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Review of Salmon Escapement Goals in Bristol Bay, Alaska, 2012

by

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November 2012

Alaska Department of Fish and Game Divisions of Sport Fish and Commercial Fisheries

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
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 (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
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
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
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	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
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.
minute (angular)	'
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
variance	
population	Var
sample	var

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ABSTRACT

The Alaska Department of Fish and Game interdivisional escapement goal review committee reviewed Pacific salmon *Oncorhynchus* spp. escapement goals for the major river systems in Bristol Bay. The committee evaluated spawner-return data for sockeye salmon *O. nerka* in the Alagnak, Egegik, Igushik, Kulukak, Kvichak, Naknek, Nushagak, Togiak, Ugashik, and Wood rivers; Chinook salmon *O. tshawytscha* in the Alagnak, Egegik, Naknek, Nushagak, and Togiak rivers; and chum salmon *O. keta* in the Nushagak River. There are no escapement goals for coho salmon *O. kisutch* or pink salmon *O. gorbuscha* for any Bristol Bay rivers. This review examined the existing 16 escapement goals and two others that were eliminated in the 2006 review: Nushagak River coho and pink salmon.

Two significant events have occurred since the last escapement goal review three years ago. The first was the transition from Bendix sonar to DIDSON for the Nushagak River, affecting goals for Chinook, chum, and sockeye salmon by applying a correction factor to historical escapements to put them in terms of DIDSON-equivalent counts. The second was an extensive run reconstruction of historical Bristol Bay sockeye salmon brood tables using comprehensive genetic stock composition estimates since 2006, along with older genetic estimates gathered from select sets of scale DNA dating back to the early 1960s.

The committee recommended changing the ranges for 8 escapement goals (Nushagak River Chinook and chum salmon, and Egegik, Igushik, Naknek, Nushagak, Ugashik, and Wood river sockeye salmon). Four of those goals would also change in type: Igushik, Naknek, Nushagak, and Wood river changing from “sustainable escapement goal” SEGs to “biological escapement goal” BEGs. Three goals were eliminated: Egegik and Togiak river Chinook salmon, and Kulukak Bay sockeye salmon. Finally, two new goals were established: Nushagak River coho and pink salmon.

Key words: Pacific salmon, *Oncorhynchus* spp., sockeye salmon, *O. nerka*, Chinook salmon, *O. tshawytscha*, chum salmon, *O. keta*, coho salmon, *O. kisutch*, pink salmon, *O. gorbuscha*, Bristol Bay, Kvichak River, Alagnak River, Naknek River, Egegik River, Ugashik River, Wood River, Igushik River, Nushagak River, Kulukak River, Togiak River, spawning escapement goal, Ricker stock-recruitment model, Alaska Board of Fisheries.

INTRODUCTION

The purpose of this report is to inform the Alaska Board of Fisheries (board) and the public about the review of Bristol Bay salmon escapement goals and the committee’s recommendations to the Division of Commercial Fisheries and Sport Fish directors. Many Bristol Bay salmon escapement goals have been set and evaluated at regular intervals since statehood. During the previous board cycle, 2009–2010, Bristol Bay escapement goals were reviewed, and recommended changes were made by the Alaska Department of Fish and Game (department; Baker et al. 2009).

The Bristol Bay management area includes all coastal and inland waters east of a line from Cape Newenham to Cape Menshikof (Figure 1). The Bristol Bay area is divided into five management districts (Egegik, Naknek-Kvichak, Nushagak, Togiak, and Ugashik) that correspond to the major river systems. Bristol Bay supports some of the largest sockeye salmon *Oncorhynchus nerka* runs in the world. Combined sockeye salmon runs to Bristol Bay have averaged approximately 38 million fish for the last 20 years (1992–2011), with nine major river systems producing more than 99% of the returning sockeye salmon: Alagnak, Egegik, Igushik, Kvichak, Naknek, Nushagak, Togiak, Ugashik, and Wood rivers (Table 1; Figure 1).

The management objective for each river is to achieve escapements within established ranges for the major salmon species while harvesting fish in excess of those ranges through orderly fisheries. Regulatory management plans have been adopted for individual species in certain districts. Escapement refers to the annual estimated size of the spawning salmon stock, and is affected by a variety of factors including exploitation, predation, disease, and physical and biological changes in the environment. Individual escapement goals for sockeye salmon have been in place for the major river systems since the early 1960s (Burgner et al. 1967; Fried 1994; Cross et al. 1997; Fair 2000; Fair et al. 2004; Baker et al. 2006, 2009). Bristol Bay also supports one of the largest runs of Chinook salmon *O. tshawytscha* in Alaska. The Chinook salmon run in the Nushagak River has averaged 215,000 since 1989 (Buck et al. 2012). Smaller runs of chum *O. keta,* coho *O. kisutch,* and pink *O. gorbuscha* salmon are also found in many Bristol Bay rivers.

The department reviews Bristol Bay escapement goals on a schedule that corresponds to the board's three-year cycle for considering area regulatory proposals. This report describes the Bristol Bay salmon escapement goals that were reviewed in 2012.

During the 2012 review process, the department evaluated escapement goals for the following stocks:

- Chinook salmon: Alagnak, Egegik, Naknek, Nushagak, and Togiak rivers;
- Chum salmon: Nushagak River;
- Coho salmon: Nushagak River;
- Pink salmon: Nushagak River; and
- Sockeye salmon: Alagnak, Egegik, Igushik, Kulukak, Kvichak, Naknek, Nushagak, Togiak, Ugashik, and Wood rivers.

Escapement goals were reviewed based on the *Policy for the Management of Sustainable Salmon Fisheries* (SSFP; 5 AAC 39.222) and the *Policy for Statewide Salmon Escapement Goals* (EGP; 5 AAC 39.223). The board adopted these policies into regulation during the winter of 2000–2001 to ensure that the state's salmon stocks are conserved, managed, and developed using the sustained yield principle. The EGP states that it is the department's responsibility to document existing salmon escapement goals for all salmon stocks that are currently managed for an escapement goal and to review existing, or propose new, escapement goals on a schedule that conforms to the board's regular cycle of consideration of area regulatory proposals. For this review, there are 2 important terms defined in the SSFP:

> 5 AAC 39.222 (f)(3) "*biological escapement goal*" or "(BEG)" means the escapement that provides the greatest potential for maximum sustained yield; BEG will be the primary management objective for the escapement unless an optimal escapement or inriver run goal has been adopted; BEG will be developed from the best available biological information, and should be scientifically defensible on the basis of available biological information; BEG will be determined by the department and will be expressed as a range based on factors such as salmon stock productivity and data uncertainty; the department will seek to maintain evenly distributed salmon escapements within the bounds of a BEG; and

> 5 AAC 39.222 (f)(36) "*sustainable escapement goal*" or "(SEG)" means a level of escapement, indicated by an index or an escapement estimate, that is known to provide for sustained yield over a 5 to 10 year period, used in situations where a BEG cannot be estimated or managed for; the SEG is the primary management objective for the

escapement, unless an optimal escapement or inriver run goal has been adopted by the board; the SEG will be developed from the best available biological information; and should be scientifically defensible on the basis of that information; the SEG will be determined by the department and will take into account data uncertainty and be stated as either an "SEG range" or "lower bound SEG"; the department will seek to maintain escapements within the bounds of the SEG range or above the level of a lower bound SEG.

During the spring of 2012, the department established an interdivisional escapement goal review committee (hereafter referred to as the committee). The committee consisted of three Division of Commercial Fisheries and three Division of Sport Fish personnel (Table 2). They provided analyses for recommending an escapement goal for each salmon stock. The committee formally met 9 February, 2012, to review escapement goals and begin developing recommendations. Department regional and headquarters staff review all committee recommendations prior to adoption as escapement goals per the SSFP and EGP.

Of particular interest in evaluating or setting Bristol Bay escapement goals, the SSFP states that "salmon escapement goals … should be established in a manner consistent with sustained yields; unless otherwise directed, the department will manage Alaska's salmon fisheries, to the extent possible, for maximum sustained yield." Even though many Bristol Bay sockeye salmon goals have changed little in the past 20 years, evidence (estimates of escapement at maximum sustained yield are above the upper end of the goal) for raising them has existed for a number of years. For some stocks, recent high productivity from larger escapements makes for an even stronger case in changing (i.e., raising) sockeye salmon escapement goal ranges. In the 2003 review, the escapement goal committee recommended raising the goals for Egegik, Igushik, Naknek, and Ugashik river sockeye salmon; however, Division of Commercial Fisheries and Sport Fish directors did not approve those recommendations.

Two recent developments have contributed to changes in historical brood tables used in this review. First, recent genetic techniques have greatly improved the ability to accurately determine sockeye salmon stock compositions of the harvest (Dann et al. 2011). In Bristol Bay, these data are currently available since 2006. The University of Washington, Fisheries Research Institute, in cooperation with the department, recently completed a study that isolated genetic information from previously collected scale samples from harvests dating back to the early 1960s (Smith et al. 2010). Cunningham et al. (2012), again in cooperation with the department, used these genetic stock composition estimates, along with information about age composition and run timing, to reconstruct brood tables for each sockeye salmon stock, greatly improving our understanding of stock productivity. The second development was the transition of many statewide sonar-based salmon escapement projects from older systems to more modern technology. One such river is the Nushagak where the Bendix sonar system has estimated salmon passage since the late 1970s; it was replaced in 2005 with a dual-frequency identification sonar (DIDSON; Belcher et al. 2002). Recognizing that the transition to more modern sonar equipment had the potential for altering the count, the department operated the Bendix sonar and DIDSON systems simultaneously at various times during the 2003–2005, 2007, and 2009 runs. From these side-by-side comparisons, Maxwell et al. (2011) and Buck et al. (2012) converted historical Bendix sonar counts to DIDSON-equivalent counts.

OBJECTIVES

Objectives of the 2012 review were to:

1) Review existing goals to determine whether they were still appropriate given (a) new data collected since the last review, (b) current assessment techniques, and (c) current management practices;
2) Review the methods used to establish the existing goals to determine whether alternative methods should be investigated;
3) Consider any new stocks for which there may be sufficient data to develop a goal; and
4) Recommend new goals if appropriate.

METHODS

Available escapement, catch, and age data for each stock were compiled from research reports, management reports, and unpublished historical databases. The committee evaluated the type, quality, and quantity of data for each stock. Generally speaking, an escapement goal for a stock should provide escapement that produces sustainable yields. An escapement goal for a stock was defined as a BEG if a sufficiently long time series of escapement, catch, and age estimates were available; the estimates were sufficiently accurate and precise; and the data were considered sufficient to estimate maximum sustained yield (MSY; Chinook Technical Committee 1999; Hilborn and Walters 1992; Quinn and Deriso 1999). An escapement goal for a stock was defined as an SEG if a sufficiently long time series of escapement estimates were available, but there was concern about the spawner-return data (lack of age composition estimates and/or concern with stock-specific catch allocation) or there was a lack of information on stock productivity.

ESCAPEMENT AND HARVEST DATA

Sockeye salmon escapements have been sampled by beach seine and visually counted using towers at Alagnak, Egegik, Igushik, Kvichak, Naknek, Togiak, Ugashik, and Wood rivers (West et al. 2012). The department has estimated Alagnak River sockeye salmon escapement using a combination of aerial surveys and towers since its inception (Clark 2005). Escapements were sampled by gillnet or beach seine and estimated using sonar for all Nushagak River salmon species beginning in the early 1980s (Brazil and Buck 2011). Prior to the implementation of sonar, Nushagak River Chinook and sockeye salmon escapement was assessed using aerial surveys. Also, tower counts prior to sonar from the Nuyakuk River, a major tributary of the Nushagak River, were combined with aerial counts for total sockeye salmon escapement. Age data have been collected from both the escapement and harvest for all of these stocks. Prior to this review, harvest allocation for each stock was estimated by harvest location and age composition (Bernard 1983). However, the run reconstruction model of Cunningham et al. (2012) estimated sockeye salmon stock-specific harvest contributions based on genetic markers, age composition, and run timing information beginning in 1959.

All other stocks (Alagnak, Egegik, Naknek, and Togiak river Chinook salmon, and Kulukak Bay sockeye salmon) whose escapements were estimated by aerial survey were not sampled for age composition, nor were their contributions to harvest (Salomone et al. 2009).

ESCAPEMENT GOAL DETERMINATION

In previous reviews, escapement goals were evaluated for Bristol Bay stocks using the following methods: (1) Stock-Recruitment Analysis; (2) Yield Analysis; (3) Smolt Information; and (4) Risk Analysis. Spawner-return data were generally used to estimate escapement goals when stock estimates of total return (escapement and stock-specific harvest) were reliable. Spawner-return data were used to estimate escapement goals based on: (1) escapements producing average yields that were 90–100% of MSY from a stock-recruitment model, and 2) the Yield Analysis, a visual examination of observed yield versus escapement. To visually aid in identifying escapements associated with higher average yields, we fit a LOcal regrESSion line (LOESS; Cleveland and Devlin 1988) to the data. Recent smolt information are not available for any Bristol Bay data stocks. When the harvest of a stock was deemed coincidental (passively managed) to harvests and management of primary stocks (e.g., chum harvests are coincidental to the directed harvests of sockeye and Chinook salmon in the Nushagak District), the risk analysis approach determined the lower bound SEG.

Stock-Recruitment Analysis

Complete spawner-return data exists for Nushagak River Chinook and coho salmon, and Alagnak, Egegik, Igushik, Kvichak, Naknek, Nushagak, Togiak, Ugashik, and Wood river sockeye salmon. Stock-recruitment models were used to analyze salmon spawner-return data for all available brood years. For this analysis, spawners were analogous to stock and return analogous to recruitment. Total returns were the sum of escapements and harvests. Sport and subsistence harvests were only included in total return estimates for the Nushagak River Chinook salmon, and were considered minor components for the other stocks.

The most commonly used stock-recruitment (S-R) model is the Ricker (1954). This model is governed by the following equation:

$$R = \alpha S e^{-\beta S} \tag{1}$$

where α and β are model parameters. After log-transforming both sides of the equation, the standard Ricker model was fit to the data using a linear regression equation:

$$\ln(R/S) = \ln(\alpha) - \beta S \tag{2}$$

A Bayesian approach estimated these parameters in the model (Appendix F). Multiplicative-error Bayesian analysis has been previously used for Ricker stock-recruitment data analysis (Rivot et al. 2001). The department has applied the Bayesian approach to Ricker models in previous escapement goal studies (Fleischman et al. 2011). The analysis in this report was the same as the Baker et al. (2009) report, except for the following two aspects. First, serial correlation was not explicitly considered in the model. Autocorrelation can be a serious problem in a non-Bayesian analysis because autocorrelation leads to worse “time-series bias” (Walters 1985 and 1990). However, after Korman et al. (1995) examined sockeye stocks in Bristol Bay, Alaska, they concluded it was not necessary to apply a bias-correction method. Second, the parameter α was not corrected for logarithm transformation bias using the formulas from Hilborn and Walters (1992) because that correction was used for the mean of an estimated parameter (Hilborn and Mangel 1997). Using a Bayesian approach, this type of transformation bias is resolved by exponentiating the entire posterior distribution of the parameter, not just its mean.

Therefore, the management parameters MSY, S_{msy}, the optimum stock size for MSY, and U_{msy}, the optimum harvest rate for MSY, represent quantities that optimize for the long term median.

We used approximate formulae given by Hilborn and Walters (1992) to estimate the fishery management parameters MSY, S_{msy}, and U_{msy}:

$$
\begin{aligned}
S_{msy} &\approx \frac{\ln(\alpha)}{\beta}\left(0.5 - 0.07\ln(\alpha)\right),\\
u_{msy} &\approx \ln(\alpha)\left[0.5 - 0.07\ln(\alpha)\right],\\
MSY &= \alpha S_{msy} e^{-\beta S_{msy}} - S_{msy}
\end{aligned}
\tag{3}
$$

The analysis was performed using WinBUGS (Bayesian Inference Using Gibbs Sampling; Spiegelhalter et al. 1996), which used Markov Chain Monte Carlo (MCMC) to sample from the joint posterior of the parameters and posteriors of the fishery management parameters. After a burn-in of 10,000 iterations, we generated another 10,000 cycles of the MCMC and thinned the chain by taking every 30th sample yielding a final chain of length 334. We performed three Markov chains and a total of 1,002 sampled from those posteriors. Estimates of S_{msy} thought to produce 90–100% of MSY came from the median of the posterior distributions of MSY generated at various escapement intervals.

To reconstruct changes in productivity (recruits per spawner [R/S] at a given spawner abundance), we used historical spawner-return data along with a Kalman filter (Peterman et al. 2003) that included a time-varying Ricker α parameter for each of the sockeye salmon stocks (Appendix G). This analysis was separated from the development of the Bayesian Ricker model discussed above. For this review, the purpose of examining changes in productivity through time was to demonstrate that changes in productivity have been occurring since 1959 for each stock. In future reviews, this information may be used to reflect changes in model parameters that occur through time. Peterman et al. (2000) showed that if the Ricker α parameter varies over time, a Kalman filter (state-space) formulation of the Ricker model with a time-varying α parameter performs better at tracking those changes than the standard Ricker model, which assumes that parameters are constant. A concern with this approach in determining S_{msy} is the uncertainty in knowing whether productivity will remain constant or change once goals are established using current productivity information.

Risk Analysis

For stocks that were passively managed and coincidentally harvested, lower bound SEGs (Bernard et al. 2009) were estimated. The six goals previously developed using these procedures were: Kulukak River sockeye salmon; Alagnak, Egegik, Naknek, and Togiak River Chinook salmon; and Nushagak River chum salmon. The nature of the risk analysis approach does not lend itself to a necessary update with every three years of additional data; therefore, we did not re-analyze the data for this review unless the historical escapement time series had been altered.

Percentile Approach

Many salmon stocks throughout Alaska have an SEG developed using the percentile approach (Munro and Volk 2012); however, this approach has not previously been applied to Bristol Bay stocks. In 2001, Bue and Hasbrouck[1] developed an algorithm using percentiles of observed escapements, whether estimates or indices, that incorporated contrast in the escapement data and exploitation of the stock. Percentile ranking is the percent of all escapement values that fall below a particular value. To calculate percentiles, escapement data are ranked from the smallest to the largest value, with the smallest value the 0^{th} percentile (i.e., none of the escapement values are less than the smallest). The percentile of all remaining escapement values is cumulative, or a summation, of 1/(n-1), where n is the number of escapement values. Contrast in the escapement data is the maximum observed escapement divided by the minimum observed escapement. As contrast increases, meaning more information about the run size are known, the percentiles used to estimate the SEG are narrowed, primarily from the upper end, to better utilize the yields from the larger runs. For exploited stocks with high contrast, the lower end of the SEG range is increased to the 25^{th} percentile as a precautionary measure for stock protection:

Escapement Contrast and Exploitation	SEG Range
Low Contrast (<4)	15^{th} Percentile to maximum observation
Medium Contrast (4 to 8)	15^{th} to 85^{th} Percentile
High Contrast (>8); Low Exploitation	15^{th} to 75^{th} Percentile
High Contrast (>8); Exploited Population	25^{th} to 75^{th} Percentile

RESULTS AND DISCUSSION

The revision of historical brood tables (Cunningham et al. 2012) had little noticeable effect on setting sockeye salmon escapement goals (i.e., estimating S_{msy}). Most revised total returns by brood year were similar to previous total returns. Escapements were unaffected by the run reconstruction. Nushagak River escapements, however, did change because of the sonar conversion.

A similar pattern between revised and previous total returns appears for Alagnak, Naknek, and Ugashik rivers (Appendices E1, E5, and E8): there was no consistency of either the revised or previous total returns being larger than the other, but there was considerable variability through time. There was little change between revised and previous total returns for all brood years to the Kvichak River (Appendix E4) and little change to all but the early 1990s and 2000s for the Nushagak River (Appendix E6), where revised total returns were smaller than previous total returns. For Egegik River (Appendix E2), revised total returns were usually smaller, largely because non-Egegik stocks from the Egegik District harvest were removed as Egegik River stock based on genetic stock identification. Conversely, Wood River (Appendix E9) revised total returns were mostly larger because genetic stock identification shows that previous harvest allocation methods were underestimating the Wood River contribution to the Nushagak District harvest. Igushik River (Appendix E3) showed the largest difference between revised and previous total returns. Revised total returns were substantially less than previous total returns because the age composition allocation model (Bernard 1983) previously used to determine harvest stock composition overestimated Igushik River's contribution to the Nushagak District

[1] Bue, B. G. and J. J. Hasbrouck. *Unpublished*. Escapement goal review of salmon stocks of Upper Cook Inlet. Alaska Department of Fish and Game, Report to the Alaska Board of Fisheries, November 2001 (and February 2002), Anchorage.

harvest. Togiak River total returns did not change because this stock was excluded from the run reconstruction.

Productivity estimated with a Kalman filter was higher for the 2005 brood year than the 1959 brood year for all sockeye salmon stocks (Figure 2). Naknek and Alagnak rivers' productivity steadily increased through time. Egegik River followed a similar pattern, except it had a large sustained increase in productivity throughout the 1980s. Nushagak and Wood rivers' productivity increased through time with bumps in production in the mid-1970s and again around 2000. Since 2000, Nushagak River productivity decreased whereas Wood River productivity increased. The most interesting trends in productivity were those of Kvichak, Ugashik, and Igushik rivers, which all showed similar cycles of lower productivity in the late 1960s, late 1970s to early 1980s, and again in early to mid-1990s. Conversely, peaks in productivity occurred in the mid to late 1970s, mid to late 1980s, and early to mid-2000s.

A total of 18 escapement goals were evaluated for Bristol Bay. The committee recommended that eight escapement goals change in range: Nushagak River Chinook and chum salmon, and Igushik, Egegik, Naknek, Nushagak, Ugashik, and Wood River sockeye salmon. Four goals would change in type: Igushik, Naknek, Nushagak, and Wood River, changing from SEGs to BEGs. Three goals were eliminated: Egegik and Togiak River Chinook salmon, and Kulukak Bay sockeye salmon. Finally, five goals did not change (Alagnak, Kvichak, and Togiak River sockeye salmon, and Alagnak and Naknek River Chinook salmon) and two new goals were established (Nushagak River coho and pink salmon).

The recommendation for each escapement goal follows by species and river. Because many of the goals have not changed for 10 to 30 years even with strong evidence suggesting they should, we took an incremental, or conservative, approach to raising goals. We changed escapement goals dependent on the fit of the stock-recruitment model. If model fit was good, we placed similar emphasis on expected (from the Ricker stock-recruitment model) and observed yields versus escapement. For large, actively-managed stocks such as Naknek and Wood River sockeye salmon, goal ranges incrementally shifted towards escapements thought to produce 90–100% of MSY, whereas for smaller, less actively-managed stocks such as Igushik, Nushagak, and Togiak River sockeye salmon, and Nushagak River Chinook salmon, goal ranges shifted to values near or equal to escapements thought to produce 90–100% of MSY when models fit well. If model fit was poor, we placed more emphasis on observed yields versus escapement, and less on predicted yields from the Ricker model. For stocks with a poor model fit such as Egegik and Ugashik River sockeye salmon, goal ranges incrementally shifted higher to reflect actual yields observed at varying escapement levels. Kvichak River sockeye salmon is in this same category but the goal was not changed for reasons described in the section below. Incremental shifts in recommended escapement goals were not consistent for each stock and varied by the difference between current goal ranges and those suggested from observed and expected yields.

CHINOOK SALMON

Alagnak River

No change is recommended to the current risk-based lower bound SEG of 2,700 Alagnak River Chinook salmon (Table 3; Appendix A1). This goal is based on aerial survey abundance estimates beginning in 1970. Escapement averaged 4,931 Chinook salmon from 1970 to 2008, and has not been surveyed since 2008 (Appendix A1). Escapements exceeded the SEG for 7 of 10 surveys from 1999 to 2008. Although surveys have not been regularly flown since initiation of the goal, ***we recommend no change to the goal*** with the intention of obtaining stable funding to regularly evaluate this stock.

Egegik River

The current risk-based lower bound SEG for Egegik River Chinook salmon is 450 based on single aerial surveys beginning in 1985 (Table 3). Escapement estimates were the sum of aerial surveys from Gertrude, Kaye's, and Takayoto creeks only. Although we have conducted surveys for most years since the goal's implementation we do not believe these estimates are a reliable indicator of spawning abundance because it is a single aerial survey with unknown Chinook salmon run timing. As such, we do not feel it adequately captures peak abundance; therefore ***we recommend that this goal be discontinued***.

Naknek River

No change is recommended to the current risk-based lower bound SEG of 5,000 Chinook salmon (Table 3; Appendix A2). The escapement goal for Naknek River Chinook salmon is based on aerial survey abundance estimates beginning in 1971 (Baker et al. 2006). Escapements have averaged 5,969 Chinook salmon from 1971 to 2008 (Appendix A2), exceeding the SEG for 6 of the last 7 surveyed years (2000–2004; 2007–2008). Escapement was not estimated in 1999, 2005–2006, and 2009–2011. Although surveys have not been regularly flown since initiation of the goal, ***we recommend no change to the goal*** with the intention of obtaining stable funding to regularly evaluate this stock.

