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Revised Biological Escapement Goal for the Sockeye Salmon Stock Returning to the East Alsek-Doame River System of Yakutat, Alaska

by

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and

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June 2003

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.

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

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
hour	h
minute	min
second	s

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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The Special Publication Series was established in 1991 for the publication of techniques and procedures manuals, informational pamphlets, special subject reports to decision-making bodies, symposia and workshop proceedings, application software documentation, in-house lectures, and other documents that do no fit in another publication series of the Division of Sport Fish. Special Publications are intended for fishery and other technical professionals. Special Publications are available through the Alaska State Library and on the Internet: http://www.sf.adfg.state.ak.us/statewide/divreports/html/intersearch.cfm. This publication has undergone editorial and peer review.

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TABLE OF CONTENTS

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

LIST OF APPENDICES

Appendix **Page**

ABSTRACT

Available information on age compositions, escapements, and harvests of sockeye salmon *Oncorhynchus nerka* returning to the East Alsek-Doame river system located southeast of Yakutat, Alaska, during the years 1972–2001 was collated. This information was used to develop annual run reconstructions for the years 1972–2001 and to develop a brood table of estimated escapements and age-specific total returns (recruits) for brood years 1972–1997. These data were subsequently used to estimate a spawner-recruit relationship. Analysis of residuals of the stock-recruit relationship demonstrated a trend with a decrease in stock productivity in the 1990s. It is hypothesized that the lack of flooding and resultant reduction in quality of spawning habitat is directly responsible for this reduced productivity. Insufficient escapement contrast, too few data points and a clumping of data points available around the replacement level prevented traditional stock-recruit analysis of the information from the lower production years of the 1990s. Instead, the replacement level was directly estimated. Next, the average ratio between escapements predicted to provide maximum sustained yield fisheries and replacement levels for other studied stocks of sockeye salmon in the Yakutat area was calculated. This average ratio was multiplied by the estimate of replacement to provide a point estimate of the escapement level predicted to provide for maximum sustained yield from the East Alsek-Doame river system stock of sockeye salmon under the reduced productivity experienced by the stock since the early 1990s. From this calculation, a revised biological escapement goal of 13,000 to 26,000 sockeye salmon counted during a peak survey of the East Alsek-Doame river system is recommended. It is recommended that this goal be considered interim and be updated in 2005. Further, it is recommended that the stock-recruit data be updated each year to evaluate productivity status and help determine if the stock dynamics have stabilized at the level observed for brood years 1991–1997. Lastly, recommendations are made to conduct mark-recapture experiments to estimate total escapements for this stock of sockeye salmon.

Key words: sockeye salmon, *Oncorhynchus nerka*, East Alsek River, Doame River, brood table, biological escapement goal, maximum sustained yield, spawner-recruit relationship, catch-age analysis

INTRODUCTION

The East Alsek-Doame river system is located southeast of Yakutat, Alaska (Figure 1). The East Alsek River was formed when the glacially occluded transboundary Alsek River changed channels about a century ago. The Alsek River now enters the ocean about three miles to the northwest of the mouth of the East Alsek River. Intergravel flow from the glacially occluded Alsek River feeds clear water through a gravel berm into the East Alsek River. Hence, the East Alsek River is simply a portion of the old Alsek River channel with clear running water and no direct interconnection with the Alsek River itself, except under extensive flood conditions. The Alsek River is a large river system draining an extensive area of the Yukon Territory in Canada and a portion of the southeastern Alaska panhandle. The East Alsek River drainage, on the other hand, is much smaller, and the river extends only about nine miles in length before entering an estuary lagoon and the Gulf of Alaska.

Prior to 1966, the East Alsek River and the Doame River were separate entities, each with a mouth that emptied into the Gulf of Alaska. An earthquake in 1966 caused the Doame River mouth to be sealed off from the ocean. The Doame River then formed a new channel to the west just inside the beach line until it joined with, and became a tributary of, the East Alsek River. The Doame River system includes a lake and this river system also has clear water. Anadromous fish returning to the Doame River system must now enter the East Alsek River and pass through the East Alsek commercial fishery area before branching off to return to spawn in the Doame River system.

It is assumed that the Doame River system has supported anadromous salmon for several centuries. The Doame River system provides spawning and rearing habitat for sockeye salmon *Oncorhynchus nerka* and coho salmon *Oncorhynchus kisutch* stocks that are commercially utilized as well as supporting minor subsistence and sport fisheries. The Doame River stock of sockeye

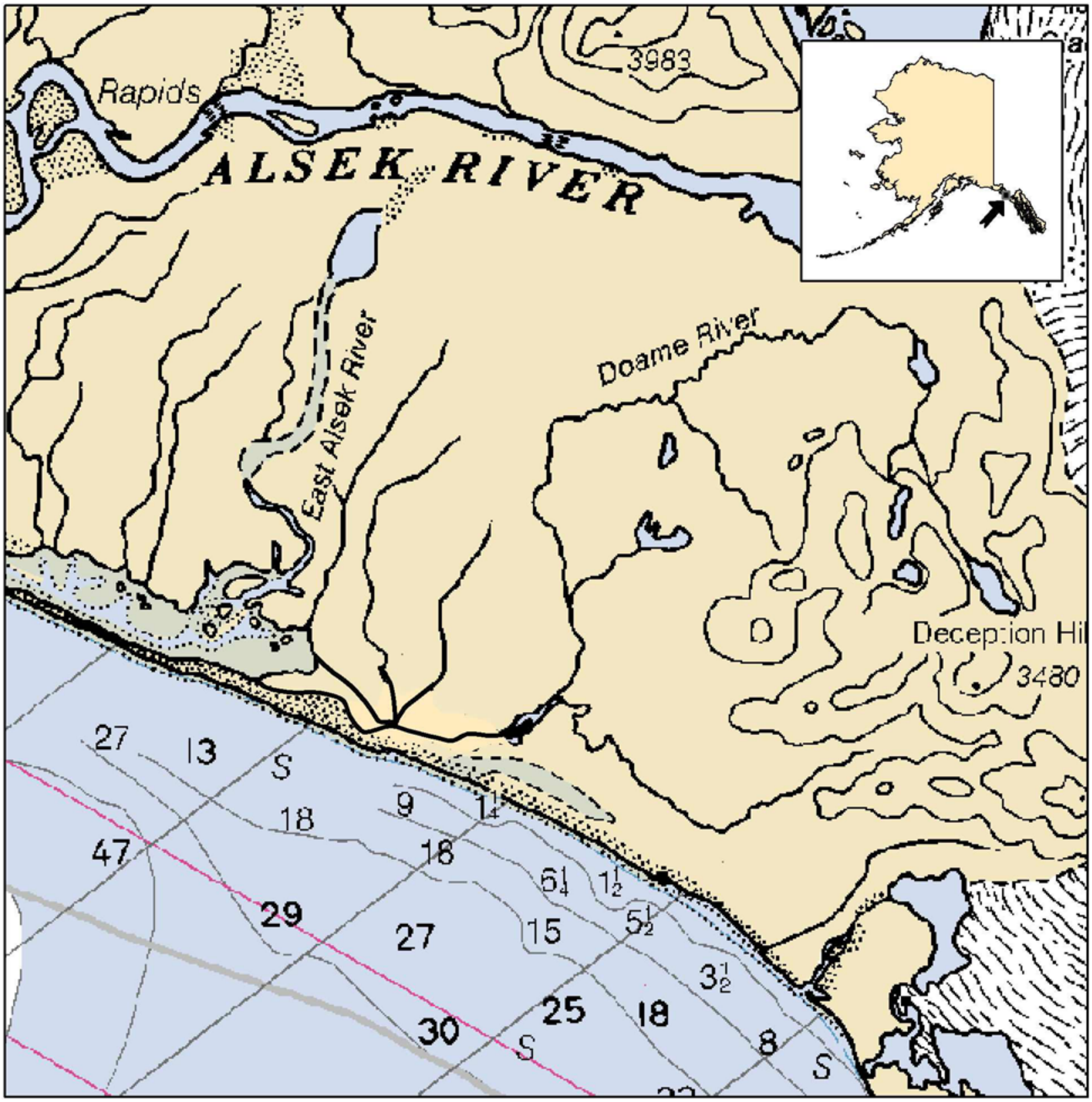

Figure 1.–Map of East Alsek-Doame river system.

salmon is small in magnitude, but is a relatively stable population that has likely never exceeded total runs in excess of about 10,000 fish.

Early in the 20th century, anadromous salmon invaded the newly created clear waters of the East Alsek River, utilizing the river's unique spring-type habitat for spawning and rearing phases of their life history. The East Alsek River provides spawning and rearing habitat for sockeye salmon, coho salmon, and chum salmon *Oncorhynchus keta* stocks that are commercially utilized as well as supporting minor subsistence and sport fisheries. The East Alsek River was not, historically, a major sockeye salmon producing river system, it was primarily considered to be a chum salmon producer. In the latter parts of the fall, runs of coho salmon returning to the river system were harvested. Historically, small family groups of commercial fishermen made wages on the sockeye salmon run, and were then joined by other commercial fishermen for the larger magnitude chum salmon fishery. From 1947 through 1970, the highest annual commercial catch reported for sockeye salmon was 17,000 fish in 1954, and from 1956 through 1968, the highest catch was 6,500 sockeye salmon in 1962. In most of those years, sockeye salmon harvests did not exceed 3,000 fish. It was not until the late 1970s and early 1980s that sockeye salmon catches started climbing exponentially. In these two decades, the sockeye salmon stock grew to a magnitude of in excess of about 250,000 fish in the annual runs in some years. From the mid-1990s to the present, the numbers of returning sockeye salmon have dropped to the point that there hasn't been a commercial opening for sockeye salmon in the East Alsek commercial fishery for the past three years. Peak counts of coho salmon observed spawning in the East Alsek-Doame river system over the past 30 years have mostly ranged from about 1,000 to 10,000 fish with annual total runs likely ranging from about 5,000 to 50,000 fish.

Sockeye salmon use the East Alsek River system for spawning, but only for very short-term rearing. The river, with its crystal clear water, favorable water temperatures, excellent substrate, and favorable flows provided exceptional spawning habitat through the 1970s and 1980s. As a result, the sockeye salmon stock quickly grew to a magnitude of up to a quarter million fish in some years. The stock is unique in that virtually all of the East Alsek River sockeye salmon are "zero checks." These fish migrate to sea the year they hatch, similar in life history patterns to chum salmon, rather than to typical sockeye salmon that rear in fresh water for one to three years after hatching. Adaptation of sockeye salmon with this unique life history characteristic and the exceptional spawning habitat in the East Alsek River allowed this stock to explode in magnitude from the mid 1970s through the early 1990s.

Available data demonstrate an approximately 25-year sockeye salmon "event." The joining of the East Alsek River and the Doame River waters in the large lagoon in 1966 is a likely contributing factor that added a large amount of rearing habitat in the lagoon. Basically, the lagoon provides some of the function of a lake as found in more traditional sockeye salmon producing systems. The 1959 earthquake was likely responsible for a second significant change. The flow of the Alsek River was shifted from a westerly to an easterly course. An examination of the geography of the Yakutat area shows that all rivers in the Yakutat area to the southeast of the Tsiu River[1] break out into the Gulf of Alaska to the west. And some of these rivers, like the East Alsek River and the Akwe River, flow westward inside the beach for several miles before actually breaking out into the ocean. With the Alsek River migrating eastward, more water was probably available for upwelling in the East Alsek River.

But likely of more importance were major flood events in the Alsek River itself. From 1964 to 1983, there were four major flood events in the Alsek River. During each of these flood events, the Alsek River overran its banks and poured down the East Alsek River. These flood events scoured the spawning gravel and cleaned out the emergent vegetation growing in the East Alsek River. The last time the Alsek River overflowed its banks and flooded the East Alsek River was in 1981 and it was a minor event lasting about 24 hours. No subsequent flood in the Alsek River has overflowed and scoured the East Alsek River, because the Alsek River by the early 1980s had resumed its migration to the west. In 1997, the Alsek River had a 100-year flood event. No one in living memory had seen the Alsek River so high, and it took out a cabin that had been on the river for over 60 years. That flood did not overflow into the East Alsek River. East Alsek commercial fishermen have had to contend with the algae produced on the sockeye salmon spawning grounds in the upper East Alsek River. Even on an incoming tide, fishermen have to continuously shake their net to clean it, and the river is all but impossible to fish on an outgoing tide. As soon as the tide turns, all nets are wrapped up to the cork line to allow the algae to pass freely under the net. By itself, the East Alsek River, even in flood stage, is not powerful enough to scour the algae. It takes the physical force of an overflowing Alsek River to scour the

[1] In the Yakutat Management Area, the Tsiu River is the river located the farthest northwest in the area.

emergent vegetation out of the East Alsek River. For the past decade, the upper East Alsek River has been choked with vegetation, and it is estimated that 60% of the spawning gravel is no longer accessible to sockeye salmon.

