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Escapement Goal Review For Susitna River Sockeye Salmon, 2009

by

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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)

Measures (fisheries)

fork length	FL
mideye to fork	MEF
mideye to tail fork	METF
standard length	SL
total length	TL

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

This report is a summary of reviews and recommendations for the Susitna River sockeye salmon escapement goals in Upper Cook Inlet, Alaska. The current sustainable escapement goal (SEG) range of 90,000 to 160,000 spawners for the Yentna River (a tributary of the Susitna River) sockeye salmon stock was adopted by the Alaska Department of Fish and Game in 2001. Considerable uncertainty is associated with the escapement assessment and productivity of the stock, which was designated as a stock of yield concern by the Alaska Board of Fisheries in 2008. The existing escapement goal was determined to be inappropriate given the escapement uncertainties associated with the Bendix sonar program. This review uses escapement information for the Chelatna, Judd, and Larson lakes within the Susitna River drainage and applies the Percentile Approach to each data set for the establishment of three new SEGs. We recommend eliminating the Yentna River sockeye salmon SEG and replacing it with two SEGs represented by Chelatna (20,000 to 65,000) and Judd (25,000 to 55,000) lakes. Additionally, on the Susitna River mainstem, we recommend a Larson Lake SEG with a range of 15,000 to 50,000 spawners.

Key words: BEG, Bendix, biological escapement goal, Chelatna Lake, DIDSON, Judd Lake, Larson Lake, *Oncorhynchus nerka*, Percentile Approach, SEG, sockeye salmon, Susitna River, sustainable escapement goal, Yentna River.

INTRODUCTION

This report summarizes the Alaska Department of Fish & Game (ADF&G) escapement goal review and recommendations for Susitna River sockeye salmon *Oncorhynchus nerka*. Recently, much debate has surrounded the Yentna River (a major tributary of the Susitna River) sockeye salmon escapement goal. This goal has been used to manage harvests of sockeye salmon spawning throughout the Susitna River watershed. There are many uncertainties surrounding the precision and accuracy of the Bendix[1] sonar, which is the primary assessment tool used to measure the Yentna River salmon escapement. Results from Susitna River sockeye salmon productivity studies prior to the February 2008 Upper Cook Inlet (UCI) Alaska Board of Fisheries (BOF) meeting raised concerns about the potential bias of the Yentna River escapement estimate derived from the Bendix sonar counter and fish-wheel species apportionment. The latest escapement goal review involving the Susitna River occurred in 2007 during a regular BOF cycle (Fair et al. 2007).

The extraordinary importance of this goal has forced this review to occur outside of its normal 3-year cycle. Some of the information from newly implemented research programs within the Susitna River drainage was not yet available for this review. The information presented here covers the escapement goal history for the Susitna River sockeye salmon, our current and historical assessment of escapement, issues surrounding those assessments, and a recommendation of new Susitna River escapement goals.

In this review, 'Susitna River' will refer to all waters (including all tributaries) draining the Susitna River. The 'Yentna River' refers to all waters draining the Yentna River upstream of its confluence with the Susitna River. The 'Susitna River mainstem' refers to all waters excluding the Yentna River and its tributaries.

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[1] Product names used in this report are included for scientific completeness, but do not constitute a product endorsement.

POLICY GUIDELINES

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) adopted by the BOF into regulation in 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 ADF&G'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 BOF's regular cycle of consideration of area regulatory proposals.

The SSFP defines biological and sustainable escapement goals as:

> *Biological Escapement Goal* (BEG): means the escapement that provides the greatest potential for maximum sustained yield (MSY); 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.
>
> *Sustainable Escapement Goal* (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 due to the absence of a stock specific catch estimate; the SEG is the primary management objective for the escapement, unless an optimal escapement or inriver run goal has been adopted by the BOF, and will be developed from the best available biological information; the SEG will be determined by the department and will be stated as a range that takes into account data uncertainty; the department will seek to maintain escapements within the bounds of the SEG.

ESCAPEMENT GOAL HISTORY

The Susitna River sockeye salmon run is considered the third largest of 4 major sockeye salmon runs in UCI (Figure 1); the other 3 are the Kenai, Kasilof, and Crescent rivers. Since 1976, the estimated total UCI sockeye salmon runs have ranged from 1.8 million to 12.4 million, while estimated Susitna River sockeye salmon runs have ranged from 147,000 to 773,000. Susitna River sockeye salmon rear as juveniles in river sloughs, and in Byers, Hewitt, Lockwood, Red Shirt, Spink, Stephan, Swan, Trapper, Trinity, and Whiskey lakes (and other small lakes); however, the majority rear in Larson, Chelatna, Shell and Judd lakes (Figure 2; King and Walker 1997).

Susitna River sockeye salmon are harvested in mixed-stock gillnet fisheries in Cook Inlet and in sport and subsistence fisheries. Management of these runs is based upon achieving spawning escapements for each river within a specific escapement goal range. In 1979, ADF&G set the initial Susitna River sockeye salmon BEG at 200,000 based on the premise that 800,000 sockeye salmon could be produced in the Susitna River watershed (Fried 1994). The rationale for the estimation of Susitna production was the number of fish harvested in Cook Inlet and knowledge of the escapements to the Kenai and Kasilof rivers. Using a return-per-spawner value of 4.0, similar to what other UCI stocks experienced, the Susitna goal was set at 200,000. In 1989, this goal was corroborated with estimates of euphotic volume from 24 major lakes in the drainage

(Tarbox and Kyle 1989). Based on a 5-year comparison (1981–1985) of estimates for the Yentna River and Susitna River mainstem, ADF&G determined that an escapement of 100,000 to 150,000 sockeye salmon into the Yentna River would generally result in a total escapement of at least 200,000 sockeye salmon into the entire Susitna River drainage (Fried 1994). The sonar comparison showed that approximately 50% (41% to 59%) of the Susitna River sockeye salmon escapement traveled upriver and entered the Yentna River. As a result, fishery managers considered the Susitna River escapement goal to be achieved when 100,000 to 150,000 sockeye salmon had entered the Yentna River.

In 2001, the escapement goal committee felt that it would be more appropriate to set the goal based on empirical estimates of escapement, which began in 1981 using the Bendix sonar, rather than conjectures regarding production or euphotic volume. Additionally, stock-specific estimates of the harvest and total return to the Susitna River were considered unreliable. Therefore, in 2001 ADF&G changed the 1979 BEG for the Susitna River to an SEG range of 90,000 to 160,000 sockeye salmon for the Yentna River. The SEG was developed by applying the Percentile Approach[2] to the annual Bendix sonar estimates of escapement into the Yentna River. In 2005, the BOF adopted an optimal escapement goal (OEG) of 75,000 to 180,000 Yentna River sockeye salmon, contingent on a run to the Kenai River greater than 4 million. The most recent escapement goal reviews for UCI, which includes the Susitna River drainage, were in 2004 and 2007 (Fair et al. 2007; Hasbrouck and Edmundson 2007). In those reviews, the Yentna River escapement goal did not change.

For 5 of the past 9 years, the Yentna River sockeye salmon escapement has failed to meet the current SEG range of 90,000 to 160,000. The chronic inability to meet the escapement goal prompted acquisition of capital improvement project (CIP) funds for a comprehensive Susitna River stock assessment project involving a mark–recapture study that used multiple adult weirs at major lakes within the system (Yanusz et al. 2007). Concurrently, Cook Inlet Aquaculture Association initiated projects on 7 lakes to estimate smolt production and evaluate limitations to sockeye salmon production in each lake.

Beginning in the 1950s various methods were used to assess the number of spawning sockeye salmon in the Susitna River (Hoffman and Crawford 1986). Initial studies began with aerial surveys, and later included counting towers, weirs, mark–recapture, and sonar for select areas of the drainage. In 1976, ADF&G tested the first Bendix sonar, moving to the Yentna site in 1981. Testing with a **D**ual-frequency **Id**entification **Son**ar (DIDSON) at the existing Yentna River sonar site began in 2005, with full season operations occurring from 2006 through 2008. For more background information on the history of assessing sockeye salmon escapement in the Susitna River, see Appendix A1.

The deficiencies of the Bendix sonar system and the apportionment process were illustrated in recent stock assessment findings, which showed that Bendix sonar estimates from 2006–2008 were significantly less than DIDSON estimates, weir counts, and mark–recapture estimates (Table 1; Yanusz et al. 2007). The high variability between the various methods of escapement assessment in recent history has added greater uncertainty to our previous assessments.

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[2] Unpublished report to the Alaska Board of Fisheries, November 2001 and February 2002, entitled *Escapement goal review of salmon stocks of Upper Cook Inlet*, by Brian G. Bue and J. J. Hasbrouck, located at Alaska Department of Fish and Game, Anchorage. Subsequently referred to as Bue and Hasbrouck *Unpublished*.

OBJECTIVES

Objectives of this review are to:

1) Review the existing Yentna River sockeye salmon escapement goal to determine whether it is still appropriate given (a) recently available productivity data, (b) current assessment techniques, and (c) current management practices;
2) Review the method used to establish the existing Yentna River sockeye salmon goal to determine whether alternative methods should be investigated; and,
3) Recommend a Susitna River escapement goal, if appropriate.

