Special Publication No. 12-15

Estimating Escapement of Western Alaskan Sockeye Salmon for Western Alaska Salmon Stock Identification Program Reporting Groups, 2006 to 2008

by

Douglas M. Eggers,

Andrew R. Munro,

and

Eric C. Volk

October 2012

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

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, Special Publications and the Division of Commercial Fisheries Regional Reports. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

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

SPECIAL PUBLICATION NO. 12-15

ESTIMATING ESCAPEMENT OF WESTERN ALASKAN SOCKEYE SALMON FOR WESTERN ALASKA SALMON STOCK IDENTIFICATION PROGRAM REPORTING GROUPS, 2006 TO 2008

by
Douglas M. Eggers,
Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau

Andrew R. Munro, and Eric C. Volk
Alaska Department of Fish and Game, Division of Commercial Fisheries, Anchorage

Alaska Department of Fish and Game
Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska, 99518-1565

October 2012

This investigation was funded by the State of Alaska.

The Special Publication series was established by the Division of Sport Fish in 1991 for the publication of techniques and procedures manuals, informational pamphlets, special subject reports to decision-making bodies, symposia and workshop proceedings, application software documentation, in-house lectures, and became a joint divisional series in 2004 with the Division of Commercial Fisheries. Special Publications are intended for fishery and other technical professionals. Special Publications are available through the Alaska State Library, Alaska Resources Library and Information Services (ARLIS) and on the Internet http://www.adfg.alaska.gov/sf/publications/. This publication has undergone editorial and peer review.

Douglas M. Eggers,
Alaska Department of Fish and Game, Division of Commercial Fisheries,
1255 W. 8th Street, Juneau AK 99801 USA

Andrew R. Munro, and Eric Volk
Alaska Department of Fish and Game, Division of Commercial Fisheries,
333 Raspberry Road, Anchorage, AK, 99518-1565 USA

This document should be cited as:
Eggers, D. M., A. R. Munro, and E .C. Volk. 2012. Estimating escapement of Western Alaskan sockeye salmon for Western Alaska Salmon Stock Identification Program reporting groups, 2006 to 2008. Alaska Department of Fish and Game,Special Publication No. 12-15, Anchorage.

TABLE OF CONTENTS

Page

LIST OF TABLES

Table **Page**

ABSTRACT

The Western Alaska Salmon Stock Identification Program (WASSIP) was initiated in 2006 with a memorandum of understanding executed by an Advisory Panel of 11 signatories, including Alaska Department of Fish and Game, and stakeholders from throughout western Alaska. The purpose of WASSIP was to identify stock contributions of sockeye (*Oncorhynchus nerka*) and chum salmon (*O. keta*) to commercial and subsistence fisheries from Chignik northward to Kotzebue Sound, and to extend those estimates to stock-specific harvest rates. This report describes the regional fishery model and estimation of escapement and harvest rates for sockeye salmon. Escapements and associated uncertainties were estimated for each of the WASSIP sockeye salmon regional reporting groups (Chignik, South Peninsula, North Peninsula, Bristol Bay, Kuskokwim Bay), and subregional reporting groups (i.e., stocks). The 2006 to 2008 escapement estimates were based on information available in annual area management reports, other monitoring and assessment reports, and department databases. Coefficients of variation (CV) were derived by applying estimators based on systematic samples (e.g., sonar, towers), estimates from mark-recapture experiments, and reasonable approximations based on summary of historical studies (aerial surveys). Biases in escapement estimates were not addressed other than with an expansion factor applied to aerial survey indices. The final CV attributed to the various escapement assessment methods was based on input and consensus from the WASSIP Technical Committee and Advisory Panel and were as follows: weir (CV = 0.04), tower (CV = 0.05), sonar (CV = 0.10), aerial counts (expansion factor = 2.47 and CV = 0.54). These escapements with associated uncertainties will be used in the estimation of total-run for each reporting group and reporting group-specific harvest rates within the WASSIP sockeye salmon fisheries.