Thus, we believe that the major factor responsible for the East Alsek River 25-year sockeye salmon "event" was the periodic (about every 5 years) flushing of the gravel beds in the East Alsek River by flood events in the much bigger transboundary Alsek River. The last flood event of this type occurred in 1981, and by the early 1990s the spawning habitat of the East Alsek River had deteriorated considerably. Although sockeye salmon escapements in the early 1990s were within the range of what was predicted to provide for excellent production, those escapements produced few recruits in subsequent years. Emergent vegetation and the silting in of the gravel beds has greatly deteriorated the quality of the spawning habitat. Thus, we believe the history of the magnitude of sockeye salmon in the East Alsek River includes the following:

1. invasion in the early 1900s,
2. adaptation to the unique environment with a subsequent unique life history feature,
3. population explosion in the 1970s and 1980s, and
4. lesser abundance since the early 1990s because of deteriorating spawning habitat.

The stock assessment program for the East Alsek-Doame river system consists of flying aerial surveys of both the East Alsek River and the Doame River to count spawners, collection and tabulation of fish tickets and subsistence catch reports, and monitoring of the sport fishery through a postal questionnaire. Sampling of the commercial catch and the East Alsek River escapement for age, sex, and length information also takes place.

The commercial fishery is actively managed, whereas only passive management (fishery monitoring) of the subsistence and sport fisheries occurs. Active management of the commercial fishery consists of weekly aerial surveys of spawning escapements and variable openings of the commercial fishery on a weekly basis. Management intent has been to achieve an escapement objective of 26,000 to 57,000 sockeye salmon in the East Alsek-Doame river system on an annual basis. The biological escapement goal was adopted by ADF&G in 1995 based on stock-recruit analysis of the 1972–1990 brood years (Clark et al. 1995a). Run timing for the two sockeye salmon spawning populations has always been considered to be different, with Doame River sockeye salmon entering the terminal fishery from early June through mid-July, and East Alsek River sockeye salmon entering the fishery from late July into September. In many years through active management, the East River commercial fishery was either curtailed or closed during the early weeks to provide additional protection for the smaller Doame River sockeye salmon population while the more dominant East Alsek River sockeye salmon population was more heavily exploited later on in the same season.

As is apparent in the preceding paragraphs there is information indicating that dynamics of the East Alsek-Doame river system sockeye salmon stock have changed substantially in the past decade. Further, there are observations that the quality of the spawning habitat has changed. Eight years have passed since the biological escapement goal used to actively manage the commercial fishery was developed. In the interim period, additional data have been collected. The objective of this technical report is to review the data available and determine if the ADF&G biological escapement goal of 26,000 to 57,000 for the East Alsek-Doame River stock of sockeye salmon is still appropriate, and if not, to identify an alternate biological escapement goal for future fishery management.

RUN RECONSTRUCTIONS

HARVESTS

A terminal commercial fishery for East Alsek-Doame river system sockeye salmon takes place in the lower East Alsek River, lagoon, and in the near shore ocean waters. Fishing gear is limited to set gillnets. Commercial harvests of sockeye salmon in the East Alsek commercial fishery (commercial fishing subdistricts 182-20, 182-21, and 182-22) from 1972 to 2001 were summarized from fish ticket information. Fish tickets are sales receipts filled out when commercial fishers sell fish to processors. These three fishing subdistricts represent the terminal commercial harvest for the East Alsek-Doame river system stock of sockeye salmon. Although it is possible that a few East Alsek-Doame river system sockeye salmon are caught in nonterminal commercial fisheries, there is no direct evidence to support this supposition and it is likely that any interceptions are very minor in comparison to the majority of annual terminal commercial harvests. The terminal commercial harvest estimates reported herein are considered to be annual censuses without biases and without sampling variances. Commercial harvests over this 30-year period ranged from no sockeye salmon harvested in the years 1999–2001 to a peak harvest of 189,207 sockeye salmon in 1993 (Table 1).

A subsistence fishery that sometimes targets East Alsek-Doame river system sockeye salmon takes place and is located in the lower East Alsek River, lagoon, and near shore ocean waters. For the most part, subsistence fishers are the same individuals that commercial fish. They use the same gear to subsistence fish when the commercial fishery is closed or they retain some fish caught during commercial fishing periods for personal use. Subsistence permits are annually issued by ADF&G to individuals who wish to participate in the subsistence fishery. At the end of the year, these individuals are required to return the permit, including a written record of the number of fish harvested. Existing subsistence catch records from these returned permits were summarized to estimate annual subsistence harvests of sockeye salmon in the East Alsek fishery. Annual subsistence harvests of East Alsek-Doame river system sockeye salmon are estimated to have been about 300 fish per year during the early 1990s (Table 1).

Subsistence harvest estimates are judged to be reliable as far as information turned in on subsistence permits. What is unaccounted for to some extent is the number of sockeye salmon retained for personal use by commercial fishers from their commercial catch. Historically, during the early weeks of the season, fishermen set nets just to hold the setnet site while they waited for the run to develop. Often these fishermen did not go to the trouble of selling the few fish they caught early in the season. The ADF&G has always requested that those fish retained for personal use be reported on fish tickets, but there is no enforceable regulation to require this action and those fish may go unreported. There is not a scientific method to estimate these numbers. However, professional judgment of the local fishery manager is that it is doubtful in any given year that more than 100 fish were kept for personal use. As a result, a moderate negative bias is likely associated with these numbers. Further, an unknown level of sampling variance is associated with these annual estimates of harvest. However, subsistence harvests are so minor in comparison to commercial harvests as to be all

Table 1.–Estimated annual terminal harvests of East Alsek-Doame River system sockeye salmon from 1972 to 2001.

Year	Commercial	Sport	Subsistence	Total harvest
1972	9,575	0	0	9,575
1973	12,342	0	0	12,342
1974	14,520	0	0	14,520
1975	18,235	0	0	18,235
1976	30,057	0	0	30,057
1977	21,500	0	0	21,500
1978	30,922	0	0	30,922
1979	47,442	0	0	47,442
1980	48,616	0	0	48,616
1981	49,126	0	0	49,126
1982	98,501	0	0	98,501
1983	81,362	0	0	81,362
1984	39,373	0	0	39,373
1985	184,962	0	0	184,962
1986	74,972	68	0	75,040
1987	133,740	0	0	133,740
1988	61,483	0	0	61,483
1989	145,426	95	70	145,591
1990	161,383	0	30	161,413
1991	45,334	45	285	45,664
1992	144,378	82	189	144,649
1993	189,207	39	235	189,481
1994	99,998	0	335	100,333
1995	11,772	134	70	11,976
1996	55,025	0	64	55,089
1997	12,665	11	0	12,676
1998	5,802	138	0	5,940
1999	0	792	0	792
2000	0	598	44	642
2001	0	EO closure	unknown	<1,000

but inconsequential in most years (Table 1). From 1999 to 2001, when commercial harvest did not occur, subsistence harvests were minor and inconsequential in comparison to documented escapement.

A minor sport harvest takes place in the East Alsek and Doame rivers. Two sport lodges are located midway between the mouth of the East Alsek River and the Doame River. Annual sport harvests are estimated from an annual post-season mail-in survey of licensed sport anglers. These annual harvest estimates are considered to be unbiased; however, they have a sampling variance associated with them. Again, however, sport harvests are so minor in comparison to commercial harvests as to be all but inconsequential in most years (Table 1). From 1999 to 2001, when commercial harvest did not occur, sport harvests were minor and inconsequential in comparison to documented escapement. An emergency order closure of the sport fishery for sockeye salmon in the East Alsek occurred in 2001.

Subsistence and sport harvest estimates for 2001 are not yet available. Based simply on historic records of harvest, it is thought that these harvests will total well under 1,000 fish in 2001 and the proxy estimate of 700 sockeye salmon is used later in the analysis when brood tables were developed. Given that virtually the entire harvest of East Alsek-Doame river system sockeye salmon has historically been taken in the commercial fishery in almost all of the years, the annual total harvest estimates provided in Table 1 are considered a census, without significant annual biases nor sampling variances.

ESCAPEMENTS

Aerial surveys of the East Alsek River to count and document escapement of sockeye salmon have taken place each year since 1972. Typically, surveys are conducted on a weekly basis. The peak (highest) count of spawning sockeye salmon in any given year is used as a relative measure of annual escapement strength. The East Alsek River is considered to be the easiest stream in the Yakutat Area to survey from the air. There is no vegetation along the intertidal area, and the vegetation upriver does not encroach on viewing. The East Alsek River has crystal clear water, and is mostly straight. Under excellent visibility conditions, the majority of the fish that are present in the river are observed (likely 90–95%). A rating of good/normal does not meaningfully diminish visibility; it might mean glare on the water or some shadows from either vegetation or clouds. Professional judgment is that about two-thirds of the annual total escapement of East Alsek River sockeye salmon is directly counted during the day of the peak survey. This expansion primarily accounts for the entry pattern and the fact that prior to the date of the peak survey, some sockeye salmon have already spawned and have been removed from the system, while others have not yet entered the spawning grounds.

Peak annual counts of sockeye salmon in the East Alsek River from 1972 to 2001 ranged from a low count of 10,000 in 1972 to a high count of 70,000 in 1982 (Table 2). These counts have a sampling variance. Our conjecture is that these sampling variances are not excessive and that observers can readily detect the difference between say 20,000 sockeye salmon on the spawning grounds and 30,000 sockeye salmon on the spawning grounds. Likewise, we believe the annual trends are statistically meaningful and that a relatively similar portion of the annual total escapement is counted from year to year. However, there is no on-the-grounds data to substantiate these conjectures with factual data. Our conjectures are provided to give the reader an indication of our opinion of the reliability of this escapement database. Until such time as a few years of independent estimates of total escapement of East Alsek River sockeye salmon escapements are obtained, the best analysts can do is provide professional opinions and conjecture. When using these data to develop brood tables, we did alternate analyses based on the assumption that peak counts represented 50% of the total escapement and 80% of the total escapement. This was done to evaluate the sensitivity of the brood tables and subsequent analysis to the two-thirds (67%) assumption that we believe is the best expansion estimate.

Aerial surveys of the Doame River to count and document escapement of sockeye salmon have taken place each year since 1988. From 1972 to 1988, escapement surveys are only available for the years 1972 and 1975 (Table 3). The peak

Table 2.–Estimated annual escapements of East Alsek River sockeye salmon from 1972 to 2001.

Year	Peak aerial survey count of sockeye salmon	Date of peak aerial survey	Visibility recorded by observer during survey	Assumed expansion factor[a]	Estimated total escapement of sockeye salmon
1972	10,000	23-Sep	no record	1.5	15,000
1973	15,000	03-Oct	no record	1.5	22,500
1974	35,000	29-Sep	no record	1.5	52,500
1975	22,000	20-Sep	no record	1.5	33,000
1976	50,000	22-Sep	no record	1.5	75,000
1977	35,000	02-Sep	no record	1.5	52,500
1978	25,000	17-Sep	no record	1.5	37,500
1979	25,000	19-Sep	no record	1.5	37,500
1980	18,000	20-Sep	no record	1.5	27,000
1981	35,000	08-Oct	no record	1.5	52,500
1982	70,000	29-Aug	no record	1.5	105,000
1983	65,000	20-Sep	excellent	1.5	97,500
1984	29,000	23-Sep	excellent	1.5	43,500
1985	60,000	14-Sep	good/normal	1.5	90,000
1986	37,000	20-Aug	excellent	1.5	55,500
1987	34,000	25-Aug	excellent	1.5	51,000
1988	38,000	27-Aug	excellent	1.5	57,000
1989	30,000	05-Sep	no record	1.5	45,000
1990	42,000	03-Sep	no record	1.5	63,000
1991	38,000	21-Sep	good/normal	1.5	57,000
1992	43,000	23-Aug	good/normal	1.5	64,500
1993	45,000	23-Aug	good/normal	1.5	67,500
1994	32,400	29-Aug	good/normal	1.5	48,600
1995	28,000	29-Aug	good/normal	1.5	42,000
1996	28,000	09-Sep	good/normal	1.5	42,000
1997	28,000	20-Aug	excellent	1.5	42,000
1998	30,000	12-Aug	good/normal	1.5	45,000
1999	19,500	09-Aug	good/normal	1.5	29,250
2000	21,000	02-Aug	excellent	1.5	31,500
2001	17,000	27-Aug	good/normal	1.5	25,500

[a] Professional judgment is that about two-thirds of the annual total escapement of East Alsek River sockeye salmon is directly counted during the day of the peak survey. This expansion primarily accounts for the entry pattern and the fact that prior to the date of the peak survey, some sockeye salmon have already spawned and have been removed from the system, while others have not yet entered the spawning grounds. These counts and escapement expansions have unknown levels of sampling variance and may be biased.

(highest) count of spawning sockeye salmon in any given year is used as a relative measure of annual escapement strength in the Doame River system. The Doame River is open and broad in the lower reaches, from where it turns westward near the beach to where it joins the East Alsek River, and it is also clear. Under good or excellent conditions almost every fish in the lower area of the river is visible to aerial observers. The river then turns up into the forelands and into heavy vegetation, and it becomes more difficult to follow, with lots of twists and bends. But long stretches of the river are open to viewing, as are most of the holding pools. Lower Doame Lake is

Table 3.–Estimated annual escapements of Doame River sockeye salmon from 1972 to 2001.