Nushagak River

The current Nushagak River Chinook salmon SEG range is 40,000 to 80,000 (Table 3; Appendix A3). In this review, we updated the Ricker stock-recruitment model with the three most recent complete brood years, 2002–2005. Buck et al. (2012) updated the historical escapement data set by converting Bendix counts to DIDSON equivalents (DIDSON:Bendix ratio of 2.08). Similar to previous reviews, the Ricker stock-recruitment model fit the data well based on a relatively small regression standard deviation, σ, and relatively small 95% credibility interval of S_{msy} (Tables 4 and 5). The Ricker model predicts that expected yields will increase at escapements above the upper end of the current escapement goal range because the posterior median of S_{msy} is 85,000. The range of escapements thought to produce 90–100% of MSY is 55,000 to 120,000. The credibility interval around expected median yields are relatively narrow throughout the range of escapements.

The relationship between observed yields and escapements visually shows that escapements between 50,000 and 150,000 have produced the highest observed yields, on average (Appendix A3). ***We recommend an increase to the Nushagak River Chinook salmon escapement goal: a range of 55,000 to 120,000***. Although the model was able to reliably estimate β, and hence, S_{msy}, the goal will remain an SEG because of uncertainty in escapement assessment. An ongoing study is estimating the proportion of Chinook salmon that travel in the unensonified midriver; preliminary findings suggest the proportion is relatively large although annual variability is unknown. The primary reason for the goal increase is the conversion of Bendix to DIDSON-equivalent counts.

From 2002 through 2011, 5 of 10 years experienced escapements (median of 109,000) within the recommended escapement goal range. Escapements averaged 170,186 Chinook salmon, total returns averaged 281,970, and return-per-spawner values averaged 2.1 from 1966 to 2005.

Togiak River

The current risk-based lower bound SEG for Togiak River Chinook salmon is 9,300 based on single aerial surveys beginning in 1980 (Table 3). The committee was unable to evaluate this goal because very few aerial surveys have been flown in the Togiak River system for Chinook salmon since its inception in 2007. The only assessment occurred in 2011 and survey quality was poor.

We do not believe that assessing this stock with single aerial surveys is a reliable estimate of spawning abundance. As such, with only one survey in the past 10 years and few management tools to control Chinook harvest ***we recommend that this goal be discontinued***.

CHUM SALMON

Nushagak River

The committee recommends a change to the current Nushagak River chum salmon lower bound SEG of 190,000 established in 2007 (Table 3; Appendix B1). This escapement goal was based on sonar counts established using the risk analysis approach (Baker et al. 2006). The escapement data used to establish the current goal began in 1980 from Nushagak River Bendix sonar counts from early June through July 20, the ending date sonar operations ceased when the goal was developed.

For this review, we used updated historical escapement data that had been converted from Bendix counts to DIDSON equivalents (DIDSON:Bendix ratio of 1.27; Buck et al. 2012). We continued to use cumulative escapements through July 20 even though the sonar project now operates until approximately August 20. This was done because (a) over 90% of the chum escapement has passed the sonar site by this date yet management actions could still be implemented inseason to conserve chum salmon, if necessary, and (b) for over 30% of the years since 1980, sonar operations ceased around July 20, allowing for a larger data set to re-evaluate the goal.

Because of changes to past escapements, we updated the risk analysis approach and ***recommend changing the lower bound SEG to 200,000***. An escapement level of 200,000 results in a 2.0% risk of an unwarranted concern and a 16.0% risk that a drop in mean escapement of 85% would not be detected over 3 consecutive years. Escapements have averaged 348,202 chum salmon from 1980–2011 (Appendix B1). Escapements have exceeded the recommended goal for each of the last 10 years (2002–2011).

COHO SALMON

The review in 2006 dropped an SEG of 50,000 to 100,000 for Nushagak River coho salmon (Baker et al. 2006). At that time, sonar operations had been reduced in duration (terminated on July 20), no longer assessing coho salmon abundance. Beginning in 2012, the sonar project operated through August 20 to assess coho and pink salmon because both species are actively managed in the Nushagak District.

For this review, we used updated historical escapement data that had been converted from Bendix counts to DIDSON equivalents (DIDSON:Bendix ratio of 1.27; Buck et al. 2012). We modeled the stock-recruitment data with a Ricker model, which fit the data well based on a relatively small regression standard deviation, σ, and relatively smaller 95% credibility interval of S_{msy} (Tables 4 and 5). The resulting estimated S_{msy} is 88,000 with a range thought to produce 90–100% of MSY of 60,000 to 125,000. The credible interval around expected median yields are relatively narrow at escapements less than 150,000.

The relationship between observed yields and escapements visually shows that escapements between 50,000 and 110,000 have produced the highest observed yields, on average (Appendix C1). Based on expected and observed yields, ***we recommend a new SEG of 60,000 to 120,000*** (Table 3). Given uncertainty about coho salmon assessment, the committee believes this goal should be an SEG. In particular, there is uncertainty about (a) the proportion of total escapement assessed through August 20 when the project stops; (b) the proportion of coho salmon that travel in the un-ensonfied midriver; and (c) the presumed conversion factor from Bendix counts to DIDSON equivalents since direct measurements are lacking.

Escapements averaged 95,989 coho salmon, total returns averaged 130,172, and return-per-spawner values averaged 1.4 from 1980 to 2002 (Appendix C1). Escapements (median of 64,000) have achieved the recommended goal for 3 of the last 10 evaluated years (1993–2002).

PINK SALMON

The review in 2006 dropped an SEG of 600,000 to 1,100,000 for Nushagak River pink salmon (Baker et al. 2006). At that time, sonar operations had been reduced in duration (terminated on July 20), no longer assessing pink salmon abundance. Beginning in 2012, the sonar project operated through August 20 to assess pink and coho salmon because both species are actively managed in the Nushagak District.

For this review, we used updated historical escapement data that had been converted from Bendix counts to DIDSON equivalents (DIDSON: Bendix ratio of 1.11; Buck et al. 2012). Rather than simply rerun the stock-recruitment model with the revised data set, we felt that a more appropriate goal would be a lower bound SEG, primarily due to the highly variable nature of pink salmon runs and our inability to reliably estimate MSY. To do this, we calculated a new goal using the percentile approach, choosing to use the 20^{th} percentile (Eggers and Clark *In prep*), appropriate for stocks with moderate exploitation. ***We recommend a new lower bound SEG of 165,000*** (Table 3). In terms of risk, an escapement level of 165,000 results in a 3.1% risk of an unwarranted concern and a 22.2% risk that a drop in mean escapement of 95% would not be detected over 3 consecutive even years. Escapements averaged 1,419,656 from 1958 to 2004 (Appendix D1), achieved the recommended goal for 7 of the last 10 even years (median of 353,000; 1986–2004).

SOCKEYE SALMON

Alagnak River

No change was recommended to the current Alagnak River sockeye salmon lower bound SEG of 320,000 (Table 3; Appendix E1). The goal has been achieved each of the last 10 years (Appendix E1). Escapement averaged 712,731, total return averaged 1,645,372, and return-per-spawner averaged 3.5 sockeye salmon from 1956–2005. The current SEG range is below S_{msy} based on an analysis of S-R data (Table 4).

The Alagnak River sockeye salmon stock is passively managed and coincidentally harvested with the Kvichak River stock. The department is not able to actively manage this stock and obtain an escapement goal range. It is for this reason that a lower bound SEG was established in 2006.

Historically, the Alagnak River was not considered a large producer of sockeye salmon compared to the Kvichak River and many other Bristol Bay sockeye salmon stocks. However, since 2003, escapements averaged 2,528,328. We do not yet know the total return from all of these large escapements. However, we should not be surprised by the recent production increase for the Alagnak River. Schindler et al. (2006) used sediment cores to show that periods of high sockeye salmon abundance have occurred in the Alagnak River approximately every 100 years for the last 5 centuries.

Egegik River

The current Egegik River sockeye salmon SEG range is 800,000 to 1,400,000 (Table 3; Appendix E2). In this review, we updated the Ricker stock-recruitment model with the newly reconstructed brood table through brood year 2005. Similar to previous reviews, the Ricker stock-recruitment model fit poorly based on a relatively large regression standard deviation, σ, and relatively large 95% credible intervals of β and S_{msy} (Tables 4 and 5). The Ricker model predicts that expected yields will increase at escapements above the upper end of the current escapement goal range, although accurately quantifying these gains is not possible. The credible interval widens at an increasing rate for expected median yields above escapements greater than 2,000,000 for which there are only two observations.

Given the poor model fit, more weight was put on the relationship between observed yields and escapements. Escapements greater than 1,200,000 have produced the highest observed yields, on average (Appendix E2). ***The committee recommends an incremental increase to the Egegik River sockeye salmon escapement goal: a range of 900,000 to 2,000,000***. With inadequate information to reliably estimate β, and hence, S_{msy}, the goal will remain an SEG.

From 2002 through 2011, each of the 10 years experienced escapements (median of 1,206,000) within the recommended escapement goal range. Escapements averaged 1,152,957 sockeye salmon, total returns averaged 6,557,719, and return-per-spawner values averaged 5.6 from 1959 to 2005.

Igushik River

The current Igushik River sockeye salmon SEG range is 150,000 to 300,000 (Table 3; Appendix E3). In this review, we updated the Ricker stock-recruitment model with the newly reconstructed brood table through brood year 2005. Similar to previous reviews, the Ricker stock-recruitment model fit the data well based on a relatively small regression standard deviation, σ, and relatively small 95% credible intervals of β and S_{msy} (Tables 4 and 5). The Ricker model estimated that S_{msy} is 291,000. The range of escapements thought to produce 90 to 100% of MSY is 194,000 to 402,000.

The relationship between observed yields and escapements visually shows that escapements between 200,000 and 400,000 have produced the highest observed yields, on average (Appendix E3). ***The committee recommends an increase to the Igushik River sockeye salmon escapement goal: a range of 200,000 to 400,000***. With sufficient information to reliably estimate β, and hence, S_{msy}, the goal will change from an SEG to a BEG. A guidepost for setting escapement goals throughout the state is a range that encompasses S_{msy} and is thought to produce 90–100% of MSY. The existing escapement goal lower bound of 150,000 has an expected yield that is

80% MSY, whereas the recommended lower bound of 200,000 has an expected yield that is 91% MSY. The existing upper bound is 300,000, which has an expected yield that is 99% MSY, and only slightly above the estimated S_{msy}. The recommended upper bound of 400,000 has an expected yield that is 90% MSY.

From 2002 through 2011, 4 of 10 years experienced escapements (median of 391,000) within the recommended escapement goal range. Escapements averaged 367,920 sockeye salmon, total returns averaged 706,034, and return-per-spawner values averaged 3.3 from 1959 to 2005.

Kulukak River

The current risk-based lower bound SEG for Kulukak River sockeye salmon is 8,000 based on single aerial surveys beginning in 1961 (Table 3; Baker et al 2006). Kulukak River sockeye salmon escapements have not been evaluated since 2004. The existing escapement goal is not currently used to affect management of this stock. Instead, management actions are driven by a weekly schedule the board set at the last board cycle, and one that is not altered. With no surveys flown in recent years and few inseason management tools to control sockeye salmon harvest, ***we recommend that this goal be discontinued***.

Kvichak River

Prior to the last review (Baker et al. 2009), the Kvichak River had two escapement goals: one for offcycle years, and one for cycle years (prepeak and peak). The SEG was 2,000,000 to 10,000,000 for offcycle years and 6,000,000 to 10,000,000 for cycle years (Table 3; Appendix E4). A cycle goal, largely composed of five-year-old two-ocean fish, was originally established in the 1960s (Rogers and Poe 1984) because it was believed that production differed from that of offcycle years. Therefore, it was advantageous to separate them. In 2009, we updated the analysis for comparing production between cycle and offcycle years and found statistical similarity in their underlying productivity. Additionally, it became difficult to identify offcycle from cycle years as the runs declined in the 2000s. For these reasons, in the 2009 review we eliminated the cycle goal, leaving one goal, an SEG of 2,000,000 to 10,000,000 for all years.

Setting an escapement goal for Kvichak River sockeye salmon has proven difficult because of the perceived divergence in productivity between offcycle and cycle years; poor density dependence found in the spawner-return data; and a subsequent lack of fit for stock-recruitment models. To help achieve escapements within the goal range and provide harvest opportunity, a maximum exploitation rate of 50% was established for Kvichak River runs of 4,000,000 to 20,000,000. For example, the management objective is to harvest 50% of the total inshore run, and that escapements less than 2,000,000 or greater than 10,000,000 are avoided.

The change of the escapement goal in 2009 was also supported by an analysis completed by Ruggerone and Link (2006). Their analysis did not support the existing escapement goal policy of higher escapement levels during peak and prepeak return years compared to other return years. They concluded that maintenance of the Kvichak River sockeye salmon cycle through management actions does not appear necessary for high salmon productivity and harvestable surpluses. A similar conclusion was also reached by Rogers and Poe (1984).

In this review, we updated the Ricker stock-recruitment model with the newly reconstructed brood table through brood year 2005. Because of the similarity between the old brood and new brood tables (Appendix E4) for Kvichak River, we did not re-evaluate the test for differences in productivity between cycle and offcycle years. Similar to previous reviews, fit of the Ricker model was poor (Tables 4 and 5). With inadequate information to reliably estimate β, and hence, S_{msy}, the goal will remain an SEG. ***The committee recommends no change to the Kvichak River sockeye salmon escapement goal***. From 2002 through 2011, 8 of 10 years experienced escapements (median of 2,539,000) within the escapement goal range. Escapements averaged 5,009,506 sockeye salmon, total returns averaged 10,751,053, and return-per-spawner values averaged 2.4 from 1959–2005.

Naknek River

The current Naknek River sockeye salmon SEG range is 800,000 to 1,400,000 (Table 3; Appendix E5). In this review, we updated the Ricker stock-recruitment model with the newly reconstructed brood table through brood year 2005. Similar to previous reviews, the Ricker stock-recruitment model fit the data well based on a relatively small regression standard deviation, σ, and relatively small 95% credible intervals of β and S_{msy} (Tables 4 and 5). The Ricker model predicts that expected yields will increase at escapements above the upper end of the current escapement goal range because the posterior median of S_{msy} is 1,858,000, although the credible interval of median yields begins to widen at an increasing rate with escapements between 1,500,000 and 2,000,000. The range of escapements thought to produce 90 to 100% of MSY is 1,326,000 to 2,480,000.

The relationship between observed yields and escapements visually shows that escapements between 900,000 and 2,800,000 have produced the highest observed yields, on average (Appendix E5). ***The committee recommends an incremental increase to the Naknek River sockeye salmon escapement goal: a range of 900,000 to 2,000,000***. With sufficient information to reliably estimate β, and hence, S_{msy}, the goal will change from an SEG to a BEG. A guidepost for setting escapement goals throughout the state is a range that encompasses S_{msy} and is thought to produce 90 to 100% of MSY. The existing escapement goal lower bound of 800,000 has an expected yield that is 69% MSY, whereas the recommended lower bound of 900,000 has an expected yield that is 75% MSY. The existing upper bound is 1,400,000, which has an expected yield that is 92% MSY. However, the upper bound is less than the posterior median of S_{msy}. The recommended upper bound of 2,000,000 raises it above S_{msy} and has an expected yield that is 96% MSY.

From 2002 through 2011, 7 of 10 years experienced escapements (median of 1,885,000) within the recommended escapement goal range. Escapements averaged 1,397,890 sockeye salmon, total returns averaged 4,060,772, and return-per-spawner values averaged 3.3 from 1959 to 2005.

Nushagak River

The current Nushagak River sockeye salmon SEG range is 340,000 to 760,000 (Table 3; Appendix E6). In this review, we updated the Ricker stock-recruitment model with the 3 most recent complete brood years, 2002–2005. Buck et al. (2012) updated the historical escapement data set by converting Bendix counts to DIDSON equivalents (DIDSON:Bendix ratio of 1.11). Similar to previous reviews, the Ricker stock-recruitment model fit the data well based on a relatively small regression standard deviation, σ, and relatively small 95% credible intervals of β and S_{msy} (Tables 4 and 5). The Ricker model estimated that the posterior median of S_{msy} is 801,000. The range of escapements thought to produce 90 to 100% of MSY is 549,000 to 1,083,000.

The relationship between observed yields and escapements visually shows that escapements between 400,000 and 900,000 have produced the highest observed yields, on average (Appendix E6). ***The committee recommends an increase to the Nushagak River sockeye salmon escapement goal: a range of 400,000 to 900,000***. With sufficient information to reliably estimate β, and hence, S_{msy}, the goal will change from an SEG to a BEG. The primary reason for the goal increase is the conversion of Bendix to DIDSON-equivalent counts.

From 2002 through 2011, 8 of 10 years experienced escapements (median of 505,000) within the recommended escapement goal range. Escapements averaged 533,573 sockeye salmon, total returns averaged 1,487,632, and return-per-spawner values averaged 3.8 from 1959 to 2005.

Togiak River

The current Togiak River sockeye salmon SEG range is 120,000 to 270,000 (Table 3; Appendix E7). A Ricker stock-recruitment model fit the data well based on a relatively small regression standard deviation, σ, and relatively small 95% credible intervals of β and S_{msy} (Tables 4 and 5). The Ricker model estimated that the posterior median of S_{msy} is 192,000. The range of escapements thought to produce 90 to 100% of MSY is 130,000 to 260,000.

The relationship between observed yields and escapements visually shows that escapements between 130,000 and 190,000 have produced the highest observed yields, on average (Appendix E7). Both expected and observed yields support the current goal; therefore, ***the committee recommends no change to the Togiak River sockeye salmon escapement goal***. The committee recommends keeping the goal as an SEG due to catch allocation issues within the Togiak District (Dann et al. 2011). However, the goal will change in one important aspect. The previous goal was for the entire Togiak River, which included the sum of aerial survey counts and tower counts. During this review, we realized that some years did not have aerial survey counts included in total escapement because not all years had been evaluated with aerial surveys. Additionally, no aerial surveys have been flown in recent years. To standardize the escapement time series we removed all aerial survey counts and recalculated the brood table accordingly. This means that the goal is strictly a tower-based goal, simplifying inseason management since aerial surveys were always flown postseason.

From 2002 through 2011, 8 of 10 years experienced escapements (median of 198,000) within the recommended escapement goal range. Escapements averaged 173,741 sockeye salmon, total returns averaged 560,491, and return-per-spawner values averaged 3.8 from 1959 to 2005.

Ugashik River

The current Ugashik River sockeye salmon SEG range is 500,000 to 1,200,000 (Table 3; Appendix E8). In this review, we updated the Ricker stock-recruitment model with the newly reconstructed brood table through brood year 2005. Similar to previous reviews, the Ricker stock-recruitment model fit poorly based on a relatively large regression standard deviation, σ, and relatively large 95% credible intervals of β and S_{msy} (Tables 4 and 5). The Ricker model predicts that expected yields will increase at escapements above the upper end of the current escapement goal range, although accurately quantifying these gains is not possible. The credible interval of expected median yields widens at an increasing rate for escapements greater than 1,500,000, for which there are seven observations.

Given the poor model fit, more weight is put into the relationship between observed yields and escapements. Escapements greater than 500,000 have produced the highest observed yields, on average (Appendix E8). ***The committee recommends an incremental increase to the Ugashik River sockeye salmon escapement goal: a range of 600,000 to 1,400,000***. With inadequate information to reliably estimate β, and hence, S_{msy}, the goal will remain an SEG.

From 2002 through 2011, 9 of 10 years experienced escapements (median of 868,000) within the recommended escapement goal range. Escapements averaged 924,695 sockeye salmon, total returns averaged 3,070,512, and return-per-spawner values averaged 4.3 from 1959 to 2005.

Wood River

The current Wood River sockeye salmon SEG range is 700,000 to 1,500,000 (Table 3; Appendix E9). In this review, we updated the Ricker stock-recruitment model with the newly reconstructed brood table through brood year 2005. Similar to previous reviews, the Ricker stock-recruitment model fit the data well based on a relatively small regression standard deviation, σ, and relatively small 95% credible intervals of β and S_{msy} (Tables 4 and 5). The Ricker model predicts that expected yields will increase at escapements above the upper end of the current escapement goal range because the posterior median of S_{msy} is 1,550,000, although the credible interval of expected median yields begins to widen at an increasing rate for escapements between 1,500,000 and 2,000,000. The range of escapements thought to produce 90 to 100% of MSY is 1,085,000 to 2,083,000.

The relationship between observed yields and escapements shows that escapements between 1,100,000 and 2,000,000 have produced the highest observed yields, on average (Appendix E9). ***The committee recommends an incremental increase to the Wood River sockeye salmon escapement goal: a range of 800,000 to 1,800,000***. With sufficient information to reliably estimate β, and hence, S_{msy}, the goal will change from an SEG to a BEG. A guidepost for setting escapement goals throughout the state is a range that encompasses S_{msy} and is thought to produce 90 to 100% of MSY. The existing escapement goal lower bound of 700,000 has an expected yield that is 72% MSY, whereas the recommended lower bound of 800,000 has an expected yield that is 78% MSY. The existing upper bound is 1,500,000, which has an expected yield that is 97% MSY. However, the upper bound is less than S_{msy}. The recommended upper bound of 1,800,000 raises it above S_{msy} and has an expected yield that is 95% MSY.

From 2002 through 2011, 9 of 10 years experienced escapements (median of 1,512,000) within the recommended escapement goal range. Escapements averaged 1,281,275 sockeye salmon, total returns averaged 3,969,877, and R/S values averaged 3.4 from 1959 to 2005.

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TABLES AND FIGURES

Table 1.–Bristol Bay sockeye salmon total runs by system, 1990–2011.

Year	Alagnak	Egegik	Igushik	Kvichak	Naknek	Nushagak	Togiak	Ugashik	Wood	Total
1990	1,701,649	12,637,915	876,172	18,189,966	8,163,457	1,804,526	318,900	2,712,067	3,195,123	49,599,776
1991	1,737,583	9,251,071	1,645,838	8,611,675	9,688,700	1,628,967	805,845	5,958,772	4,506,271	43,834,721
1992	1,489,221	17,899,123	470,348	10,627,883	5,188,655	1,888,874	853,945	6,341,101	3,071,690	47,830,840
1993	2,512,409	24,268,431	717,075	8,063,207	5,501,841	2,580,049	690,518	6,216,394	4,748,132	55,298,057
1994	2,195,065	12,777,526	906,828	21,588,688	3,535,600	1,436,463	489,917	5,569,307	3,696,594	52,195,987
1995	2,338,713	15,416,175	1,184,425	28,422,825	3,266,372	810,995	738,246	5,912,259	4,938,613	63,028,623
1996	2,410,081	12,424,020	942,696	4,473,942	4,629,505	1,623,169	556,842	5,370,520	5,959,844	38,390,618
1997	824,652	7,932,989	208,759	2,394,703	1,897,379	817,647	242,343	2,508,869	3,879,034	20,706,375
1998	1,208,943	4,696,477	426,034	3,810,384	2,336,117	991,560	285,583	1,892,158	4,421,018	20,068,275
1999	3,103,292	6,501,522	859,318	13,202,982	4,608,730	451,807	521,485	5,223,624	7,403,081	41,875,841
2000	2,247,374	8,174,785	982,740	3,582,461	3,892,043	1,344,618	1,089,824	2,300,669	6,541,118	30,155,634
2001	1,298,362	3,567,026	818,733	1,978,264	5,843,560	2,093,785	1,103,557	1,469,530	4,644,099	22,816,916
2002	991,581	5,543,847	199,684	915,974	2,746,786	691,785	391,206	2,499,988	3,859,722	17,840,572
2003	4,269,058	3,216,304	492,184	2,041,843	4,714,012	2,409,660	899,686	2,542,318	6,233,372	26,818,438
2004	7,602,372	11,653,816	268,354	8,103,494	3,968,470	2,062,469	501,842	4,203,288	6,430,417	44,794,522
2005	5,396,064	9,403,191	801,087	2,926,045	8,538,432	3,672,976	576,607	3,093,000	5,881,534	40,288,937
2006	2,959,105	8,611,295	730,987	5,212,193	6,244,656	3,182,432	907,365	3,769,197	12,186,375	43,803,605
2007	4,192,470	7,871,418	856,587	5,010,550	9,438,712	2,499,070	1,069,101	7,408,795	7,930,681	46,277,384
2008	4,625,323	7,892,592	1,685,397	6,132,383	9,249,393	1,548,644	868,475	2,722,282	7,366,573	42,091,063
2009	2,411,665	13,014,336	915,844	6,899,793	4,438,134	1,674,977	855,555	3,605,013	7,745,923	41,561,241
2010	2,857,063	5,156,493	1,540,795	10,931,213	5,270,545	1,035,601	739,352	4,953,525	8,847,397	41,331,985
2011	2,333,170	4,503,430	1,297,732	7,587,656	5,109,389	1,123,579	854,666	4,273,505	4,711,499	31,794,625
Mean	3,763,787	7,686,672	878,865	5,576,114	5,971,853	1,990,119	766,386	3,907,091	7,119,349	37,660,237
Median	3,575,787	7,882,005	828,837	5,672,288	5,189,967	1,868,723	855,111	3,687,105	6,898,495	41,446,613
Min	991,581	3,216,304	199,684	915,974	2,746,786	691,785	391,206	2,499,988	3,859,722	17,840,572
Max	7,602,372	13,014,336	1,685,397	10,931,213	9,438,712	3,672,976	1,069,101	7,408,795	12,186,375	46,277,384

Note: Small runs (less than 1% of total Bristol Bay) of sockeye salmon not shown here occur in the Kulukak, Matogak, Osviak, and Snake rivers.

Table 2.–List of members on the Alaska Department of Fish and Game (ADF&G) Bristol Bay salmon escapement goal committee and other participants who assisted with the escapement goal review.