DEVELOPMENT OF A NEW ESCAPEMENT GOAL

EVALUATION OF HISTORICAL SOCKEYE SALMON SONAR ESCAPEMENT

Given the recent studies of escapement in the Susitna River, there is little confidence in the reliability of the Bendix sonar estimates. Since 2006, when additional escapement studies began, Bendix sockeye salmon estimates have ranged from 56% to 70% of the DIDSON estimate, and just 31% and 32% of the Yentna River mark–recapture estimates in 2007 and 2008. Perhaps even more significantly, the Bendix sonar estimates appear to be a poor index of Susitna sockeye abundance, especially in even-numbered years when pink salmon abundance is high (Figure 3), as is often the case. To examine the efficacy of the Bendix sockeye salmon estimates as an index of Susitna sockeye abundance, we ran linear regressions of 1981–2008 Bendix sonar estimates against (a) Northern District (eastside only) sockeye salmon commercial catch per delivery; and (b) Larson Lake weir counts (Figure 4) since these were the only relevant data sets with an adequate number of years. The same regressions were also performed for (1) Bendix estimates adjusted by the relationship between Bendix and DIDSON [This adjustment is based on daily comparisons for 2006–2008 (n>100); see Appendix B1 for more information] and (2) Bendix estimates adjusted for DIDSON and fish wheel selectivity (based on results from Meehan 1961 and ADF&G 1983). In both instances, actual DIDSON estimates were used for 2006 to 2008, rather than Bendix estimates adjusted for DIDSON. In each case, significant ($P< 0.10$) regressions occurred for odd-numbered years (Figure 4). However, in even-numbered years of high pink salmon abundance, all models were insignificant. We also fit (a) and (b) above to the DIDSON-adjusted sonar estimates with and without fish wheel selectivity adjustments and found similar results (Table 2).

The poor performance of the Bendix sonar estimates as an index in years of high pink salmon abundance is likely a consequence of fish wheel species apportionment. Previous studies (Meehan 1961; ADF&G 1983) showed that fish wheel species selectivity is highly variable by year and location (Tables 3 and 4). Fish wheel selectivity estimates from those studies applied to the Yentna River sonar data demonstrate the large effects they can have on final sockeye salmon abundance estimates (Table 5). For example, in 2008 the sockeye salmon estimate (99,324) based on selectivity coefficient Data Set 5 (Tables 3–4) is about one-half that from data set 6 (192,909). As another example that fish wheel selectivity is likely a major source of error in the estimation of sockeye salmon abundance past the sonar site, we compared total unapportioned DIDSON counts to the mark–recapture estimates. Assuming that the DIDSON is reasonably estimating fish passage, the ratio of (a) the ratio of mark–recapture to total DIDSON counts to (b) the proportion of sockeye salmon in fish wheel catches, shows that fish wheels are underestimating the sockeye salmon proportion by a factor of 2.4 on average (based on 2007 and 2008; Table 6).

Another concern we have with historical Bendix estimates relates to a change in the design of the transducer mounting system. Bendix transducer systems are mounted on 15.2 cm diameter aluminum tubing 18.3 m in length and positioned on the bottom of the river, perpendicular to the bank. This arrangement forces fish to move across the 15.2 cm artificial substrate tube and through the sonar beam. A transition to substrate-less counters was initiated in 1994 because of the effect that artificial substrates had on fish behavior and the constant maintenance and safety problems (trees and brush) associated with the tube (Westerman and Willette 2007). Undocumented comparison studies with and without a substrate suggested that fish were detecting the substrate, modifying their migration pattern, and forcing them beyond the sonar beam undetected.

Additionally, the Yentna River sonar project has experienced other important operational changes since it began in 1981. In 1996, the weirs used to guide fish into the fish wheels were significantly modified to catch more fish and in a number of instances fish wheels were relocated in an attempt to become more efficient or out of necessity when bottom profiles changed. Unfortunately, any one of these changes may have had an unknown impact on fish wheel species apportionment, and hence on the index of sockeye salmon escapement.

Concerns regarding sonar as a reliable index of abundance lead us to believe it would be inappropriate to use the historical Bendix estimates to establish a new escapement goal. Since Bendix escapement estimates are unreliable in some years with uncertain measurement error, traditional stock-recruitment modeling cannot be applied to set an escapement goal or develop a reliable brood table.

LAKE PERCENTILE APPROACH

An approach commonly used by ADF&G (Fair et al. 2007, 2008, Honnold et al. 2007 a-b; Otis and Szarzi 2007; Witteveen et al. 2007) to establish an SEG when data quality is insufficient to support a BEG is the Percentile Approach (Bue and Hasbrouck *Unpublished*). In essence the Percentile Approach is a way of keeping escapements in the middle of the range where they have been. Percentile ranking is the percent of all escapement values that fall below a particular value. To calculate percentiles, escapement data are ranked from smallest to largest values, 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 a cumulative, or summation, of 1/(n-1), where n is the number of escapement values. The incorporation of contrast in the escapement data and exploitation of the stock to estimate an SEG range was first discussed in Bue and Hasbrouck (*Unpublished)*. Contrast in the escapement data is simply the maximum value divided by the minimum value. As contrast increased, and thereby the implied knowledge of stock productivity, the percentiles used to estimate the SEG were narrowed, primarily from the upper end, while still allowing the SEG to include a wide range of escapements. For exploited stocks with high contrast, the lower end of the SEG range was increased to the 25^{th} percentile as a precautionary measure for stock protection (Table 7; Bue and Hasbrouck *Unpublished*).

We identified 4 lakes within the Susitna River (Chelatna, Shell, Judd, and Larson) that have the quality and quantity of escapement data necessary for application of the Percentile Approach to set an SEG. Upon further examination we dropped Shell Lake from the analysis because of concerns that beaver dams may have limited migrating salmon in some years. A major problem in Shell Creek is that sockeye salmon must often traverse up to 25 beaver dams to reach their spawning grounds (Fox 1998). During the studies from 2006–2008 we regularly flew Shell

Creek to look for beaver dam blockage, but found none. According to local residents of the area however, in recent years beaver dams have been dismantled each season to allow fish to pass. Other lakes considered but excluded because of limited data (≤ 3 years) were Hewitt, Swan, Stephan, and Byers. Initially, we completed a thorough literature review for all historical Susitna River escapement data, regardless of the method used to gather the information (Appendices C1-C4). Based on the type of data collected and the success of the estimate in regards to timing, completeness, and quality we scored each escapement estimate with either a poor, fair, or good rating. Escapement estimates with a rating of fair or good were included in the Percentile Approach. Aerial surveys were only considered valid if (1) there were at least 3 surveys in a year, (2) the peak count occurred in one of the middle surveys (i.e., not the first or last survey), and (3) the timing of the surveys coincided around historical peak dates. The survey data selected for inclusion in the SEG analysis is in Table 8 (Judd Lake; 1973, 1980).

In some cases, reported escapement measures were expanded to best reflect true abundance. For Chelatna Lake, the 1996 and 1998 weir counts were linearly expanded for the time period that the weir was inoperable due to high water events. For the high water weir closures in 2006 and 2007, the proportion of Chelatna radio tags having passed through the weir at the time of shut down was used to estimate the number of fish that were not counted. For this interpolation to be valid Chelatna Lake fish would have had to be tagged in proportion to abundance and tagged fish could not have shown any adverse tagging effects, such as delayed run timing. Evidence from Yanusz et al. 2007 suggesting delayed migration of tagged fish elsewhere in the drainage, could bias the Chelatna Lake escapement estimate high, but probably not by more than 20%.

For 2 escapement estimates in Judd Lake, peak aerial surveys were expanded. Previous salmon studies comparing unbiased measures of escapement (weirs, towers, etc.) to the potentially biased method of aerial surveys demonstrate that without adjustment of aerial surveys, the estimated measure of escapement is, on average, substantially biased low (Bue et al. 1998; Jones et al. 1998; Clark 2005). For Susitna River sockeye salmon aerial surveys, we chose to expand the counts based on findings between aerial surveys and tower counts for Alagnak River (Clark 2005) since that study also focused on sockeye salmon. The Bue et al. (1998) and Jones et al. (1998) studies involved pink salmon, however, their expansion factors were similar to Clark (2005). The Clark study had 9 valid comparisons between tower counts and aerial surveys with a range of expansions from 0.97 to 4.34, and an average of 2.55. Clark (2005) concluded that the use of 9 years of paired data to estimate an average expansion factor provided an unbiased estimate of the relationship between the 2 stock assessment methods. Assuming that an expansion factor of 2.55 is appropriate for the Susitna River, the expanded estimates are equivalent, on average, with weir counts. Because aerial surveys tend to substantially underestimate the number of fish present and since an insufficient number of aerial surveys were conducted to use an area-under-the-curve approach (Bue et al. 1998) it can be reasonably presumed that expanding the Susitna River sockeye salmon aerial counts leads to a more realistic estimate of the true number of fish that were present. A sensitivity analysis of the aerial expansion factor on the Judd Lake SEG shows that expansion factors ranging from 1 to 4 have little change on the upper range (<10%) while only an expansion factor of 1 causes a change greater than 20% on the lower range. Because previous studies have shown expansion factors less than 2 to be uncommon and since an expansion factor of 2.55 provides for a higher, and more conservative lower range we do not have concerns about its potential effect in our development of the Judd Lake goal.

Long term average escapements for Chelatna, Judd, and Larson lakes are each similar, ranging from approximately 34,000 to 41,000 (Table 8). Chelatna, Judd, and Larson lakes each have medium range contrast in escapement as defined in the Percentile Approach, leading to a range of escapement percentiles between 15 and 85. Escapement goals were estimated for each lake, however, because of the missing historical escapements the SEG estimates cannot be summed. For the Percentile Approach to be valid despite the missing information, the individual time series of weir counts must at least be positively correlated so that the percentile values derived from each weir can be assumed to be from similar patterns of escapement over time. Unfortunately, this was not the case. After taking natural logarithms of the lake escapement data in Table 8, we calculated the Pearson correlation coefficients of the pairs of escapement data and found that 2 of the 3 comparisons were negatively correlated suggesting that the lower and upper bounds of a summated escapement goal would be derived from entirely different time series that are not related to one another. The summated goal range might be a meaningful expression of the expected sum of escapements over time, but it is much more likely that it is not. Therefore, we developed an SEG for each lake (Table 8; rounded to the nearest 5,000): Chelatna (20,000 to 65,000), Judd (25,000 to 55,000), and Larson (15,000 to 50,000).