Key words: Western Alaska Salmon Stock Identification Program, WASSIP, sockeye salmon, *Oncorhynchus nerka*, mixed stock analysis, escapement

INTRODUCTION

The Western Alaska Salmon Stock Identification Program (WASSIP) was initiated to identify the stock contributions of sockeye (*Oncorhynchus nerka*) and chum (*O. keta*) salmon to commercial and subsistence fisheries of western Alaska from Chignik northward to Kotzebue Sound. The WASSIP Memorandum of Understanding (ADF&G 2006) specifically recognizes the desires of signatories to extend stock contribution estimates, *where practicable*, to stock-specific harvest rates in the study areas. To calculate stock-specific harvest rates, estimates of stock-specific escapements and harvests, with associated uncertainties, must be generated. This document will address only escapement estimates for sockeye salmon. For WASSIP, regional and subregional reporting groups approved by the Advisory Panel (Dann et al. 2012) will serve as stocks for estimating stock-specific parameters for sockeye salmon. As such, the reporting groups (i.e., stocks) in WASSIP can consist of groups of populations that spawn within single drainages or across multiple drainages.

This document deals exclusively with the escapement (E) component of the denominator of the harvest rate estimation equation described below and will outline how escapements and associated uncertainties are estimated for sockeye salmon in each of the WASSIP sockeye salmon reporting groups. The 2006 to 2008 escapement data and coefficient of variation (CV) are presented for each WASSIP sockeye salmon regional and subregional reporting group that will be used in the harvest rate estimation. The information summarized in this document combined with a future report on sockeye salmon harvest estimates will be used to estimate reporting group-specific harvest rates where possible.

REGIONAL FISHERY MODEL

We propose a statistical approach for estimating reporting group-specific harvest rates within WASSIP fisheries. These harvest rates do not account for fish harvested in fisheries outside the WASSIP area, including terminal and inriver fisheries. The regional fisheries consist of multiple interacting fisheries collectively exploiting multiple reporting groups. Each reporting group may occur to some extent in each of the component fisheries of the region. This approach will be applied to reporting group-specific harvest estimated from WASSIP studies and to estimates of reporting group-specific terminal harvest and escapements.

In a regional fishery there are a number of component fisheries (f) and a number of reporting groups (y), with each reporting group occurring to some extent in all component fisheries. A subregional reporting group may consist of several assessed drainage- or area-wide groups of populations, in which case the assessed population(s) or escapements and terminal harvests for the reporting group must be aggregated. Subregional reporting groups are aggregated into regional reporting groups. From here forward, the term *reporting groups* without the *subregional* or *regional* prefix will refer generically to both regional and subregional reporting groups.

The key elements necessary to calculate the annual total run for each reporting group (N_y) are annual estimates (and associated CV) of each run component of the y^{th} reporting group:

$$N_y = T_y + E_y + \sum_f C_{f,y},$$

where T_y is the terminal harvest of the y^{th} reporting group, E_y is the escapement of the y^{th} reporting group, and $C_{f,y}$ is the harvest in WASSIP fisheries of the y^{th} reporting group in the f^{th} fishery. Terminal harvest occurs for reporting groups exploited in nonsampled fisheries within the WASSIP area where it is assumed that 100% of the fish harvested belong to a single regional or subregional reporting group (e.g., inriver subsistence, recreational fishing, or commercial fisheries).

A measurement error model will be used to express the uncertainty in each component (O_i) of the reporting group's run (N_y). Each run component (O_i) is modeled as a lognormal random variable,

$$O_i \sim \log N\left(\mu_{O_i}, \lambda_{O_i}^2\right), \text{ where}$$

$$\hat{\mu}_{O_i} = \ln(\hat{O}_i) - \hat{\lambda}_{O_i}^2/2 \text{ and}$$

$$\hat{\lambda}_{O_i}^2 = \ln(CV^2(\hat{O}_i) + 1),$$

where $\hat{O}_i$ is the estimated value of the quantity O_i, and $CV(\hat{O}_i)$ is the coefficient of variation of the estimate. These relationships were derived from Evans et al. (1993).

Estimate and distribution of harvest rate ($\widehat{HR}_{f,y}$) in a given regional fishery, for each reporting group (y) and component fishery (f) can be obtained by Monte Carlo simulation. Here, a number of independent realizations of the state of the regional fishery is determined by reporting group-specific catches ($C_{f,y}^{(i)}$), terminal harvests ($T_y^{(i)}$) and reporting group-specific escapement ($E_{f,y}^{(i)}$). Each realization of the regional fishery is drawn randomly from the lognormal probability distribution associated with the measurement error for each of the individual run components:

$$N_y^{(i)} = T_y^{(i)} + E_y^{(i)} + \sum_f C_{f,y}^{(i)}$$

$$HR_{f,y}^{(i)} = {C_{f,y}^{(i)}}\Big/{N_y^{(i)}}$$

$$\widehat{HR}_{f,y} = median\ of\ the\ K\ observations\ of\ HR_{f,y}^{(i)}.$$

Estimates of escapement CVs are not routinely reported in ADF&G escapement and management reports. CVs for escapement estimated by counts (e.g., weir, tower, and sonar) are generally quite low and can easily be calculated by applying estimators based on systematic sampling (Reynolds et al. 2007) to the counts. CVs of escapements from mark–recapture experiments are available for most scenarios. CVs for escapements based on expanded aerial counts are unknown and problematic. However, reasonable approximations will be presented based on summary of historical studies where paired peak aerial counts and more exact estimates of escapement (i.e., weir counts, tower counts, and mark–recapture experiments) are compared.