Name	Position	Affiliation
Escapement Goal Committee:		
Charles Brazil	Area Research Biologist	ADF&G, Division of Commercial Fisheries
Bob Clark	Chief Fisheries Scientist	ADF&G, Division of Sport Fish
Jack Erickson	Regional Research Coordinator	ADF&G, Division of Sport Fish
Lowell Fair	Regional Research Coordinator	ADF&G, Division of Commercial Fisheries
Steve Fleischman	Fisheries Scientist	ADF&G, Division of Sport Fish
Xinxian Zhang	Regional Biometrician	ADF&G, Division of Commercial Fisheries
Other Participants:		
Tim Baker	Regional Management Biologist	ADF&G, Division of Commercial Fisheries
Greg Buck	Asst. Area Research Biologist	ADF&G, Division of Commercial Fisheries
Jason Dye	Area Management Biologist	ADF&G, Division of Sport Fish
Dan Gray	Regional Management Biologist	ADF&G, Division of Commercial Fisheries
Jim Hasbrouck	Regional Supervisor	ADF&G, Division of Sport Fish
Matt Jones	Asst. Area Management Biologist	ADF&G, Division of Commercial Fisheries
Tracy Lingnau	Regional Supervisor	ADF&G, Division of Commercial Fisheries
Matt Miller	Regional Management Biologist	ADF&G, Division of Sport Fish
Slim Morstad	Area Management Biologist	ADF&G, Division of Commercial Fisheries
Paul Salomone	Area Management Biologist	ADF&G, Division of Commercial Fisheries
Tim Sands	Area Management Biologist	ADF&G, Division of Commercial Fisheries
Craig Schwanke	Asst. Area Management Biologist	ADF&G, Division of Sport Fish
Erik Volk	Chief Fisheries Scientist	ADF&G, Division of Commercial Fisheries
Fred West	Asst. Area Research Biologist	ADF&G, Division of Commercial Fisheries

Table 3.–Summary of current escapement goals and recommended escapement goals for salmon stocks in Bristol Bay, 2012.

	Current Escapement Goal				Recommended Escapement Goal		
System	Goal	Type	Year Adopted	Escapement Data	Action	Goal	Type
Chinook Salmon							
Alagnak	2,700 minimum	SEG	2007	Aerial	No Change		
Egegik	450 minimum	SEG	2007	Aerial	Drop		
Naknek	5,000 minimum	SEG	2007	Aerial	No Change		
Nushagak	40,000–80,000	SEG	2007; Changed to SEG in 2007	Sonar	Change in range	55,000–120,000	SEG
Togiak	9,300 minimum	SEG	2007	Aerial	Drop		
Chum Salmon							
Nushagak	190,000 minimum	SEG	2007	Sonar	Change in range	200,000 minimum	SEG
Coho Salmon							
Nushagak	50,000–100,000	SEG	2007	Sonar	New Goal	60,000–120,000	SEG
Pink Salmon							
Nushagak				Sonar	New Goal	165,000 minimum	SEG
Sockeye Salmon							
Alagnak	320,000 minimum	SEG	2007	Tower	No Change		
Egegik	800,000–1,400,000	SEG	1995; Changed to SEG in 2007	Tower	Change in range	900,000–2,000,000	SEG
Igushik	150,000–300,000	SEG	2001; Changed to SEG in 2007	Tower	Change in range and type	200,000–400,000	BEG
Kvichak	2,000,000–10,000,000	SEG	One goal for all years in 2010	Tower	No Change		
Kulukak Bay	8,000 minimum	SEG	2007	Aerial	Drop		
Naknek	800,000–1,400,000	SEG	1983; Changed to SEG in 2007	Tower	Change in range and type	900,000–2,000,000	BEG
Nushagak	340,000–760,000	SEG	1998; Changed to SEG in 2007	Sonar	Change in range and type	400,000–900,000	BEG
Togiak	120,000–270,000	SEG	2007; Changed from a BEG in 2010	Tower	No Change		
Ugashik	500,000–1,200,000	SEG	1995; Changed to SEG in 2007	Tower	Change in range	600,000–1,400,000	SEG
Wood	700,000–1,500,000	SEG	2001; Changed to SEG in 2007	Tower	Change in range and type	800,000–1,800,000	BEG

Table 4.–Recommended escapement goals and estimates of S_{msy}, escapement at 90–100% of MSY, and S_{eq} for Bristol Bay salmon.

		Escapement Goal (x thousands)					S_{msy} 95% CI				Escapement at 90–100% of MSY		S_{eq} ($\ln\alpha / \beta$)
Sockeye salmon	Goal Type	Lower	Upper	Spawner-Return Data	n	Model	Median	CV	Lower	Upper	Lower	Upper	Median
Alagnak	SEG	320		1959–2005	47	Ricker	1,480	7.76	910	4,616	1,061	1,950	9,576
Egegik	SEG	900	2,000	1959–2005	47	Ricker	5,242	140.71	1,530	142,100	3,704	7,213	42,749
Igushik	BEG	200	400	1959–2005	47	Ricker	291	0.18	232	423	194	402	2,141
Kvichak	SEG	2,000	10,000	1959–2005	47	Ricker	13,280	36.33	5,777	169,300	10,905	15,681	85,762
Naknek	BEG	900	2,000	1959–2005	47	Ricker	1,858	8.60	1,167	6,385	1,326	2,480	13,778
Nushagak	BEG	400	900	1978–2005	25	Ricker	801	0.37	571	1,549	549	1,083	5,869
Ugashik	SEG	600	1,400	1959–2005	47	Ricker	2,602	15.37	1,031	38,650	1,972	3,178	17,312
Togiak	SEG	120	270	1959–2005	47	Ricker	192	0.43	133	384	130	260	1,637
Wood	BEG	800	1,800	1959–2005	47	Ricker	1,550	3.08	962	5,741	1,085	2,083	12,191
Bristol Bay	SEG	6,240	18,790										
Chinook Salmon													
Nushagak	SEG	55	120	1966–2005	40	Ricker	85	0.11	73	106	55	120	747
Coho Salmon													
Nushagak	SEG	60	120	1980–1997	17	Ricker	88	1.91	59	235	60	125	560

Note: A Bayesian analysis estimated stock-recruitment parameters for a Ricker model with multiplicative error. Median parameter estimates are given with CVs and lower and upper 95% credible intervals (CI).

Table 5.–Recommended escapement goals and estimates of stock-recruitment parameters (α, β, and σ) for Bristol Bay salmon.

	Spawner-Return			α				β			σ		
				95% CI				95% CI			95% CI		
Sockeye salmon	Data	n	Model	Lower	Median	ln Median	Upper	Lower	Median	Upper	Lower	Median	Upper
Alagnak	1959–2005	47	Ricker	2.34	3.12	1.14	4.15	9.32E-08	3.26E-07	5.42E-07	0.68	0.82	1.02
Egegik	1959–2005	47	Ricker	3.81	5.07	1.62	8.19	4.16E-09	1.19E-07	4.73E-07	0.65	0.80	0.99
Igushik	1959–2005	47	Ricker	2.84	4.11	1.41	5.92	1.17E-06	1.92E-06	2.73E-06	0.67	0.83	1.04
Kvichak	1959–2005	47	Ricker	1.55	2.05	0.72	2.92	1.66E-09	2.39E-08	6.40E-08	0.69	0.84	1.05
Naknek	1959–2005	47	Ricker	2.99	4.26	1.45	6.03	7.57E-08	3.09E-07	5.69E-07	0.48	0.58	0.74
Nushagak	1978–2005	25	Ricker	3.14	4.12	1.42	5.48	3.25E-07	7.02E-07	1.08E-06	0.56	0.68	0.85
Togiak	1959–2005	47	Ricker	3.90	5.63	1.73	8.25	1.48E-03	3.44E-03	5.56E-03	0.46	0.56	0.71
Ugashik	1959–2005	47	Ricker	2.40	3.40	1.22	5.42	1.08E-08	1.96E-07	6.06E-07	0.83	1.01	1.26
Wood	1959–2005	47	Ricker	3.19	4.70	1.55	7.33	8.64E-08	3.86E-07	7.30E-07	0.49	0.59	0.74
Bristol Bay													
Chinook Salmon													
Nushagak	1966–2005	40	Ricker	3.67	5.78	1.75	9.26	5.21E-06	7.70E-06	1.03E-05	0.46	0.57	0.72
Coho Salmon													
Nushagak	1980–1997	17	Ricker	1.40	2.24	0.81	3.73	9.08E-07	4.01E-06	7.11E-06	0.40	0.56	0.85

Note: A Bayesian analysis estimated stock-recruitment parameters for a Ricker model with multiplicative error. Median parameter estimates are given along with lower and upper 95% credible intervals.

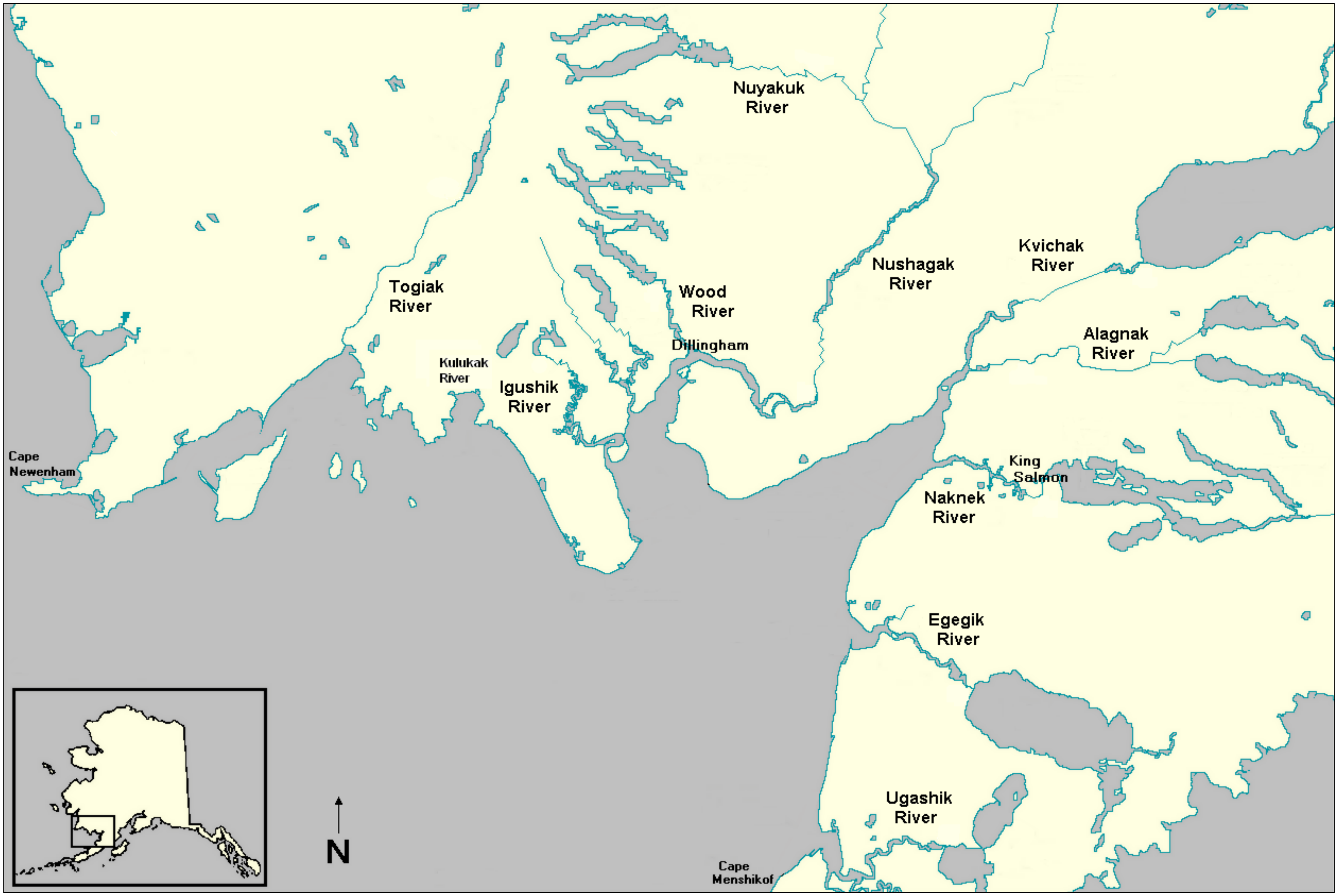

Figure 1.–Map of Bristol Bay showing major rivers.

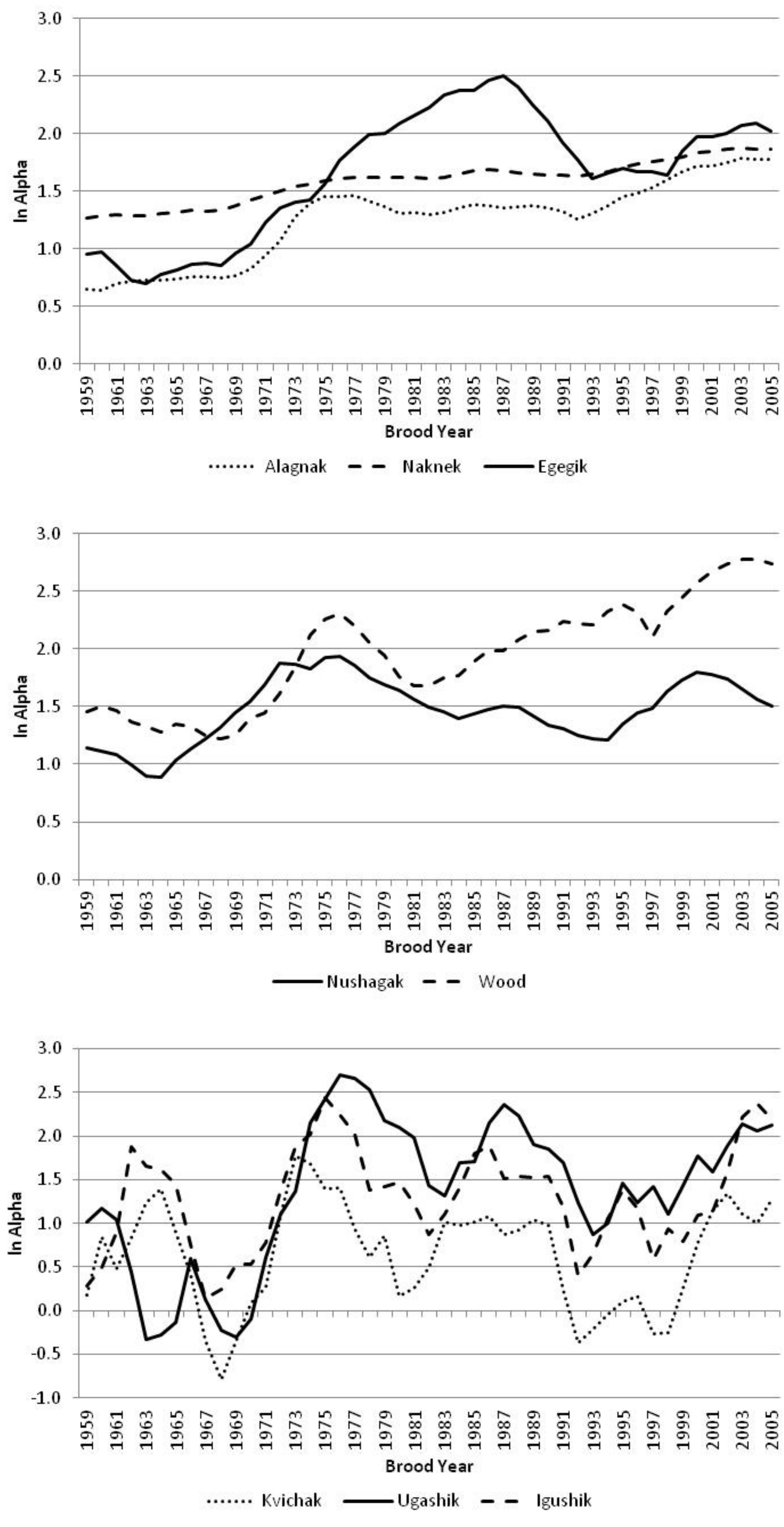

Figure 2.–Kalman filter estimates of Ricker stock-recruitment ln α by brood year for Bristol Bay sockeye salmon stocks.

APPENDIX A. CHINOOK SALMON

Appendix A1.–Escapement goal for Alagnak River Chinook salmon.

System: Alagnak River

Species: Chinook salmon

Description of stock and escapement goals

Management Division:	Sport Fish
Previous Escapement Goal:	2,700 lower bound SEG
Inriver Goal:	None
Optimal Escapement Goal:	None
Recommended Escapement Goal:	No change
Escapement Estimation:	Aerial survey counts since 1970
Summary:	
Data Quality	Fair
Data Type	Aerial survey; limited age data
Methodology	Risk analysis
Years within recommended goal	7 out of last 10 years (1999–2008) – no surveys since 2008

-continued-

System: Alagnak River

Species: Chinook salmon

Data available for analysis of escapement goals

Year	Escapement	ln(Escapement)
1970	5,250	8.57
1971	1,475	7.30
1972	2,256	7.72
1973	824	6.71
1974	1,596	7.38
1975	6,620	8.80
1976	7,593	8.93
1977	9,425	9.15
1978	11,650	9.36
1979		
1980	2,930	7.98
1981	2,430	7.80
1982	3,400	8.13
1983	2,980	8.00
1984	6,090	8.71
1985	3,920	8.27
1986	3,090	8.04
1987	2,420	7.79
1988	4,600	8.43
1989	3,650	8.20
1990	1,720	7.45
1991	2,531	7.84
1992	3,042	8.02
1993	10,170	9.23
1994	8,480	9.05
1995	6,860	8.83
1996	9,885	9.20
1997	15,210	9.63
1998	4,148	8.33
1999	2,178	7.69
2000	2,220	7.71
2001	5,458	8.60
2002	3,675	8.21
2003	8,209	9.01
2004	6,755	8.82
2005	5,084	8.53
2006	4,278	8.36
2007	3,455	8.15
2008	1,825	7.51
1970–2008		
Average	4,931	8.30
St. dev.	3,247	0.66
Median	3,798	8.24
No. of Years	38	38

Note: no surveys were flown in 1979.

Appendix A2.–Escapement goal for Naknek River Chinook salmon.

System: Naknek River

Species: Chinook salmon

Description of stock and escapement goals

Management Division:	Sport Fish
Previous Escapement Goal:	5,000 lower bound SEG (2007)
Inriver Goal:	None
Optimal Escapement Goal:	None
Recommended Escapement Goal:	No change
Escapement Estimation:	Aerial survey counts since 1971
Summary:	
Data Quality	Fair
Data Type	Aerial survey and Big Creek weir; limited age data
Methodology	Risk analysis
Years within recommended goal	6 out of 7 years (2000–2004; 2007–2008); no escapement estimates in 1999, 2005–2006, and 2009–2011

-continued-

System: Naknek River

Species: Chinook salmon

Data available for analysis of escapement goals

Year	Escapement	ln(Escapement)
1971	2,885	7.97
1972	2,791	7.93
1973	2,536	7.84
1974	[a]	
1975	3,452	8.15
1976	7,131	8.87
1977	[a]	
1978	[a]	
1979	[a]	
1980	[a]	
1981	4,271	8.36
1982	8,610	9.06
1983	7,830	8.97
1984	4,995	8.52
1985	[a]	
1986	3,917	8.27
1987	4,450	8.40
1988	11,730	9.37

[a] Escapement not available.

Year	Escapement	ln(Escapement)
1989	2,710	7.90
1990	7,000	8.85
1991	4,391	8.39
1992	2,691	7.90
1993	8,016	8.99
1994	9,678	9.18
1995	4,960	8.51
1996	5,010	8.52
1997	10,453	9.25
1998	5,505	8.61
1999	[a]	
2000	3,233	8.08
2001	6,340	8.75
2002	7,503	8.92
2003	6,081	8.71
2004	12,878	9.46
2005	[a]	
2006	[a]	
2007	5,498	8.61
2008	6,559	8.79
1971–2008		
Average	5,969	8.59
St. dev.	2,781	0.47
Median	5,498	8.61
No. of Years	29	29

Appendix A3.–Escapement goal for Nushagak River Chinook salmon.

System: Nushagak River

Species: Chinook salmon

Description of stock and escapement goals

Management Division:	Commercial Fisheries
Previous Escapement Goal:	40,000–80,000 BEG (2007)); changed to SEG in 2007
Inriver Goal:	75,000
Optimal Escapement Goal:	None
Recommended Escapement Goal:	55,000–120,000 SEG
Escapement Estimation:	Expanded aerial survey counts plus Nuyakuk tower from 1966–1979; sonar counts from 1980 to present; converted Bendix to DIDSON 1966 to 2005; DIDSON counts uncorrected since 2006; 40 years of complete return data available
Summary:	
Data Quality	Good
Data Type	Aerial survey, tower, and sonar escapement estimates; sport, subsistence, and commercial harvests; age data
Methodology	Ricker stock-recruitment, yield analysis
Years within recommended goal	5 of last 10 years (2002–2011)

-continued-

System: Nushagak River

Species: Chinook salmon

Data available for analysis of escapement goals

Year	Spawning Escapement [a]	Total Return	Return per Spawner	Year	Escapement [a]	Total Return	Return per Spawner
1966	83,224	206,417	2.48	1991	210,282	281,973	1.34
1967	135,240	207,822	1.54	1992	166,915	251,785	1.51
1968	145,643	228,162	1.57	1993	197,038	367,493	1.87
1969	72,821	102,029	1.40	1994	190,063	151,351	0.80
1970	104,030	288,555	2.77	1995	172,962	166,918	0.97
1971	83,224	363,524	4.37	1996	102,317	178,538	1.74
1972	52,015	477,250	9.18	1997	165,013	184,497	1.12
1973	72,821	422,771	5.81	1998	235,773	283,161	1.20
1974	145,643	260,059	1.79	1999	123,868	330,945	2.67
1975	145,643	833,159	5.72	2000	110,647	311,763	2.82
1976	208,061	585,648	2.81	2001	184,261	157,237	0.85
1977	135,240	989,404	7.32	2002	174,651	119,881	0.69
1978	270,479	322,448	1.19	2003	158,259	178,879	1.13
1979	197,658	448,355	2.27	2004	233,404	78,551	0.34
1980	293,366	218,931	0.75	2005	224,106	110,236	0.49
1981	312,091	289,258	0.93	2006	117,364	[b]	
1982	305,849	138,241	0.45	2007	50,960	[b]	
1983	336,497	153,865	0.46	2008	91,364	[b]	
1984	168,404	123,079	0.73	2009	74,781	[b]	
1985	240,768	188,210	0.78	2010	56,088	[b]	
1986	81,456	219,125	2.69	2011	101,572	[b]	
1987	169,510	283,382	1.67				
1988	112,971	315,081	2.79	1966–2005			
1989	158,504	315,727	1.99	Average	170,186	281,970	2.10
1990	126,708	145,103	1.15	No. of Years	40	40	40

[a] DIDSON conversion factor of 2.08 applied to all years prior to 2005. Escapement estimate for 2005 used strata- and species-specific correction factors applied to the Bendix north bank counting stratum. Counts from 2006 through 2011 are uncorrected DIDSON counts.

[b] Incomplete returns from brood year escapement.

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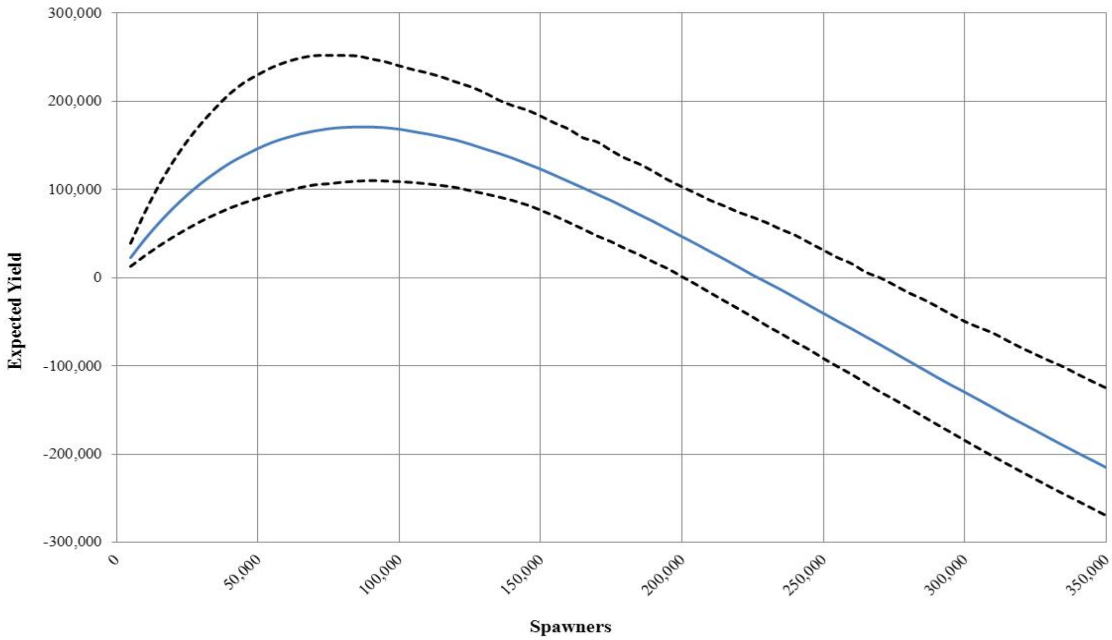
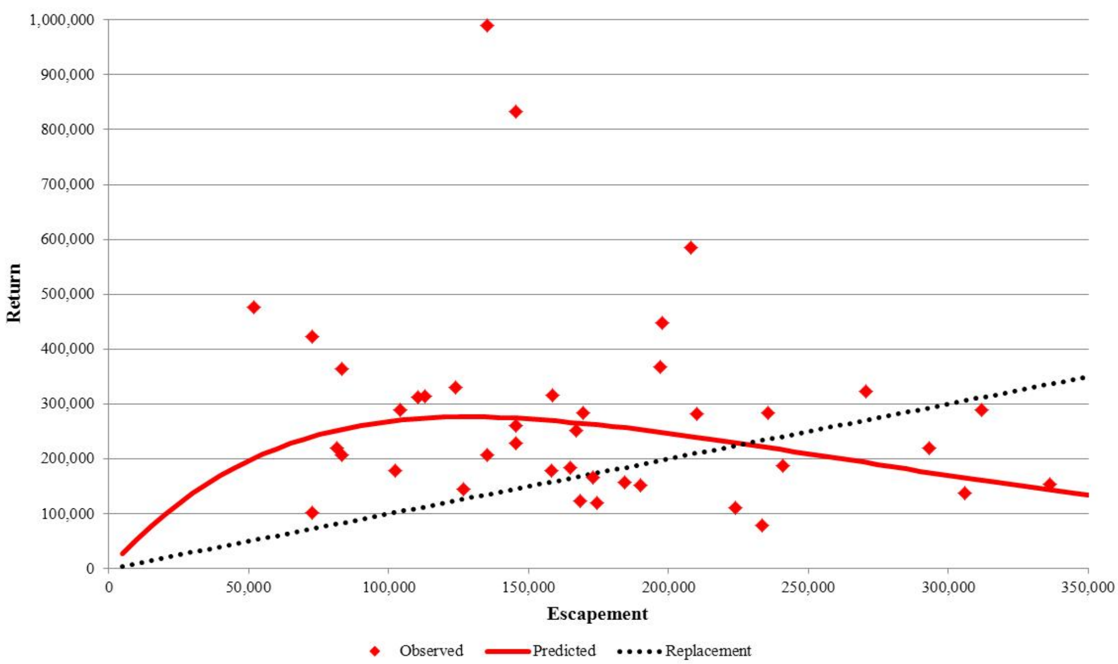
Expected Ricker median yields with 95% credible intervals against escapements (top), and predicted Ricker returns and observed returns against escapements (bottom).