Year	Peak aerial survey count of sockeye salmon	Date of peak aerial survey	Visibility recorded by observer during survey	Assumed expansion factor[a]	Estimated total escapement of sockeye salmon
1972	800	18-Aug	no record	1.5	1,200
1973	none[b]				*2,000*[b]
1974	none				*2,000*
1975	120	06-Aug	no record	1.5	180
1976	none				*2,000*
1977	none				*2,000*
1978	none				*2,000*
1979	none				*2,000*
1980	none				*2,000*
1981	none				*2,000*
1982	none				*2,000*
1983	none				*2,000*
1984	none				*2,000*
1985	none				*2,000*
1986	none				*2,000*
1987	none				*2,000*
1988	50	19-Jul	good/normal	1.5	75
1989	700	27-Jul	no record	1.5	1,050
1990	1,270	24-Jun	no record	1.5	1,905
1991	700	22-Jun	excellent	1.5	1,050
1992	900	29-Jun	excellent	1.5	1,350
1993	3,200	22-Sep	good/normal	1.5	4,800
1994	2,900	26-Jun	excellent	1.5	4,350
1995	850	01-Aug	good/normal	1.5	1,275
1996	1,400	19-Jun	good/normal	1.5	2,100
1997	2,000	27-Jun	excellent	1.5	3,000
1998	1,200	15-Jun	excellent	1.5	1,800
1999	1,400	28-Jun	good/normal	1.5	2,100
2000	2,200	27-Jun	excellent	1.5	3,300
2001	1,545	25-Jun	good/normal	1.5	2,318

[a] Professional judgment is that about two-thirds of the annual total escapement of Doame River sockeye salmon is directly counted during peak surveys. This expansion accounts for the entry pattern and the fact that prior to the date of the peak survey, some sockeye salmon have already spawned and have been removed from the system, while others have not yet entered the spawning grounds.

[b] Aerial surveys were not conducted in the Doame River in 1973, 1974 and from 1976 through 1987. The approximate average estimated total escapement for the other years in the series of 2,000 total spawners is used as a proxy value for these years and that value is listed in *italics*. These annual counts and escapement expansions have unknown levels of sampling variance and may be biased.

also easy to survey and sockeye salmon are readily observed and counted. Professional judgment is that about two-thirds of the annual total escapement of Doame River sockeye salmon is directly counted during peak surveys. This expansion accounts for the entry pattern and the fact that prior to the date of the peak survey, some sockeye salmon have already spawned and have been removed from the system, while others have not yet entered the spawning grounds.

In the years when aerial surveys were not conducted in the Doame River (1973, 1974, 1976 through 1987), the approximate average estimated total escapement for the other years in the series of 2,000 total spawners is used as a proxy value. As brood tables were being developed, we felt it more appropriate to include a proxy value than not including a value for these annual escapements.

Peak annual counts of sockeye salmon in the Doame River from 1972–2001 when escapements were counted ranged from a low count of 50 fish in 1988 to a high count of 3,200 fish in 1993 (Table 3). These counts have a sampling variance. Our conjecture is that these sampling variances are not excessive and that observers can readily detect the difference between say 1,000 sockeye salmon on the spawning grounds and 1,500 sockeye salmon on the spawning grounds in a given day. However, the peak counts as being representative of the annual total escapements in the Doame River are likely not as reliable an index of total escapement as is the case for the East Alsek River, simply because the river is not surveyed nearly as often. In some years the peak count represents the only survey. We believe the annual trends are likely meaningful in that at least large annual escapement years are readily identifiable from small annual escapement years and that in general, this stock is substantially smaller in magnitude than the East River stock of sockeye salmon. There are no on-the-grounds data to substantiate these conjectures with factual data. Again, our conjectures are provided to give the reader an indication of our opinion of the reliability of this escapement database. Until such time as a few years of independent estimates of total escapement of Doame River sockeye salmon escapements are obtained, the reliability of this database will be somewhat questionable.

Total annual escapements of sockeye salmon in the East Alsek-Doame river system were calculated by adding annual expanded estimates of escapement already independently calculated for the East Alsek River and the Doame River. Based on this approach, total escapements of sockeye salmon ranged from a low of 16,200 in 1972 to a high of 107,000 in 1982 over the 30-year period of 1972–2001 (Table 4). This provides a 6.6-fold level of contrast for stock-recruit analysis, a moderate level and according to the CTC (1999), adequate to proceed, so long as measurement error is not extreme and some of the production to spawner ratios are below one at higher levels of spawning abundance.

ANNUAL EXPLOITATION

Estimated total harvests and estimated total escapements of East Alsek-Doame river system sockeye salmon were added to obtain estimated annual total runs for the years 1972–2001 (Figure 2). Inspection of Figure 2 shows how the stock built up to peak levels of about 250,000 sockeye salmon by 1985. The magnitude of the annual runs at the beginning of the time series in the early 1970s was about the same as the magnitude of the runs at the end of the time series in the late 1990s. The major difference was that a larger proportion of the runs in the late 1990s was in the escapement. Inspection of Figure 2 also indicates that the lower magnitude runs in the last half of the 1990s was not a result of escapement shortages in their parental years, two to six years earlier, as relatively large escapements were achieved throughout the 1980s and 1990s.

Annual estimated harvests were subsequently divided by estimated annual total runs to estimate annual exploitation rates of East Alsek-Doame river sockeye salmon populations. Based on the assumption that peak survey counts of spawners represent two-thirds of total escapement, exploitation rates over the 30-year period of 1972–2001 ranged from a low of 2% in 1999, 2000, and 2001 to a high of 76% in 1989 and averaged 43% (Table 5). Recent years are associated with the smallest estimated exploitation rates. Calculations that assume peak survey counts of escapement represent 50% or 80% of total escapement were completed and then the above process of re-estimating annual exploitation rates was repeated and those results are included in Table 5 for comparative purposes. Even if observed peak counts of spawners represented 80% of the total annual escapements, annual exploitation rate averaged under 50% over the period of 1972–2001.

AGE COMPOSITION

Sockeye salmon spawning in the East Alsek River were sampled to estimate annual age compositions in the years 1982–1987, 1994, 1995, 1997, 2000,

Table 4.–Estimated total annual escapements of sockeye salmon in the East Alsek-Doame drainage, 1972–2001.

Year	Estimated total escapement of sockeye salmon in Doame River	Estimated total escapement of sockeye salmon in East Alsek River	Estimated total escapement of sockeye salmon in East Alsek-Doame drainage
1972	1,200	15,000	16,200
1973	*2,000* [a]	22,500	24,500
1974	*2,000*	52,500	54,500
1975	180	33,000	33,180
1976	*2,000*	75,000	77,000
1977	*2,000*	52,500	54,500
1978	*2,000*	37,500	39,500
1979	*2,000*	37,500	39,500
1980	*2,000*	27,000	29,000
1981	*2,000*	52,500	54,500
1982	*2,000*	105,000	107,000
1983	*2,000*	97,500	99,500
1984	*2,000*	43,500	45,500
1985	*2,000*	90,000	92,000
1986	*2,000*	55,500	57,500
1987	*2,000*	51,000	53,000
1988	75	57,000	57,075
1989	1,050	45,000	46,050
1990	1,905	63,000	64,905
1991	1,050	57,000	58,050
1992	1,350	64,500	65,850
1993	4,800	67,500	72,300
1994	4,350	48,600	52,950
1995	1,275	42,000	43,275
1996	2,100	42,000	44,100
1997	3,000	42,000	45,000
1998	1,800	45,000	46,800
1999	2,100	29,250	31,350
2000	3,300	31,500	34,800
2001	2,318	25,500	27,818
Min.	75	15,000	16,200
Max.	4,800	105,000	107,000
Contrast	6.4	7.0	6.6

[a] Values in *italics* are proxy values because direct observations were not made.

and 2001 (Table 6). Only in the years 2000 and 2001 were the sample sizes less than 400 indicating that age compositions estimated for the majority of these years are reasonably precise. Age composition sampling of the Doame River sockeye salmon escapements has never taken place. In this analysis, annual age composition estimates for the East Alsek River were applied to the Doame River escapements. These assumed age compositions are likely biased with the Doame River sockeye likely being older, on average, than East Alsek River sockeye salmon. However, because the East Alsek River escapements are so much larger in magnitude than the Doame River escapements, this likely bias has but a minor effect on brood table estimates.

Sockeye salmon caught in the East Alsek commercial set gillnet fishery were sampled to estimate annual age compositions in the years 1982–1998 (Table 7). Annual sample sizes ranged from just under 400 fish to almost 1,600 fish per year and, as a result, estimates of age composition of annual commercial harvests are fairly precise. In this report, the annual commercial harvest age compositions were considered adequately representative of the harvest age compositions for fish caught in the subsistence and sport fisheries. Commercial and subsistence harvests are with the same selective fishing gear, set gillnets. Age composition of sport harvests is likely different than that of sockeye salmon caught in set gill-net gear; however, sport harvests are minor in magnitude when compared to the set net harvests in this data set.

Average age compositions of sockeye salmon sampled from the commercial harvest and from the escapement are marginally different, presumably because of gillnet selectivity. Differences are as follows:

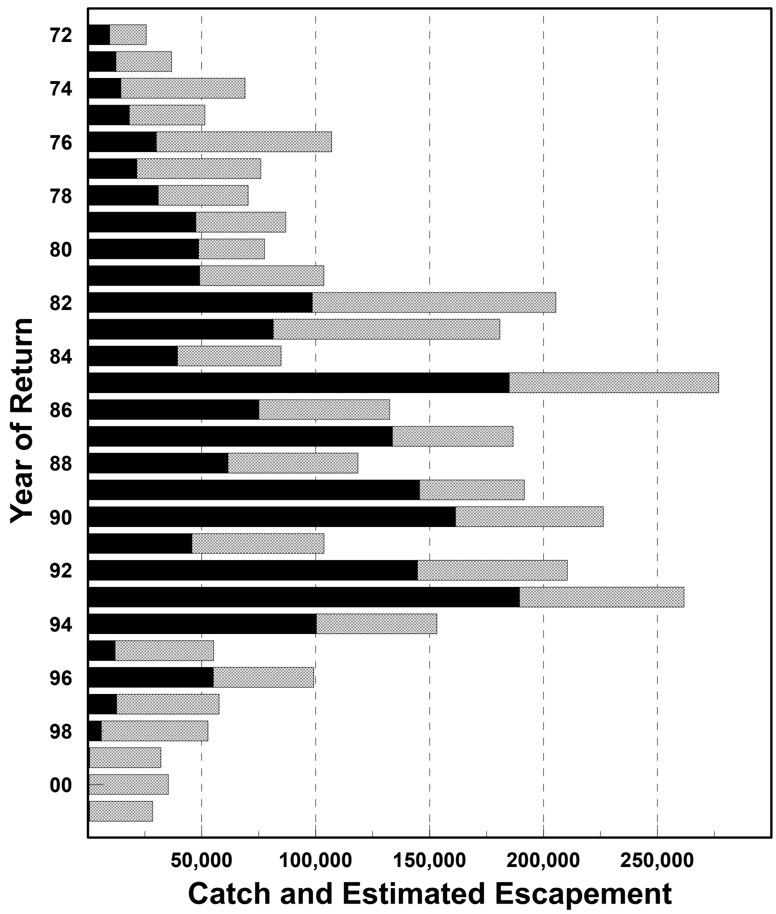

Figure 2.–Catches (black bars) **and estimated escapements** (gray bars) **of East Alsek-Doame river system sockeye salmon assuming peak aerial counts represent two-thirds of the total escapement, 1972–2001.**

Age 2	Age 3	Age 4	Age 5	Age 6
AVERAGE HARVEST (%)				
0.8	18.9	71.9	8.3	0.1
AVERAGE ESCAPEMENT (%)				
0	12.7	77.1	9.9	0.3
DIFFERENCE (%)				
0.8	6.2	-5.2	-1.6	-0.2

We wanted to identify proxy values for age composition of harvests and escapements for years when direct observational sampling did not occur. We elected to use adjusted observational catch annual data for years when escapements were not sampled and visa versa, when possible. Hence, for the years 1988–1993, 1996, and 1998, when escapements were not directly sampled, the year-specific harvest age composition minus the above mean differences by age with subsequent rounding was used as a proxy estimate. By doing so, we could incorporate the annual differences in run age compositions into the proxy escapement age compositions while still adjusting for mean differences caused by gillnet selectivity. In 1999, neither catch nor escapement were directly sampled. The proxy escapement age composition used in 1999 was the average escapement age composition over the entire time series. In a similar fashion, harvest age compositions for the years 2000 and 2001 were obtained and the overall age composition for sampled years was used for the harvest age

Table 5.–Estimated annual harvests, escapements, total runs, and exploitation rates of sockeye salmon returning to the East Alsek-Doame river system under the three alternate peak aerial survey count expansion assumptions, 1972–2001.