DISCUSSION

Sockeye salmon escapement data for the Susitna River drainage is patchy through time and space, and widespread in quality. Prior to the use of sonar, aerial surveys were flown periodically in varying conditions with different observers, and without temporal or spatial consistency. While there may be a significant amount of *data* in regards to sockeye salmon abundance in the Susitna River, the amount of *information* is sparse. At first glance the sheer number of escapement data sets within the drainage (Appendices C1–C4) appears to provide much information, but further inspection reveals that the majority of the data are aerial surveys that are often hampered by poor survey conditions, an insufficient number of surveys per year, or surveys that do not cover the full survey area. The actual quantity of high quality data sets is relatively small given the large number of years that research has focused on Susitna River sockeye salmon escapement.

For many years, the use of sonar for escapement enumeration appeared to be reliable, but beginning in 2006 a 3-year study using alternative methods (weir counts, mark–recapture) suggested that both the Bendix and DIDSON were grossly under-estimating the number of sockeye salmon spawning in the Yentna River. Most likely the greatest source of error associated with these sonar estimates emanates from the use of fish wheels as a means to apportion sonar counts to species. The current apportionment program presumes that selectivity in the fish wheel is equal for all species; however 2 studies conducted elsewhere suggest this may not be the case (Mehan 1961; ADF&G 1983). Assuming that Northern District catch per delivery and Larson Lake escapement is correlated with Susitna River abundance, Bendix estimates appear to be a poor indicator of Susitna River sockeye salmon abundance in even-numbered years of high pink salmon abundance (Figure 4). The Bendix's bias was a driving force for this escapement goal examination. Without useful Bendix estimates, the only continuous time series of Yentna River sockeye salmon escapement since the early 1980s, the choice for setting a new escapement goal is limited to using sporadic lake counts or non-escapement based estimates of lake productivity.

In addition to stock-recruitment analyses, other methods for setting sockeye salmon escapement goals are to estimate adult production based on euphotic volume (Koenings and Burkett 1987) or zooplankton abundance (Koenings and Kyle 1997). The euphotic volume model has been well documented in the literature as a valid approach; however it may not be a good indicator of sockeye salmon productivity for many Alaskan lake systems (Hal Geiger, Commercial Fisheries Scientist [retired], ADF&G, personal communication). Unfortunately, results showing that euphotic volume does not reliably estimate production are rarely documented in reports and we suspect this may bias the perceived utility of this method. One documented example of the euphotic volume model inaccurately estimating sockeye salmon production as demonstrated through an enhancement project is Piston (2003).

After various alternative approaches for setting an escapement goal were considered, but then dropped due to the many uncertainties surrounding each, we concluded that until more information is available a simple approach is preferable. The premise of this review is that not much can be done with the available data, so we've taken escapements believed to be sustainable and used those in the interim to set a goal while better data is collected. The Percentile Approach provides an ad-hoc mechanism to produce an escapement goal range from a history of escapement series. It is reasonably easy to argue that the SEG range is sustainable so long as the stock has repeatedly recovered from the escapements chosen as the SEG. Based on 3 years of DIDSON to weir data we recognize that there are alternative strategies for establishing a goal, however, we do not believe that 3 years is sufficient for understanding this relationship. Given that the Bendix estimates appear to be stronger indices of abundance in odd-numbered years we also considered a run reconstruction model whereby even-numbered years of escapement are estimated from the lake data. Unfortunately, the large data gaps in the historical time series of escapement do not support a scientifically defensible model.

Based on mark–recapture studies in 2007 and 2008, Chelatna and Judd lakes together represent about 43% of the sockeye salmon production in the Yentna River. Likewise, mark–recapture studies from 2006–2008 indicate that Larson Lake represents about 52% of the sockeye salmon production in the Susitna River mainstem.

The long-term research goal is to collect the necessary information to develop brood tables. Specific options for developing brood tables may include:

- If fish wheel net selectivity's are successfully estimated for each species, and if reasonable historical corrections can be made to the old data we could reconstruct brood tables using Bendix sonar estimates adjusted by DIDSON, mark–recapture studies, and selectivity estimates. At the conclusion of a successful 4-year fish wheel net selectivity study (2009–2012), and with 4 additional years of Yentna mark–recapture estimates, we would have the necessary information to adjust historical sonar estimates of escapement to total escapement, and this combined with estimates of harvest could be used to develop a Yentna brood table, and a subsequent stock-recruitment model. With this approach, we would still be left with some uncertainty in our harvest estimates prior to 2005 that are based on the age composition allocation model (Bernard 1983).

- If historical sonar estimates cannot reliably be used as a measure of escapement for the Yentna, and also for the Susitna mainstem, there are 2 likely approaches for developing a brood table: (a) continue to collect smolt data from Chelatna, Judd, and Larson lakes, and after perhaps (depending on the observed variability) 10 brood years develop a stock-recruitment model using weir counts and smolt estimates for each lake, and/or (b) develop a stock-recruitment model using weir counts and total return for Judd, Chelatna, and Larson lakes individually by estimating catch for each stock, which can be accomplished with genetic markers beginning in 2005. And again, with perhaps 10 years of brood data we could begin to develop a stock-recruitment model.

RECOMMENDATIONS

With the relative simplicity of the proposed SEG, perhaps the most relevant aspect of this report is to stress the importance of a continuing research program designed to improve our understanding of Susitna River sockeye salmon production. Accurate and precise estimates of escapement are not only important for setting and measuring escapement goals, but also for understanding annual harvest rates in the various UCI fisheries and forecasting future runs. Additionally, at the 2008 BOF meeting, in response to the guidelines established in the SSFP (5 AAC 39.222), the BOF identified the Yentna River sockeye salmon stock as a stock of yield concern. Correspondingly, a future research plan was described within the Yentna River sockeye salmon stock status and action plan; much of that is discussed below.

To increase our knowledge about the proposed SEG, ADF&G should continue to collect escapement counts from the major lakes upon which the goal is based. To minimize the frequency that the Chelatna Lake weir will need to be pulled because of high water in future operations, ADF&G installed a floating weir in 2008 designed to better withstand a wide array of water levels. Furthermore, we recommend the assessment of other major sockeye salmon lakes in the Susitna River. Other Susitna lakes known to be important for sockeye salmon that should be considered for long-term weirs include: Byers, Hewitt, Lockwood, Red Shirt, Spink, Stephan, Swan, Trapper, Trinity, and Whiskey.

A 3-year mark–recapture project in the Susitna River has provided important information about spawning distribution and abundances in the Yentna River and Susitna River mainstem (Yanusz et al. 2007). For the Susitna River mainstem, the relationship between Larson Lake weir counts for 2006–2008 and the mark–recapture estimate has been consistent, ranging from 50% to 54%. For the Yentna River, the variability between lake counts and mark–recapture estimates for 2007–2008 also appears to be stable on average, ranging from 41% to 44% for Chelatna and Judd as a whole. However, the variability within some of the lakes is much greater. Shell Lake escapements, for example, ranged from nearly 70,000 in 2006 to less than 3,000 in 2008. Additional mark–recapture studies should be conducted in the Yentna River to provide further insight into lake production versus non-lake production, and its relationship with DIDSON estimates.

Lake productivity studies in the Susitna River provide another important aspect of drainage-wide production by (1) estimating freshwater production of sockeye salmon, (2) identifying lake systems that may no longer produce significant numbers of sockeye salmon, (3) identifying factors limiting sockeye salmon production, and (4) determining potential effects of invasive northern pike on sockeye salmon production. Identification of bottom-up or top-down factors limiting sockeye salmon production provides information needed to restore stock productivity, if necessary. For example, of the 24 sockeye salmon producing lakes in the Susitna River drainage (Tarbox and Kyle 1989), invasive northern pike are present in 14 (Table 9). Pike are top-level predators in aquatic food chains and are highly piscivorous (fish eating). Outside their native range, trout, salmon and other fish have not had time to adapt defenses against pike's predatory tactics. Generally, when pike are introduced to a shallow lake like many in the Susitna River, they eventually consume a majority of the juvenile salmon and trout. They are known to selectively prey on salmonids throughout the year and migrate to lake outlets during heavy salmonid smolt migrations (Rutz 1996). Preliminary estimates of sockeye salmon production in some of these lakes suggest that salmon survival is very poor, but the cause is not clear. In addition to these lake productivity studies, estimates of smolt outmigration from the major lakes should continue. Reliable smolt and escapement data may provide the necessary information for one of the first applications of a spawner-recruit model to estimate escapement at maximum sustained yield.

If historical Bendix estimates of sockeye salmon production can reliably be adjusted to reflect past escapements in the Yentna River, they could perhaps be used to set an escapement goal. Currently however, this is not appropriate without further understanding species selectivity in fish wheels. A series of fish wheel selectivity experiments have recently been funded by the Alaska Sustainable Salmon Fund, similar to previous studies by ADF&G (1983) and on the Taku River (Meehan 1961). It is likely that Yentna River selectivity estimates, once established, will differ from previous studies, and is dependent on factors such as fish wheel location, water level, and fish abundance.

Three years of paired daily data comparisons between the Bendix and DIDSON have provided a consistent expansion factor for Bendix estimates. However, there are other sources of potential sonar error that should be tested. DIDSON appears to be an improved indicator of abundance over the Bendix, but it underestimates sockeye salmon fish passage as judged by the weirs and mark–recapture studies. Estimates of sockeye salmon abundance using DIDSON have been shown to be both accurate and precise when compared in a clear river against counts from an observer in a tower (Holmes et. al. 2006; Maxwell and Gove 2007); however, site-specific differences can bias the estimates. Potential error sources for sonar include: 1) the sampling design, 2) observer counting errors, 3) truncating the field season, 4) fish migrating outside the sonar beam, and 5) reduced detection of fish within the sonar beam.