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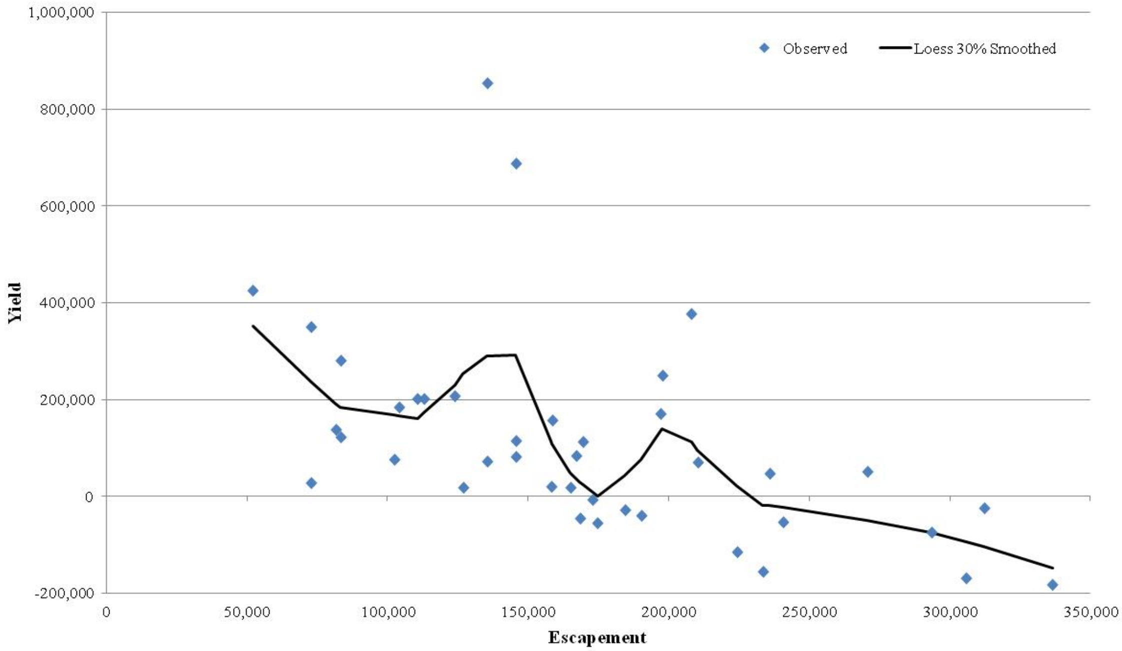
Observed yields fitted with a LOESS 30% smoothed line against escapements.



APPENDIX B. CHUM SALMON

Appendix B1.–Escapement goal for Nushagak River chum salmon.

System: Nushagak River

Species: chum salmon

Description of stock and escapement goals

Management Division:	Commercial Fisheries
Previous Escapement Goal:	190,000 lower bound SEG (2007)
Inriver Goal:	None
Optimal Escapement Goal:	None
Recommended Escapement Goal:	200,000 lower bound SEG
Escapement Estimation:	Sonar counts since 1980; converted Bendix to DIDSON 1980 to 2005; DIDSON counts uncorrected since 2006; 26 years of complete return data available; converted Bendix counts to DIDSON-equivalent counts in 2012
Summary:	
Data Quality	Good
Data Type	Sonar escapement estimates; commercial harvest; age data
Methodology	Risk analysis
Years within recommended goal	10 out of last 10 years (2002–2011)

-continued-

System: Nushagak River

Species: chum salmon

Data available for analysis of escapement goals

Year	Escapement [a]	ln(Escapement)	Year	Escapement [a]	ln(Escapement)
1980	415,727	12.94	1999	296,408	12.60
1981	182,021	12.11	2000	173,712	12.07
1982	262,597	12.48	2001	646,984	13.38
1983	107,780	11.59	2002	509,106	13.14
1984	450,031	13.02	2003	375,175	12.84
1985	245,797	12.41	2004	332,347	12.71
1986	203,810	12.22	2005	569,034	13.25
1987	175,551	12.08	2006	839,473	13.64
1988	217,772	12.29	2007	205,083	12.23
1989	461,456	13.04	2008	414,401	12.93
1990	373,126	12.83	2009	556,871	13.23
1991	350,186	12.77	2010	347,871	12.76
1992	383,303	12.86	2011	315,312	12.66
1993	272,278	12.51	Mean	348,202	12.65
1994	467,930	13.06	St. dev.	162,186	0.51
1995	266,432	12.49	Median	340,109	12.74
1996	279,406	12.54	No. of Years	32	32
1997	76,034	11.24			
1998	369,447	12.82			

[a] DIDSON conversion factor of 1.27 applied to all years prior to 2005. Escapement estimate for 2005 used strata- and species-specific correction factors applied to the Bendix north bank counting stratum. Counts from 2006 through 2011 are uncorrected DIDSON counts.

APPENDIX C. COHO SALMON

Appendix C1.–Escapement goal for Nushagak River coho salmon.

System: Nushagak River

Species: coho salmon

Description of stock and escapement goals

Management Division:	Commercial Fisheries
Previous Escapement Goal:	50,000 to 100,000 SEG dropped in 2007
Inriver Goal:	None
Optimal Escapement Goal:	None
Recommended Escapement Goal:	60,000 to 120,000 SEG
Escapement Estimation:	Sonar counts since 1980; converted Bendix to DIDSON 1980 to 2002; 26 years of complete return data available; converted Bendix counts to DIDSON-equivalent counts in 2012
Summary:	
Data Quality	Good
Data Type	Sonar escapement estimates; commercial harvest; age data
Methodology	Ricker stock-recruitment, yield analysis
Years within recommended goal	6 out of last 10 years (1987–1991, 1992–1997)

-continued-

System: Nushagak River

Species: coho salmon

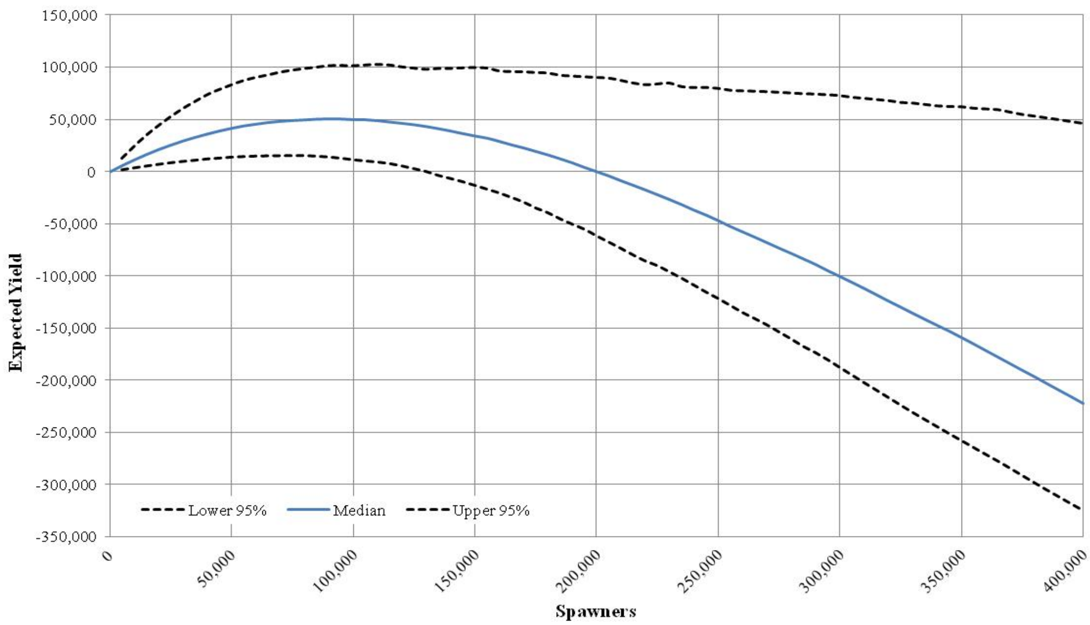
Data available for analysis of escapement goals

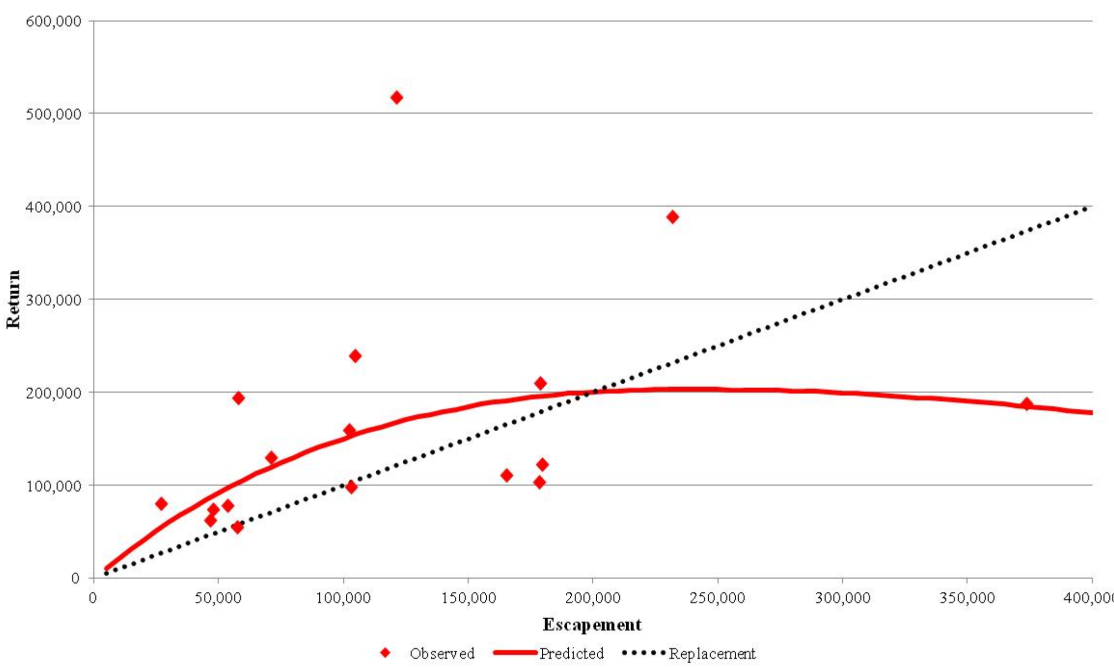
Year	Spawning Escapement [a]	Total Return	Return per Spawner
1980	95,411	407,100	4.3
1981	141,468	96,740	0.7
1982	294,151	148,150	0.5
1983	36,885	49,151	1.3
1984	140,804	165,050	1.2
1985	82,258	188,273	2.3
1986	45,483	152,472	3.4
1987	21,268	63,074	3.0
1988	130,171	86,853	0.7
1989	81,107	77,353	1.0
1990	140,500	81,822	0.6
1991	37,584	58,024	1.5
1992			
1993	42,161	61,619	1.5
1994	80,470	125,739	1.6
1995	45,137	43,677	1.0
1996	182,460	305,932	1.7
1997	55,882	101,893	1.8
1998	103,194		
1999	33,991		
2000	200,938		
2001	72,388		
2002	48,054		
1980–1996			
Average	95,989	130,172	1.4
No. of Years	22	17	17

[a] DIDSON conversion factor of 1.27 applied to all years.

-continued-

Expected Ricker median yields with 95% credible intervals against escapements (top), and predicted Ricker returns and observed returns against escapements (bottom).





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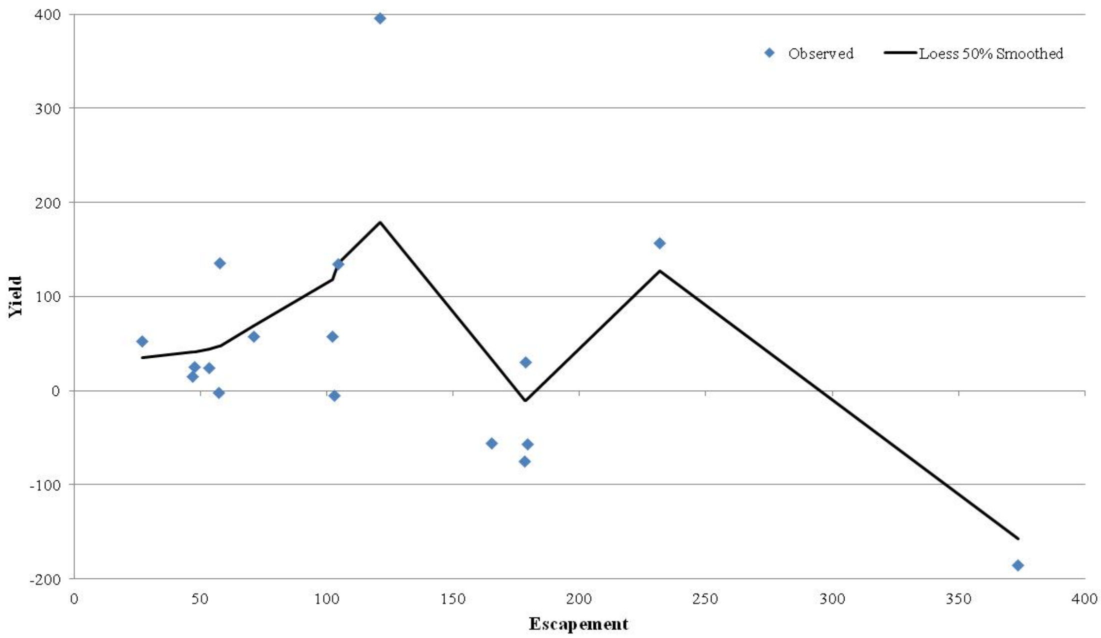
Observed yields fitted with a LOESS 30% smoothed line against escapements.



APPENDIX D. PINK SALMON

Appendix D1.–Escapement goal for Nushagak River pink salmon.

System: Nushagak River

Species: pink salmon

Description of stock and escapement goals

Management Division:	Commercial Fisheries
Previous Escapement Goal:	600,000 to 1,100,000 SEG dropped in 2007
Inriver Goal:	None
Optimal Escapement Goal:	None
Recommended Escapement Goal:	165,000 lower bound SEG
Escapement Estimation:	Expanded aerial survey in 1958; Nuyakuk tower counts from 1960–1979; sonar counts from 1980–2004; converted Bendix to DIDSON 1958 to 2004; 23 years of complete return data available, even years only
Summary:	
Data Quality	Good
Data Type	Sonar escapement estimates; commercial harvest; age data
Methodology	Percentile approach
Years within recommended goal	7 out of last 10 years (1986–2004)

-continued-

System: Nushagak River

Species: pink salmon

Data available for analysis of escapement goals

Year	Escapement [a]
1958	4,440,000
1960	111,000
1962	555,016
1964	1,008,435
1966	1,601,091
1968	2,398,839
1970	169,364
1972	64,975
1974	590,871
1976	928,269
1978	10,169,580
1980	3,052,218
1982	1,788,461
1984	3,145,032
1986	80,130
1988	549,017
1990	889,587
1992	209,429
1994	212,867
1996	911,656
1998	146,966
2000	150,166
2002	352,604
2004	617,233
Average	1,419,656
Median	617,233
Contrast	157

[a] DIDSON conversion factor of 1.11 applied to all years.

APPENDIX E. SOCKEYE SALMON

Appendix E1.–Escapement goal for Alagnak River sockeye salmon.

System: Alagnak River

Species: sockeye salmon

Description of stock and escapement goals

Management Division:	Commercial Fisheries
Previous Escapement Goal:	320,000 lower bound SEG (2007)
Inriver Goal:	None
Optimal Escapement Goal:	None
Recommended Escapement Goal:	No change
Escapement Estimation:	Tower counts from 1956–1976 and 2001–2011; expanded aerial survey counts from 1977–2001
Summary:	
Data Quality	Fair to Good
Data Type	Tower counts; aerial surveys; commercial harvest; age data
Methodology	Escapement goal based on risk analysis
Years within recommended goal	Escapement goal minimum has been met in each of the last 20 years; this stock is passively managed and coincidentally harvested; the department is not able to actively manage to obtain an escapement goal range

-continued-

System: Alagnak River

Species: sockeye salmon

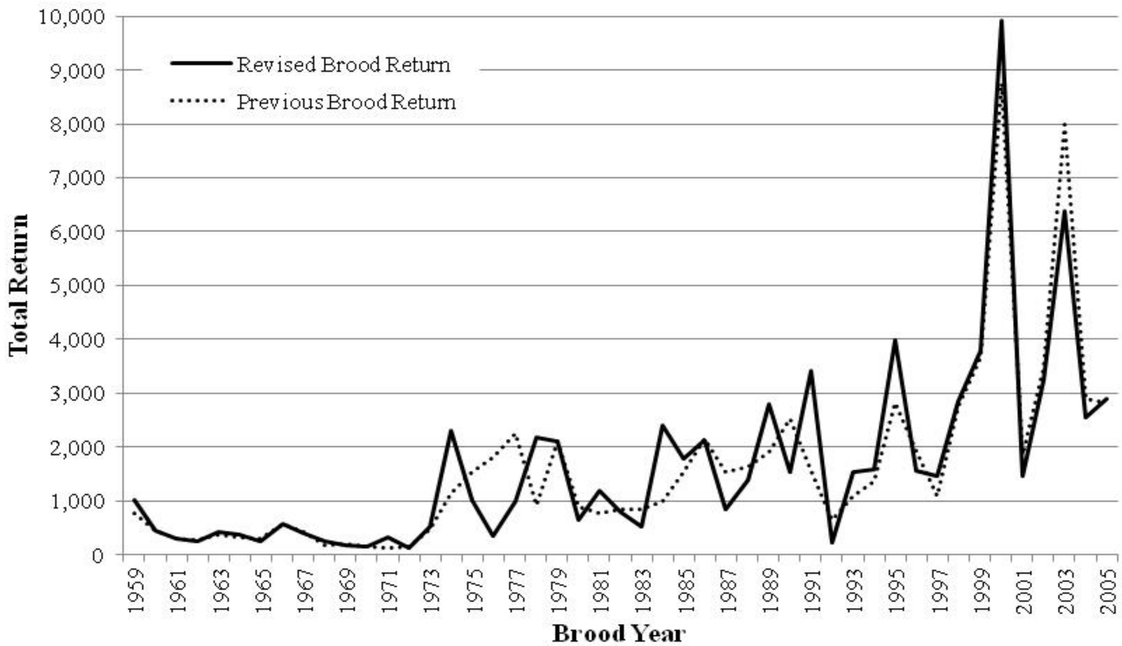
Data available for analysis of escapement goals

Year	Escapement	Total Return	Return per Spawner
1959	825,431	1,009,100	1.22
1960	1,240,530	448,154	0.36
1961	90,036	294,559	3.27
1962	90,630	252,129	2.78
1963	203,304	414,873	2.04
1964	248,700	381,900	1.54
1965	175,020	259,729	1.48
1966	174,336	565,584	3.24
1967	202,626	389,349	1.92
1968	193,872	249,192	1.29
1969	182,490	180,185	0.99
1970	177,060	145,642	0.82
1971	187,302	324,752	1.73
1972	151,188	124,168	0.82
1973	35,280	512,940	14.54
1974	214,848	2,290,909	10.66
1975	100,480	1,022,274	10.17
1976	81,822	344,709	4.21
1977	108,911	1,002,659	9.21
1978	584,970	2,175,018	3.72
1979	750,210	2,108,944	2.81
1980	759,645	649,461	0.85
1981	209,636	1,189,250	5.67
1982	610,215	783,215	1.28
1983	245,361	519,999	2.12
1984	549,194	2,395,855	4.36
1985	300,977	1,782,638	5.92
1986	586,959	2,129,631	3.63
1987	393,236	843,196	2.14
1988	496,307	1,376,837	2.77
1989	501,738	2,796,371	5.57
1990	430,338	1,532,335	3.56
1991	707,852	3,402,940	4.81
1992	577,940	226,603	0.39
1993	887,336	1,523,485	1.72
1994	618,464	1,585,492	2.56
1995	550,068	3,989,777	7.25
1996	782,213	1,549,878	1.98
1997	556,193	1,467,972	2.64
1998	643,110	2,851,140	4.43
1999	1,182,180	3,790,191	3.21
2000	1,150,815	9,915,981	8.62
2001	680,850	1,464,957	2.15
2002	766,962	3,234,177	4.22
2003	3,676,146	6,387,177	1.74
2004	5,396,592	2,548,096	0.47
2005	4,218,990	2,899,060	0.69
2006	1,773,966[a]		
2007	2,466,414[a]		
2008	2,180,502[a]		
2009	970,818[a]		
2010	1,187,730[a]		
2011	883,794[a]		
1959–2005			
Average	712,731	1,645,372	3.48
No. of Years	47	47	47

[a] Incomplete returns from brood year escapement.

-continued-

Total returns by brood year from previous brood tables compared with total returns from the revised brood tables of Cunningham et al. (2012).



Appendix E2.–Escapement goal for Egegik River sockeye salmon.

System: Egegik River

Species: sockeye salmon

Description of stock and escapement goals

Management Division:	Commercial Fisheries
Previous Escapement Goal:	800,000–1,400,000 SEG (1995); changed to SEG in 2007
Inriver Goal:	None
Optimal Escapement Goal:	None
Recommended Escapement Goal:	900,000–2,000,000 SEG
Escapement Estimation:	Tower counts from 1956 to present; smolt data from 1983–2001; 47 years of complete return data available
Summary:	
Data Quality	Excellent
Data Type	Tower counts; commercial harvest; smolt data; age data
Methodology	Escapement goal based on Ricker stock-recruitment and yield analysis
Years within recommended goal	10 out of last 10 years (2002–2011)

-continued-

System: Egegik River

Species: sockeye salmon

Data available for analysis of escapement goals

Year	Escapement	Total Return	Return per Spawner
1959	1,072,459	2,122,136	1.98
1960	1,798,764	7,118,837	3.96
1961	701,538	1,487,493	2.12
1962	1,027,482	1,093,256	1.06
1963	997,602	993,872	1.00
1964	849,576	1,937,882	2.28
1965	1,444,608	2,388,485	1.65
1966	804,246	2,058,271	2.56
1967	636,864	1,631,431	2.56
1968	338,654	377,056	1.11
1969	1,015,554	2,755,728	2.71
1970	919,734	1,202,584	1.31
1971	634,014	2,700,676	4.26
1972	546,402	2,909,902	5.33
1973	328,842	1,451,686	4.41
1974	1,275,630	2,441,308	1.91
1975	1,173,840	3,040,169	2.59
1976	509,160	4,480,475	8.80
1977	692,514	4,167,610	6.02
1978	895,698	9,914,904	11.07
1979	1,032,042	4,039,957	3.91
1980	1,060,860	8,224,600	7.75
1981	694,680	5,444,111	7.84
1982	1,034,628	6,441,614	6.23
1983	792,282	10,829,622	13.67
1984	1,165,345	11,792,825	10.12
1985	1,095,192	6,401,009	5.84
1986	1,152,180	14,229,272	12.35
1987	1,273,553	25,748,671	20.22
1988	1,612,745	19,484,271	12.08
1989	1,611,566	10,167,814	6.31
1990	2,191,582	16,096,303	7.34
1991	2,786,925	9,957,467	3.57
1992	1,945,632	8,673,758	4.46
1993	1,517,000	1,939,491	1.28
1994	1,897,977	7,996,226	4.21
1995	1,266,692	7,532,365	5.95
1996	1,076,460	4,161,538	3.87
1997	1,104,004	6,062,442	5.49
1998	1,110,938	1,270,197	1.14
1999	1,728,397	13,014,334	7.53
2000	1,032,138	11,992,735	11.62
2001	968,872	4,904,532	5.06
2002	1,036,092	5,590,048	5.40
2003	1,152,120	9,110,326	7.91
2004	1,290,144	14,704,858	11.40
2005	1,621,734	6,128,621	3.78
2006	1,465,158[a]		
2007	1,432,500[a]		
2008	1,259,568[a]		
2009	1,146,276[a]		
2010	927,054[a]		
2011	961,200[a]		
1959–2005			
Average	1,152,957	6,557,719	5.64
No. of Years	47	47	47

[a] Incomplete returns from brood year escapement.