When the escapement of a reporting group is an aggregate of assessed populations or groups of populations, the aggregate escapement (O_A) can be estimated as:

$$\hat{O}_A = \sum_i \hat{O}_i,$$

where $\hat{O}_i$ is the assessed escapement for each component in terms of total number of fish (see below for details about expanding escapement indices). Note that each assessed escapement component is a lognormal random variable, with coefficient of variation ($CV(\hat{O}_i)$) and mean ($\hat{O}_i$). The uncertainty in the estimate of the aggregate escapement component ($CV(\hat{O}_A)$) is estimated by summing the variances of the individual components (assuming independence among the components):

$$Var(\hat{O}_A) = \sum_i Var(\hat{O}_i).$$

Therefore, to express this in terms of CV, we use the formula:

$$CV(\hat{O}_A) = \sqrt{{\sum_i (CV^2(\hat{O}_i) * \hat{O}_i^2)}\Big/{\sum_i \hat{O}_i^2}}.$$

ESCAPEMENT BASED ON WEIR COUNTS

Sockeye salmon escapements enumerated using weirs make up components of total escapement for all regional reporting groups except for Bristol Bay. Weirs are used to assess sockeye salmon escapement (or inform the escapement estimate) on the Chignik River, 7 rivers in the North and South Alaska Peninsula, 3 Kuskokwim rivers, and 5 rivers within the area encompassed by Norton Sound regional reporting group. Generally, for each salmon species, all individuals that pass through the weir are counted and the count is considered to provide an absolute count. One exception within the WASSIP area is the Chignik weir, which uses a video system and fish are counted for 10 minutes out of every hour, similar to the method used for tower counts (see below).

Weirs are regarded as the most accurate method to enumerate escapement and are often used as the benchmark against which other escapement enumeration methods are compared (Cousens et al. 1982). Despite this, weir counts are likely not error free. A review of salmon escapement estimation methods by Cousens et al. (1982) reported that no information on accuracy and precision of weir counts can be found in the literature and, to the best of our knowledge, this is still true. Therefore, estimates of uncertainty related to weir counts must be based on informed judgment.

Uncertainty and bias in weir-based escapement estimates can be introduced by a number of factors. These include counting errors due to factors such as weather and water conditions as well as observer variability and incomplete counting of the escapement because the weir project was started after the beginning of the migration, ended before migration was complete, or the weir was inoperable during monitored periods of the run.

Counting (or observer) error for weir counts is likely small, even though it is not clear whether this has ever been measured specifically for weir projects. It could be assumed that like tower counts, differences in counts between observers could be quite large, but would tend to cancel out over the season (Becker 1962; Cousens et al. 1982; Woody 2007). Because passage of fish in weir projects is controlled through the use of gates or traps, it is conceivable that the counting error is lower than the 1.0% or less assumed for tower projects (see below).

Due to the protracted nature of salmon runs, underestimation of escapement (i.e., downward bias) is introduced because weir projects generally cannot be deployed for the entire duration of the run. This bias is probably small because counts at the beginning and end of the project are typically a small percentage of the entire run. For some systems, escapements after the assessment project is terminated for the season are estimated in order to correct for this bias. For example, postweir (and in some cases preweir) escapement estimates are provided for weir projects on the North Alaska Peninsula. These estimates are based on aerial surveys, commercial fisheries performance, run timing indicators, effort levels and weather conditions (Murphy and Hartill 2009; Murphy et al. 2008; Murphy and Tschersich 2007). Because aerial surveys likely had the largest influence on these postweir escapement estimates, it was assumed the CV associated with these estimates is similar to that of aerial surveys (0.54; see below). Another example of a postweir escapement estimate is with Chignik River late-run sockeye salmon. Escapement after the weir is removed in late August/early September is estimated for the Chignik River late-run using time series analysis (Jackson and Anderson 2009; Stichert 2007; Stichert et al. 2009). This estimate is based primarily on the last several days of weir counts and is likely to underestimate escapement because it does not account for the potential for late pulses of fish (Todd Anderson, Division of Commercial Fisheries Fishery Biologist, ADF&G, Kodiak, personal communication). Furthermore, there is no information to base an estimate of uncertainty associated with this postweir escapement estimate. Therefore, for lack of any available information or expert judgment, we assumed CV of 0.20 for the postweir escapement estimate for late-run Chignik River sockeye salmon. This assumed CV is 5 times the uncertainty of actual weir counts and about half the uncertainty of aerial surveys and a reasonable upper bound on the uncertainty.