ADF&G has established a long-term funding source for the harvest sampling program, which includes the separation of harvests by stock using genetic techniques (Habicht et al. 2007). The genetics program in recent years has greatly advanced our understanding of stock productivity and along with quality estimates of escapement (of which Susitna River is a part), it will remain a key aspect of the management and research program. In conjunction with the genetics catch sampling program, stock composition of catches from the Offshore Test Fishery (OTF) in Lower Cook Inlet (Shields and Willette 2008) may become a more important inseason management tool.

The studies and data collection mentioned above are designed for long-term sustainability of Susitna River sockeye salmon, by relating escapement levels to overall production at levels conducive to maximum sustained yield. However, we expect that several years of study will be required to develop an understanding of the errors in our sonar abundance estimates and harvest allocations to stocks. Once completed, we will determine whether sonar can be used to accurately estimate sockeye salmon abundance in the Yentna River and whether our historical time series of escapements can be reasonably corrected. Our preference is the renewed viability of using sonar as an inseason management tool.

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TABLES AND FIGURES

Table 1.–Susitna River sockeye salmon escapement estimates for 2006–2008 based on Bendix sonar, DIDSON, weir counts, and mark–recapture.

	Yentna River					Susitna River		
Year	Bendix	DIDSON	Weirs	Mark-Recapture	95% CI	Weirs	Mark-Recapture	95% CI
2006	92,051	166,697	128,866	Unknown		57,411	107,000	(49,000 - 165,000)
2007	79,901	125,146	126,208	239,849	(206,000 - 274,000)	47,736	87,883	(80,000 - 96,000)
2008	90,146	131,772	130,397	288,988	(251,000 - 327,000)	35,040	70,772	(61,000 - 80,000)

Source: Yanusz et al. (2007); Westerman and Willette (2007).

Source: The 2007 and 2008 mark–recapture abundance estimates are preliminary (ADF&G unpublished data).

Note: Weir counts for the Yentna River represent Chelatna, Shell, and Judd lakes, while Susitna River mainstem weir counts are represented by Larson Lake.

Table 2.–Regression p-values for Bendix estimates adjusted by DIDSON with and without adjustments for fish wheel selectivity against Northern District CPUE and Larson Lake escapement in odd- and even-numbered years.

	DIDSON-Adjusted Bendix		DIDSON-Adjusted Bendix with Fish Wheel Selectivity	
	Odd Years	Even Years	Odd Years	Even Years
Northern District CPUE	0.04	0.54	0.03	0.60
Larson Lake Weir Counts	0.14	0.36	0.20	0.97

Table 3.–Susitna Hydroelectric Project fish wheel selectivity studies at Curry and Talkeetna locations, 1981–1982.

Site	Data Set	Year	Species	n2	m2	Capture Probability
Talkeetna	1	1981	Sockeye	4,167	299	0.07
Talkeetna	1	1981	Pink	724	86	0.12
Talkeetna	1	1981	Chum	5,944	357	0.06
Talkeetna	1	1981	Coho	852	125	0.15
Talkeetna	2	1982	Sockeye	2,126	284	0.13
Talkeetna	2	1982	Pink	13,936	2,596	0.19
Talkeetna	2	1982	Chum	9,588	502	0.05
Talkeetna	2	1982	Coho	1,065	117	0.11
Curry	3	1981	Sockeye	3,040	386	0.13
Curry	3	1981	Pink	69	12	0.17
Curry	3	1981	Chum	4,033	333	0.08
Curry	3	1981	Coho	105	12	0.11
Curry	4	1982	Sockeye	1,970	172	0.09
Curry	4	1982	Pink	4,470	732	0.16
Curry	4	1982	Chum	7,802	362	0.05
Curry	4	1982	Coho	398	26	0.07

Source: ADF&G 1983.

Table 4.–Taku River fish wheel selectivity studies, 1958–1959.

Site	Data Set	Year	Species	n2	m2	Capture Probability
Taku	5	1958	Sockeye	241	8	0.033
Taku	5	1958	Pink	1,024	81	0.079
Taku	5	1958	Chum	599	13	0.022
Taku	5	1958	Coho	74	0	0.000
Taku	6	1959	Sockeye	342	3	0.009
Taku	6	1959	Pink	1,081	90	0.083
Taku	6	1959	Chum	610	11	0.018
Taku	6	1959	Coho	591	4	0.007

Source: Meehan 1961.

Table 5.–Yentna River sockeye salmon DIDSON-adjusted Bendix estimates calculated from 6 estimates of fish wheel selectivity coefficients.

Year	Original Bendix	DIDSON Adj.- no FW Selectivity	DIDSON Adj. w/ Fish Wheel Selectivity Coefficient Estimates							Coefficient of Variation
			1	2	3	4	5	6	Average	
1982	113,847	253,982	308,498	265,167	276,340	297,927	278,462	482,807	309,026	26%
1983	104,414	210,105	238,598	209,781	219,608	226,593	205,917	286,944	228,221	12%
1984	149,375	298,383	365,764	316,895	329,144	360,727	359,694	594,528	375,019	27%
1985	107,124	211,806	256,782	220,992	231,674	248,541	236,318	357,882	251,999	19%
1986	92,076	169,048	242,376	191,860	202,983	242,188	254,149	616,085	274,098	56%
1987	66,054	130,040	159,325	131,816	141,555	152,282	150,294	239,993	157,901	24%
1988	52,330	101,854	119,178	93,069	105,073	108,015	106,616	190,755	117,794	28%
1989	96,269	189,554	236,136	186,685	205,061	218,852	210,736	369,122	230,878	27%
1990	140,290	259,729	330,218	266,084	286,955	311,907	295,412	529,418	325,675	29%
1991	109,632	217,158	265,300	210,623	223,021	223,517	154,977	280,242	224,977	18%
1992	66,074	130,966	179,467	139,386	149,218	166,603	141,105	319,479	175,175	38%
1993	141,694	282,837	347,068	291,587	306,180	324,231	278,942	467,680	328,361	20%
1994	128,032	251,856	296,995	240,541	259,564	263,298	206,944	348,561	266,823	17%
1995	121,220	232,856	298,544	216,653	236,699	232,806	138,427	309,398	237,912	24%
1996	90,660	172,882	203,743	156,210	171,275	168,519	115,821	231,727	174,311	21%
1997	157,822	308,949	329,666	292,961	307,772	304,995	263,449	347,148	307,849	9%
1998	119,623	211,500	268,553	223,994	233,337	251,097	207,334	366,210	251,718	22%
1999	99,029	186,981	225,663	181,427	190,958	190,080	126,179	230,131	190,203	18%
2000	133,094	291,848	323,282	287,253	294,851	294,491	234,336	339,664	295,103	11%
2001	83,532	153,847	198,587	159,266	169,011	180,584	149,769	283,058	184,875	25%
2002	78,591	158,564	211,251	163,386	173,740	186,568	140,342	317,655	193,072	31%
2003	180,813	344,224	414,403	341,106	362,914	374,287	302,441	503,828	377,600	17%
2004	71,281	142,187	200,521	145,486	154,631	161,000	95,751	238,745	162,617	28%
2005	36,921	71,264	103,581	65,192	71,151	68,240	34,653	89,548	71,947	30%
2006	92,051	166,697	242,841	171,895	180,738	185,993	98,448	263,273	187,126	29%
2007	79,901	125,146	157,530	121,891	129,064	128,864	79,823	161,534	129,122	21%
2008	90,146	131,772	162,631	132,886	138,444	142,190	99,324	192,909	142,880	20%
Average	103,774	200,224	247,648	200,892	212,999	222,755	183,913	331,790	228,603	24%

Table 6.–A comparison of total DIDSON counts to mark–recapture sockeye salmon abundance estimates for the Yentna River.

Year	Total DIDSON Count	Fish Wheel Catch					Proportion Sockeye (b)	Sockeye M-R Estimate	Ratio M-R to DIDSON (a)	Ratio of (a) to (b)
		Sockeye	Coho	Pink	Chum	Total Catch				
2006	921,398	9,087	13,370	34,083	1,368	57,908	0.157			
2007	318,093	3,552	1,903	3,762	413	9,630	0.369	239,849	0.75	2.04
2008	391,429	3,524	1,591	7,298	548	12,961	0.272	288,988	0.74	2.72
									Average	2.4

Table 7.–Percentiles of escapement for the SEG Percentile Approach related to contrast and exploitation.

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

Table 8.–Historical Susitna River escapements, including Bendix sonar estimates adjusted by DIDSON and weir counts.

	Sockeye Salmon Escapement Estimates			
Year	Bendix adj. DIDSON	Chelatna	Judd	Larson
1973			26,428	
1974				
1975				
1976				
1977				
1978				
1979				
1980			43,350	
1981				
1982	253,982			
1983	210,105			
1984	298,383			35,254
1985	211,806			37,874
1986	169,048			32,322
1987	130,040			16,753
1988	101,854			
1989	189,554		12,792	
1990	259,729			
1991	217,158			
1992	130,966	35,300		
1993	282,837	20,235		
1994	251,856	28,303		
1995	232,856	20,124		
1996	172,882	35,747		
1997	308,949	84,899		40,282
1998	211,500	51,798	34,416	63,514
1999	186,981			18,943
2000	291,848			11,987
2001	153,847			
2002	158,564			
2003	344,224			
2004	142,187			
2005	71,264			9,751
2006	166,697	18,433	40,633	57,411
2007	125,146	41,290	58,134	47,736
2008	131,772	73,469	54,304	35,040
Average	202,856	40,960	38,580	33,906
n	27	10	7	12
Min	71,264	18,433	12,792	9,751
Max	344,224	84,899	58,134	63,514
Contrast	4.8	4.6	4.5	6.5
L_SEG		20,163	25,065	15,085
U_SEG		65,884	54,687	51,122

Note: Actual DIDSON counts were used for 2006–2008. See Appendix C for more detail about the lake estimates.