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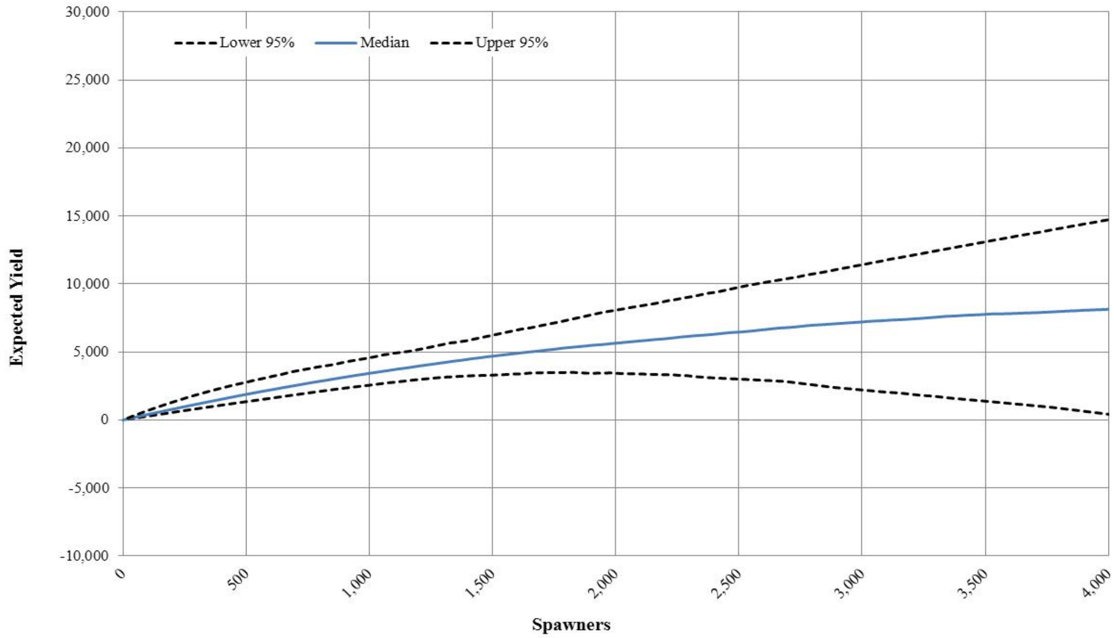
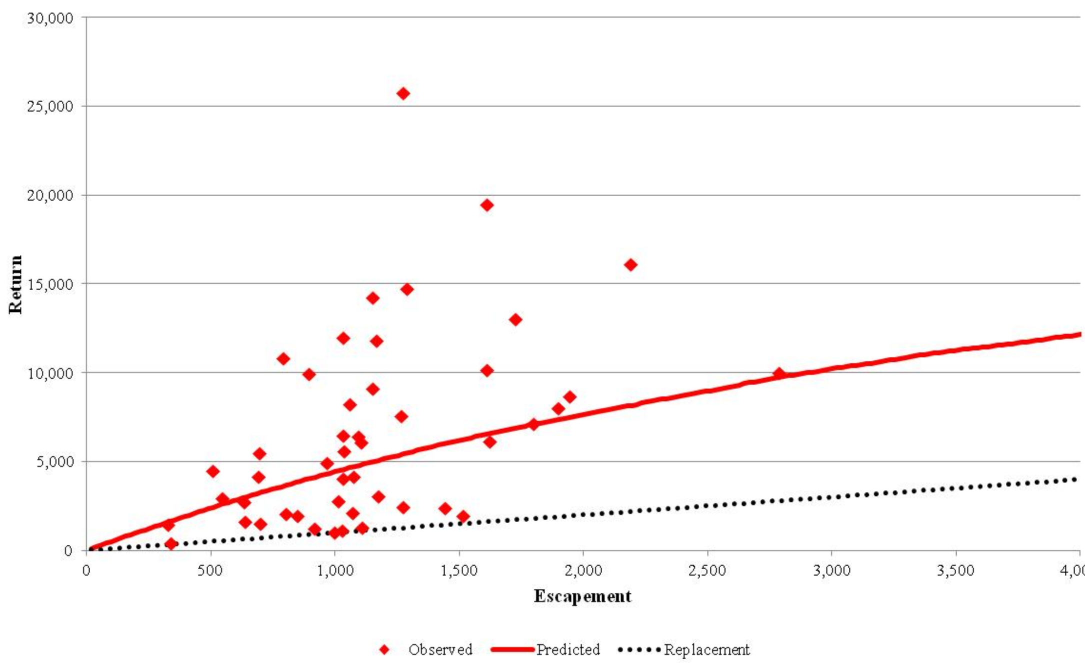
Expected Ricker median yields with 95% credible intervals against escapements (top), and predicted Ricker returns and observed returns against escapements (bottom). Numbers are in thousands of fish.





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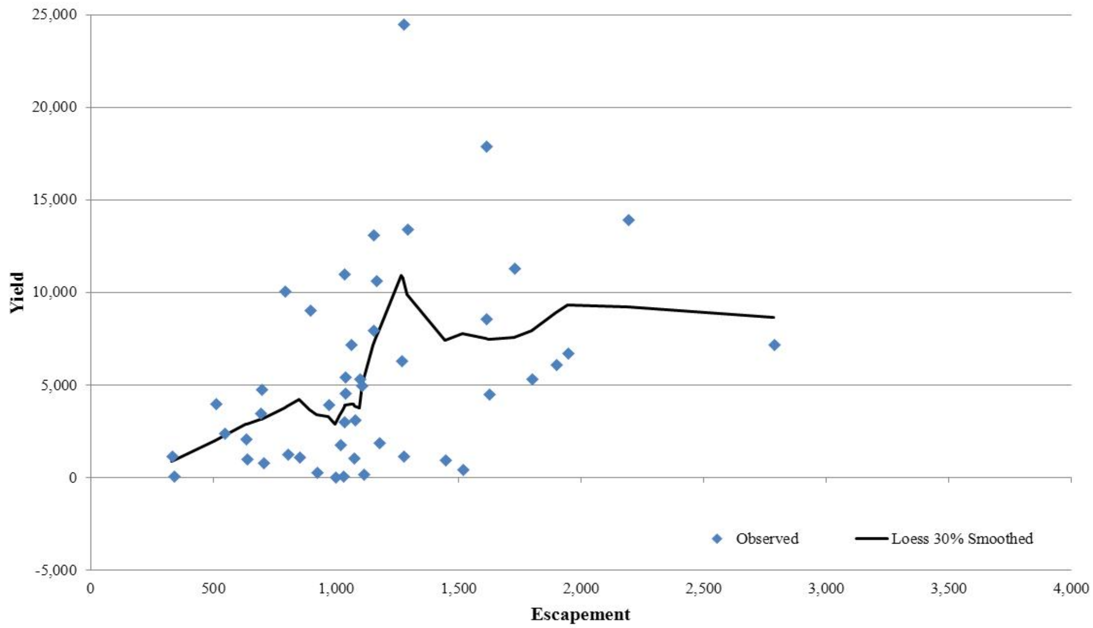
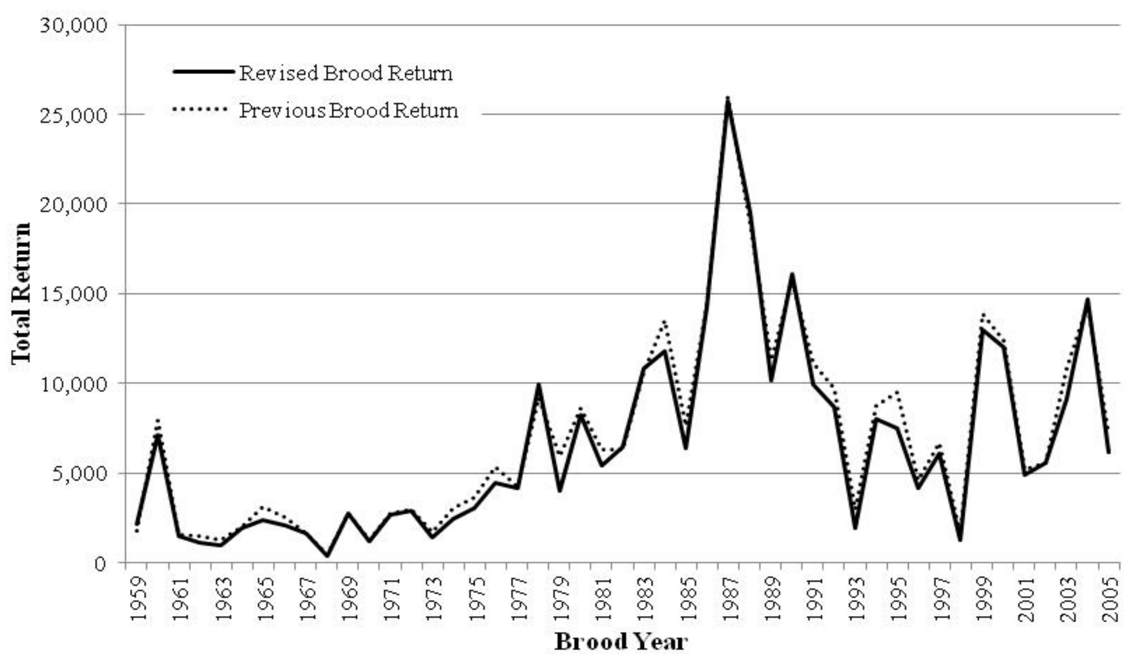
Observed yields fitted with a LOESS 30% smoothed line against escapements (top), and total returns by brood year from previous brood tables compared with total returns from the revised brood tables (bottom) of Cunningham et al. (2012). Numbers are in thousands of fish.





Appendix E3.–Escapement goal for Igushik River sockeye salmon.

System: Igushik River

Species: sockeye salmon

Description of stock and escapement goals

Management Division:	Commercial Fisheries
Previous Escapement Goal:	150,000–300,000 SEG (2001); changed to SEG in 2007
Inriver Goal:	None
Optimal Escapement Goal:	None
Recommended Escapement Goal:	200,000–400,000 BEG
Escapement Estimation:	Tower counts from 1956 to present; 47 years of complete return data available
Summary:	
Data Quality	Excellent
Data Type	Tower counts; commercial harvest; age data
Methodology	Ricker stock-recruitment, yield analysis
Years within recommended goal	4 out of last 10 years (2002–2011)

-continued-

System: Igushik River

Species: sockeye salmon

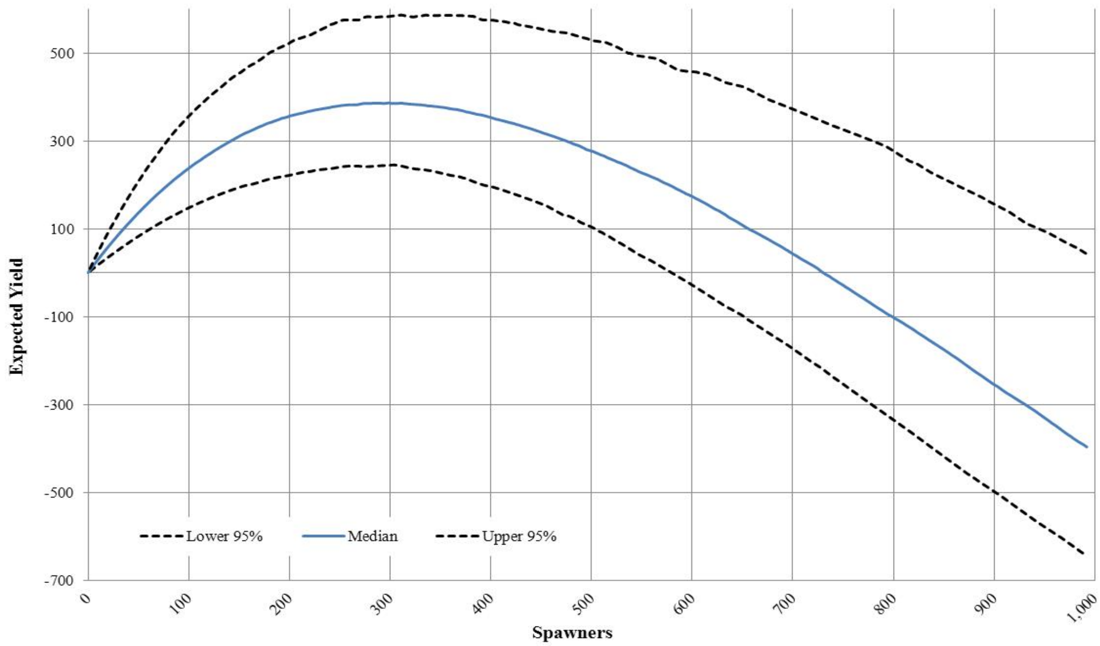
Data available for analysis of escapement goals

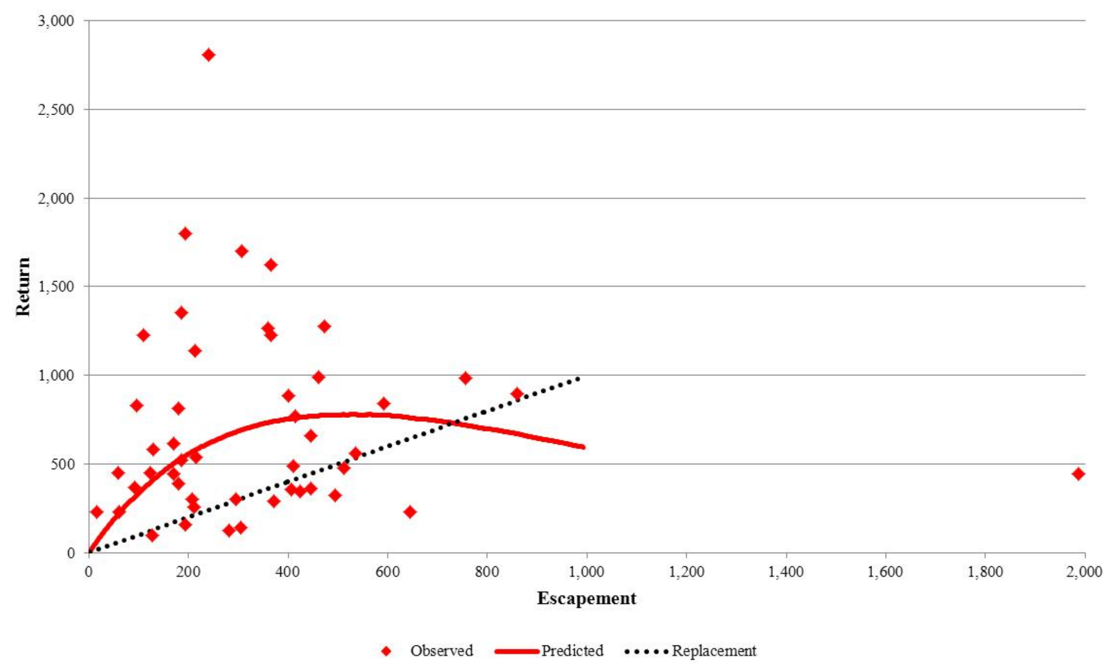
Year	Escapement	Total Return	Return per Spawner
1959	643,808	227,626	0.35
1960	495,087	324,150	0.65
1961	294,252	300,743	1.02
1962	15,660	229,117	14.63
1963	92,184	368,205	3.99
1964	128,532	583,060	4.54
1965	180,840	810,920	4.48
1966	206,360	301,093	1.46
1967	281,772	125,745	0.45
1968	194,508	158,923	0.82
1969	512,328	476,722	0.93
1970	370,920	287,436	0.77
1971	210,960	259,415	1.23
1972	60,018	232,049	3.87
1973	59,508	452,000	7.60
1974	358,752	1,267,130	3.53
1975	241,086	2,810,903	11.66
1976	186,120	1,354,667	7.28
1977	95,970	830,426	8.65
1978	536,154	562,275	1.05
1979	859,560	896,476	1.04
1980	1,987,530	443,803	0.22
1981	591,144	838,645	1.42
1982	423,768	346,608	0.82
1983	180,438	391,104	2.17
1984	184,872	522,953	2.83
1985	212,454	1,138,951	5.36
1986	307,728	1,700,597	5.53
1987	169,236	445,515	2.63
1988	170,454	614,898	3.61
1989	461,610	991,784	2.15
1990	365,802	1,229,498	3.36
1991	756,126	983,939	1.30
1992	304,920	139,561	0.46
1993	405,564	358,174	0.88
1994	445,920	659,953	1.48
1995	473,382	1,278,256	2.70
1996	400,746	886,426	2.21
1997	127,704	99,345	0.78
1998	215,904	536,354	2.48
1999	445,536	362,488	0.81
2000	413,316	767,881	1.86
2001	409,596	490,207	1.20
2002	123,156	448,204	3.64
2003	194,088	1,799,058	9.27
2004	109,650	1,227,254	11.19
2005	365,712	1,623,044	4.44
2006	305,268[a]		
2007	415,452[a]		
2008	1,054,704[a]		
2009	514,188[a]		
2010	518,040[a]		
2011	421,380[a]		
1959–2005			
Average	367,920	706,034	3.29
No. of Years	47	47	47

[a] Incomplete returns from brood year escapement.

-continued-

Expected Ricker median yields with 95% credible intervals against escapements (top), and predicted Ricker returns and observed returns against escapements (bottom). Numbers are in thousands of fish.





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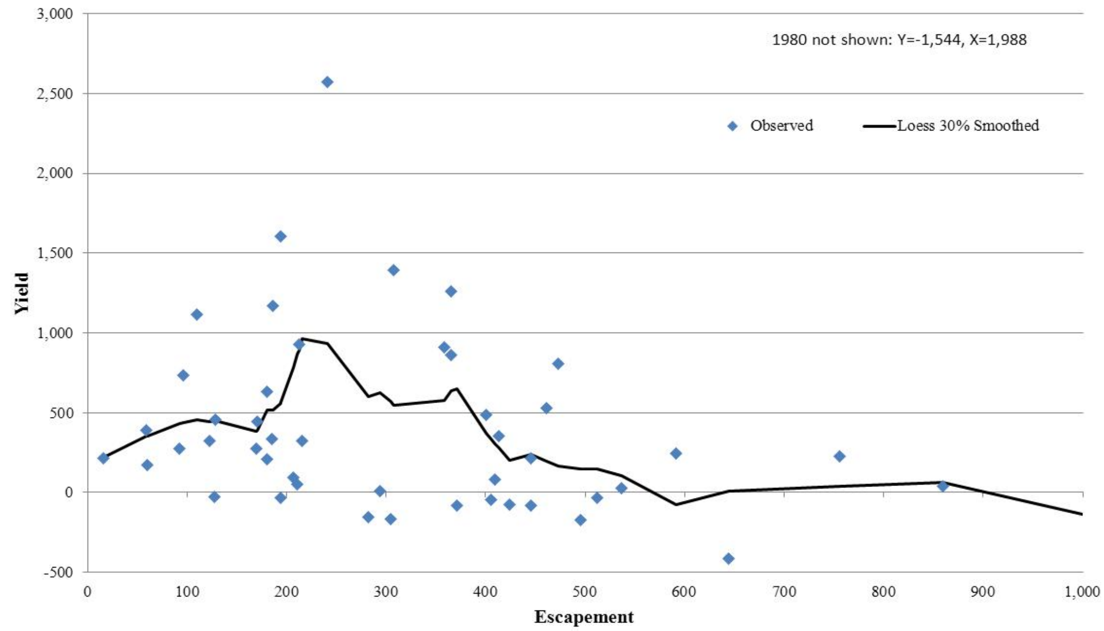
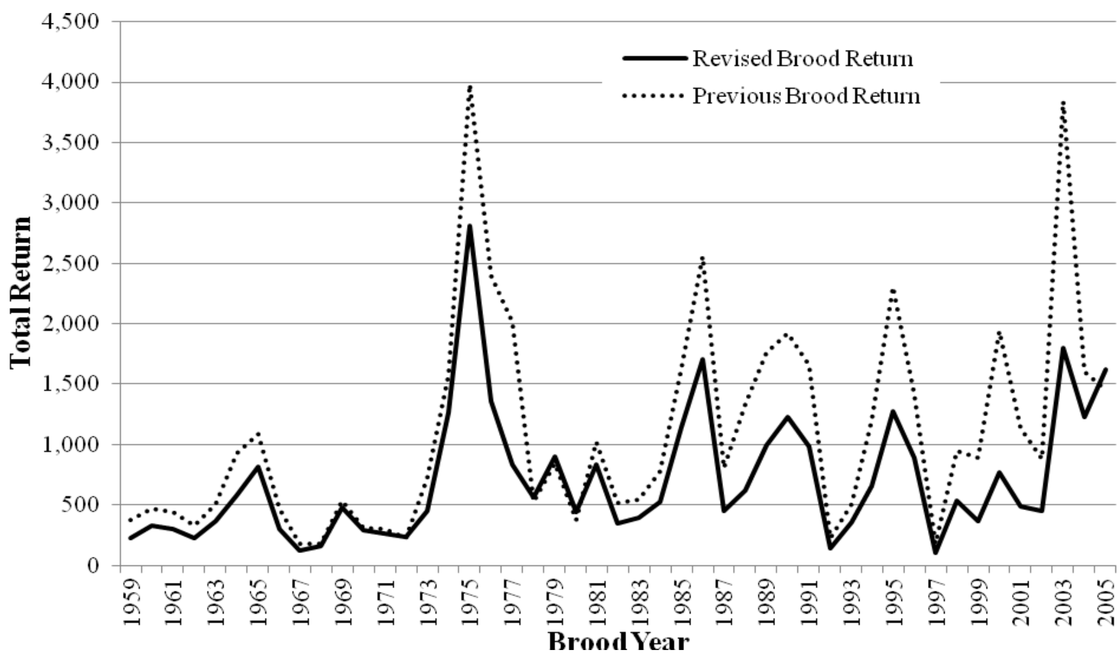
Observed yields fitted with a LOESS 30% smoothed line against escapements (top), and total returns by brood year from previous brood tables compared with total returns from the revised brood tables (bottom) of Cunningham et al. (2012). Numbers are in thousands of fish.





Appendix E4.–Escapement goal for Kvichak River sockeye salmon.