Additional downward bias, or increased uncertainty, may be introduced when weirs are inoperable during the main part of the migration due to flooding, debris or mechanical issues. These periods when fish cannot be counted or are partially counted are generally minor, but can be substantial if it occurs during peak migration. For example, in 2008 high water delayed the start of weir operations by 3 weeks on the Kanektok River and issues with the boat gate further delayed full operation by an additional 10 days (Taylor and Clark 2010b). Counts during these inoperable periods may be estimated through interpolation or from correlation with other years when run timing and abundance are similar in order to account for bias (e.g., Taylor and Clark, 2010b). While these estimates correct for bias, they introduce additional uncertainty in the estimate. For example, it is estimated that the uncertainty in the interpolated escapement during minor breaches of the weir on the Middle Fork of the Goodnews River weir is <10% (Toshihide Hamazaki, Division of Commercial Fisheries Biometrician, ADF&G, Anchorage, personal communication). However, estimating a level of uncertainty for extended periods of inoperability, especially at the beginning or end of the season, using past patterns of escapement is difficult because it has not been measured and there is little information to form an expert judgment. As with the postweir estimates for late-run Chignik River sockeye salmon, a CV of 0.20 was assumed for portions of escapements that were estimated using patterns of past escapements for periods when weirs were inoperable.

In the following analysis, a CV of 0.04 was used as an estimate of uncertainty for the portion of the run that was actually counted as part of the weir project (including Chignik weir; see below). This CV is based on input from area management staff and consensus of the Advisory Panel, and represents counting (observation error) and additional uncertainty not explicitly accounted for. In addition, for portions of the escapement that were estimated, area and project-specific estimates of uncertainty are applied and detailed below for each specific subregional reporting group. For example, postweir escapement estimates for North Peninsula weir projects are assumed to have a CV of 0.54 (the same as aerial surveys). Therefore, most escapements that are assessed with weirs have different CVs associated with the total escapement depending upon what proportion was counted versus estimated and the method used to determine the estimated portion of the escapement. Thus, the CVs for escapement assessed with weirs vary from 0.04 (for systems and years where the entire run was counted and no periods were estimated) to 0.46 where 63% of the run was estimated by aerial survey for Orzinski Lake weir in 2006.

ESCAPEMENT BASED ON TOWER COUNTS

Towers are used to count sockeye salmon on 8 river systems in Bristol Bay. For tower projects, counts are made for 10 minutes of every hour on each bank of the river. Counts are then expanded to hourly counts and summed to estimate daily and seasonal total escapement (Seibel 1967; Cousens et al. 1982).

Counting towers do not provide error-free estimates of escapement (Woody 2007). Weather, water conditions, characteristics of the migration, observer variability, and systematic sampling design all affect accuracy and precision of counts. Overviews of these factors with respect to counting fish using towers are provided in Becker (1962) and Woody (2007). While weather, water conditions, and migration characteristics are uncontrollable; steps are taken to minimize their impact on counts (e.g., project placement). The effects of these factors on the uncertainty of count estimates are difficult to measure, but are assumed to be minimal; perhaps <1.0%. In addition, underestimation of escapement (i.e., downward bias) may be introduced if the counting project starts after the start of the run or ends before the run is complete. However, this bias, which is often not formally estimated, is considered to be small (5–10%) for the tower projects and years included in WASSIP (Tim Baker, Division of Commercial Fisheries Biologist, ADF&G, Anchorage, personal communication) and no corrections were made to the escapement estimates.

Differences in counts between observers can be quite large and are a result of variability in seeing, counting, and recording the number of fish passing the tower (Becker 1962; Woody 2007). Studies of paired observer counts taken over a variety of observer conditions found that while differences in individual counts ranged between –22.1% and 17.9% (Becker 1962), they appeared to be random and probably did not bias the escapement estimate because these differences tended to cancel out when total counts for the season were considered (Becker 1962; Cousens et al. 1982; Woody 2007). Studies investigating observer variability found the total error of paired tower counts was 0.4% (Anderson 2000) and 1.0% (Becker 1962).

