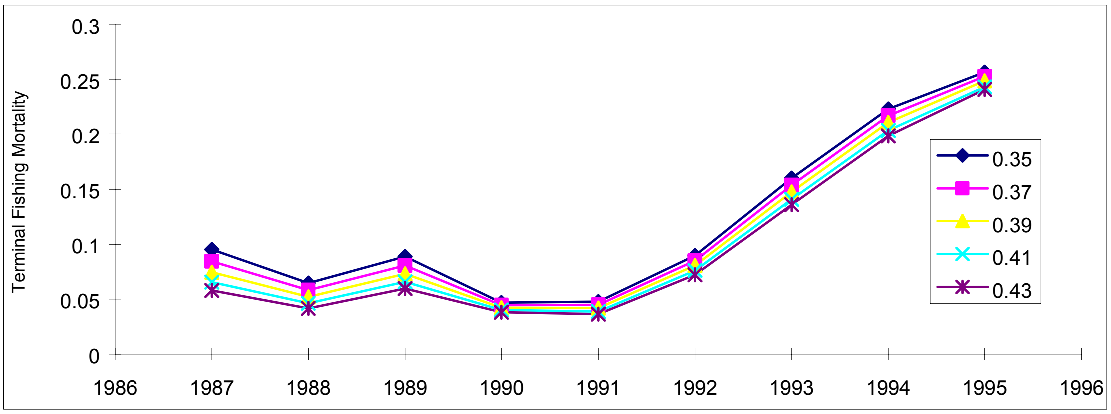
APPENDIX D
Iterations of the CAGEAN model to examine the affects of various ages of full recruitment, instantaneous natural mortality rates, and effort lambda values on model residual root mean square, terminal fishing mortality estimates, and total absolute abundance.

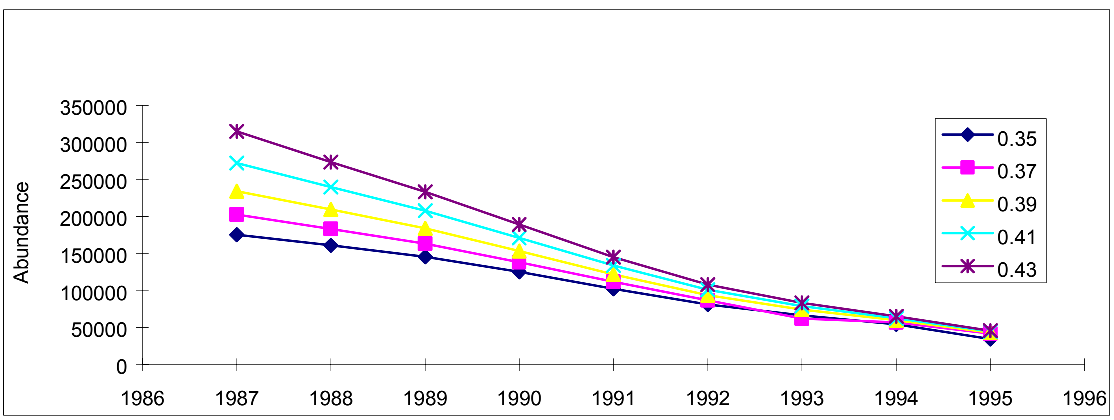
Appendix D1.-Effects of various age of full recruitment values on model residual root mean square, terminal fishing mortality estimates, and total absolute abundance.