System: Kvichak River

Species: sockeye salmon

Description of stock and escapement goals

Management Division:	Commercial Fisheries
Previous Escapement Goal:	2,000,000–10,000,000 SEG (2010)
Inriver Goal:	None
Optimal Escapement Goal:	None
Recommended Escapement Goal:	No change
Escapement Estimation:	Tower counts from 1956 to present; smolt data from 1971–2000; 47 years of complete return data available
Summary:	
Data Quality	Excellent
Data Type	Tower counts; smolt data; commercial harvest; age data
Methodology	Escapement goal based on Ricker stock-recruitment, yield analysis
Years within recommended goal	8 out of last 10 years (2002–2011)

-continued-

System: Kvichak River

Species: sockeye salmon

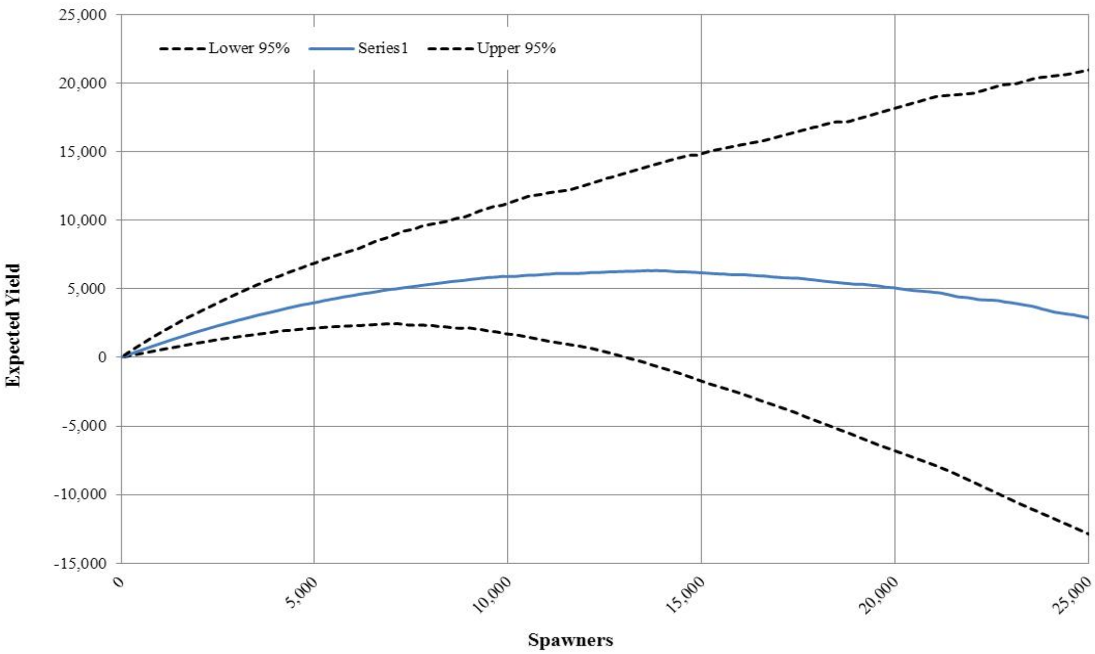
Data available for analysis of escapement goals

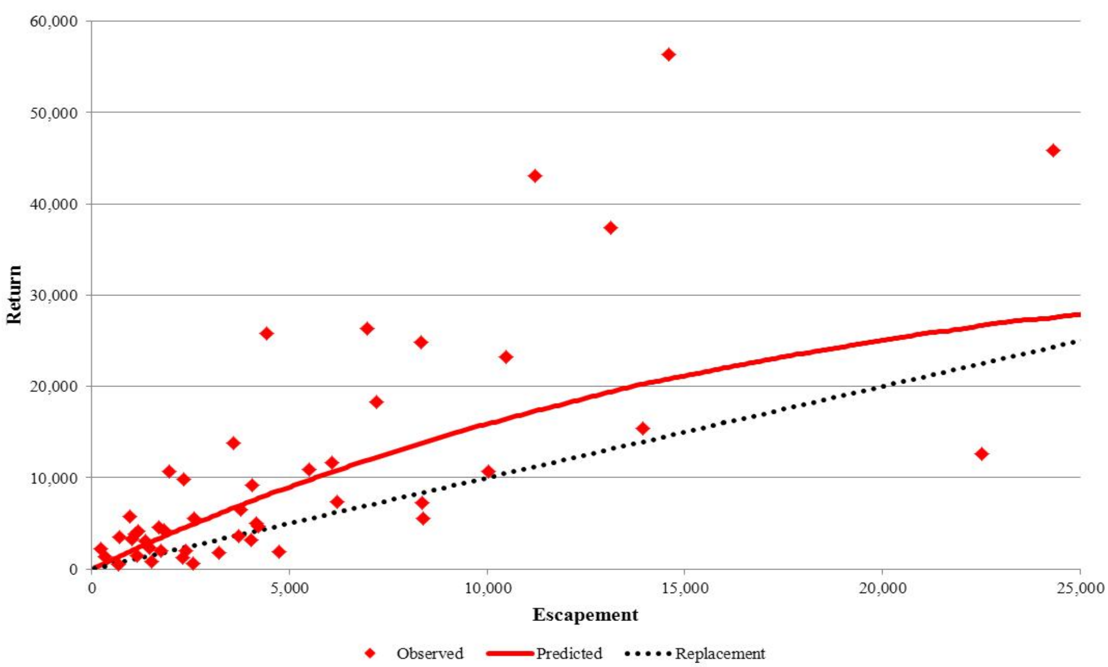
Year	Escapement	Total Return	Return per Spawner
1959	673,811	453,641	0.67
1960	14,602,360	56,411,705	3.86
1961	3,705,849	3,580,935	0.97
1962	2,580,884	5,506,892	2.13
1963	338,760	1,388,216	4.10
1964	957,120	5,763,515	6.02
1965	24,325,926	45,820,689	1.88
1966	3,755,185	6,522,062	1.74
1967	3,216,208	1,784,048	0.55
1968	2,557,440	635,324	0.25
1969	8,394,204	5,513,626	0.66
1970	13,935,306	15,363,872	1.10
1971	2,387,392	2,036,285	0.85
1972	1,009,962	3,248,671	3.22
1973	226,554	2,203,241	9.73
1974	4,433,844	25,784,407	5.82
1975	13,140,450	37,439,011	2.85
1976	1,965,282	10,716,323	5.45
1977	1,341,144	3,089,502	2.30
1978	4,149,288	5,055,228	1.22
1979	11,218,434	43,049,711	3.84
1980	22,505,268	12,597,129	0.56
1981	1,754,358	2,048,731	1.17
1982	1,134,840	1,509,147	1.33
1983	3,569,982	13,774,175	3.86
1984	10,490,670	23,284,320	2.22
1985	7,211,046	18,311,756	2.54
1986	1,179,322	4,113,937	3.49
1987	6,065,880	11,646,723	1.92
1988	4,065,216	9,204,227	2.26
1989	8,317,500	24,796,919	2.98
1990	6,970,020	26,294,888	3.77
1991	4,222,788	4,636,825	1.10
1992	4,725,864	1,876,573	0.40
1993	4,025,166	3,131,830	0.78
1994	8,355,936	7,304,603	0.87
1995	10,038,720	10,647,375	1.06
1996	1,450,578	2,300,492	1.59
1997	1,503,732	842,686	0.56
1998	2,296,074	1,280,847	0.56
1999	6,196,914	7,397,614	1.19
2000	1,827,780	4,277,407	2.34
2001	1,095,348	3,860,432	3.52
2002	703,884	3,470,460	4.93
2003	1,686,804	4,607,129	2.73
2004	5,500,134	10,923,565	1.99
2005	2,320,332	9,792,806	4.22
2006	3,068,226[a]		
2007	2,810,208[a]		
2008	2,757,912[a]		
2009	2,266,140[a]		
2010	4,207,410[a]		
2011	2,264,352[a]		
1959–2005			
Average	5,009,506	10,751,053	2.41
No. of Years	47	47	47

[a] Incomplete returns from brood year escapement.

-continued-

Observed yields fitted with a LOESS 30% smoothed line against escapements (top), and total returns by brood year from previous brood tables compared with total returns from the revised brood tables (bottom) of Cunningham et al. (2012). Numbers are in thousands of fish.





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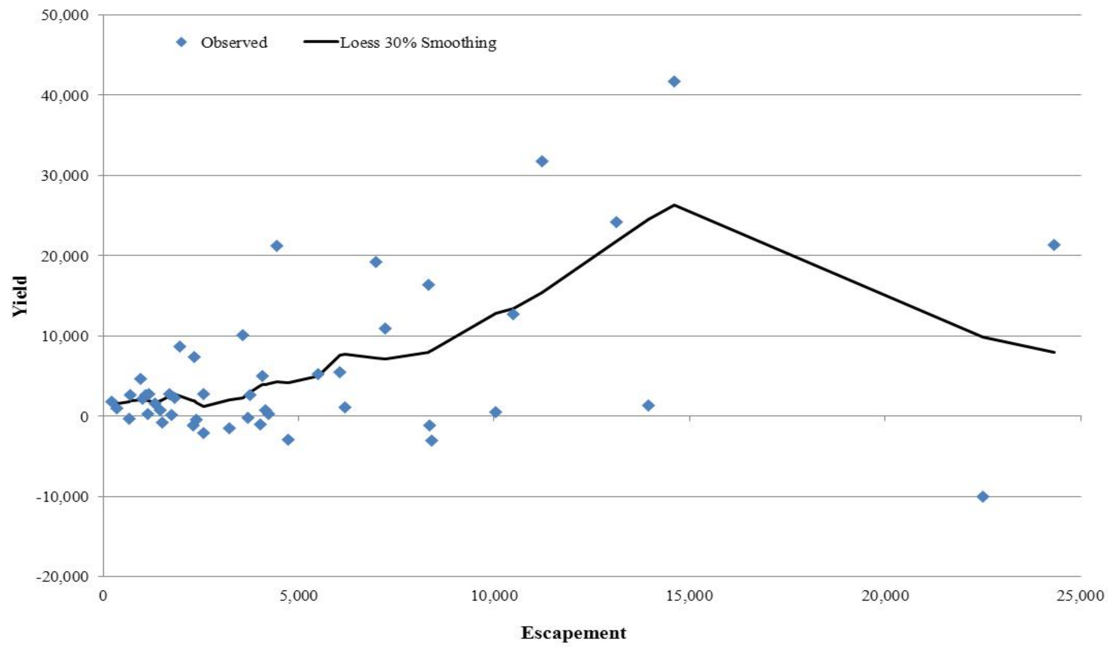
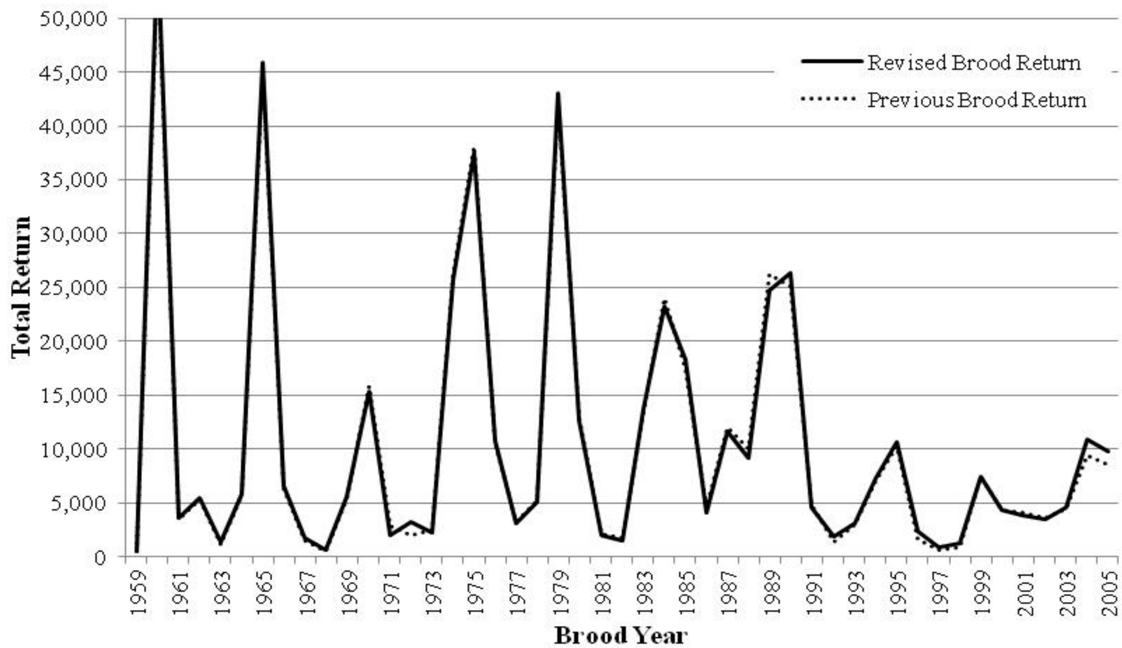
Observed yields fitted with a LOESS 30% smoothed line against escapements (top), and total returns by brood year from previous brood tables compared with total returns from the revised brood tables (bottom) of Cunningham et al. (2012). Numbers are in thousands of fish.





Appendix E5.–Escapement goal for Naknek River sockeye salmon.

System: Naknek River

Species: sockeye salmon

Description of stock and escapement goals

Management Division:	Commercial Fisheries
Previous Escapement Goal:	800,000–1,400,000 SEG (1983)); changed to SEG in 2007
Inriver Goal:	None
Optimal Escapement Goal:	2,000,000
Recommended Escapement Goal:	900,000–2,000,000 BEG
Escapement Estimation:	Tower counts from 1956 to present; 47 years of complete return data available
Summary:	
Data Quality	Excellent
Data Type	Tower counts; commercial harvest; age data
Methodology	Escapement goal based on Ricker stock-recruitment, yield analysis
Years within recommended goal	7 out of last 10 years (2002–2011)

-continued-

System: Naknek River

Species: sockeye salmon

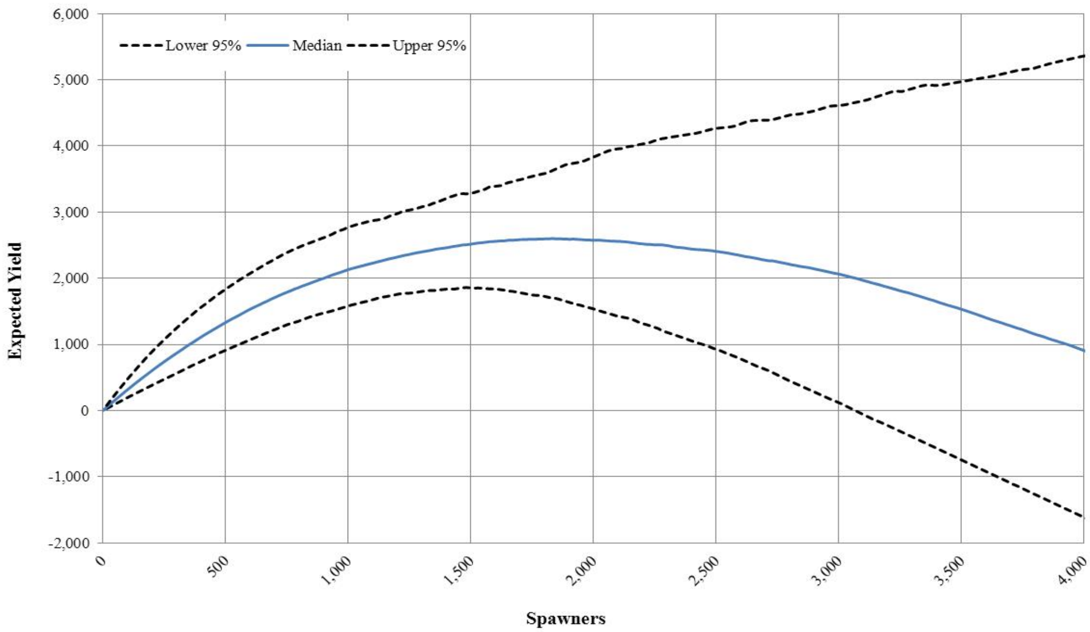
Data available for analysis of escapement goals

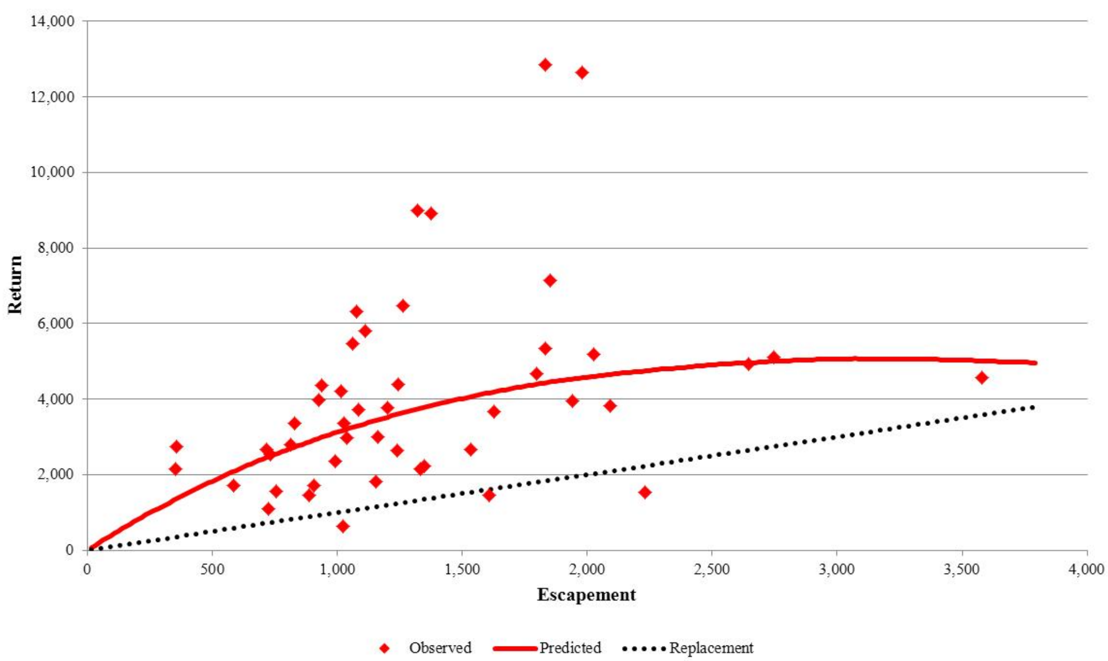
Year	Escapement	Total Return	Return per Spawner
1959	2,231,807	1,524,714	0.68
1960	828,381	3,360,315	4.06
1961	351,078	2,151,891	6.13
1962	723,066	1,106,335	1.53
1963	905,358	1,706,836	1.89
1964	1,349,604	2,223,531	1.65
1965	717,798	2,654,768	3.70
1966	1,016,445	4,205,622	4.14
1967	755,640	1,552,168	2.05
1968	1,023,222	638,312	0.62
1969	1,331,202	2,143,778	1.61
1970	732,502	2,535,306	3.46
1971	935,754	4,350,422	4.65
1972	586,518	1,715,207	2.92
1973	356,676	2,742,669	7.69
1974	1,241,058	2,642,513	2.13
1975	2,026,686	5,195,705	2.56
1976	1,320,750	8,991,732	6.81
1977	1,085,856	3,721,059	3.43
1978	813,378	2,788,295	3.43
1979	925,362	3,963,916	4.28
1980	2,644,698	4,922,134	1.86
1981	1,796,220	4,683,500	2.61
1982	1,155,552	1,820,719	1.58
1983	888,294	1,451,803	1.63
1984	1,242,474	4,384,278	3.53
1985	1,849,938	7,147,411	3.86
1986	1,977,645	12,634,896	6.39
1987	1,061,806	5,472,177	5.15
1988	1,037,862	2,972,686	2.86
1989	1,161,984	3,006,870	2.59
1990	2,092,578	3,824,685	1.83
1991	3,578,508	4,574,329	1.28
1992	1,606,650	1,469,491	0.91
1993	1,535,658	2,671,487	1.74
1994	990,810	2,351,000	2.37
1995	1,111,140	5,810,346	5.23
1996	1,078,098	6,316,443	5.86
1997	1,025,664	3,360,610	3.28
1998	1,202,172	3,764,484	3.13
1999	1,625,364	3,663,375	2.25
2000	1,375,488	8,902,997	6.47
2001	1,830,360	5,351,531	2.92
2002	1,263,918	6,474,702	5.12
2003	1,831,170	12,843,690	7.01
2004	1,939,674	3,946,527	2.03
2005	2,744,622	5,119,004	1.87
2006	1,953,228[a]		
2007	2,945,304[a]		
2008	2,472,690[a]		
2009	1,169,466[a]		
2010	1,463,928[a]		
2011	1,177,074[a]		
1959–2005 Average	1,397,890	4,060,772	3.29
No. of Years	47	47	47

[a] Incomplete returns from brood year escapement.

-continued-

Observed yields fitted with a LOESS 30% smoothed line against escapements (top), and total returns by brood year from previous brood tables compared with total returns from the revised brood tables (bottom) of Cunningham et al. (2012). Numbers are in thousands of fish.





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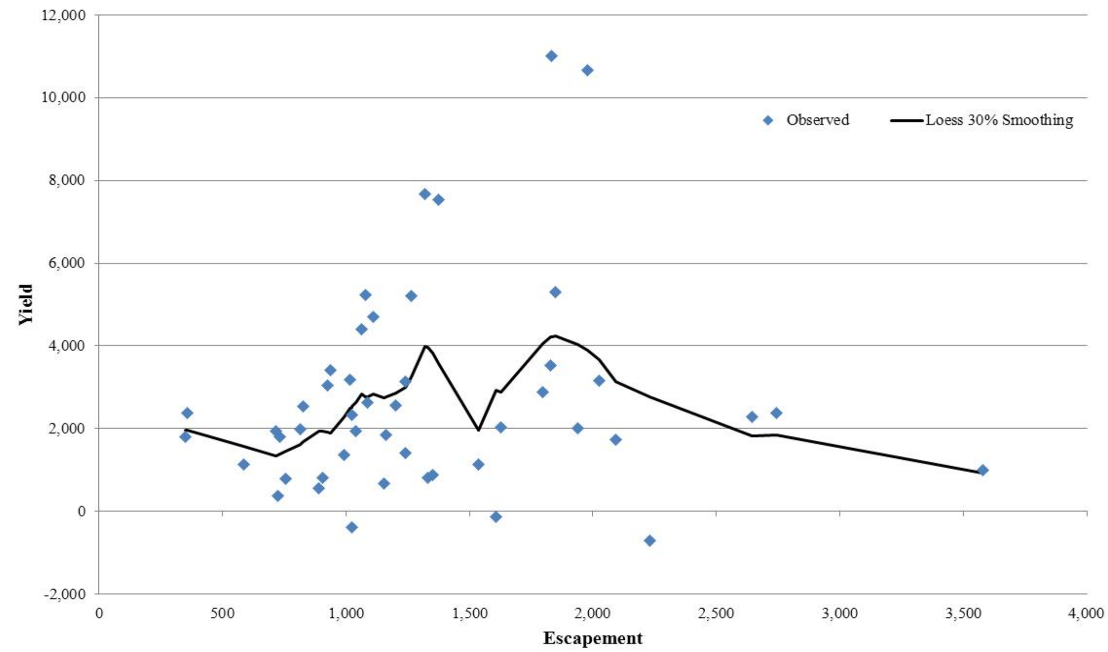
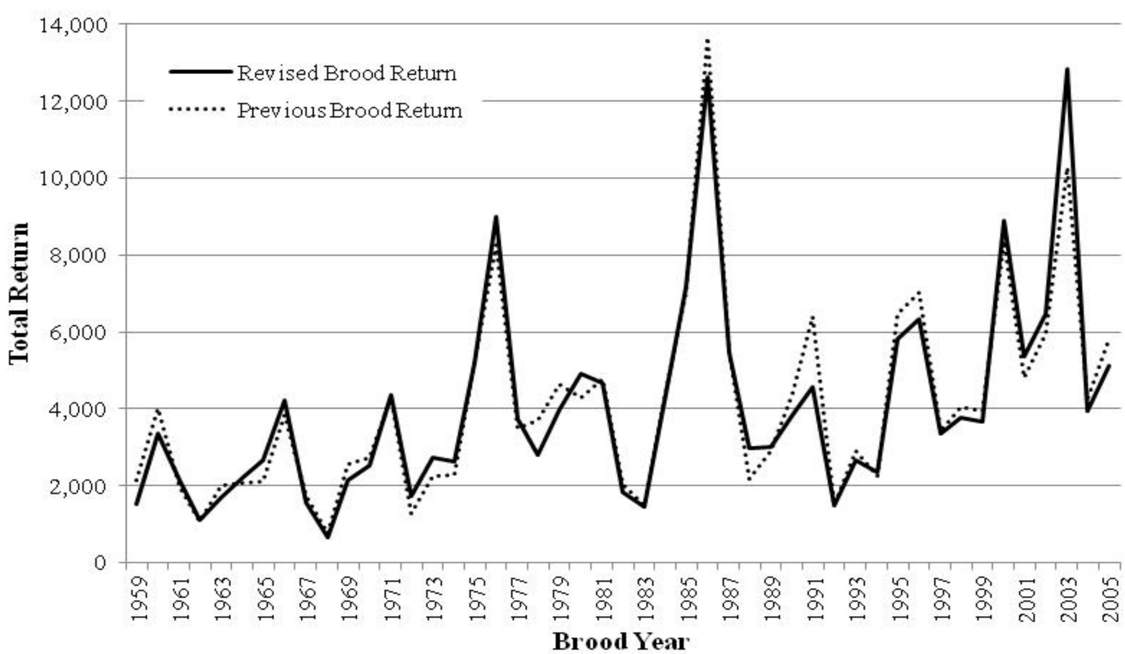
Observed yields fitted with a LOESS 30% smoothed line against escapements (top), and total returns by brood year from previous brood tables compared with total returns from the revised brood tables (bottom) of Cunningham et al. (2012). Numbers are in thousands of fish.





Appendix E6.–Escapement goal for Nushagak River sockeye salmon.