The systematic sampling method used to collect escapement data from towers provides an unbiased estimate of total escapement, but influences uncertainty in the estimate and bias of the uncertainty estimate (Woody 2007). The efficiency of systematic 10-minute counts of salmon from towers was tested in 1965 and 1966 for 8 tower projects (Seibel 1967). In this study, counts were conducted for a full hour, and counts during the first 10 minutes of the hour were expanded and compared to the total hourly count. It was found that the relative errors in the 10-minute counting over the season were unbiased and low; with relative errors generally less than 10% and bias not significantly different from zero (Seibel 1967; Table 1).

Sampling error (i.e., counting 10 minutes out of each hour) can be estimated using the V5 estimator for variance in systematic sampling proposed by Wolter (1984, 1985) and recommended by Reynolds et al. (2007) because it was found to be the least biased variance estimator. While estimates of sampling error for tower projects are not available for the WASSIP years (2006–2008), estimated sampling error using historical sockeye count data from 9 Bristol Bay tower projects were available (unpublished ADF&G data obtained from Tim Baker, Division of Commercial Fisheries Biologist, Anchorage). Using the V5 estimator, the average CV of total sockeye salmon escapement for the 9 tower projects in 2004 and 2005 was estimated to be 0.02 (range: 0.01–0.03).

For comparison, a quasi-estimate of variance and CV of the total escapement was calculated using the data available in Seibel (1967). The estimate of CV for total escapement averaged 0.07 and ranged from 0.002 to 0.31 for all projects and species (Table 1). The CV for just the projects that counted sockeye salmon averaged 0.03 (range: 0.002–0.09), which is lower than the average CV of 0.11 (range: 0.04–0.31) for other species in the study. Only a limited number of hours were fully counted for each project (12–80 hours), but tower projects typically run a month or longer (i.e., ~1440 hours of observation; 30 days and 2 towers per project). Therefore, to estimate CVs for the whole season we estimated total escapement and variance of the estimate. Total escapement for the season was calculated based upon the proportion of total migration that was counted as part of the study (Seibel 1967; Table 1). Variance of the total escapement was estimated from the variance of the errors between the 10-minute and full-hour counts expanded by the proportion of hours counted in the season (assuming a total of 1440 potential hour counts). It was also assumed that the variance of the errors for the hours that were counted were representative of the whole season. It should be noted that the CV estimates using the V5 estimator assumes no errors in the counts over the 10 minutes sampled, whereas the estimates based on the data from Seibel (1967) incorporate both sampling and counting error.

In the following, a CV of 0.05 was used as an estimate of uncertainty for tower counts when estimating escapement of sockeye salmon within the subregional and regional reporting groups and no adjustments for bias were made. The estimated CV for tower escapement estimates accounts for sampling error (0.02), observer error (0.01), plus an additional 0.01 for uncertainties that are difficult to measure (e.g., weather, water conditions, etc.), and another 0.01 because the Advisory Panel and Technical Committee were of the opinion that a CV of 0.04 was too low for tower counts of sockeye salmon in Bristol Bay systems. This estimate of uncertainty in tower counts for sockeye salmon is on the lower end of estimates that have been speculated on in the literature. For example, Woody (2007) suggested that reasonable estimates of salmon escapements can be achieved using towers with ±6–10% using appropriate methods. Similarly, an estimate of ±5–10% accuracy was postulated for tower counts made on clear rivers in Alaska (personal communication cited in Cousens et al. 1982). However, specific details on how these estimates were derived were not provided in the references. Given the information detailed above, it is believed that a CV of 0.05 is a reasonable estimate of uncertainty for sockeye salmon escapements assessed by tower count projects within the WASSIP area (i.e., Bristol Bay) for the WASSIP study years.