	67% Assumption				50% Assumption		80% Assumption	
Year	Estimated harvest	Estimated total escapement	Estimated total run	Estimated exploitation rate	Est. total escape.	Est. expl. rate	Est. total escape.	Est. expl. rate
1972	9,575	16,200	25,775	37%	21,600	31%	13,500	41%
1973	12,342	24,500	36,842	33%	32,667	27%	20,417	38%
1974	14,520	54,500	69,020	21%	72,667	17%	45,417	24%
1975	18,235	33,180	51,415	35%	44,240	29%	27,650	40%
1976	30,057	77,000	107,057	28%	102,667	23%	64,167	32%
1977	21,500	54,500	76,000	28%	72,667	23%	45,417	32%
1978	30,922	39,500	70,422	44%	52,667	37%	32,917	48%
1979	47,442	39,500	86,942	55%	52,667	47%	32,917	59%
1980	48,616	29,000	77,616	63%	38,667	56%	24,167	67%
1981	49,126	54,500	103,626	47%	72,667	40%	45,417	52%
1982	98,501	107,000	205,501	48%	142,667	41%	89,167	52%
1983	81,362	99,500	180,862	45%	132,667	38%	82,917	50%
1984	39,373	45,500	84,873	46%	60,667	39%	37,917	51%
1985	184,962	92,000	276,962	67%	122,667	60%	76,667	71%
1986	75,040	57,500	132,540	57%	76,667	49%	47,917	61%
1987	133,740	53,000	186,740	72%	70,667	65%	44,167	75%
1988	61,483	57,075	118,558	52%	76,100	45%	47,563	56%
1989	145,591	46,050	191,641	76%	61,400	70%	38,375	79%
1990	161,413	64,905	226,318	71%	86,540	65%	54,088	75%
1991	45,664	58,050	103,714	44%	77,400	37%	48,375	49%
1992	144,649	65,850	210,499	69%	87,800	62%	54,875	72%
1993	189,481	72,300	261,781	72%	96,400	66%	60,250	76%
1994	100,333	52,950	153,283	65%	70,600	59%	44,125	69%
1995	11,976	43,275	55,251	22%	57,700	17%	36,063	25%
1996	55,089	44,100	99,189	56%	58,800	48%	36,750	60%
1997	12,676	45,000	57,676	22%	60,000	17%	37,500	25%
1998	5,940	46,800	52,740	11%	62,400	9%	39,000	13%
1999	792	31,350	32,142	2%	41,800	2%	26,125	3%
2000	642	34,800	35,442	2%	46,400	1%	29,000	2%
2001	700	27,818	28,518	2%	37,091	2%	23,182	3%
Avg 72–01	61,058	52,240	113,298	43%	69,653	37%	43,533	47%
Avg 72–90	66,516	54,995	121,511	49%	73,327	42%	45,829	53%
Avg 91–01	51,631	47,481	99,112	33%	63,308	29%	39,568	36%
Avg 95–01	12,545	39,020	51,565	17%	52,027	14%	32,517	19%

composition in 1999. When developing brood tables, average age composition from the sampled years of 1982–1998 were used as proxy estimates for the years 1972–1981.

Annual estimates of age compositions as described above were combined with annual estimates of total harvests to estimate age-specific annual harvests (Table 8). Similarly, annual escapement age compositions were combined with annual estimates of total escapement to estimate age-specific annual escapements (Table 9). These two sets of age- and year-specific estimates were added to develop age-specific estimates of total runs in

Table 6.–Estimated annual age compositions (percents) **for sockeye salmon escapements in the East Alsek-Doame River drainage, 1972–2001.**

Year	Age 2	Age 3	Age 4	Age 5	Age 6	Total	Sample size	Method used for proxy estimates
1982	0.2	32.4	60.3	7.1	0	100	537	
1983	0.2	8.1	89.1	2.6	0	100	430	
1984	0.2	7.3	55.4	36.6	0.5	100	440	
1985	1.4	32.3	65.2	1.1	0	100	424	
1986	0.4	32.4	60.6	6.2	0.4	100	519	
1987	1.2	6.0	89.7	3.1	0	100	415	
1988	0.8	31.8	64.7	2.7	0	100	0	adjusted 1988 catch
1989	0.8	27.2	70.5	1.3	0.2	100	0	adjusted 1989 catch
1990	0.8	9.0	82.0	8.2	0	100	0	adjusted 1990 catch
1991	0.8	30.6	67.4	1.2	0	100	0	adjusted 1991 catch
1992	0.8	17.6	79.5	2.1	0	100	0	adjusted 1992 catch
1993	0.8	13.7	84.8	0.7	0	100	0	adjusted 1993 catch
1994	1.9	5.7	91.7	0.7	0	100	424	
1995	1.1	29.8	60.8	8.3	0	100	446	
1996	0.8	16.6	75.1	7.5	0	100	0	adjusted 1996 catch
1997	1.2	10.5	80.6	7.7	0	100	430	
1998	0.8	11.7	83.3	4.2	0	100	0	adjusted 1998 catch
1999	0.8	18.9	71.9	8.3	0.1	100	0	average escapement 1982–2001
2000	0	18.5	67.7	13.8	0	100	65	
2001	0	15.7	75.2	9.1	0	100	121	
Average	0.8	18.9	71.9	8.3	0.1	100	–	
Sum							4,251	

Note: Annual age composition of samples collected from the East Alsek River were considered representative of the age composition of the escapement into the entire East Alsek-Doame River drainage.

Table 7.–Estimated annual age compositions for sockeye salmon harvested in the East Alsek terminal fishery, 1972–2001.

Year	Age 2	Age 3	Age 4	Age 5	Age 6	Total	Sample size	Method used for proxy estimates
1982	0	17.8	73.0	9.0	0.2	100	624	
1983	0	4.1	89.2	6.5	0.2	100	1,594	
1984	0	17.2	57.2	25.4	0.2	100	1,356	
1985	0	10.3	83.2	6.3	0.2	100	1,268	
1986	0	20.1	68.9	10.2	0.8	100	1,147	
1987	0.4	3.9	74.3	20.2	1.2	100	1,369	
1988	0	25.6	70.1	4.3	0	100	1,012	
1989	0	21.0	75.7	2.9	0.4	100	900	
1990	0	2.8	87.2	9.8	0.2	100	564	
1991	0	24.4	72.8	2.8	0	100	418	
1992	0	11.4	84.9	3.7	0	100	490	
1993	0	7.5	90.2	2.3	0	100	429	
1994	0	2.3	95.1	2.6	0	100	396	
1995	0	26.4	60.9	11.8	0.9	100	450	
1996	0	10.4	80.3	9.1	0.2	100	482	
1997	0	6.3	83.5	10.2	0	100	491	
1998	0	5.5	88.7	5.8	0	100	530	
1999	0	12.7	77.1	9.9	0.3	100	0	average catch 1982–1999
2000	0	11.5	72.9	15.4	0.2	100	0	adjusted escapement 2000
2001	0	8.7	80.4	10.7	0.2	100	0	adjusted escapement 2001
Average	0	12.7	77.1	9.9	0.3	100		
Sum							13,520	

Note: Annual age composition of samples collected from the terminal East Alsek River set gillnet fishery were assumed representative of the age composition of the harvests of sockeye salmon harvested by all terminal commercial, sport and subsistence fisheries.

Table 8.–Estimated annual total harvests of sockeye salmon by age in the East Alsek River terminal area, 1972–2001.

	Numbers by age of sockeye salmon harvested in the East Alsek terminal area					
Year	Age 2	Age 3	Age 4	Age 5	Age 6	Total
1972	–	1,216	7,382	948	29	9,575
1973	–	1,567	9,516	1,222	37	12,342
1974	–	1,844	11,195	1,437	44	14,520
1975	–	2,316	14,059	1,805	55	18,235
1976	–	3,817	23,174	2,976	90	30,057
1977	–	2,731	16,577	2,129	65	21,500
1978	–	3,927	23,841	3,061	93	30,922
1979	–	6,025	36,578	4,697	142	47,442
1980	–	6,174	37,483	4,813	146	48,616
1981	–	6,239	37,876	4,863	147	49,126
1982	–	17,533	71,906	8,865	197	98,501
1983	–	3,336	72,575	5,289	163	81,362
1984	–	6,772	22,521	10,001	79	39,373
1985	–	19,051	153,888	11,653	370	184,962
1986	–	15,083	51,703	7,654	600	75,040
1987	535	5,216	99,369	27,015	1,605	133,740
1988	–	15,740	43,100	2,644	–	61,483
1989	–	30,574	110,212	4,222	582	145,591
1990	–	4,520	140,752	15,818	323	161,413
1991	–	11,142	33,243	1,279	–	45,664
1992	–	16,490	122,807	5,352	–	144,649
1993	–	14,211	170,912	4,358	–	189,481
1994	–	2,308	95,417	2,609	–	100,333
1995	–	3,162	7,293	1,413	108	11,976
1996	–	5,729	44,236	5,013	110	55,089
1997	–	799	10,584	1,293	–	12,676
1998	–	327	5,269	345	–	5,940
1999	–	101	611	78	2	792
2000	–	74	468	99	1	642
2001	–	61	563	75	1	700
Averages	18	6,936	49,170	4,768	166	61,058

the years 1972–2001 (Table 10). These estimates represent our best estimates of age-specific run reconstructions for the East Alsek-Doame River stock of sockeye salmon for the years 1972–2001.

RECRUITMENT ESTIMATES

Estimates of total production or recruits resulting from the brood year 1972–1997 escapements were calculated by summing the age-specific estimates of total runs for any given brood year as follows: age-2's in year y+2 + age-3's in year y+3 + age-4's in year y+4 + age-5's in year y+5 + age-6's in year y+6. An estimate of the age five return from brood year 1997 is not yet available; a proxy estimate was developed and represents the average age-5 return for the previous five years. Age six returns from the brood years of 1996 and 1997 are also not yet available; proxy values of zero were used. These two age classes (5's and 6's) typically represent a very minor portion of the total runs (less than 10%) and hence, the lack of estimates from sampling data in these cases, has little effect on estimates of total recruits.

Table 9.–Estimated annual total escapements of sockeye salmon by age in the East Alsek-Doame river system, 1972–2001.

	Numbers by age of sockeye salmon spawners in the East Alsek-Doame river system					
Year	Age 2	Age 3	Age 4	Age 5	Age 6	Total
1972	130	3,062	11,648	1,345	16	16,200
1973	196	4,631	17,616	2,034	25	24,500
1974	436	10,301	39,186	4,524	55	54,500
1975	265	6,271	23,856	2,754	33	33,180
1976	616	14,553	55,363	6,391	77	77,000
1977	436	10,301	39,186	4,524	55	54,500
1978	316	7,466	28,401	3,279	40	39,500
1979	316	7,466	28,401	3,279	40	39,500
1980	232	5,481	20,851	2,407	29	29,000
1981	436	10,301	39,186	4,524	55	54,500
1982	214	34,668	64,521	7,597	–	107,000
1983	199	8,060	88,655	2,587	–	99,500
1984	91	3,322	25,207	16,653	228	45,500
1985	1,288	29,716	59,984	1,012	–	92,000
1986	230	18,630	34,845	3,565	230	57,500
1987	636	3,180	47,541	1,643	–	53,000
1988	457	18,150	36,928	1,541	–	57,075
1989	368	12,526	32,465	599	92	46,050
1990	519	5,841	53,222	5,322	–	64,905
1991	464	17,763	39,126	697	–	58,050
1992	527	11,590	52,351	1,383	–	65,850
1993	578	9,905	61,310	506	–	72,300
1994	1,006	3,018	48,555	371	–	52,950
1995	476	12,896	26,311	3,592	–	43,275
1996	353	7,321	33,119	3,308	–	44,100
1997	540	4,725	36,270	3,465	–	45,000
1998	374	5,476	38,984	1,966	–	46,800
1999	251	5,925	22,541	2,602	31	31,350
2000	–	6,438	23,560	4,802	–	34,800
2001	–	4,367	20,919	2,531	–	27,818
Averages	398	10,112	38,337	3,360	33	52,240

Note: Escapements listed in this table were estimated by multiplying peak annual aerial survey counts of sockeye salmon by a factor of 1.5, assuming the peak survey count represented two-thirds of total annual escapement.

Total estimated number of sockeye salmon recruits from the East Alsek-Doame river system for brood years 1972–1997 ranged from a low of 31,696 fish for brood year 1997 to a high of 263,853 fish for brood year 1989 (Table 11). Estimated number of recruits per spawner for this 26-year time series ranges from a low of 0.70 for the brood year 1997 escapement to a high of 6.10 for the 1979 brood year. Inspection of the plot of recruits per spawner for the 1972–1997 brood years (Figure 3) shows the type of relationship expected for brood years 1972–1990, but the subsequent brood years of 1991–1997 are all clumped and located at about the replacement level, indicating that productivity has changed substantially.