Table 9.–Twenty-four sockeye salmon producing lakes in the Susitna River drainage.

Tributary/ Drainage	Lake	Surface area (acres)	Northern Pike Presence/Absence
Chulitna	Byers	368	Absent
	Swan	385	Absent
	Spink	252	Absent
	Bunco	106	Absent
Mainstem	**Caswell**	159	Present
	Trapper	1,188	Present
	Fish	132	Present
	Sucker	273	Present
	Red Shirt	1,272	Present
	Neil	115	Present
Talkeetna	Larson	437	Absent
	Stephan	899	Absent
Yentna	**Chelatna**	3,906	Present
	Trinity	308	Absent
	Whiskey	271	Present
	Fish Creek	111	Present
	Shell	1,293	Present
	Puntilla	90	Absent
	Eightmile	115	Present
	Movie	110	Absent
	Lockwood	233	Present
	Judd	316	Present
	Hewitt	697	Present
	Red Salmon	113	Absent

Source: Tarbox and Kyle 1989.

Note: Bold text indicates lake with presence of northern pike. The area of each lake and the presence or absence of northern pike (ADF&G SFD website) is listed for comparison: http://www.sf.adfg.state.ak.us/Statewide/InvasiveSpecies/index.cfm/FA/pike.SCListing

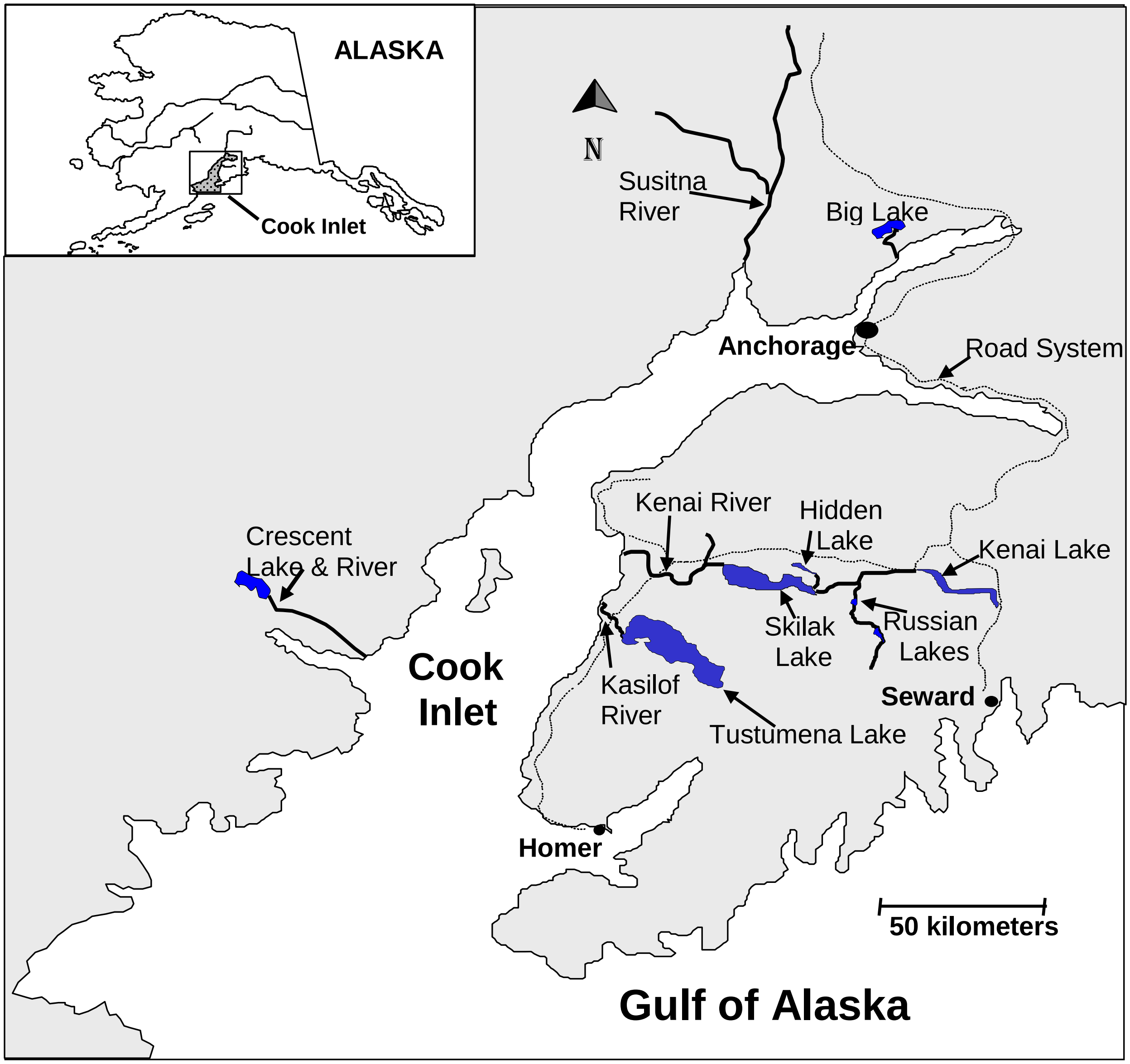

Figure 1.–Locations of the Susitna River and 3 other major sockeye salmon producing watersheds (Crescent, Kasilof, and Kenai rivers) in the Upper Cook Inlet region.

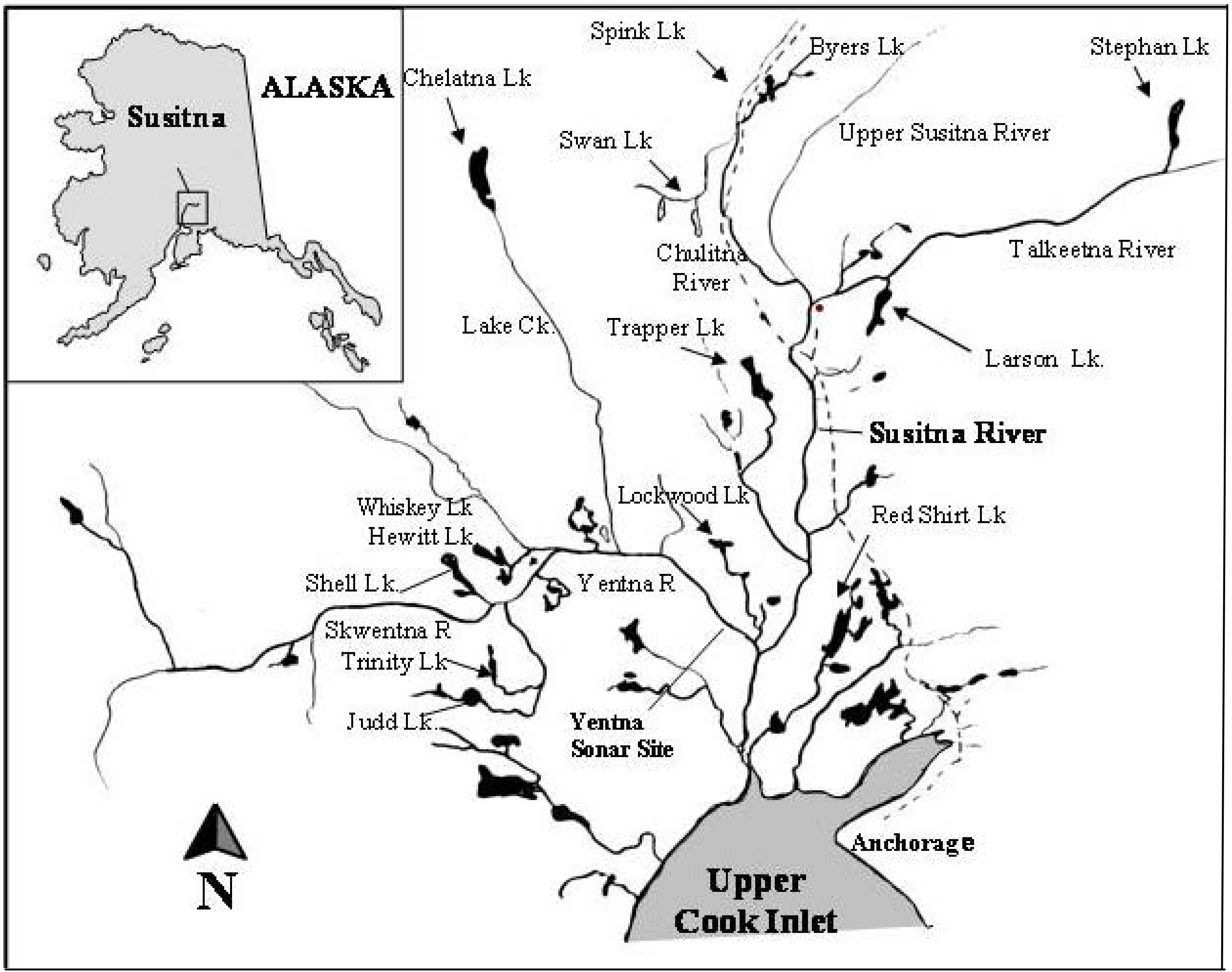

Figure 2.–Locations of major tributaries and sockeye salmon rearing lakes in the Susitna River watershed.