System: Nushagak River

Species: sockeye salmon

Description of stock and escapement goals

Management Division:	Commercial Fisheries
Previous Escapement Goal:	340,000–760,000 SEG (1998)); changed to SEG in 2007
Inriver Goal:	None
Optimal Escapement Goal:	235,000
Recommended Escapement Goal:	400,000–900,000 BEG
Escapement Estimation:	Nuyakuk tower and expanded aerial survey counts from 1959–1984; sonar counts from 1985 to present; converted Bendix to DIDSON 1980 to 2005; DIDSON counts uncorrected since 2006; 47 years of complete return data available
Summary:	
Data Quality	Good
Data Type	Tower, aerial survey, and sonar counts; commercial harvest; age data
Methodology	Ricker stock-recruitment, yield analysis
Years within recommended goal	8 out of last 10 years (2002–2011)

-continued-

System: Nushagak River

Species: sockeye salmon

Data available for analysis of escapement goals

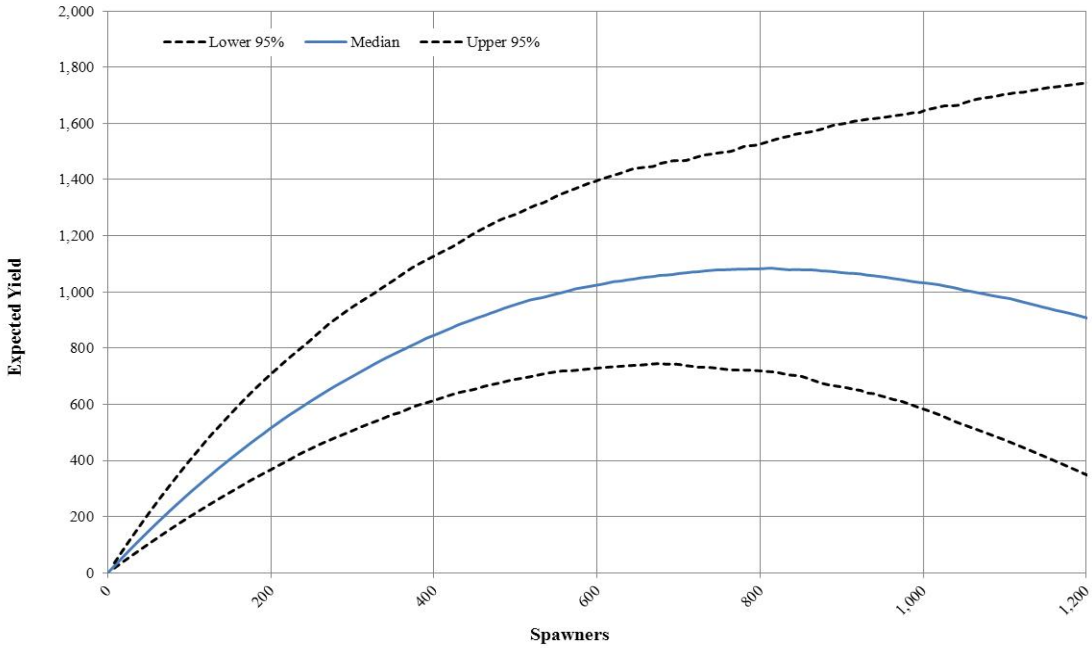
Year	Escapement [a]	Total Return	Return per Spawner
1959	67,553	251,110	3.72
1960	201,161	554,162	2.75
1961	110,369	466,173	4.22
1962	51,273	152,649	2.98
1963	234,821	214,841	0.91
1964	134,853	93,342	0.69
1965	255,794	779,754	3.05
1966	233,578	701,566	3.00
1967	74,003	227,033	3.07
1968	142,360	344,179	2.42
1969	95,805	493,692	5.15
1970	452,892	988,764	2.18
1971	312,699	1,010,999	3.23
1972	39,851	1,147,980	28.81
1973	210,601	1,380,189	6.55
1974	204,190	383,623	1.88
1975	832,093	5,995,149	7.20
1976	520,303	4,351,924	8.36
1977	611,588	3,236,089	5.29
1978	734,040	1,513,725	2.06
1979	551,272	1,846,153	3.35
1980	3,669,136	1,210,266	0.33
1981	1,118,873	1,976,757	1.77
1982	664,580	1,335,148	2.01
1983	446,845	1,548,738	3.47
1984	655,739	761,247	1.16
1985	551,319	1,416,870	2.57
1986	1,095,241	2,092,574	1.91
1987	429,182	1,905,456	4.44
1988	534,460	2,557,339	4.78
1989	567,863	1,398,722	2.46
1990	752,513	1,189,247	1.58
1991	544,748	1,491,482	2.74
1992	768,816	1,212,574	1.58
1993	790,927	1,074,278	1.36
1994	563,334	425,915	0.76
1995	311,136	1,198,477	3.85
1996	557,057	2,335,512	4.19
1997	412,591	544,302	1.32
1998	507,532	2,665,496	5.25
1999	344,972	1,753,716	5.08
2000	446,286	3,956,541	8.87
2001	897,112	3,076,644	3.43
2002	349,155	2,121,281	6.08
2003	642,093	1,863,316	2.90
2004	543,872	1,463,695	2.69
2005	1,102,833	1,210,008	1.10
2006	548,410[b]		
2007	518,041[b]		
2008	492,546[b]		
2009	484,149[b]		
2010	468,696[b]		
2011	428,191[b]		
1959–2005 Average	533,573	1,487,632	3.80
No. of Years	47	47	47

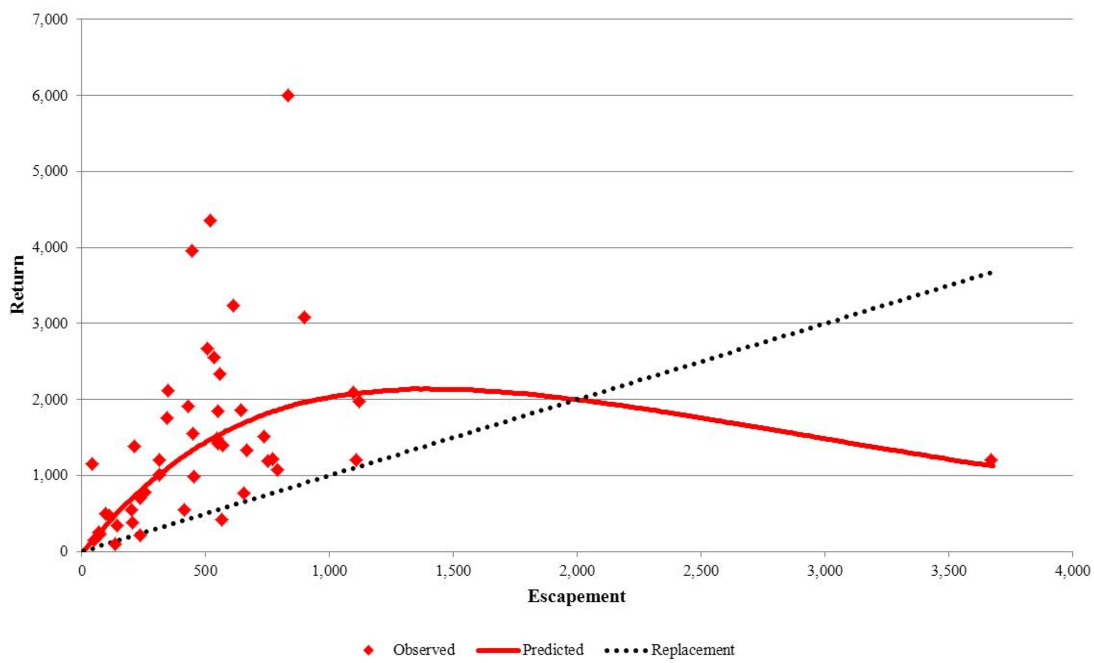
[a] DIDSON conversion factor of 1.11 applied to all years prior to 2005. Escapement estimate for 2005 used strata- and species-specific correction factors applied to the Bendix north bank counting stratum. Counts from 2006 through 2011 are uncorrected DIDSON counts.

[b] Incomplete returns from brood year escapement.

-continued-

Observed yields fitted with a LOESS 30% smoothed line against escapements (top), and total returns by brood year from previous brood tables compared with total returns from the revised brood tables (bottom) of Cunningham et al. (2012). Numbers are in thousands of fish.





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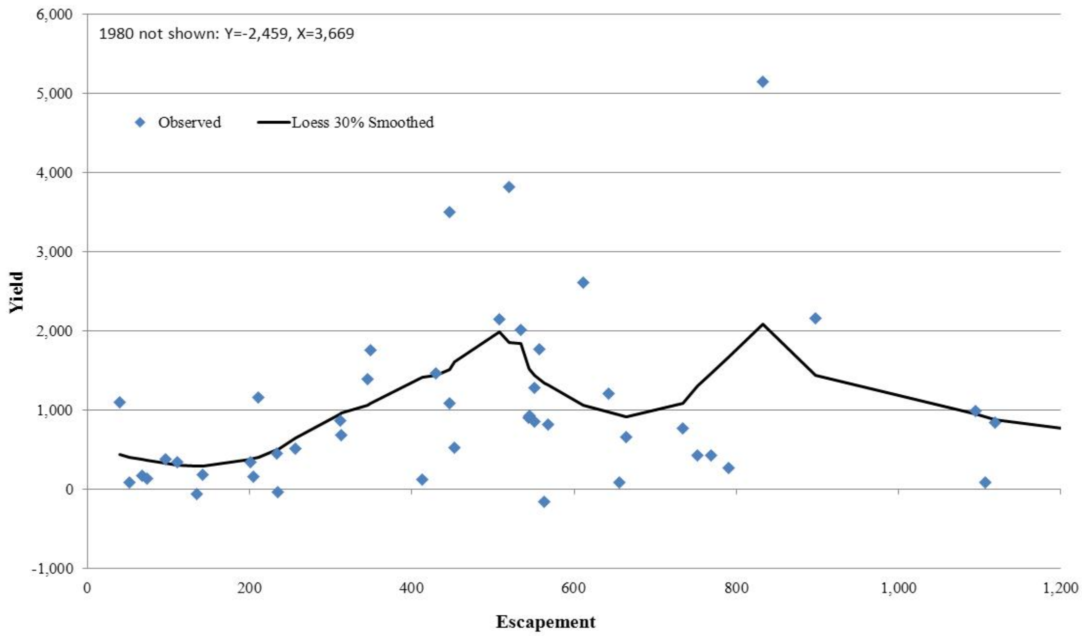
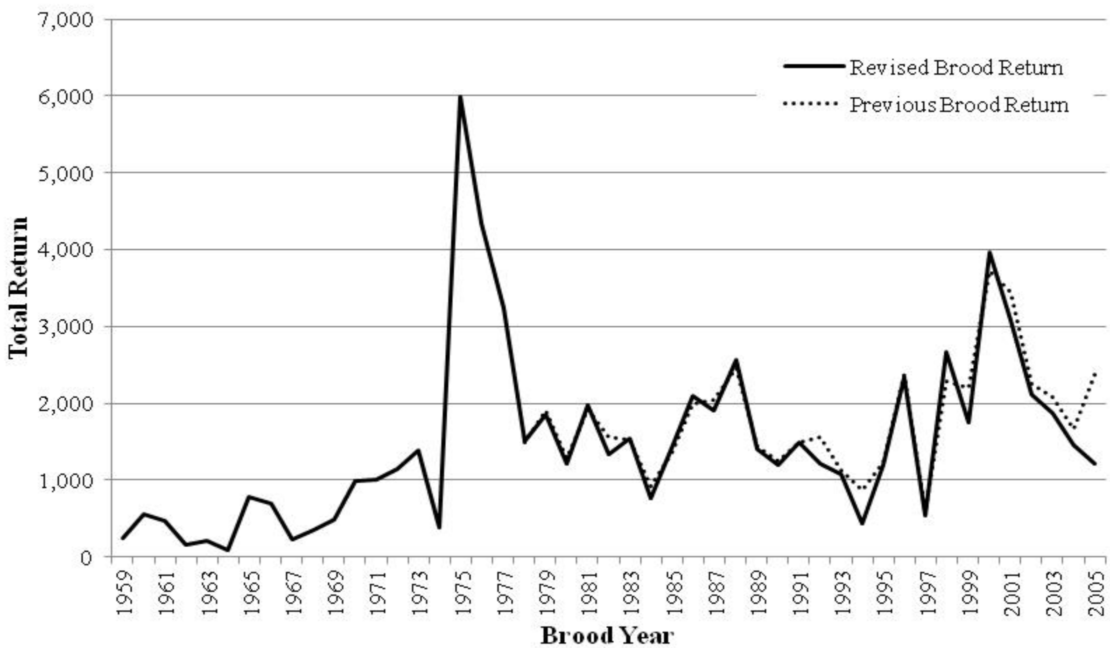
Observed yields fitted with a LOESS 30% smoothed line against escapements (top), and total returns by brood year from previous brood tables compared with total returns from the revised brood tables (bottom) of Cunningham et al. (2012). Numbers are in thousands of fish.





Appendix E7.–Escapement goal for Togiak River sockeye salmon.

System: Togiak River

Species: sockeye salmon

Description of stock and escapement goals

Management Division:	Commercial Fisheries
Previous Escapement Goal:	120,000–270,000 SEG (2007)); changed to SEG in 2007
Inriver Goal:	None
Optimal Escapement Goal:	None
Recommended Escapement Goal:	No change
Escapement Estimation:	Tower counts from 1956 to present; 47 years of complete return data available
Summary:	
Data Quality	Good; data quality would be excellent except for concerns with regard to stock-specific harvest
Data Type	Tower counts; commercial harvest; age data
Methodology	Ricker stock-recruitment, yield analysis
Years within recommended goal	8 out of last 10 years (2002–2011)

-continued-

System: Togiak River

Species: sockeye salmon

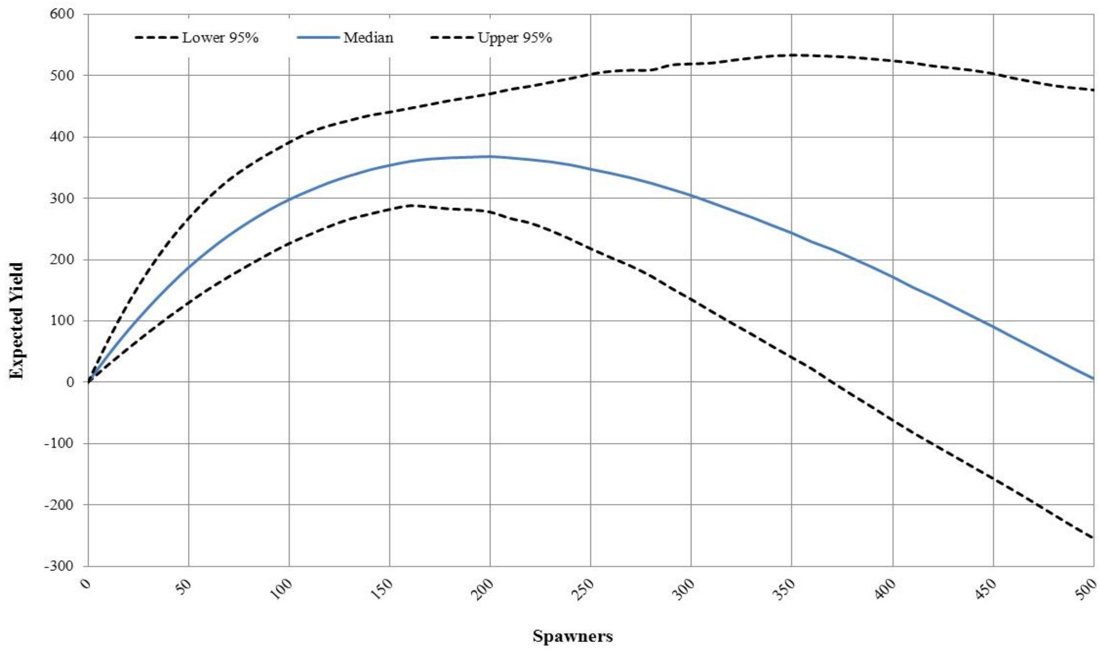
Data available for analysis of escapement goals

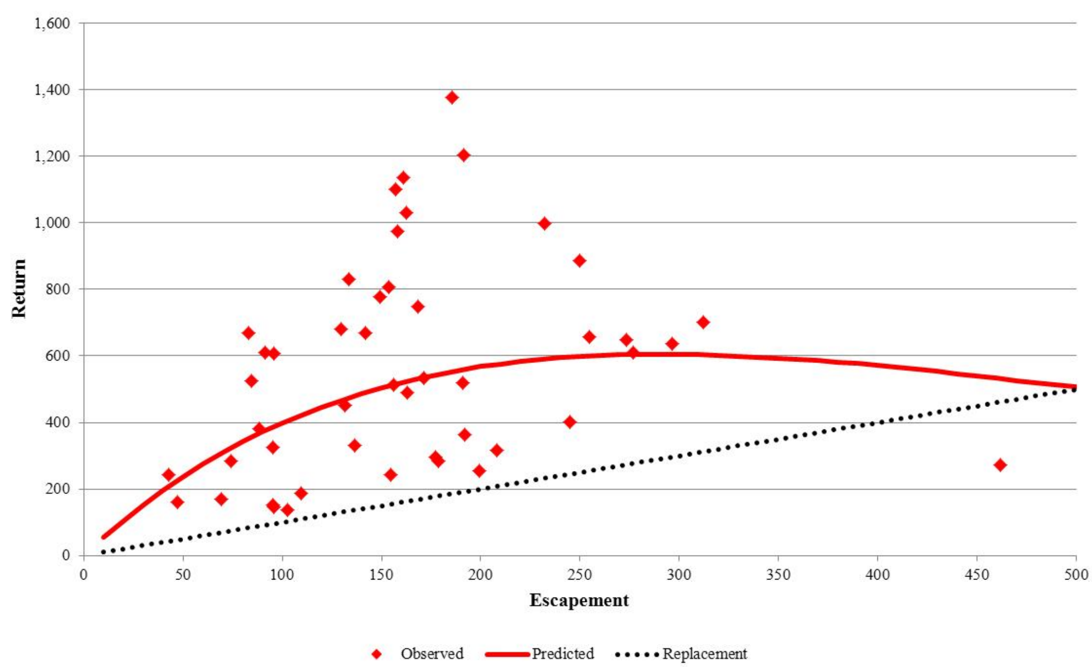
Year	Escapement	Total Return	Return per Spawner
1959	178,740	284,478	1.59
1960	162,810	490,021	3.01
1961	95,454	323,897	3.39
1962	47,352	159,716	3.37
1963	102,396	135,835	1.33
1964	95,574	145,179	1.52
1965	88,486	381,239	4.31
1966	91,098	610,132	6.70
1967	69,330	169,033	2.44
1968	42,918	242,379	5.65
1969	109,266	187,658	1.72
1970	192,096	362,266	1.89
1971	190,842	519,148	2.72
1972	74,070	284,762	3.84
1973	95,730	607,520	6.35
1974	82,992	670,282	8.08
1975	160,962	1,137,264	7.07
1976	158,190	975,806	6.17
1977	133,734	829,373	6.20
1978	273,576	646,977	2.36
1979	171,138	532,695	3.11
1980	461,850	272,164	0.59
1981	208,080	317,516	1.53
1982	244,734	401,789	1.64
1983	191,520	1,204,548	6.29
1984	95,448	152,706	1.60
1985	136,542	332,161	2.43
1986	168,384	748,532	4.45
1987	249,676	886,753	3.55
1988	276,612	610,191	2.21
1989	84,480	524,119	6.20
1990	141,977	669,580	4.72
1991	254,683	657,996	2.58
1992	199,134	254,771	1.28
1993	177,185	294,488	1.66
1994	154,752	243,963	1.58
1995	185,718	1,377,953	7.42
1996	156,954	1,101,047	7.02
1997	131,682	450,361	3.42
1998	153,576	807,711	5.26
1999	155,898	514,498	3.30
2000	311,970	702,280	2.25
2001	296,676	636,824	2.15
2002	162,402	1,029,368	6.34
2003	232,302	998,817	4.30
2004	129,462	680,764	5.26
2005	149,178	776,533	5.21
2006	312,126[a]		
2007	269,646[a]		
2008	205,680[a]		
2009	313,946[a]		
2010	188,298[a]		
2011	190,970[a]		
1959–2005 Average	173,741	560,491	3.77
No. of Years	47	47	47

[a] Incomplete returns from brood year escapement.

-continued-

Observed yields fitted with a LOESS 30% smoothed line against escapements (top), and total returns by brood year from previous brood tables compared with total returns from the revised brood tables (bottom) of Cunningham et al. (2012). Numbers are in thousands of fish.





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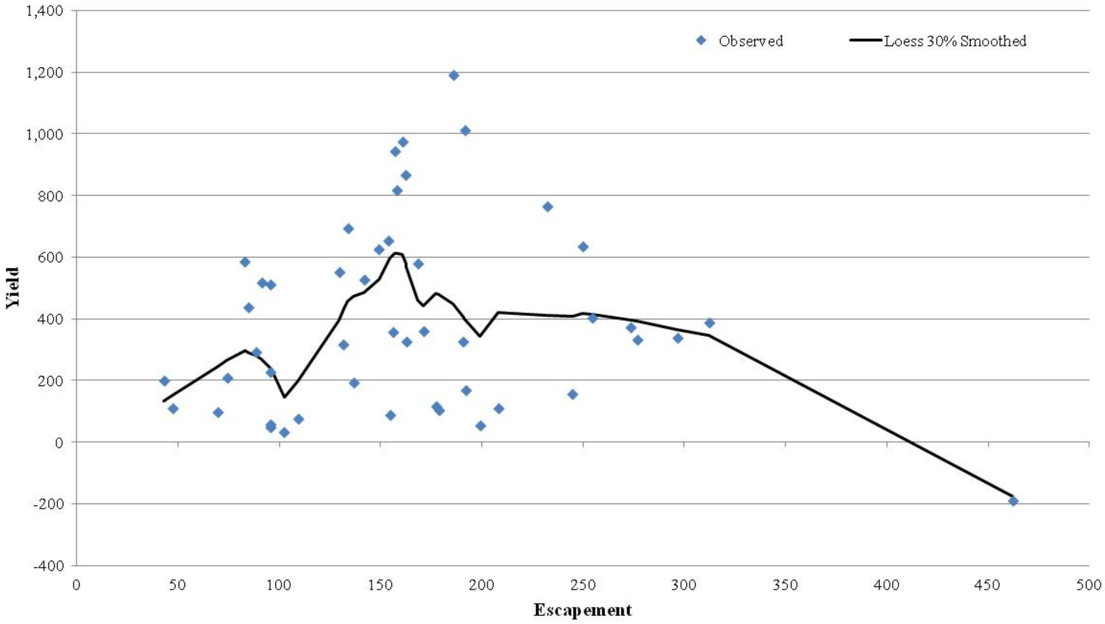
Observed yields fitted with a LOESS 30% smoothed line against escapements. Numbers are in thousands of fish.



Appendix E8.–Escapement goal for Ugashik River sockeye salmon.

System: Ugashik River

Species: sockeye salmon

Description of stock and escapement goals

Management Division:	Commercial Fisheries
Previous Escapement Goal:	500,000–1,200,000 SEG (1995)
Inriver Goal:	None
Optimal Escapement Goal:	None
Recommended Escapement Goal:	600,000–1,400,000 SEG
Escapement Estimation:	Tower counts from 1956 to present; 47 years of complete return data available
Summary:	
Data Quality	Excellent
Data Type	Tower counts; commercial harvest; age data
Methodology	Ricker stock-recruitment and yield analysis
Years within recommended goal	9 of last 10 years (2002–2011)

-continued-

System: Ugashik River

Species: sockeye salmon

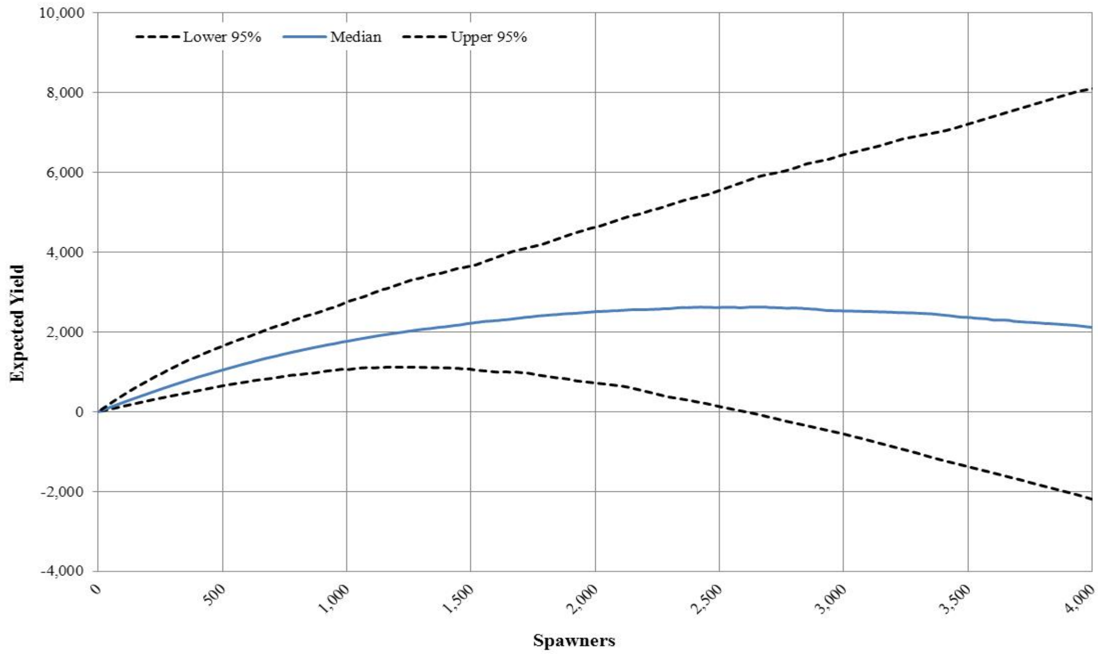
Data available for analysis of escapement goals

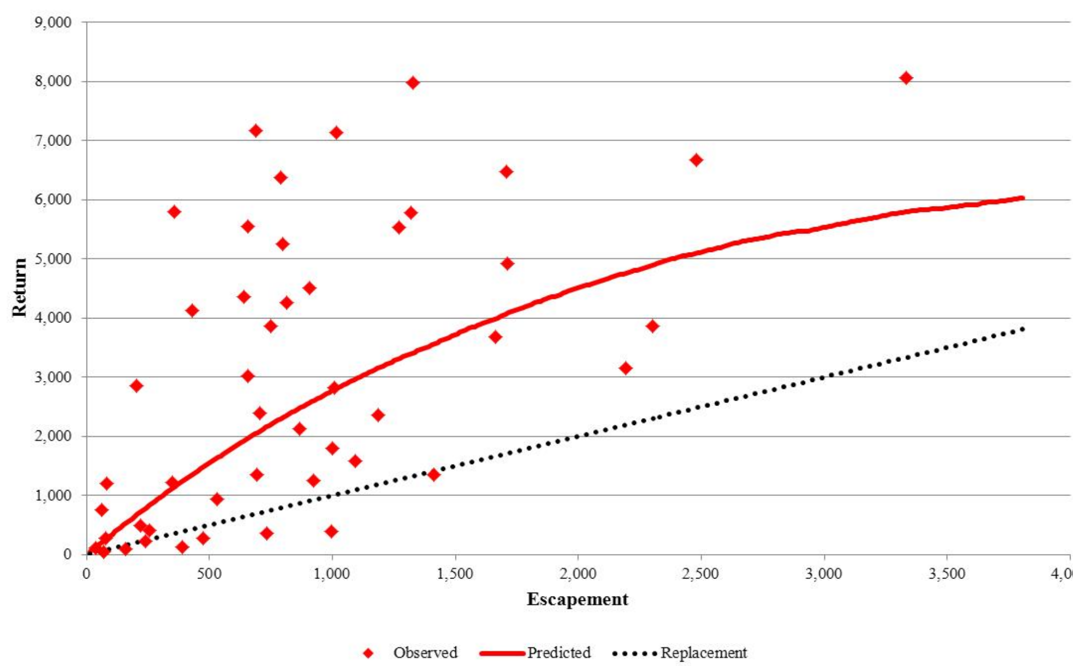
Year	Escapement	Total Return	Return per Spawner
1959	219,228	496,911	2.27
1960	2,304,200	3,867,461	1.68
1961	348,639	1,220,755	3.50
1962	255,426	407,565	1.60
1963	388,254	132,741	0.34
1964	472,770	274,733	0.58
1965	996,612	392,954	0.39
1966	704,436	2,388,187	3.39
1967	238,830	230,351	0.96
1968	70,896	45,088	0.64
1969	160,380	89,243	0.56
1970	735,024	355,709	0.48
1971	529,752	935,802	1.77
1972	79,428	276,170	3.48
1973	38,988	102,308	2.62
1974	61,854	757,907	12.25
1975	429,336	4,125,834	9.61
1976	356,308	5,801,029	16.28
1977	201,520	2,853,151	14.16
1978	82,435	1,194,448	14.49
1979	1,706,904	6,480,877	3.80
1980	3,335,284	8,062,907	2.42
1981	1,327,699	7,976,367	6.01
1982	1,185,551	2,359,880	1.99
1983	1,001,364	1,789,090	1.79
1984	1,270,318	5,529,343	4.35
1985	1,006,407	2,823,431	2.81
1986	1,015,582	7,142,245	7.03
1987	686,894	7,164,093	10.43
1988	654,412	5,544,390	8.47
1989	1,713,287	4,912,515	2.87
1990	749,478	3,858,144	5.15
1991	2,482,016	6,680,530	2.69
1992	2,194,927	3,149,052	1.43
1993	1,413,454	1,357,576	0.96
1994	1,095,068	1,586,369	1.45
1995	1,321,108	5,774,021	4.37
1996	692,167	1,355,916	1.96
1997	656,641	3,026,473	4.61
1998	924,853	1,248,478	1.35
1999	1,662,042	3,675,007	2.21
2000	638,420	4,360,152	6.83
2001	866,368	2,133,622	2.46
2002	905,584	4,500,313	4.97
2003	790,202	6,369,928	8.06
2004	815,104	4,260,305	5.23
2005	799,612	5,244,674	6.56
2006	1,003,158[a]		
2007	2,599,186[a]		
2008	596,332[a]		
2009	1,364,338[a]		
2010	830,886[a]		
2011	1,029,853[a]		
1959–2005			
Average	924,695	3,070,512	4.33
No. of Years	47	47	47

[a] Incomplete returns from brood year escapement.