Table 10.–Estimated annual total runs of sockeye salmon by age in the East Alsek-Doame river system, 1972–2001.

	Numbers by age of sockeye salmon in annual runs to the East Alsek-Doame river system					
Year	Age 2	Age 3	Age 4	Age 5	Age 6	Total
1972	130	4,278	19,030	2,293	45	25,775
1973	196	6,198	27,131	3,255	62	36,842
1974	436	12,145	50,380	5,961	98	69,020
1975	265	8,587	37,916	4,559	88	51,415
1976	616	18,370	78,537	9,367	167	107,057
1977	436	13,031	55,762	6,652	119	76,000
1978	316	11,393	52,241	6,340	132	70,422
1979	316	13,491	64,978	7,975	182	86,942
1980	232	11,655	58,334	7,220	175	77,616
1981	436	16,540	77,062	9,387	202	103,626
1982	214	52,201	136,427	16,462	197	205,501
1983	199	11,395	161,229	7,876	163	180,862
1984	91	10,094	47,728	26,654	306	84,873
1985	1,288	48,767	213,872	12,665	370	276,962
1986	230	33,713	86,548	11,219	830	132,540
1987	1,171	8,396	146,910	28,658	1,605	186,740
1988	457	33,889	80,027	4,185	–	118,558
1989	368	43,100	142,678	4,821	674	191,641
1990	519	10,361	193,974	21,141	323	226,318
1991	464	28,905	72,369	1,975	–	103,714
1992	527	28,080	175,158	6,735	–	210,499
1993	578	24,116	232,222	4,864	–	261,781
1994	1,006	5,326	143,972	2,979	–	153,283
1995	476	16,058	33,605	5,005	108	55,251
1996	353	13,050	77,356	8,321	110	99,189
1997	540	5,524	46,854	4,758	–	57,676
1998	374	5,802	44,253	2,310	–	52,740
1999	251	6,026	23,151	2,680	34	32,142
2000	–	6,512	24,028	4,901	1	35,442
2001	–	4,428	21,482	2,606	1	28,518
Averages	416	17,048	87,507	8,127	200	113,298

Note: Escapements included in the total runs listed in this table were estimated by multiplying peak annual aerial survey counts of sockeye salmon by a factor of 1.5, assuming the peak survey count represented two-thirds of total annual escapement.

Table 11.–Estimated brood year escapements, estimated returns by age (recruits) from those escapements, and estimated return per spawner ratios for sockeye salmon returning to the East Alsek-Doame river system, brood years 1972 through 1997.

Brood year	Estimated parental escapement	Age 2 return	Age 3 return	Age 4 return	Age 5 return	Age 6 return	Estimated total return	Estimated return per spawner
1972	16,200	436	8,587	78,537	6,652	132	94,344	5.82
1973	24,500	265	18,370	55,762	6,340	182	80,919	3.30
1974	54,500	616	13,031	52,241	7,975	175	74,038	1.36
1975	33,180	436	11,393	64,978	7,220	202	84,229	2.54
1976	77,000	316	13,491	58,334	9,387	197	81,725	1.06
1977	54,500	316	11,655	77,062	16,462	163	105,658	1.94
1978	39,500	232	16,540	136,427	7,876	306	161,380	4.09
1979	39,500	436	52,201	161,229	26,654	370	240,890	6.10
1980	29,000	214	11,395	47,728	12,665	830	72,833	2.51
1981	54,500	199	10,094	213,872	11,219	1,605	236,989	4.35
1982	107,000	91	48,767	86,548	28,658	0	164,064	1.53
1983	99,500	1,288	33,713	146,910	4,185	674	186,770	1.88
1984	45,500	230	8,396	80,027	4,821	323	93,797	2.06
1985	92,000	1,171	33,889	142,678	21,141	0	198,879	2.16
1986	57,500	457	43,100	193,974	1,975	0	239,506	4.17
1987	53,000	368	10,361	72,369	6,735	0	89,833	1.69
1988	57,075	519	28,905	175,158	4,864	0	209,446	3.67
1989	46,050	464	28,080	232,222	2,979	108	263,853	5.73
1990	64,905	527	24,116	143,972	5,005	110	173,730	2.68
1991	58,050	578	5,326	33,605	8,321	0	47,829	0.82
1992	65,850	1,006	16,058	77,356	4,758	0	99,177	1.51
1993	72,300	476	13,050	46,854	2,310	34	62,724	0.87
1994	52,950	353	5,524	44,253	2,680	1	52,811	1.00
1995	43,275	540	5,802	23,151	4,901	1	34,396	0.79
1996	44,100	374	6,026	24,028	2,606	0	33,034	0.75
1997	45,000	251	6,512	21,482	*3,451*	0	31,696	0.70

Note: Sampling data for the age-5 return for brood year 1997 are not available; the recent five-year average of 3,451 was used as a proxy estimate. Estimates for the six-year old returns for brood years 1996 and 1997 are not available; proxy values of 0 were used.

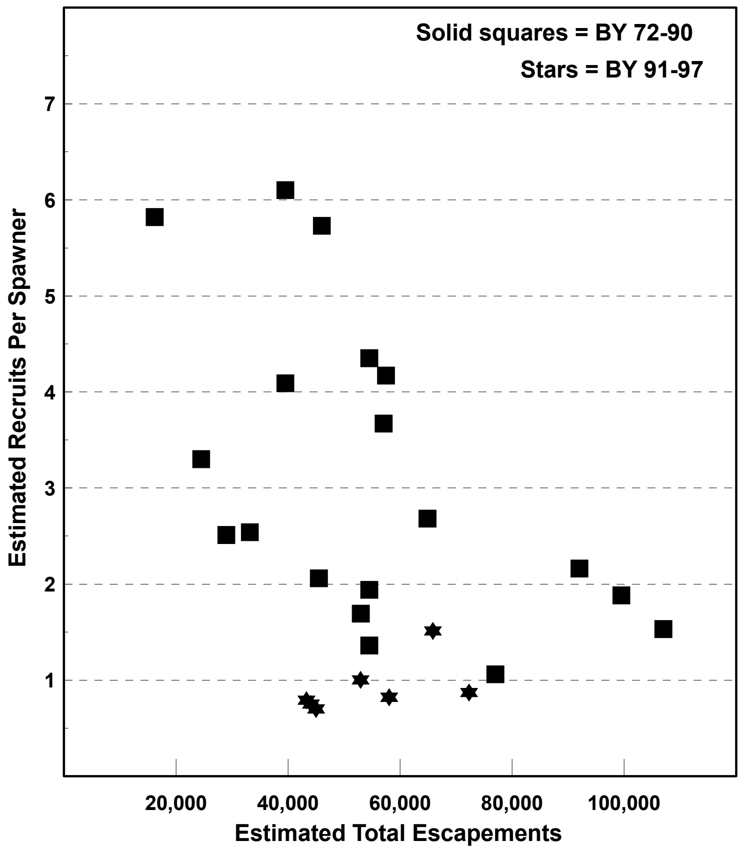

Figure 3.–Estimated East Alsek-Doame river system sockeye salmon spawners, under the assumption that peak aerial counts represent two-thirds of the total escapement with estimated recruits per spawner for brood years 1972–1997.

STOCK-RECRUIT RELATIONSHIPS

A paired data set was defined that consisted of the estimated total escapements of East Alsek-Doame River sockeye salmon from 1972–1997 (Table 11, column 2) and estimated resultant recruits from those escapements (Table 11, column 8). Once the paired data set was defined, a spawner-recruit relationship was developed by fitting the paired data set to the following model:

$$R_y = \alpha S_y e^{-\beta S_y} \exp(\varepsilon_y) \qquad (1)$$

where R_y = estimated total recruitment by brood y;
S_y = spawning escapement that produced brood y;
α = intrinsic rate of population increase in the absence of density-dependent limitations;
β = density-dependent parameter; and
ε_y = process error with mean 0 and variance σ_ε^2.

This model, commonly referred to as a Ricker recruitment curve (Ricker 1975), has two parameters, α and β, to estimate, given a series of spawner and resultant recruitment observations or estimates. We assumed the errors were log-normal (as is common for salmon returns), resulting in the log-transformed linear equation:

$$\ln(R_y / S_y) = \ln(\alpha) - \beta S_y + \varepsilon_y \qquad (2)$$

Linear regression procedures provided estimates of the intercept (ln α) and the slope (β) in equation 2. Hilborn and Walters (1992:271–2) published the following empirical approximation of the estimated spawning size that produces maximum sustained yield or MSY (S_{MSY}) as a function of estimated parameters:

$$\hat{S}_{MSY} \cong \frac{\ln\hat{\alpha} + \hat{\sigma}_\varepsilon^2/2}{\hat{\beta}}[0.5 - 0.07(\ln\hat{\alpha} + \hat{\sigma}_\varepsilon^2/2)] \qquad (3)$$

where $\hat{\sigma}_{\varepsilon}^{2}$ = the mean square error from the regression.

Once the brood year 1972–1997 stock-recruit relationship was developed, residuals in the relationship were calculated (Table 12). A residual plot was prepared, and visual examination of this residual plot revealed that stock productivity had changed over the 26-year time series (Figure 4; upper panel). The residual pattern indicated a trend with a change in productivity occurring in the early 1990s. Similar calculations as described in the sections above were then completed using the assumption that peak counts of escapement represented 50% of the total escapement rather than 67% of the total escapement. And a third set of calculations was completed under the assumption that peak counts represented 80% of the total escapement. Residual analysis and residual plots of the subsequent stock-recruit relationships under those two alternate assumptions about peak escapement count expansion revealed similar residual patterns (Table 12 and Figure 4, middle and lower panels).

The residual pattern of the 1972–1997 stock-recruit data set indicates that the environment was not stable across the period of time that the data extended, but instead a significant change occurred in the early 1990s. A basic tenet when using historic stock-recruit information from salmon stocks to estimate productivity and thus to estimate the maximum sustained yield escapement goal for use in future fishery management is that the past is representative of the future. Earlier in this report, we provided hypotheses concerning observed changes in run strength of the sockeye salmon stock returning to the East Alsek-Doame river system. Whether or not we are correct concerning the reasons for observed recent run strength declines, the stock-recruit residuals make clear that at least a portion of the past does not adequately represent the present nor is it likely to represent the immediate future. Therefore, the stock-recruit data for the East Alsek-Doame river system stock were split into a historic brood year 1972–1990 data set and a more recent brood year 1990–1997 data set.

The brood year 1972–1990 data set was fit with the above stock-recruit model and residuals were calculated. The stock-recruit relationship developed from this analysis is shown in Figure 5, and residuals are provided in Table 12 and plotted in Figure 6. The residual pattern associated with the brood year 1972–1990 stock-recruit relationship appear random and they do not demonstrate an observable trend. Analyses indicate that the escapement level, on average, that is predicted to provide for maximum sustained yield fisheries is about 68,000 total spawners or a peak survey count of about 45,000. This estimate is not substantially different than the estimate of about 40,000 spawners counted in a peak survey as estimated by Clark et al. (1995a). However, that

Table 12.–Residuals (recruits) from the stock-recruit relationships developed for East Alsek-Doame river system sockeye salmon.