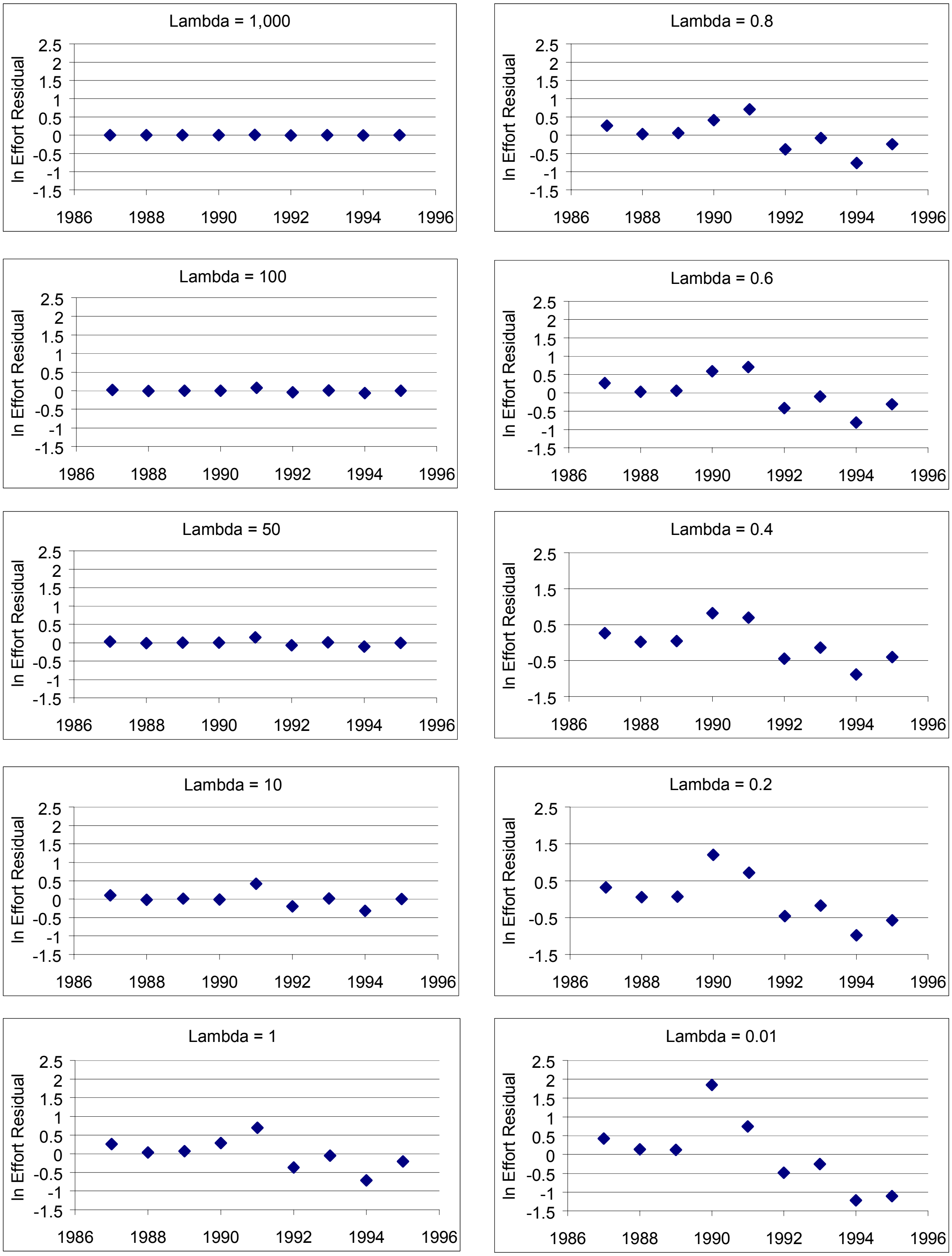
Appendix D2.-Effects of various instantaneous natural mortality values on model residual root mean square, terminal fishing mortality estimates, and total absolute abundance.