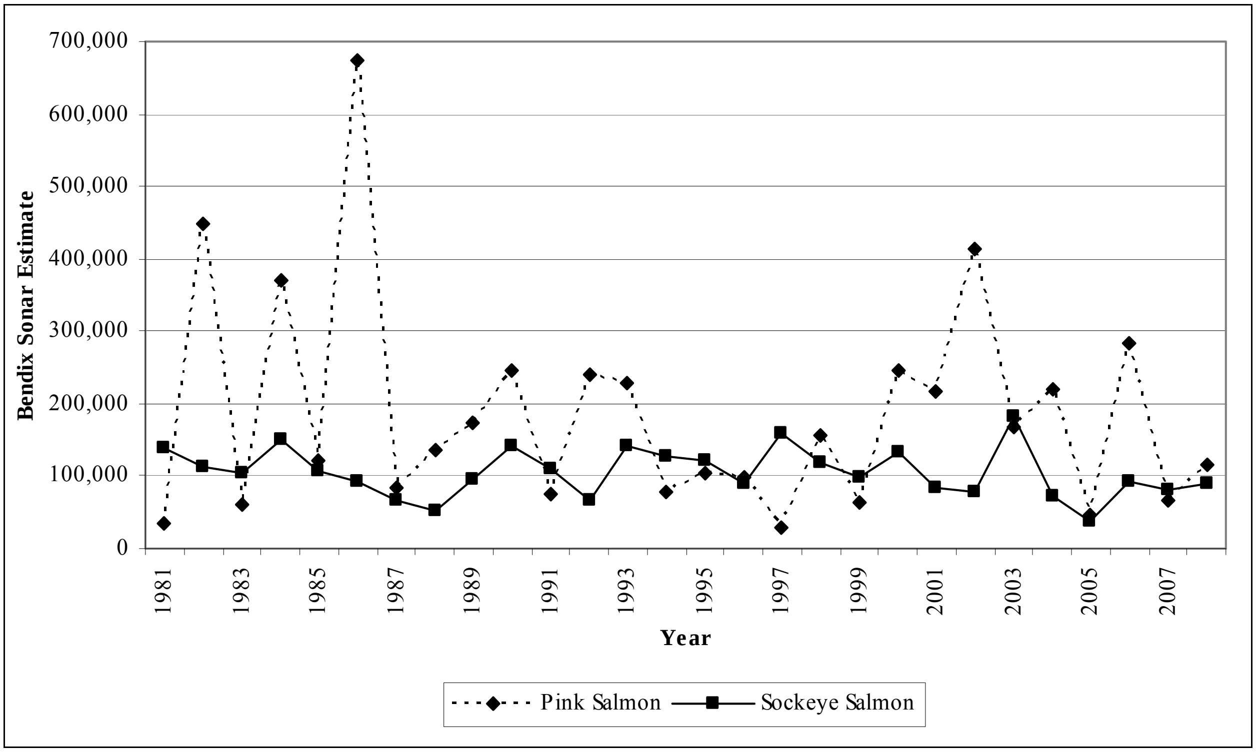

Figure 3.–Yentna River Bendix sonar estimates for sockeye and pink salmon, 1981–2008.

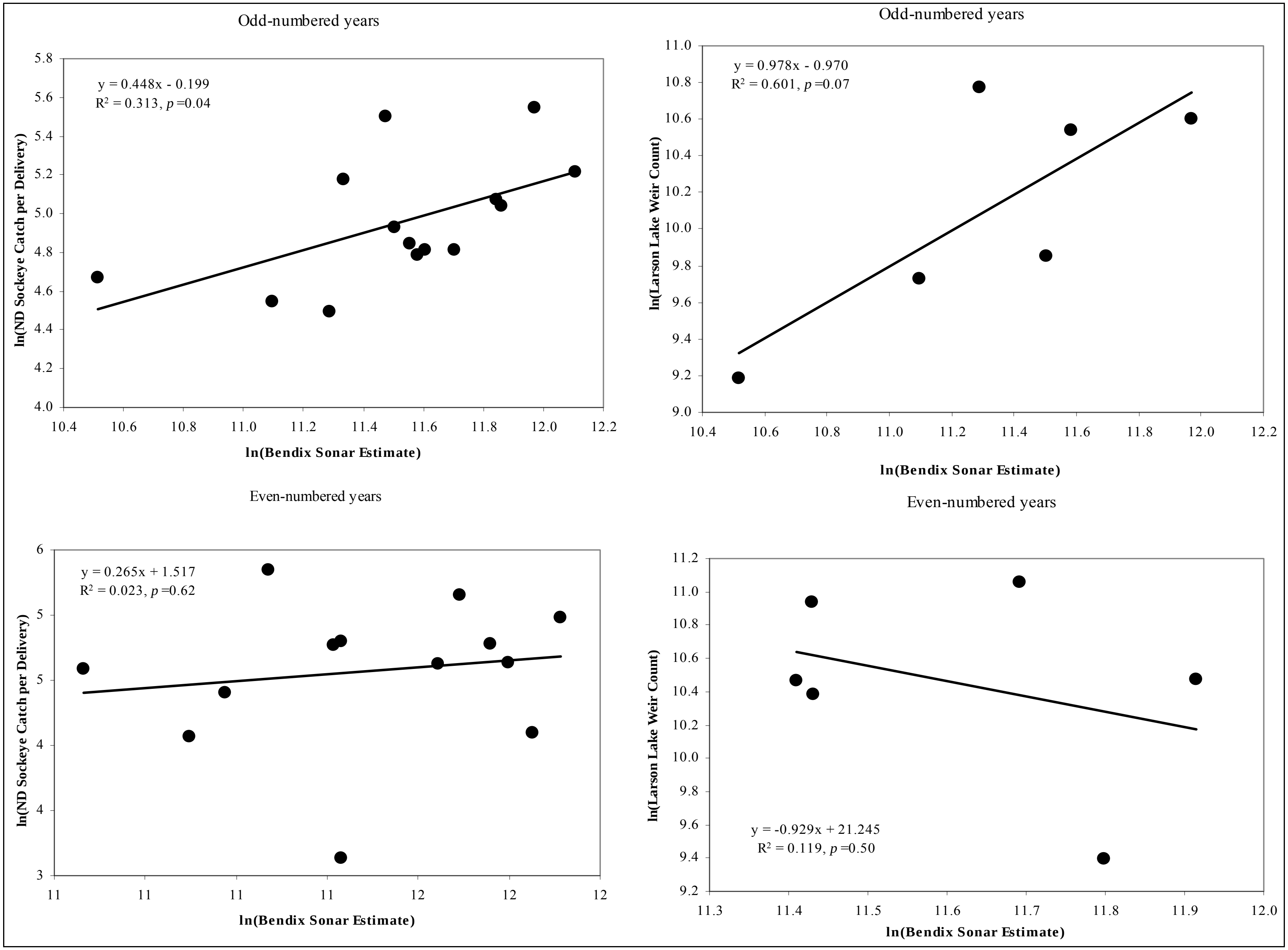

Figure 4.–Relationships between Yentna River Bendix sockeye salmon abundance estimates and Northern District (ND) commercial sockeye salmon catches and Larson Lake weir counts in odd- and even-numbered years.

APPENDIX A

Appendix A1.–Susitna River sockeye salmon escapement assessment background.

Prior to 1968 sockeye salmon escapement estimates in UCI were based on surveys of clear water spawning areas and provided no information about the distribution or number of fish that spawned in glacially occluded waters. Initial efforts to estimate the number of sockeye salmon spawning and rearing in the Susitna River were limited in scope and duration. Adult spawner counts were primarily the product of aerial surveys. Various lakes within the drainage were visited sporadically in the 1950s and 1960s by United States Fish and Wildlife Service (USFWS) and ADF&G personnel to collect salmonid juvenile and adult data, and lake limnology information. These early data were the result of short site visits during which gillnets, seines, and other equipment were used to sample juveniles.

Beginning in the 1970s, attempts were made to monitor the sockeye salmon escapement entering selected tributaries, and to estimate total escapement into the Susitna River. The Susitna River mainstem combines with the large Yentna River at Susitna Station, where it continues to flow another 52 km before dumping into Cook Inlet (Figure 2). Escapement into the Talachulitna River, a tributary of the Yentna River, was monitored using counting towers near its confluence with Skwentna River from 1972 to 1974 (Barrett 1975). The project used a fish wheel in 1973 and 1974 to obtain age, weight and length (AWL) information. In 1974, salmon escapement into the Fish Lakes system of the Yentna River was also enumerated with a weir installed in Quig Creek above Lower Fish Lake (Barrett 1975).

Mark–recapture projects were conducted on the Susitna River mainstem in 1974 and 1975 to estimate juvenile and adult anadromous fish populations in the upper Susitna between Devil's Canyon and the confluence of the Susitna and Chulitna Rivers. These studies were part of the preauthorization investigation for the proposed Susitna Hydroelectric Project (Barrett 1974, Friese 1975). Sockeye and chum salmon were tagged in the vicinity of the old town known as Susitna Station. Tag recovery fish wheels were operated at the confluence of the Talachulitna and Skwentna rivers, and at a site on the Susitna River approximately 8 km upstream of the town of Talkeetna. A tagging program was also conducted in the upper reaches of the Susitna River between the Chulitna River confluence and Portage Creek. The results of these studies indicated that the majority of sockeye salmon entering the Susitna River were bound for the Yentna and Skwentna drainages (Namtvedt et al. 1978).