	Residuals from BY 72–97 relationship			Residuals from BY 72–90 relationship
Brood year or statistic	67% expansion assumption	50% expansion assumption	80% expansion assumption	67% expansion assumption
1972	46,595	57,778	41,062	24,775
1973	14,343	18,818	12,206	(14,550)
1974	(36,360)	(42,051)	(33,312)	(75,431)
1975	1,413	(2,909)	3,715	(32,570)
1976	(43,407)	(51,306)	(39,286)	(80,545)
1977	(4,741)	(7,114)	(3,352)	(43,811)
1978	68,706	76,141	65,156	32,251
1979	148,217	176,499	134,242	111,761
1980	(2,574)	(7,120)	(179)	(34,373)
1981	126,591	129,048	125,564	87,520
1982	34,444	41,748	30,770	5,361
1983	57,049	64,079	53,576	25,646
1984	(6,862)	(12,541)	(3,838)	(44,856)
1985	69,795	71,532	69,022	36,226
1986	126,403	128,755	125,430	87,252
1987	(19,115)	(23,392)	(16,776)	(58,097)
1988	96,711	100,479	95,031	57,564
1989	162,525	167,723	160,112	124,425
1990	54,991	56,040	54,668	16,141
1991	(65,742)	(74,621)	(61,099)	
1992	(20,181)	(23,122)	(18,511)	
1993	(60,303)	(64,314)	(58,112)	
1994	(56,088)	(60,381)	(53,741)	
1995	(63,449)	(71,399)	(59,295)	
1996	(65,875)	(74,247)	(61,507)	
1997	(68,346)	(77,390)	(63,640)	

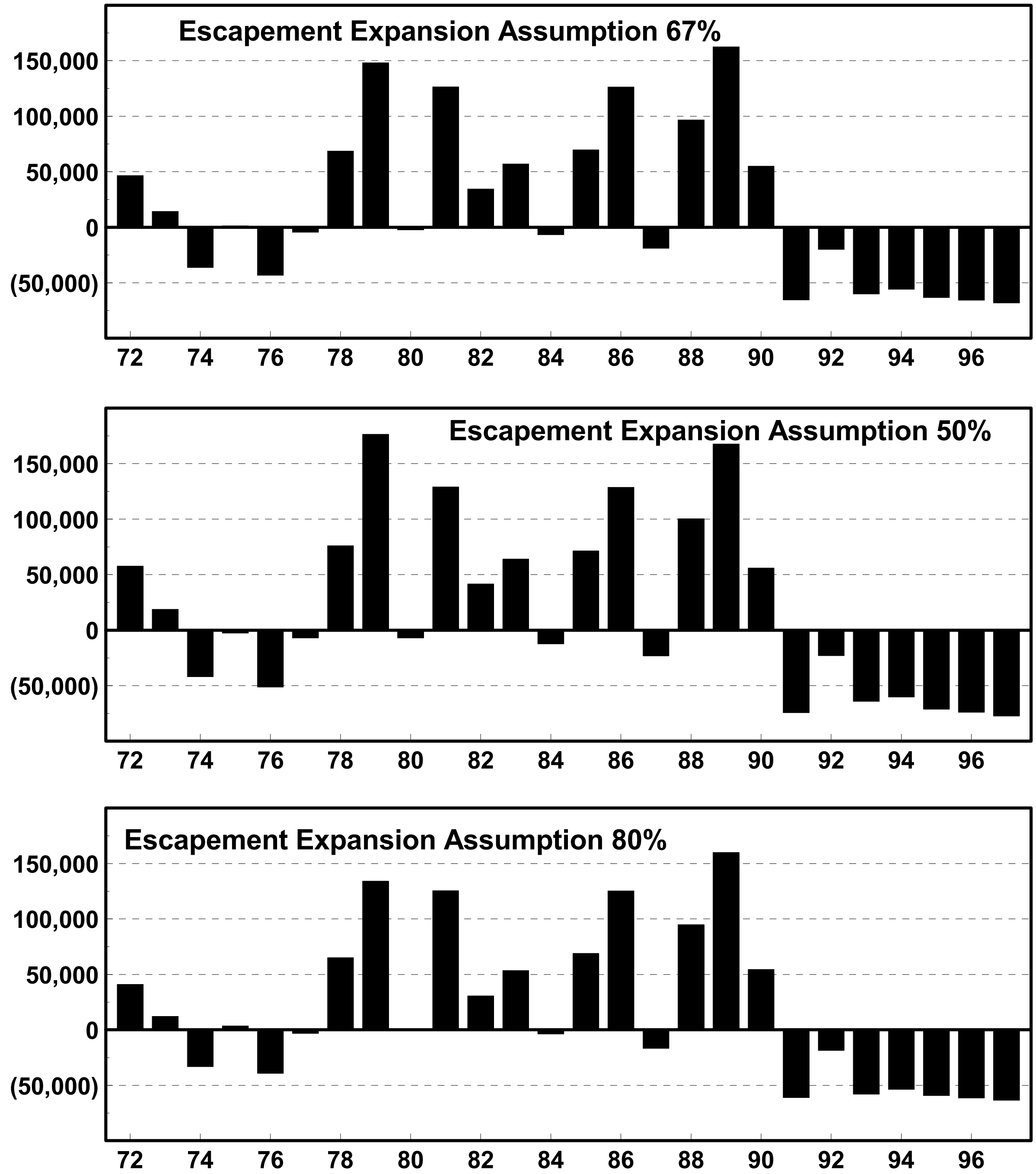

Figure 4.–Residuals from three stock-recruit relationships for East Alsek-Doame River system sockeye salmon developed under three alternate assumptions concerning the portion of total escapement counted with peak aerial surveys using brood year 1972–1997 paired data. Note the consecutive large negative residuals for brood years 1991–1997 associated with all three stock-recruit relationships.

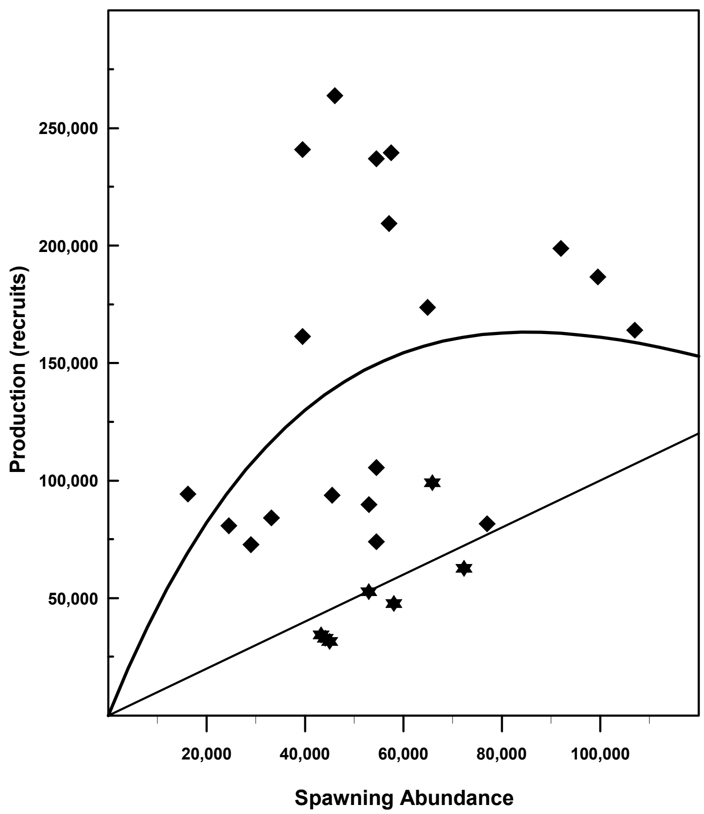

Figure 5.–Stock-recruit relationship for the East Alsek-Doame river system sockeye salmon population assuming two-thirds of the total escapement is counted during peak aerial surveys and using data for the 1972–1990 brood years. Diamonds are the annual escapement-recruit data points for brood years 1972–1990 that were used to develop the stock-recruit relationship. The stars are the annual escapement-recruit data points for brood years 1991–1997 when productivity for this stock markedly decreased. The brood year 1991–1997 data points were not included in the calculation of the stock-recruit relationship shown, but are included in the graphic to demonstrate the recent change in productivity.

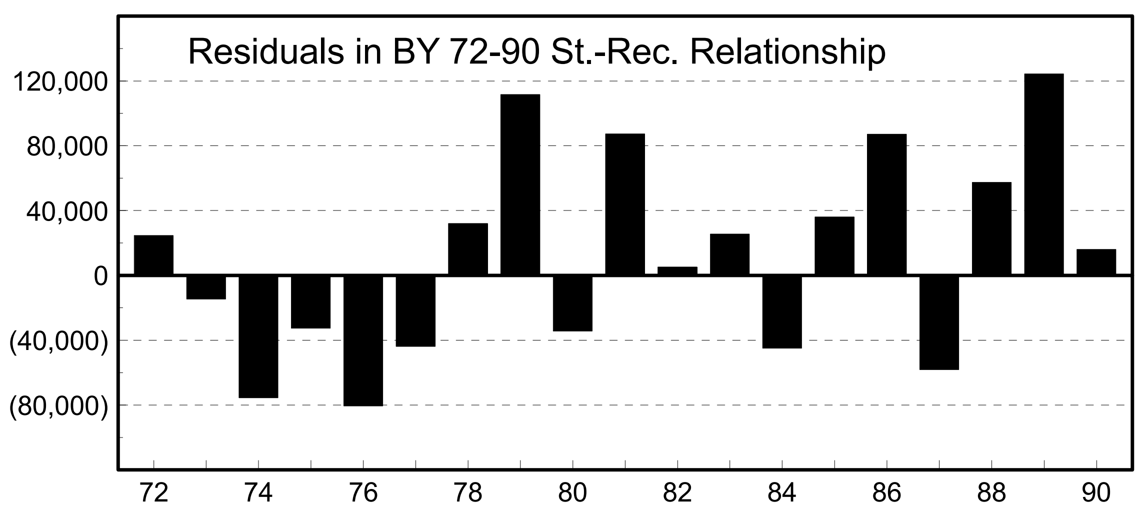

Figure 6.–Residuals from the BY 1972–1990 stock-recruit relationship for the East Alsek-Doame river system sockeye salmon population using the 67% expansion assumption.

estimate of the escapement level of the East Alsek-Doame River stock predicted to provide for maximum sustained fisheries is applicable only to the period 1972–1990. Production for the 1991–1997 broods was far less than expected (Figure 5). We have a credible basis to believe the MSY escapement level of about 45,000 sockeye salmon counted during a peak survey was not applicable to the stock for brood years 1991–1997, and we believe it unlikely that this metric is applicable to the current nor near future time periods.

REVISED BIOLOGICAL ESCAPEMENT GOAL

Traditional analysis of the stock-recruit data set for brood years 1991–1997 was deemed pointless for three reasons. First, brood year 1991–1997 escapement levels were estimated to have ranged from a low value of 43,275 fish in 1995 to a high value of 72,300 fish in 1993 (Table 11) and hence, escapement contrast associated with the data set is only about 1.7. Second, only seven brood years of data are available in this time series. Third, all seven of these escapements produced returns that just fluctuate around replacement level (Figure 3). Given this set of circumstances, we felt that application of the traditional approach of fitting these data to a Ricker model would produce spurious results.

On the other hand, we noted that the seven recent stock-recruit data points appear to fluctuate around the replacement level and thus are likely to provide a good approximation of the replacement level that is associated with the brood year 1991–1997 stock-recruit relationship. Further, we know that in the prior time series, S_{MSY} was about 33% of replacement and that on average, S_{MSY} was about 43% of replacement for sockeye salmon stocks in the Yakutat area (Table 13). We felt that the best approach for identifying an alternate escapement goal range was to key off of an estimate of the recent replacement value and the ratio of S_{MSY} to replacement values for other Yakutat area sockeye salmon stock-recruit relationships.

Point estimates of the replacement value in the brood year 1991–1997 East Alsek-Doame river system were estimated by regressing estimates of total escapement versus estimated return per spawner and solving the relationship for a return per spawner level of 1.0. This procedure was completed under the favored peak survey count expansion assumption of 67% as well as under the two alternate assumptions of 50% and 80%. Under the favored assumption of 67%, replacement was estimated to be about 56,000 or a peak count of about 37,000 (Table 14). Under the 50% and 80% assumptions, replacement expressed as a total value was estimated at about 77,000 and 46,000, respectively, or expressed as peak counts was estimated to be about 39,000 and 37,000, respectively. Given these data, we believe we have a good handle on replacement expressed as a peak aerial survey count, as the three estimates only varied from about 37,000 to 39,000 under the three alternate assumptions.

Application of the ratio between S_{MSY} and replacement value from the BY 1972–1990 stock recruit relationship developed earlier in this report of 0.33 would provide an estimate of S_{MSY} for the 1991–1997 time period of about 12,000 sockeye salmon counted in a peak survey. Using Eggers (1993) approach to setting a biological escapement goal range would result in a range of about 10,000 to 20,000 sockeye salmon counted in peak surveys of the East Alsek-Doame river system (Table 14).

However, we note that the estimate of 0.33 for the ratio between S_{MSY} and replacement value obtained from our analysis of the 1972–1990 East Alsek-Doame River sockeye salmon stock is the lowest value of those reported for sockeye salmon stocks in the Yakutat area. Hence, we believe that use of the average value of 0.43 from Table 13 is likely a more appropriate statistic to use than 0.33. Under the 67% expansion assumption, use of this average value of 0.43 results in an estimate of S_{MSY} of about 24,000 spawners expressed as total escapement or about 16,000 sockeye salmon counted in a peak aerial survey (Table 15). Use of the Eggers (1993) approach to define an appropriate biological escapement goal range results in 13,000 to 26,000 sockeye salmon counted during a peak survey.

The largest uncertainty in our minds when recommending 13,000–26,000 (peak count in a survey) as a biological escapement goal for use in future fishery management of the East Alsek-

Table 13.–Ratios of estimated S_{MSY} divided by estimated replacement value for sockeye salmon stocks in the Yakutat area, from published technical reports.