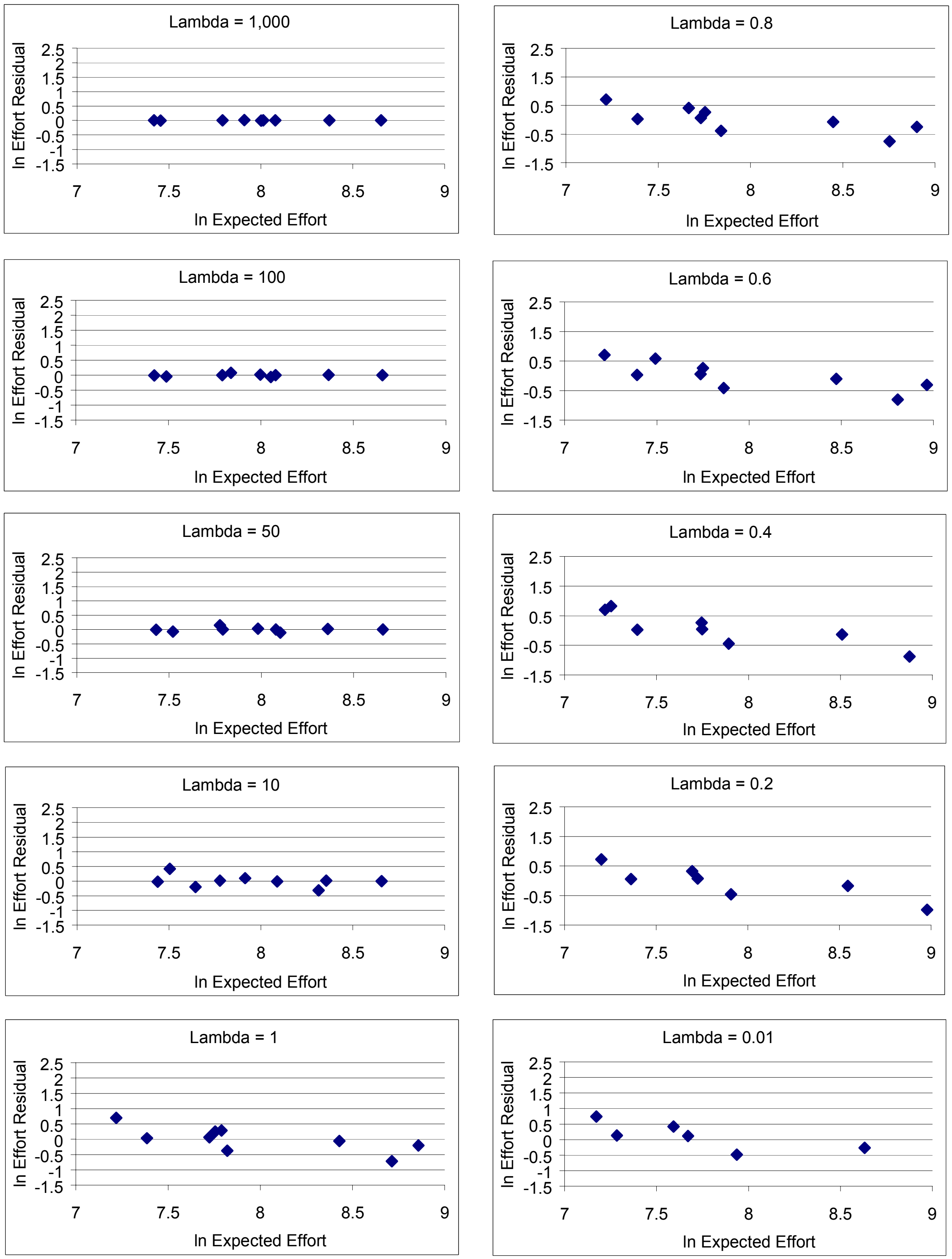




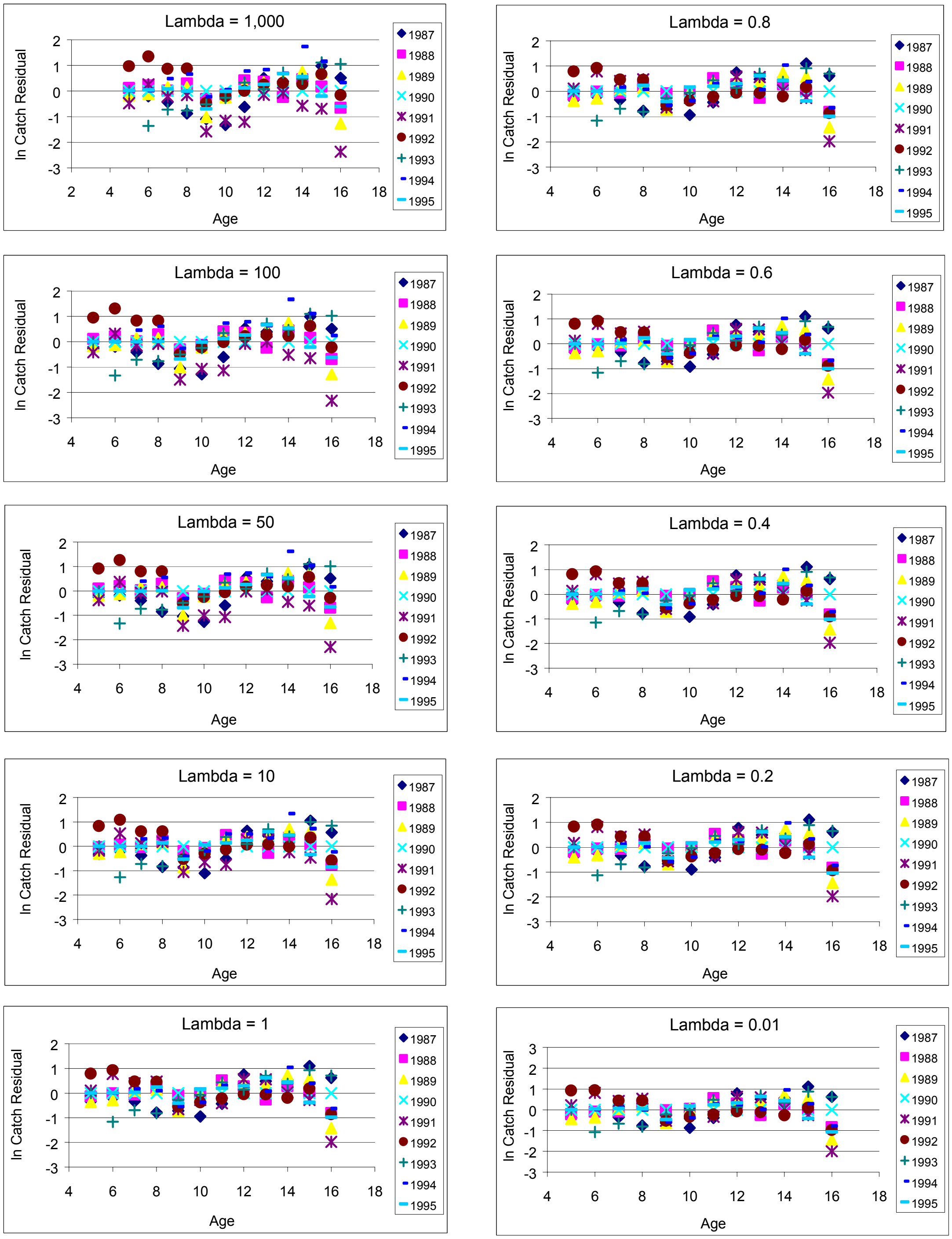
Appendix D3.-Plots of effort residuals by year for various lambda values.