Anadromous and resident fish populations of the mainstem Susitna River were investigated from 1981 to 1985 as part of the Environmental Impact Assessment (EIA) for a revised Susitna Hydroelectric Project. Salmon escapement reports produced as part of the EIA, and all known historical escapement data dating from 1951 were summarized by Hoffman and Crawford (1986). Mark–recapture projects were once again conducted on the Susitna River during 1982–1985 to estimate the inriver return of sockeye salmon (Barrett et al. 1985, Thompson et al. 1986). All sockeye salmon captured in fish wheels operated at Sunshine (RM 80), Talkeetna (RM 103) and Curry (RM 120) stations were marked with Petersen disc or Floy tags. Marked fish were recaptured at upstream fish wheels and during spawning ground surveys.

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Escapement into Shell Creek from 1973 to 1975 was enumerated with a weir (Barrett 1973, 1975 and Friese 1978). The weir also provided a recapture location for fish tagged as part of the Susitna Hydroelectric Project. Subsequent Shell Lake studies conducted by Cook Inlet Aquaculture Association consisted of escapement counts in conjunction with beaver dam modification activities along the outlet stream in 1983 and adult escapement and smolt enumeration in 1986 (Marcuson 1987). From 1984–1987, 1997–2000, and 2005 to present, adult escapements into Larson Lake were monitored at a weir placed at the lake outlet (Table 6). At Chelatna Lake, escapements were monitored at a weir at the lake outlet in 1992–1998. At Judd Lake, escapements were monitored at a weir at the lake outlet in 1984, 1989, and 1998.

The use of Bendix sonar to monitor salmon escapement began with an unsuccessful attempt in the mid-1970s by ADF&G to enumerate adults returning to the Lake Creek-Chelatna Lake drainage (Namtvedt et al. 1978). Adult salmon escapements into the Susitna River were monitored with Bendix sonar at Susitna Station from 1976 to 1980 (Figure 1). An average of 216,000 sockeye salmon (range of 94,000 to 340,000) was estimated annually at the site (Davis and King 1996). In 1981, ADF&G operated 2 separate sonar sites, one on the Susitna River mainstem and the other on the adjoining Yentna River. However, in 1986, a flood destroyed the Susitna River mainstem sonar site and no nearby alternative sonar sites were available. Based on a five-year comparison (1981–1985) of estimates for the Yentna River and Susitna River mainstem, ADF&G determined that an escapement of 100,000 to 150,000 sockeye salmon into the Yentna River would generally result in a total escapement of at least 200,000 sockeye salmon into the entire Susitna River drainage (Fried 1994). The sonar comparison showed that approximately 50% of the Susitna River sockeye salmon escapement traveled upriver and entered the Yentna River, with an annual range of 41% to 59%.

Bendix sonar operated annually after 1981, and then beginning in 2006, ADF&G began the full time operation of a new sonar system known as **D**ual-frequency **Id**entification **Son**ar (DIDSON). ADF&G has now completed its transition from the Bendix sonar counter to the more robust and modern DIDSON counter. The DIDSON provides greater coverage of the water column and a longer offshore range because of the larger beam, higher power level, and ability to interact with boundary layers without losing fish images. The output of the Bendix sonar counter is limited to automated counts by range sector and a visual display of voltage spikes on an oscilloscope. In contrast, the DIDSON produces detailed fish images at close range. The DIDSON beam can be aimed into the river bottom without compromising fish detection, while the Bendix sonar counter's beams must be positioned high enough off the river bottom and far enough below the surface to avoid encountering either boundary.

In 1998, ADF&G conducted a project to develop and improve techniques for estimating escapements of sockeye and coho salmon in the Susitna River. A sampling program was designed to determine if there was a difference in the number of stocked sockeye salmon caught in the Yentna River sonar site fish wheels and weir counts at Chelatna Lake. However, the Chelatna Lake weir washed out during the peak of the run in 1998, so the stocked proportions could not be accurately determined and compared. Thermally marked otoliths from stocked

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sockeye salmon were recovered from 7.1 % of the sampled fish at Chelatna Lake and 3.2% of the Yentna River samples; of which 64.5% and 35.4% were from the north and south bank fish wheels, respectively (Todd et al. 2001).

Also in 1998, a Yentna River mark–recapture experiment was also conducted to obtain a second sockeye salmon escapement estimate for comparison with the sonar-derived estimate. Fish wheels operated continuously to capture fish for marking, so tagging was assumed proportional to salmon abundance. Fish were dual dart-tagged. Recovery weirs showed that sockeye salmon were partially bank oriented by destination at the fish wheels; the majority of North Bank recovered fish migrated to Chelatna Lake (82.5%), and South Bank fish migrated to Judd Lake (62.8% of recoveries). Recovery rates were significantly different ($P<0.05$), and arrival times were also different between tagged and untagged fish at the 2 lakes, so escapement estimates were not calculated because the assumptions of a mark–recapture experiment were not met.

In conjunction with total sonar abundance, ADF&G uses fish wheel catches to apportion total sonar counts to species. From this, we estimate sockeye salmon escapement. Unfortunately, the apportionment of sonar counts by species from fish wheels adds a potential source of error in the assessment of sockeye salmon total spawner abundance. Factors affecting the precision and accuracy of species apportioned sonar counts include: (1) sample sizes used to estimate species composition, (2) changes in the cross-river distribution of salmon species, (3) species-related selectivity of fish wheels, and (4) diel changes in fish wheel catches.

Previous studies of fish wheel selectivity during the ADF&G (1983) and on the Taku River (Meehan 1961) demonstrated that fish wheels select for pink salmon, because they sample the nearshore habitat primarily used by this species. Both selectivity studies found the smaller-sized pink salmon were over-represented in fish wheel catches, and that larger chum, coho, and sockeye salmon were under-represented. Given equal abundances, the studies suggest that pink salmon are approximately four times more likely to be captured than chum salmon and about twice as likely to be captured as either sockeye or coho salmon. The relationship between capture probability and fish wheel catches determines the abundance correction factor for each species. As fish wheel catches change, the correction factor changes.

In 1998, a mark–recapture experiment was also done to test the selectivity of fish wheel catches of sockeye and coho salmon. A total of 44 tagged sockeye and 53 tagged coho salmon were recovered at the fish wheels (4.3% and 6.1% of marks, respectively). Chi-square analysis of these recovery proportions showed no difference in recovery rates between the 2 species (Todd et al. 2001).

APPENDIX B

Appendix B1.–Method for adjusting Bendix sonar estimates.

Our transition from an older sonar, the Bendix counter (Gaudet 1990), to a newer technology, a dual-frequency identification sonar (DIDSON; Belcher et al. 2001, 2002) involved side-by-side comparisons of the 2 sonars along both banks of the Yentna River (personal communication, Suzanne Maxwell, ADF&G Fishery Biologist). The study's primary goal was to convert the historical Bendix estimates into DIDSON equivalents (or units) and re-evaluate existing escapement goals. Specifically, we 1) determined whether paired estimates from the 2 sonars were equivalent; 2) applied an appropriate conversion factor if not equivalent; 3) evaluated whether the resulting predicted and actual DIDSON estimates were equivalent; 4) examined density and range effects on the comparison, and 5) evaluated the escapement goal in DIDSON units.

Analyzing daily time series data often lead to correlation between successive days, which violates the least squares regression (LSR) assumption that the error terms are uncorrelated and underestimates the standard error. We attempted to remove the autocorrelation using the Cochrane-Orcutt procedure (Neter et al. 1996), but the results included numerous negative fish days, which did not make biological sense. Instead, we subsampled the data, selecting the number of lags of autocorrelation as our sampling interval. The assumptions of homogeneity and normality in the residuals were also not met, so both variables were logged, and bootstrapping techniques were applied to results compiled from each subsample to obtain 90% confidence intervals (CI) for each statistic. The LSR slope CI did not include a slope of 1 for either the north or south bank data. To convert the Bendix data to equivalent DIDSON units, we selected a model with a single multiplier because including additive (or subtractive) terms would result in negative fish days. We tested several multipliers and selected (in logged units) 1.057 and 1.070 for the north and south bank data. The magnitude of difference is better understood in original units, which were similar to 1.62 (north bank) and 1.76 (south bank). After converting the Bendix estimates to DIDSON equivalents using the selected multipliers, we examined the relationship between the predicted and actual DIDSON values using the subsample-bootstrap routine and obtained slope CIs of 0.86-1.14 (north bank) and 0.86-1.18 (south bank); and sigma (slope) values of 0.041 and 0.049. To determine the effects of fish density on the comparison, we examined the *CCC* values (Lin et al. 2002) and regression plots of the predicted and actual DIDSON values. A poor fit (low *CCC*) might indicate a need for a second multiplier. The *CCC's* were close to one (0.967 and 0.931) indicating a high correlation between the datasets and slope close to one. If fish density were a factor, high or low passage regions would tend to fall on one side or the other of the regression line; this was not observed. In range distributions, the majority of fish counted were within 10 m of the north and south bank transducers for both sonars.

APPENDIX C

Appendix C1.–Historical Chelatna Lake escapement numbers, dates of operation, methods, quality, and data source.