Literature citation	Sockeye stock/river and brood years	Estimated S_{MSY}	Estimated replacement value	S_{MSY}/ replacement ratio
Current analysis	East Alsek-Doame BY 72–90	about 68,000	about 204,000	0.33
Clark, McPherson, and Burkholder (1995b)	Situk River BY 76–89	48,535	123,562	0.39
Clark and Etherton (2000) (Model 1)	Klukshu River BY 76–92	9,505	24,000	0.40
Clark, Burkholder, and Clark (1995a) (60% Model)	Alsek drainage By 76–89	15,641	41,621	0.37
Clark, Burkholder, and Clark (1995a)	Akwe River BY 73–87	10,791	26,237	0.41
Clark, Burkholder, and Clark (1995a)	East Alsek-Doame BY 72–90	62,124	158,367	0.39
Clark, Burkholder, and Clark (1995a)	Italio River BY 72–89	9,136	22,281	0.41
Clark, Burkholder, and Clark (1995a)	Lost River BY 72–88	2,381	3,594	0.66
Minimum S_{MSY}/replacement ratio from published Yakutat reports				0.37
Maximum S_{MSY}/replacement ratio from published Yakutat reports				0.66
Average S_{MSY}/replacement ratio from published Yakutat reports				0.43

Doame sockeye salmon stock is whether or not the productivity in the near future will mimic the observed productivity demonstrated by brood years 1990–1997. If the productivity stabilizes at levels observed from 1991–1997, the goal is likely fully appropriate. If productivity continues to decrease, the 13,000–26,000 recommendation would most likely be too high and the stock would be underutilized as occurred in the 1991–1997 time period. Because of the changing stock dynamics, it will be critically important to update information of the East Alsek-Doame stock of sockeye salmon on an annual basis to determine if productivity is stable or changing. We believe the revised goal we are recommending should be considered a short-term biological escapement goal. Evaluation should take place each year and the revised goal should have a life span of no more than three years. Further, if the spawning habitat in the East Alsek River is adequately restored through a major flood event such as historically occurred, it would be prudent to revert to the biological escapement goal as recommended by Clark et al. (1995a). Thus the current recommendation concerning a revised biological escapement goal range for the East Alsek-Doame River stock of sockeye salmon should be considered: (1) short-term and (2) appropriate for the unflushed habitat conditions on the spawning grounds as they currently exist, not as they existed a decade ago.

Table 14.–Peak aerial spawner counts, estimated total escapements and resultant recruits under three assumed expansion factors, estimated replacement values in the stock-recruit relationships with these three alternate assumptions, and estimated S_{MSY} levels for brood years 1991–1997, East Alsek-Doame river system sockeye salmon.

Brood year and statistic	Assumed escapement expansion	Peak aerial count of escapement	Estimated BY total escapement	Estimated brood year recruits	Estimated return per spawner ratio
1991	67%	38,700	58,050	47,829	0.82
1992	67%	43,900	65,850	99,177	1.51
1993	67%	48,200	72,300	62,724	0.87
1994	67%	35,300	52,950	52,811	1.00
1995	67%	28,850	43,275	34,396	0.79
1996	67%	29,400	44,100	33,034	0.75
1997	67%	30,000	45,000	31,696	0.70
Average	67%	36,336	54,504	51,667	0.92
Estimated replacement	67%	37,000	56,000	56,000	1.00
Estimated S_{MSY}	67%	12,000			
Eggers BEG range	67%	10,000–20,000			
1991	50%	38,700	77,400	58,901	0.76
1992	50%	43,900	87,800	116,006	1.32
1993	50%	48,200	96,400	78,079	0.81
1994	50%	35,300	70,600	68,366	0.97
1995	50%	28,850	57,700	45,516	0.79
1996	50%	29,400	58,800	43,831	0.75
1997	50%	30,000	60,000	41,922	0.70
Average	50%	36,336	72,671	64,660	0.87
Estimated replacement	50%	39,000	77,000	77,000	1.00
Estimated S_{MSY}	50%	13,000			
Eggers BEG range	50%	10,000–21,000			
1991	80%	38,700	48,375	42,294	0.87
1992	80%	43,900	54,875	90,763	1.65
1993	80%	48,200	60,250	55,047	0.91
1994	80%	35,300	44,125	45,034	1.02
1995	80%	28,850	36,063	28,836	0.80
1996	80%	29,400	36,750	27,636	0.75
1997	80%	30,000	37,500	26,582	0.71
Average	80%	36,336	45,420	45,170	0.96
Estimated replacement	80%	37,000	46,000	46,000	1.00
Estimated S_{MSY}	80%	12,000			
Eggers BEG range	80%	10,000–20,000			

Note: Estimates of replacement, S_{MSY} and Eggers BEG ranges were rounded to the nearest 1,000 fish. The S_{MSY}/replacement ratio value from the current analysis of 0.33 was used to estimate S_{MSY} after the replacement values were estimated.

Table 15.–Peak aerial spawner counts, estimated total escapements and resultant recruits using the 67% assumed escapement expansion factor, estimated replacement value in the stock-recruit relationship, and estimated S_{MSY} level for brood years 1991–1997, East Alsek-Doame river system sockeye salmon assuming the average S_{MSY}/replacement ratio of 0.43.

Brood year and statistic	Peak aerial count of escapement	Estimated BY total escapement	Estimated brood year recruits	Estimated return per spawner ratio
1991	38,700	58,050	47,829	0.82
1992	43,900	65,850	99,177	1.51
1993	48,200	72,300	62,724	0.87
1994	35,300	52,950	52,811	1.00
1995	28,850	43,275	34,396	0.79
1996	29,400	44,100	33,034	0.75
1997	30,000	45,000	31,696	0.70
Average	36,336	54,504	51,667	0.92
Estimated replacement	37,000	56,000	56,000	1.00
Estimated S_{MSY}	16,000	24,000		
Eggers BEG range	13,000–26,000			

Note: Estimates of replacement, S_{MSY} and Eggers BEG range were rounded to the nearest 1,000 fish. The average S_{MSY}/replacement ratio value of 0.43 from published studies of sockeye salmon stock-recruitment relationships in the Yakutat area was used to estimate S_{MSY} after the replacement value was estimated.

During initial review of this report, a recommendation was made to use catch-age analysis to estimate the peak count expansion factor and MSY escapement levels. We used a Bayesian adaptation of catch-age analysis, which has the advantages of straightforward assessments of uncertainty and formal incorporation of auxiliary data (Appendix A). Our analysis met with only limited success, since informative prior distributions were required in order to obtain reasonable estimates of absolute abundance. On the other hand, catch-age estimates of optimal observed escapements appeared to be fairly robust to such prior information, and were reasonably consistent with the results earlier described.

The results of catch-age analysis were not perfectly consistent with professional judgment of the authors regarding the fraction of the total escapement observed during peak aerial escapement counts. The 95% credibility interval for this parameter was 21–58%, compared to 67% hypothesized by the authors. We recommend that field work be conducted to scientifically estimate total escapement and therefore document the annual relationship between peak counts of spawners and total escapement of sockeye salmon in the East Alsek-Doame drainage.

RECOMMENDATIONS

We recommend that the following biological escapement goal for the East Alsek-Doame river system stock of sockeye salmon be formally adopted by the Alaska Department of Fish and Game, as an interim (next three years) fishery management target:

EAST ALSEK-DOAME RIVER PEAK SPAWNER COUNT OF SOCKEYE SALMON:

13,000 to 26,000 fish per year

We recommend that the stock and recruit database be updated each year to track productivity trends and to determine if productivity has stabilized. We recommend that a technical report be prepared no later than 2005 that recommends an updated biological escapement goal range.

We also recommend the existing stock assessment program be continued, advanced, and improved upon. Changes we recommend include:

Estimate the proportion of the East Alsek River sockeye salmon total escapement that is counted during peak aerial surveys. We suggest an on-the-grounds mark-recapture study to esti-mate the total escapement of sockeye salmon spawning in this river as a methodology to address this information gap. It will be important to determine annual variation in this statistic, and a minimum three years of usable estimates should be collected.

Estimate the proportion of the Doame River sockeye salmon total escapement that is counted during peak aerial surveys. We suggest an on-the-grounds mark-recapture study to estimate the total escapement of sockeye salmon spawning in this river as a methodology to address this information gap. It will be important to determine annual variation in this statistic, and a minimum of three years of usable estimates should be collected. In conjunction with this work, age composition sampling of sockeye salmon spawning in the Doame River should be implemented.

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APPENDIX A

BAYESIAN CATCH-AGE ANALYSIS

Catch-age analyses with auxiliary information (Quinn and Deriso 1999, p. 333) can provide estimates of abundance in stocks where dominant cohorts express themselves across several years. This technique is commonly used for long-lived iteroparous species, and has recently been applied to salmon, which are semelparous (Savereide 2001). We used a Bayesian adaptation of catch-age analysis, which has the advantages of straightforward assessments of uncertainty and formal incorporation of auxiliary data. See Millar and Meyer (2000) and Nielsen (2001) for other Bayesian catch-age analyses of fisheries data. As can be seen below, our analysis met with only limited success, since informative prior distributions were required in order to obtain reasonable estimates of absolute abundance. Nevertheless, we document the analysis here for two reasons: (1) because these results were consistent with results presented earlier in the main body of this report with respect to MSY escapement estimates, and (2) because we are optimistic that this approach may prove useful with this and other stocks as more data become available.

METHODS

Sockeye salmon catch and escapement data from the East Alsek and Doame rivers from 1982 through 2001 were used in the analysis. Peak annual spawning counts from the East Alsek and Doame drainages combined were obtained from Tables 2 and 3 and summed across drainages. Catch-at-age data from commercial, sport, and subsistence fisheries combined were obtained from Table 8. Because ages 2 and 6 together composed less than 0.5% of the total catch, age-2 catches were included with age-3, and age-6 with age-5. Effort data (boat-days) from the East Alsek commercial set gillnet fishery were obtained (Table A1).

Returns R of sockeye salmon originating from spawning escapement S in brood year y were assumed to follow a Ricker stock-recruit function with lognormal errors,

$$\ln\left(R_y/S_y\right) = N\left(\ln(\alpha) - \beta S_y, \sigma^2_{RS}\right)$$

Table A1.–Commercial fishing effort in the East Alsek sockeye salmon fishery, 1982–2001.

Year	Boat-days
1982	633
1983	569
1984	301
1985	1,017
1986	761
1987	1,306
1988	922
1989	1,580
1990	1,364
1991	434
1992	1,098
1993	1,429
1994	1,469
1995	198
1996	569
1997	97
1998	66
1999	0
2000	0
2001	0

where N() denotes "is normally distributed as", α and β describe the shape of the Ricker spawner-recruit relationship, and σ^2_{RS} is the process error variance. Because there is evidence that environmental changes have been occurring, and that stock productivity has recently declined, starting and ending sets of Ricker parameters ($\ln(\alpha)$, β) were estimated, and each parameter was assumed to change linearly between the beginning and end of the time period 1985–2001.

Abundance N of age-a sockeye in year t was modeled as the age proportion p_a of the total return R from brood year $y = t\text{-}a$:

$$N_{t,a} = R_{t-a}\, p_a$$

In the model, we assumed a constant maturity schedule; i.e., that the proportions $\{p_a\}$ did not vary across years. This assumption is probably not warranted; however, deviations from it are confounded with catch sampling errors below. Thus we could not estimate the maturity schedules for individual brood years.

Catch of age-*a* sockeye during year *t* was modeled as the product of abundance N and exploitation fraction μ, with lognormal error variance $\sigma^2{}_C$:

$$\ln(C_{t,a}) = N\left(\ln(N_{t,a}\mu_t), \sigma_C^2\right).$$

where

$$\mu_t = 1 - e^{-F_t}$$

and F is the exponential fishing mortality, modeled as proportional to effort *E* with catchability coefficient q_c:

$$F_t = q_c E_t$$

In this model, the catch-sampling error variance $\sigma^2{}_C$ includes deviations from a constant maturity schedule, as well as measurement error in the age composition of the catch. No age-based selectivity was incorporated into the model. Effort was considered known during 1982–1998 when the commercial fishery was responsible for the vast majority of harvest. Effort was unknown during 1999–2001, when the commercial fishery was not operating and harvest was due to sport and subsistence fishing alone. The 1999–2001 level of sport and subsistence effort was estimated as a parameter E_{SS} in the model.

Spawning abundance during year t was:

$$S_t = N_t - C_t\,.$$

Aerial survey escapement counts *A* were modeled as a constant fraction q_A of spawning escapement S, with lognormal error variance $\sigma^2{}_A$.

$$\ln(A_t) = N\left(\ln(q_A S_t), \sigma_A^2\right)$$

where q_A is the fraction of the total escapement observed with each aerial count.

Spawning abundance yielding maximum sustained catch S_{MSC} was calculated from the Ricker parameters using Hilborn's (1985) approximation, incorporating a correction for lognormal process error:

$$S_{MSC} = \frac{\ln(\alpha) + \frac{\sigma_{RS}^2}{2}}{\beta}\left(0.5 - 0.07\left(\ln(\alpha) + \frac{\sigma_{RS}^2}{2}\right)\right)$$

The optimal number of spawning salmon *observed* during aerial surveys A_{MSC} was the product of S_{MSC} and the proportion q_A of sockeye counted during peak surveys.

$$A_{MSC} = q_A S_{MSC}$$

Markov-chain Monte Carlo methods (WinBUGS 1.4: Gilks et al. 1994) were used to generate the joint posterior probability distribution of all unknowns in the model. Four Markov chains with overdispersed starting values were initiated, and 50,000–100,000 updates were generated. Gelman-Rubin statistics were monitored to assess convergence. Some parameters converged slowly; thus, a 5,000–10,000 sample burn-in period was discarded and the remainder of the samples were thinned 10:1 and used to estimate the marginal posterior means, standard deviations, and percentiles.