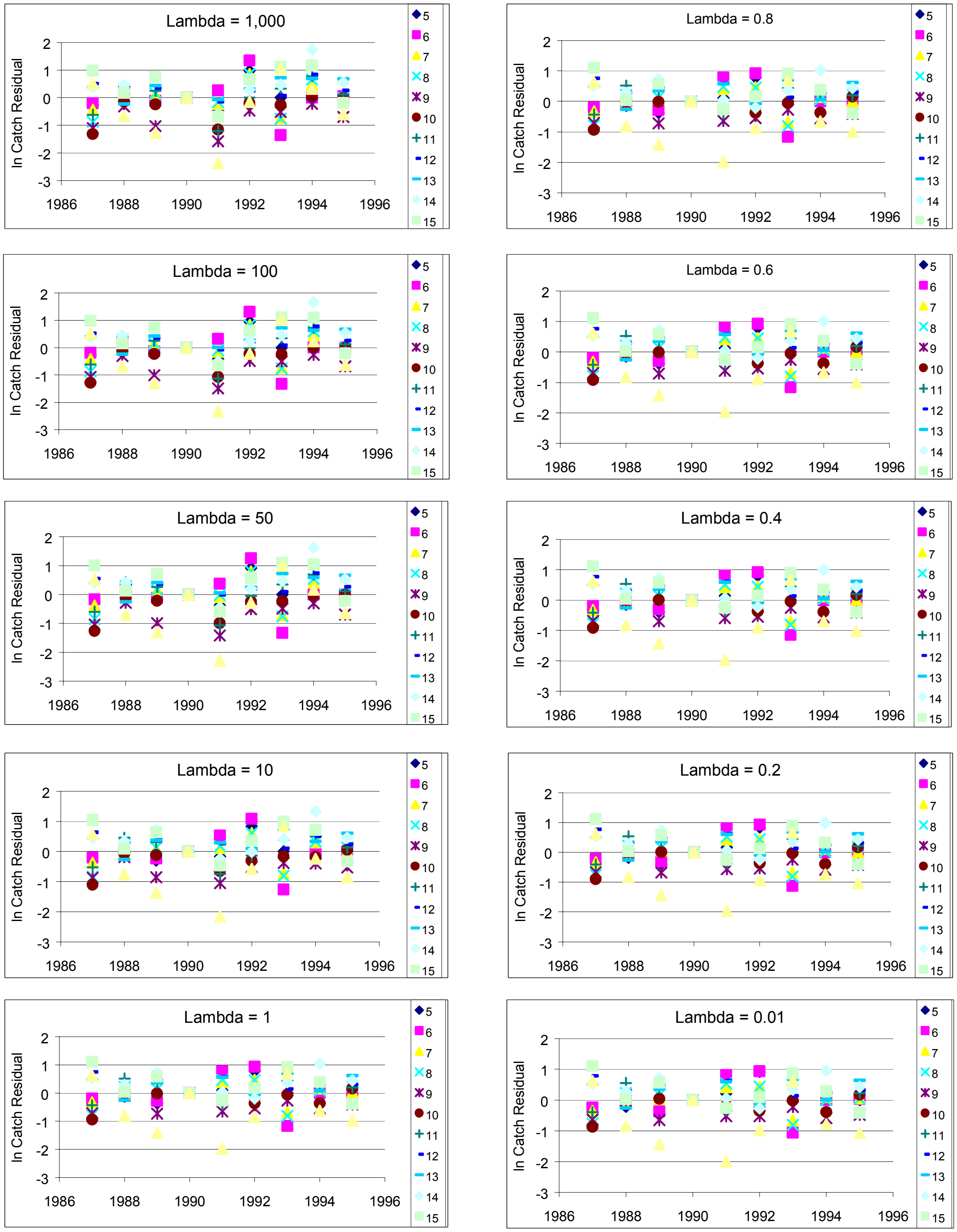
Appendix D4.-Effort residuals versus expected effort for various lambda values.