Year	Dates	Raw Data	Applied	Method	Comments	Quality	Reference
1972	Unknown	57		Single Aerial	Only Coffee and Snowslide Creeks	Poor	Tarbox et al. (1983)
1973	Unknown	11		Single Aerial	Only Coffee and Snowslide Creeks	Poor	Tarbox et al. (1983)
1974	Unknown	0		Single Aerial	Only Coffee and Snowslide Creeks	Poor	Tarbox et al. (1983)
1975	8/29	50		Peak Aerial	Coffee and Snowslide Creeks only; 2 surveys	Poor	Tarbox et al. (1983)
1976	Unknown						Tarbox et al. (1983)
1977	Unknown	171		Single Aerial	Only Coffee and Snowslide Creeks	Poor	Tarbox et al. (1983)
1978	Unknown	0		Single Aerial	Only Coffee and Snowslide Creeks	Poor	Tarbox et al. (1983)
1979	Unknown	0		Single Aerial	Only Coffee and Snowslide Creeks	Poor	Tarbox et al. (1983)
1980	8/29	4,120		Single Aerial	Only Coffee and Snowslide Creeks	Poor	Tarbox et al. (1983)
1981	8/27	14,500		Single Aerial	Only Coffee and Snowslide Creeks	Poor	Tarbox et al. (1983)
1982	8/20	23,180		Single Aerial	Area surveyed unknown	Poor	King and Tarbox (1986)
1983	8/25	520		Single Aerial	Area surveyed unknown	Poor	King and Tarbox (1986)
1984	8/08-8/26	575		Peak Aerial	Peak count from 3 surveys, First highest	Poor	King and Tarbox (1986)
1985	Unknown	554		Single Aerial	Only Peat, Coffee and Snowslide Creeks	Poor	King and Tarbox (1986)
1986							
1987							
1988	7/19-8/24	217		Tower		Unknown	Marcuson (1989)
1989	8/4-8/22	3,725		M-R	Marked & recaptured fish only in lake outlet	Poor	Schollenberger (1989a)
1990	7/13-8/14	5,283		M-R	Marked at outlet, recaptured in tribs & outlet	Poor	Schollenberger (1991)
1991	7/09-8/16	7,689		M-R	Marked at outlet, recaptured in tribs & outlet	Poor	Fandrei (1992)
1992	7/09-8/11	35,300	35,300	M-R	Marked at outlet, recaptured in tribs & outlet	Fair	Fandrei (1993)
1993	7/09-8/14	20,235	20,235	Weir		Good	Fandrei (1994a)
1994	7/12-8/25	28,303	28,303	Weir		Good	Fandrei (1994b)
1995	7/10-8/27	20,124	20,124	Weir		Good	Fandrei (1995)
1996	7/08-8/09	28,684	35,747	Partial Weir	Weir out 7/30-8/05; linear interpolation	Fair	Unknown
1997	7/11-8/11	84,899	84,899	Weir		Good	Todd et al. (2001)
1998	7/15-8/22	27,284	51,798	Partial Weir	Weir out 7/26-8/01; linear interpolation	Fair	Todd et al. (2001)
1999							
2000							
2001							
2002							
2003							
2004							
2005							
2006	7/27-8/10	13,272	18,433	Partial Weir	Weir out 8/11; interpolation with radio tags	Fair	CIAA *Unpublished*
2007	7/11-8/4	23,342	41,290	Partial Weir	Weir out 8/05; interpolation with radio tags	Fair	CIAA *Unpublished*
2008	7/10-8/26	73,469	73,469	Weir		Good	CIAA *Unpublished*

Appendix C2.–Historical Shell Lake escapement numbers, dates of operation, methods, quality, and data source.

Year	Dates	Raw Data	Applied	Method	Comments	Quality	Reference
1973	7/15-8/14	26		Single Weir	Single weir; bear problems	Poor	Marcuson (1987)
1974	7/18-8/17	958	958	Double Weir		Poor	Marcuson (1987)
1975	7/26-8/15	2,027	2,027	Double Weir		Poor	Namtvedt et al. (1977)
1976	8/26-9/14	344		Peak Aerial	Peak count of 3 surveys; last highest	Poor	King and Tarbox (1986)
1977	8/24-9/01	247		Peak Aerial	Peak count of 3 surveys; last highest	Poor	King and Tarbox (1986)
1978	8/24	127		Single Aerial		Poor	King and Tarbox (1986)
1979	9/07	1,480		Peak Aerial	Peak count of 2 surveys	Poor	King and Tarbox (1986)
1980	8/22-9/11	5,800		Peak Aerial	Peak count of 2 surveys	Poor	Marcuson (1987)
1981	9/04-10/02	9,550	24,353	Peak Aerial	Peak count of 7 surveys; middle highest	Fair	Marcuson (1987)
1982	8/23-8/27	3,150	8,033	Peak Aerial	Peak count of 3 surveys; middle highest	Fair	Marcuson (1987)
1983	7/21	2,810		Single Aerial		Poor	Marcuson (1987)
1984	8/28-9/04	8,600		Peak Aerial	Peak count of 2 surveys	Poor	King and Tarbox (1986)
1985	8/09	35,000	35,000	Ground Count	Counts from notched beaver dam	Fair	Marcuson (1986)
1986	7/08-9/02	4,237	4,237	Weir		Good	Marcuson (1987)
1987	8/09	0		Single Aerial	Helicopter survey	Poor	ADF&G, CF
1988							
1989	8/22	900		Single Aerial	Fixed-wing survey	Poor	ADF&G, CF
1990							
1991							
1992							
1993	8/24	200		Single Aerial	Fixed-wing survey	Poor	Fandrei (1993)
1994							
1995							
1996							
1997							
1998							
1999							
2000							
2001							
2002							
2003							
2004							
2005	8/09	0		Single Aerial	Helicopter survey	Poor	Fandrei (pers. comm.)
2006	7/15-8/19	69,800	69,800	Weir		Good	CIAA *Unpublished*
2007	7/15-9/13	26,784	26,784	Weir		Good	CIAA *Unpublished*
2008	7/14-9/03	2,624	2,624	Weir		Good	CIAA *Unpublished*

Appendix C3.–Historical Judd Lake escapement numbers, dates of operation, methods, quality, and data source.

Year	Dates	Raw Data	Applied	Method	Comments	Quality	Reference
1970	9/01	600		Unknown		Poor	ADFG *Unpublished*
1971							
1972							
1973	8/17-9/28	10,364	26,428	Peak Aerial	Peak count of 3 surveys; middle highest	Fair	Barrett (1973)
1974	8/28-9/10	5,675		Peak Aerial	Peak count of 2 surveys	Poor	Barrett (1975)
1975	8/29	4,720		Single Aerial		Poor	ADFG (1983)
1976							
1977							
1978	9/06	6,500		Ground Survey		Poor	ADFG *Unpublished*
1979							
1980	8/22-10/2	17,000	43,350	Peak Aerial	Peak count of 3 surveys; middle highest	Fair	ADFG *Unpublished*
1981	9/08-10/02	1,800		Peak Aerial	Peak count of 2 surveys	Poor	ADFG *Unpublished*
1982							
1983	8/27	440		Single Aerial		Poor	ADFG *Unpublished*
1984	8/28-9/04	18,104		Peak Aerial	Peak count of 2 surveys	Poor	Schollenberger (1989b)
1985	8/03	3,000		Single Aerial		Poor	Schollenberger (1989b)
1986							
1987	8/02	3,851		Peak Aerial	Peak count of 2 surveys	Poor	Schollenberger (1989b)
1988							
1989	7/25-8/27	12,792	12,792	Weir		Good	Schollenberger (1989b)
1990							
1991							
1992							
1993							
1994							
1995							
1996							
1997							
1998	7/18-8/29	34,416	34,416	Weir		Good	Todd et al. (2001)
1999							
2000							
2001							
2002							
2003							
2004							
2005	9/2	4,000		Single Aerial		Poor	ADFG *Unpublished*
2006		40,633	40,633	Weir		Good	CIAA *Unpublished*
2007		58,134	58,134	Weir		Good	CIAA *Unpublished*
2008		54,304	54,304	Weir		Good	CIAA *Unpublished*

Appendix C4.–Historical Larson Lake escapement numbers, dates of operation, methods, quality, and data source.

Year	Dates	Raw Data	Applied	Method	Comments	Quality	Reference
1972	9/07	300		Single Aerial		Poor	Barrett (1973)
1973	9/06	20		Single Aerial		Poor	Barrett (1973)
1974	9/09	19		Single Aerial		Poor	Barrett (1975)
1975	7/06-9/13	63		Peak Aerial	Peak count of 3 surveys; middle highest	Fair	Freise (1976)
1976	9/02	85		Peak Aerial	Peak count of 2 surveys	Poor	Waltemyer et al. (1980)
1977	8/05-9/12	330		Peak Aerial	Unknown	Poor	Waltemyer et al. (1980)
1978	Unknown	117		Peak Aerial	Unknown	Poor	Waltemyer et al. (1980)
1979	8/28	160		Aerial	Unknown		ADFG *Unpublished*
1980							
1981	8/23-8/25	5,500		Peak Aerial	Peak count of 2 surveys	Poor	ADFG *Unpublished*
1982	Unknown	2,150		Single Aerial		Poor	ADFG *Unpublished*
1983	9/07	650		Single Aerial		Poor	ADFG *Unpublished*
1984	7/01-8/20	35,254	35,254	Weir		Good	Shields *In prep*
1985	7/14-8/29	37,874	37,874	Weir		Good	Shields *In prep*
1986	7/21-8/26	32,322	32,322	Weir		Good	Shields *In prep*
1987	6/15-8/26	16,753	16,753	Weir		Good	Shields *In prep*
1988							
1989							
1990							
1991							
1992							
1993							
1994							
1995							
1996							
1997	7/21-9/13	40,282	40,282	Weir		Good	Shields *In prep*
1998	7/19-8/23	63,514	63,514	Weir		Good	Todd et al. (2001)
1999	7/24-8/26	18,943	18,943	Weir		Good	Shields *In prep*
2000	7/21-8/18	11,987	11,987	Weir		Good	Shields *In prep*
2001							
2002							
2003							
2004							
2005	7/16 - 8/22	9,751	9,751	Weir		Good	Shields *In prep*
2006		57,411	57,411	Weir		Good	Shields *In prep*
2007		47,736	47,736	Weir		Good	CIAA *Unpublished*
2008		35,040	35,040	Weir		Good	CIAA *Unpublished*