Preliminary results led us to run some additional analyses on simulated data. Such data were generated from the model described above, except that the maturity schedule varied annually and followed a Dirichlet distribution.

Results from preliminary versions of the analysis were compared to those from a frequentist (non-Bayesian) analysis of the same data, modified from the methods of Savereide (2001). For these versions of the model, Bayesian posterior medians were similar to point estimates generated by the frequentist model.

Bayesian analyses require that prior probabilities be specified for all unknowns in the model (Table A2). We used non-informative locally uniform priors for N[1,3], N[1,4], N[1,5], N[2,3], N[3,3], β^{-1}, and E_{SS}. Diffuse conjugate inverse gamma priors were used for $\sigma^2{}_A$, $\sigma^2{}_{RS}$, and $\sigma^2{}_C$. Initially, non-informative priors were also used for ln(α) (local uniform) and q_A (beta(1,1)). However, the resulting posterior distribution was not reasonable with these priors (this is discussed further below). Consequently, informative priors were developed for these two parameters. A normal prior with mean 1.27 and standard deviation 0.37 was assigned to ln(α), based on estimates of ln(α) for nine sockeye salmon populations in Bristol Bay. This probability

Table A2.–Prior probability distributions assigned to Bayesian catch-age model parameters.

Parameter	Distribution	Non-informative	Informative
N[1,1]	uniform	lower=0, upper=10^7	
N[1,2]	uniform	lower=0, upper=10^7	
N[1,3]	uniform	lower=0, upper=10^7	
N[2,1]	uniform	lower=0, upper=10^7	
N[3,1]	uniform	lower=0, upper=10^7	
β^{-1} [1985]	uniform	lower=0, upper=10^7	
β^{-1} [2001]	uniform	lower=0, upper=10^7	
ln(α) [1985]	normal	mean=0, SD=10	mean=1.27 SD=0.37
ln(α) [2001]	normal	mean=0, SD=10	mean=1.27 SD=0.37
p	Dirichlet	alpha=[1,1,1]	
q_A	beta	alpha=1, beta=1	alpha=25, beta=13
q_C	beta	alpha=1, beta=1	
σ_A	root inverse gamma	alpha=0.001, beta=0.001	
σ_C	root inverse gamma	alpha=0.001, beta=0.001	
σ_{RS}	root inverse gamma	alpha=0.001, beta=0.001	

distribution places 68% of the prior mass within the interval $2.5 < \alpha < 5.2$, and 95% of the mass within $1.7 < \alpha < 7.4$. A beta prior with $\alpha = 25$ and $\beta = 13$ was assigned to q_A. This prior, shown in Figure A1, quantifies the professional judgment of the authors that q_A could range between 0.5 and 0.8. A beta(25, 13) prior has 95% of its mass between 0.5 and 0.8.

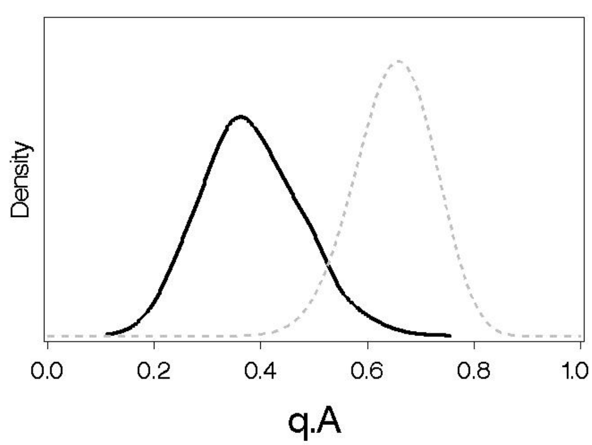

Figure A1.–Prior (gray dashed) **and posterior** (black solid) **probability density functions for the aerial survey detection fraction qA in Table A4.**

RESULTS AND DISCUSSION

The end product of a Bayesian analysis is the joint posterior probability distribution of all unknowns in the model. For our model, this distribution has many dimensions and cannot be presented in its entirety. Generally, what is of interest are the marginal (one-dimensional) probability distributions of the parameters. These probability distributions can be graphed, and one can extract whichever statistics are needed, such as the mean, standard deviation, and/or various percentiles like 2.5, 5, 25, 50 (the median), 75, 95, 97.5. For values that can be interpreted as point estimates, we've chosen the posterior median. The interpretation of this value is as follows: there is an even (50/50) chance that the true value of the parameter lies above or below the posterior median. The posterior standard deviation (SD) is analogous to the standard error of an estimate from a frequentist (non-Bayesian) statistical analysis. The 95% credibility interval is analogous to a 95% confidence interval.

When non-informative priors were used for all parameters, the model yielded some estimates which were not credible (Table A3, posterior medians for q_A = 0.01, $\beta^{-1} > 10^6$). Assignment of an informative prior for ln(a) did not materially improve the results (not shown). When an informative prior was also assigned to q_A (as well as $\ln(\alpha)$), the results were much more reasonable (Table A4).

The posterior mean for q_A was 0.38 and the 95% credibility interval 0.21 to 0.58 (Figure A1). These results indicate that the proportion of total escapement represented by peak aerial surveys may be less than indicated by professional judgment.

Optimal observed spawning escapement A_{MSC} was estimated to have changed from about 51,000 (28K to 115K) in 1985 to 10,000 (5K to 22K) in 2001. Estimated error variances were quite high[2], especially σ^2_C (posterior median 0.58, interval 0.47 to 0.73).

Several analyses were subsequently run on simulated data to better understand the reasons for these results. The simulated data were intended to mimic the East Alsek / Doame River sockeye data with different levels of process and measurement error. When simulated data were generated with low levels of error, and a moderately informative prior was assigned to $\ln(\alpha)$, the Bayesian posterior medians were similar to the actual parameter values used to generate the data. (Table A5, compare columns 2 and 3). When simulated data were generated with moderate levels of error, and the same priors used, the posterior medians no longer reflected the actual values of all parameters. The estimate of the detectability coefficient q_A was too low, and of β^{-1} far too high (Table A6, columns 2 and 3). When an informative prior was assigned to q_A (as well as $\ln(\alpha)$), the estimates reflected the actual values much more closely (Table A6, columns 2 and 5). Informative priors on the error variances did not improve estimation of optimal spawning abundance (not shown). Interestingly, the ending (2001) optimal observed spawning abundance A_{MSC} was estimated reasonably well with either set of priors (posterior medians 9,346 to 10,470; actual value 7,910, Table A6).

CONCLUSIONS

The East Alsek/Doame River data appear to contain little information about absolute abundance. This is probably caused by excessive variability in the age-specific catches. Analyses of simulated data bear this out. When process error variances are too large, patterns of persistent large and small returns among cohorts are blurred or extinguished, and the catch-age approach fails to provide viable estimates of abundance. Aerial survey detection probability q_A is underestimated and abundance N is overestimated.

This can be remedied by providing auxiliary information about q_A (or N). Reasonable prior information about the Ricker productivity parameter α also seems to be required. This can be accomplished by collecting estimates of α from other sockeye stocks.

The catch-age results corroborate results reported elsewhere in this document. The analysis presented in the main body of this report indicates that the escapement level predicted to provide for MSY fisheries was about 45,000 sockeye salmon counted during a peak survey for brood years 1972–1990 versus the A_{MSC} value of 51,000 for 1985; these are similar values. Similarly, the analysis presented in the main body of this report indicates that the escapement level predicted to provide for MSY fisheries for brood years 1991–1997 was about 12,000 sockeye salmon counted during a peak survey (Table 14; 67% model). The A_{MSC} value was 10,000 for 2001; these are reasonably similar values.

The catch-age results do not add substantial new information for this stock, at this time. However the approach may prove useful for this and/or other stocks, as more data become available. We are also hopeful that modifications of the model may improve its performance, especially if the catch-age variance σ^2_C can be decomposed into process and measurement error.

[2] Lognormal error variances can be conveniently interpreted as coefficients of variation of their respective processes. Thus the observed catches differed from the expected catches (given the model) by an average of between 47% and 73% of their true value.

Table A3.–Marginal means, standard deviations, medians, and percentiles of the Bayesian posterior probability distribution for Bayesian catch-age model parameters, using the non-informative prior distributions in Table A1.

Parameter	Mean	Std. dev.	2.5%	Median	97.5%
A_{MSC}[1985]	18620.0	1847.0	15040.0	18590.0	22350.0
A_{MSC} [2001]	7525.0	1692.0	2522.0	7700.0	10290.0
β^{-1} [1985]	3.699E+6	844200.0	1.966E+6	3.793E+6	4.94E+6
β^{-1} [2001]	1.791E+6	1.246E+6	591500.0	1.21E+6	4.768E+6
ln(α) [1985]	1.07	0.3247	0.5318	1.022	1.824
ln(α) [2001]	1.319	0.6662	0.07801	1.491	2.324
p[1]	0.1241	0.01983	0.08912	0.1227	0.1664
p[2]	0.7995	0.02612	0.7453	0.8007	0.8472
p[3]	0.07632	0.01277	0.05398	0.07538	0.1041
q_A	0.0122	0.003284	0.007836	0.0116	0.02037
q_C	0.002983	8.785E-4	0.001764	0.002828	0.005159
σ_A	0.1195	0.04349	0.03774	0.1176	0.2128
σ_C	0.6222	0.06471	0.5104	0.617	0.764
σ_{RS}	0.1029	0.06188	0.02442	0.08923	0.2445

Table A4.–Marginal means, standard deviations, medians, and percentiles of the Bayesian posterior probability distribution for Bayesian catch-age model parameters, using the informative prior distributions in Table A1.

Parameter	Mean	Std. dev.	2.5%	Median	97.5%
A_{MSC}[1985]	50690.0	594.3	28320.0	44680.0	114500.0
A_{MSC}[2001]	9864.0	96.45	4830.0	8502.0	21910.0
β^{-1} [1985]	271800.0	2259.0	121100.0	237900.0	6.52E+5
β^{-1} [2001]	64140.0	856.6	22370.0	47510.0	217400.0
ln(α) [1985]	1.225	0.004559	0.6802	1.219	1.819
ln(α) [2001]	1.129	0.007428	0.353	1.145	1.816
p[1]	0.1157	9.401E-4	0.08178	0.1143	0.1603
p[2]	0.8158	0.001157	0.7606	0.8175	0.8608
p[3]	0.06842	2.554E-4	0.04861	0.06769	0.09278
q_A	0.3825	0.003936	0.2137	0.3766	0.5792
q_C	0.07285	0.001031	0.03876	0.06937	0.128
σ_A	0.292	0.007155	0.04495	0.2747	0.6732
σ_C	0.5874	0.001306	0.4748	0.5829	0.7274
σ_{RS}	0.3523	0.004087	0.124	0.3438	0.6173

Table A5.–Medians and standard deviations of the Bayesian posterior probability distribution for catch-age model parameters from simulated data, using all non-informative prior distributions in Table A1, except that a moderately informative prior was used for ln(α). The data were meant to simulate East Alsek / Doame River sockeye salmon with low levels of process and measurement error.

Parameter	Actual value	Median	Std. dev.
A_{MSC}[1985]	19,800	17,650	2838
A_{MSC}[2001]	8,000	8,783	994
β^{-1} [1985]	100,000	104,000	46,120
β^{-1} [2001]	40,000	51,330	22,160
ln(α) [1985]	1.7	1.75	0.35
ln(α) [2001]	1.7	1.74	0.27
q_A	0.30	0.26	0.07
q_C	0.07	0.060	0.012
Dirichlet sum	400		
σ_A	0.2	0.26	0.06
σ_C	0.1	0.16	0.02
σ_{RS}	0.2	0.22	0.05

Table A6.–Medians and standard deviations of the Bayesian posterior probability distribution for catch-age model parameters from simulated data, using informative prior distributions for one or two parameters. The data were meant to simulate East Alsek/Doame River sockeye salmon with moderate levels of process and measurement error.

		Priors non-informative except for ln(α)		Priors non-informative except for ln(α) and q_A	
	Actual value	Median	Std. dev.	Median	Std. dev.
A_{MSC}[1985]	19,800	12,540	2,327	16,640	5,252
A_{MSC}[2001]	7,910	9,348	1,630	10,470	3,057
β^{-1} [1985]	100,000	388,900	265,000	87,590	48,190
β^{-1} [2001]	40,000	306,500	239,600	61,300	39,210
ln(α) [1985]	1.7	1.85	0.39	2.00	0.39
ln(α) [2001]	1.7	1.73	0.43	1.69	0.41
q_A	0.30	0.048	0.064	0.266	0.054
q_C	0.07	0.013	0.015	0.061	0.011
Dirichlet sum	100				
σ_A	0.3	0.37	0.08	0.34	0.07
σ_C	0.1	0.31	0.04	0.29	0.03
σ_{RS}	0.3	0.21	0.10	0.33	0.08