-continued-

Observed yields fitted with a LOESS 30% smoothed line against escapements (top), and total returns by brood year from previous brood tables compared with total returns from the revised brood tables (bottom) of Cunningham et al. (2012). Numbers are in thousands of fish.





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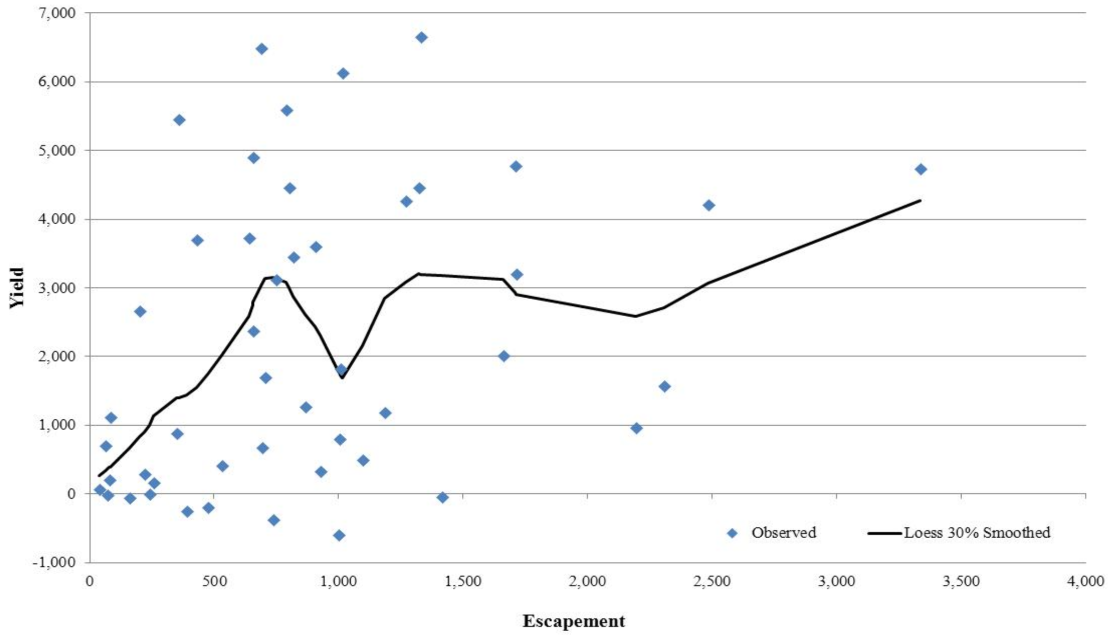
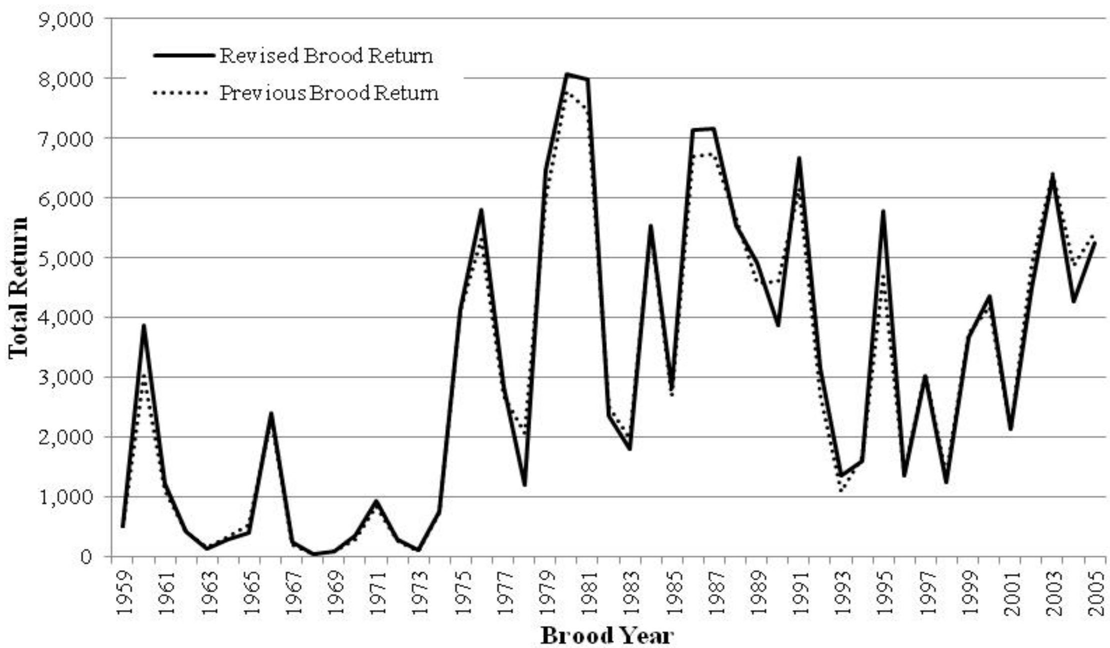
Observed yields fitted with a LOESS 30% smoothed line against escapements (top), and total returns by brood year from previous brood tables compared with total returns from the revised brood tables (bottom) of Cunningham et al. (2012). Numbers are in thousands of fish.





Appendix E9.–Escapement goal for Wood River sockeye salmon.

System: Wood River

Species: sockeye salmon

Description of stock and escapement goals

Management Division:	Commercial Fisheries
Previous Escapement Goal:	700,000–1,500,000 SEG (2001)); changed to SEG in 2007
Inriver Goal:	None
Optimal Escapement Goal:	None
Recommended Escapement Goal:	800,000–1,800,000 BEG
Escapement Estimation:	Tower counts from 1956 to present; 47 years of complete return data available
Summary:	
Data Quality	Excellent
Data Type	Tower counts; commercial harvest; age data
Methodology	Ricker stock-recruitment, yield analysis
Years within recommended goal	9 of last 10 years (2002–2011)

-continued-

System: Wood River

Species: sockeye salmon

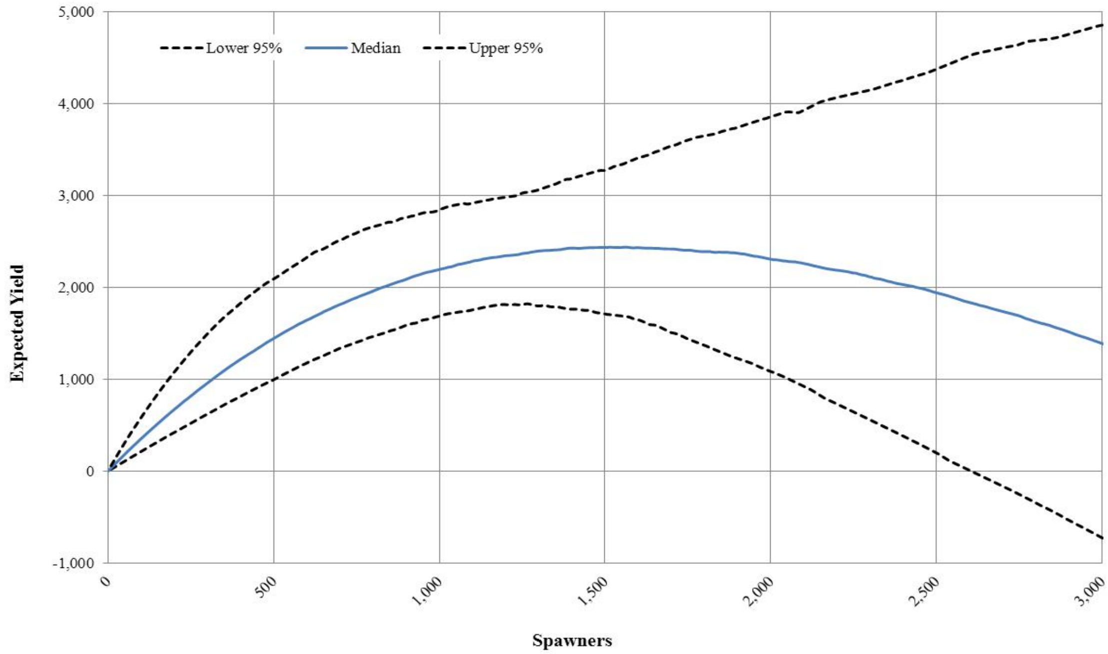
Data available for analysis of escapement goals

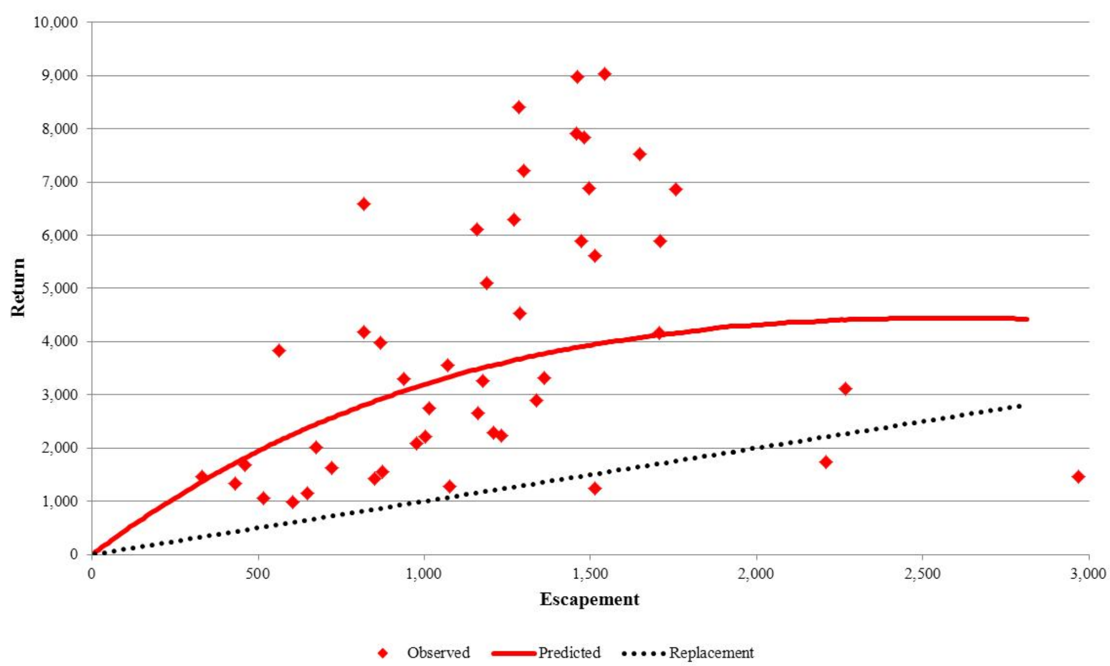
Year	Escapement	Total Return	Return per Spawner
1959	2,209,266	1,738,125	0.79
1960	1,016,073	2,748,924	2.71
1961	460,737	1,685,024	3.66
1962	873,888	1,550,870	1.77
1963	721,404	1,632,836	2.26
1964	1,076,112	1,286,903	1.20
1965	675,156	2,021,719	2.99
1966	1,208,682	2,290,780	1.90
1967	515,772	1,054,264	2.04
1968	649,344	1,154,367	1.78
1969	604,338	989,848	1.64
1970	1,161,964	2,648,102	2.28
1971	851,202	1,425,140	1.67
1972	430,602	1,338,679	3.11
1973	330,474	1,460,260	4.42
1974	1,708,836	5,893,430	3.45
1975	1,270,116	6,290,687	4.95
1976	817,008	6,590,536	8.07
1977	561,828	3,824,313	6.81
1978	2,267,238	3,117,207	1.37
1979	1,706,352	4,154,669	2.43
1980	2,969,040	1,471,792	0.50
1981	1,233,318	2,231,913	1.81
1982	976,470	2,085,371	2.14
1983	1,360,968	3,326,753	2.44
1984	1,002,792	2,218,822	2.21
1985	939,000	3,304,167	3.52
1986	818,652	4,176,305	5.10
1987	1,337,172	2,897,914	2.17
1988	866,778	3,978,870	4.59
1989	1,186,410	5,106,291	4.30
1990	1,069,440	3,555,678	3.32
1991	1,159,920	6,110,265	5.27
1992	1,286,250	4,539,123	3.53
1993	1,176,126	3,267,339	2.78
1994	1,471,890	5,887,328	4.00
1995	1,482,162	7,844,736	5.29
1996	1,649,598	7,529,945	4.56
1997	1,512,396	1,237,317	0.82
1998	1,755,768	6,866,961	3.91
1999	1,512,426	5,621,078	3.72
2000	1,300,026	7,214,553	5.55
2001	1,458,732	7,908,115	5.42
2002	1,283,682	8,414,497	6.55
2003	1,459,782	8,971,062	6.15
2004	1,543,392	9,037,345	5.86
2005	1,496,550	6,884,016	4.60
2006	4,008,102 [a]		
2007	1,528,086 [a]		
2008	1,724,676 [a]		
2009	1,319,232 [a]		
2010	1,804,344 [a]		
2011	1,098,006 [a]		
1959–2005 Average	1,281,275	3,969,877	3.43
No. of Years	47	47	47

[a] Incomplete returns from brood year escapement.

-continued-

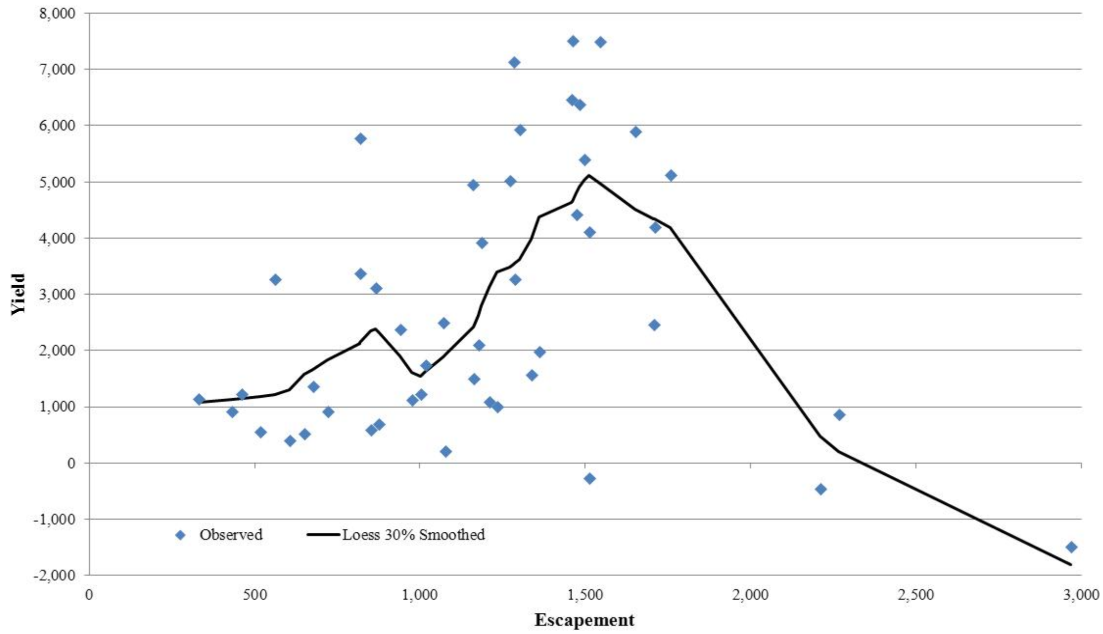
Observed yields fitted with a LOESS 30% smoothed line against escapements (top), and total returns by brood year from previous brood tables compared with total returns from the revised brood tables (bottom) of Cunningham et al. (2012). Numbers are in thousands of fish.

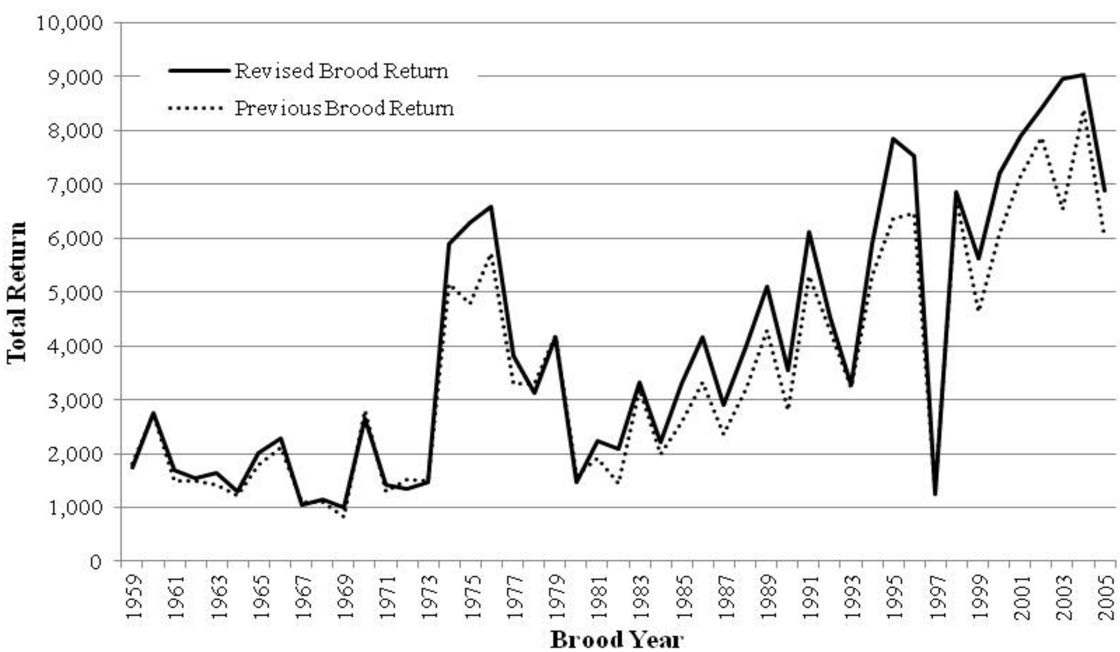




-continued-

Observed yields fitted with a LOESS 30% smoothed line against escapements (top), and total returns by brood year from previous brood tables compared with total returns from the revised brood tables (bottom) of Cunningham et al. (2012). Numbers are in thousands of fish.





APPENDIX F. WINBUGS CODE

```
#Ricker model for stock-recruitment analysis
model Ricker{

 lnalpha ~ dunif(0, 10)
 beta ~ dunif(0, 10)
 phi <- 0
 sigma.white ~ dunif(0,10)
 resid.red.0 ~ dnorm(0,tau.red)

 for(y in 1:n) {lnRS[y] ~ dnorm(mean2.lnRS[y],tau.white) }

 mean2.lnRS[1]     <- mean1.lnRS[1] + phi * resid.red.0
 for (y in 2:n) { mean2.lnRS[y] <- mean1.lnRS[y] + phi * resid.red[y-1] }

 for(y in 1:n) {  mean1.lnRS[y] <- lnalpha - beta * S[y]  }
 for(y in 1:n) {  resid.red[y]     <- lnRS[y] - mean1.lnRS[y]  }
 for(y in 1:n) {  resid.white[y] <- lnRS[y] - mean2.lnRS[y]  }

 tau.white <- 1 / sigma.white / sigma.white
 tau.red <- tau.white * (1-phi*phi)
 sigma.red <- 1 / sqrt(tau.red)
 sigma<-sigma.red

#lnalpha.c <- lnalpha + (sigma.red * sigma.red / 2)
 lnalpha.c <- lnalpha
 alpha<-exp(lnalpha.c)
 S.max <- 1 / beta
 S.eq <- S.max * lnalpha.c
 S.msy <- S.eq * (0.5 - 0.07*lnalpha.c)
 U.msy <- lnalpha.c * (0.5 - 0.07*lnalpha.c)
 R.msy <- S.msy * exp(lnalpha.c - beta * S.msy)
 MSY <- R.msy - S.msy

 start<-0
 end<-5000000
 step<-(end-start)/1000
 S.star[1]<-0
 for (i in 2:1002) {                    #LOOP TO FIND Pr(SY>90%MSY)
   S.star[i] <- S.star[i-1]+step
   R.star[i] <- S.star[i] * exp(lnalpha.c - beta * S.star[i])
   SY[i] <- R.star[i] - S.star[i]
   I90[i] <- step(SY[i] - 0.9 * MSY)
   }
 }
```

APPENDIX G. KALMAN FILTER

For the Ricker stock-recruitment relationship, there is an "observation equation" that describes the relationship between the observed quantities, *R* and *S*:

$$\ln(R_t / S_t) = a_t - b * S_t + v_t,$$

where R_t = recruitment of the year, *t;* S_t = stock size of the year, *t;* $a_t = \ln(\alpha_t)$, and α_t is productivity, α, of the year, *t;* and $b = \beta$; $v_t \sim N(0, \sigma_v^2)$. There is also an "updating equation" that reflects how the parameter α varies over time, which is assumed to follow a random-walk process: $a_t = a_{t-1} + w_t$, where $w_t \sim N(0 \quad \sigma_w^2)$.

The Kalman filter procedure recursively estimates a_t each year based on the previous year's estimate, a_{t-1}, and the new observation of $\ln(R_t / S_t)$. Other model parameters (b, σ_v, and σ_w) are assumed to be constant over time and are estimated using maximum likelihood.

<u>Prediction phase</u>: $a_{t|t-1} = a_{t-1}$, with variance $P_{t|t-1} = P_{t-1} + \sigma_w^2$. Prediction of $Y_t = \ln(R_t/S_t)$: $\hat{Y}_{t|t-1} = a_{t|t-1} - bS_t$ with prediction error (e_t): $e_t = \ln(R_t / S_t) - (a_{t|t-1} - bS_t) = Y_t - \hat{Y}_{t|t-1}$. The variance of this prediction error is $f_t = P_{t|t-1} + \sigma_v^2$.

<u>Update phase:</u> Next, inferences regarding the state variable were updated by computing posterior (or "filtered") estimates for the mean (a_t) and variance (P_t) of a_t:

$$a_t = a_{t|t-1} + \frac{P_{t|t-1} e_t}{f_t} \text{, and}$$

$$P_t = P_{t|t-1} - \frac{P_{t|t-1}^2}{f_t} = \frac{P_{t|t-1}\sigma_v^2}{f_t}.$$

The updated or filtered estimate of Y_t : $\hat{Y}_t = a_t - bS_t$.

Maximum likelihood estimates of constant parameters phase: Estimates for the constant parameters (b, σ_v, and σ_w) are obtained by maximizing the log-likelihood function across years:

$$\ln(L) = \frac{1}{2} \sum_{t=2}^{N} \left[\ln(f_t) + \frac{e_t^2}{f_t} \right].$$