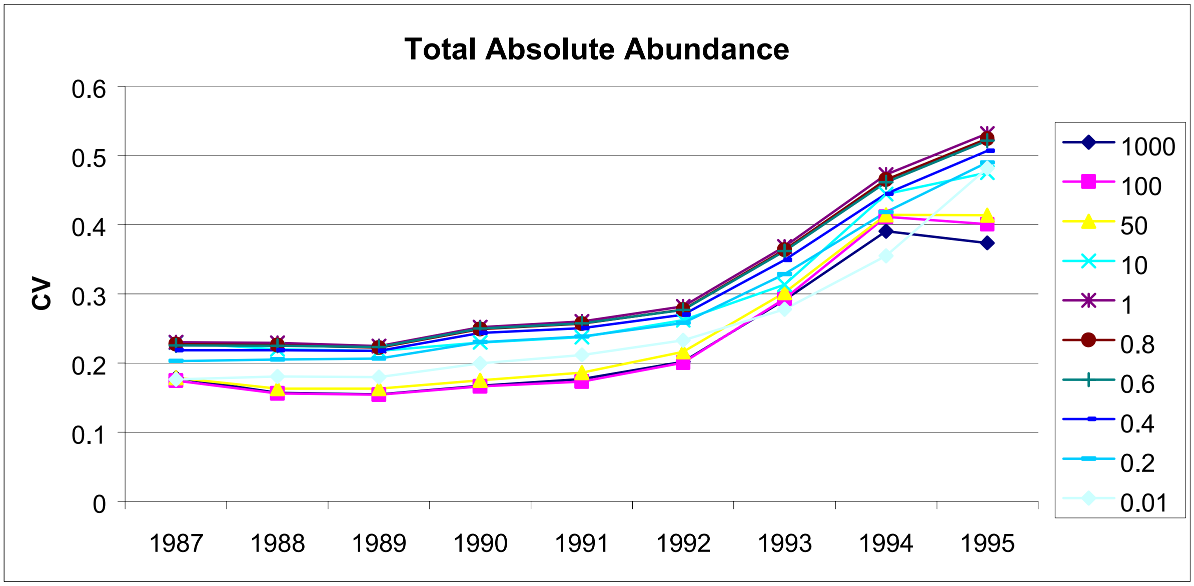
Appendix D5.-Plots of catch residuals by age using years as labels for various lambda values.

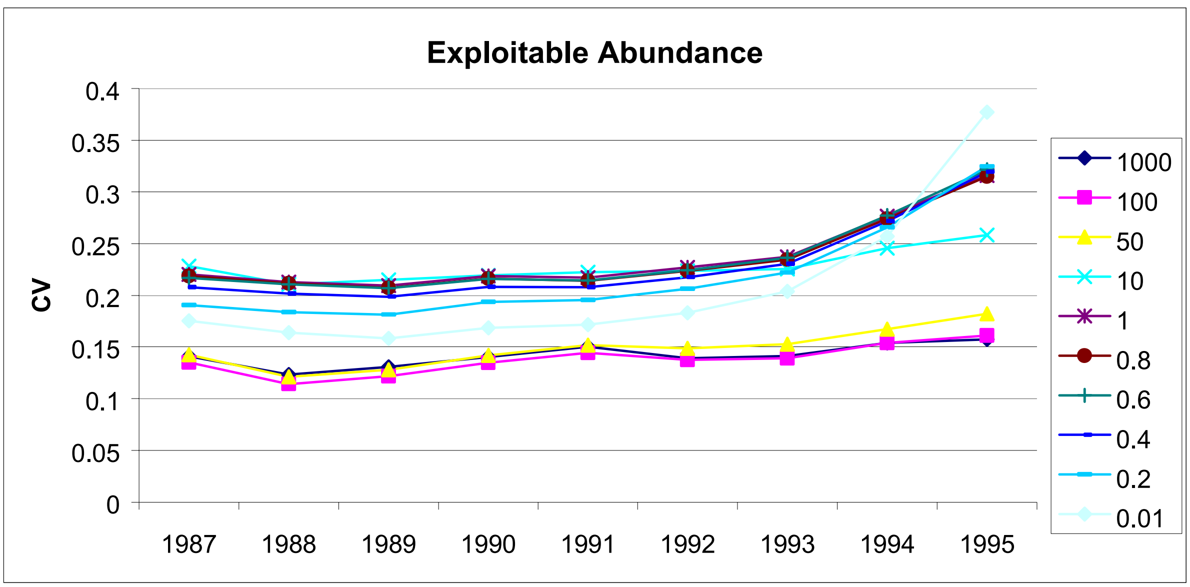


Appendix D6.-Plots of catch residuals by year using age as labels for various lambda values.



Appendix D7.-Plots of coefficient of variation by year for estimates of total absolute abundance and exploitable abundance for various lambda values.





Appendix D8.-Plots of estimates of total absolute abundance and exploitable abundance for various lambda values.