ESCAPEMENT BASED ON SONAR COUNTS

Nushagak River is the only system within the WASSIP area that uses sonar to assess escapement of sockeye salmon. The variance of the escapement estimates are routinely provided in project reports (e.g., Brazil and Buck 2011). The estimated CV for the Nushagak River sockeye salmon escapement was 0.031 in 2006 (Brazil and Buck 2011), 0.026 in 2007, and 0.033 in 2008 (unpublished ADF&G data obtained from Tim Baker, Commercial Fisheries Division Biologist, Anchorage). These estimates only account for uncertainty in species apportionment and the variance due to sampling. The sonar counts are stratified by time period with associated drift gillnet sampling to apportion the counts to species. The drift gillnet sampling is often incomplete or limited by low catch, hence stratified estimates of species proportions are incomplete; therefore, the published CVs are likely underestimates of the true uncertainty. In the following a CV of 0.10 was assumed for the Nushagak River sonar sockeye salmon counts. The higher assumed CV is a matter of professional judgment. Errors in species apportionment are not an issue in weir and tower counts.

Bias in the escapement estimate based on sonar counts can be introduced if fish migrate beyond the range of detection of the sonar units (or behind the units). However, measures are taken to minimize these biases, such as using newer sonar technology (i.e., DIDSON), as is the case with the Nushagak River sonar project. As with weir and tower projects, biases can also be introduced if the project is not operational for the full run. It is assumed that at least 95% of the sockeye salmon migration had occurred during the operational period of the Nushagak sonar in the years of interest. This assumption is based on historical escapement information summarized in Brazil and Buck (2011). No corrections were made to the escapement estimates to account for the small portion of the migration that might have occurred after the project was terminated for the season.

ESCAPEMENT BASED ON EXPANDED AERIAL COUNTS

Sockeye salmon escapements based on aerial counts make up components of total escapement for 3 of the 6 regional reporting groups (South Peninsula, North Peninsula, and Kuskokwim Bay) and 10 of the 23 subregional reporting groups within the WASSIP area. Aerial surveys are particularly common for reporting groups in areas with multiple small spawning streams and rivers that drain directly into the ocean such as the Alaska Peninsula. Here, assessments of escapement are based on aerial surveys of a number of streams that encompass most of the spawning habitat within the area. The index of escapement is the peak count, which is the largest count of live fish observed among surveys conducted during the season. For populations that spawn in coastal areas and use a large number of streams it is not feasible to implement enumeration programs that provide absolute abundance estimates. It is recognized that peak counts are escapement indices and are biased low relative to the actual escapement.

In a typical salmon population, entry to the natal stream occurs over a protracted period on the order of weeks. During the period of entry, salmon are continuously spawning and dying and consequently lost to aerial observers. Because the residence time (i.e., the stream life) of salmon in the stream is short relative to the period of entry (Dangel and Jones 1988; Fried et al. 1998) the number of fish present in the stream at any given time is below the total escapement. Even with perfect (i.e., without error) aerial observation, the observed peak count is a highly conservative estimate of escapement. The peak live abundance, derived from the temporal pattern of entry (i.e., from daily weir counts) and stream life, are at most one half of the escapement (Dangel and Jones 1988). Other factors such as observer bias and poor visibility further affect the bias in peak aerial counts as an escapement estimate.

The department has conducted many studies that pair aerial count data from multiple aerial surveys during the course of a spawning period with escapement enumeration based on weir counts, mark-recapture, and tower counts. Many of these studies are coupled with direct measurement of stream life, and data can be used to derive the temporal pattern of live fish in the stream. Rather than model the temporal pattern of live fish in the stream and compare to aerial count data to evaluate the bias (e.g., Hilborn et al. 1999; Bue et al. 1998; Quinn and Gates 1997; Adkison and Su 2001; Su et al. 2001), an empirical approach will be used to estimate a relevant expansion factor and CV for sockeye salmon that scale peak aerial counts to total escapement and provide an estimate of uncertainty associated with the escapement estimate. The empirical approach of comparing peak aerial counts to actual estimates of escapement integrates both the variation in stream life and errors in the aerial counts (e.g., observer bias, visibility of the fish, etc.). Therefore, the CV of expanded escapement is equivalent to the CV of the estimated expansion factor:

$$CV(\hat{O}_i) = CV(\hat{x} I_i) = CV(\hat{x}),$$

where $\hat{O}_i$ is the expanded escapement estimate and I_i is the index count, which in this case is assumed to be known without error (i.e., a constant) because any observation error is integrated into the expansion factor ($\hat{x}$).

Paired aerial counts and absolute estimates of escapement for sockeye salmon from the WASSIP area are summarized in Table 2. The data include observations of sockeye salmon above the Chignik River weir (Anderson 2011), Alagnak River tower (Clark 2005), Middle Fork of the Goodnews River weir (Taylor and Clark 2010a), Glacial Lake weir, and Pilgrim River weir

(Menard et al. 2011). Aerial surveys were conducted at or around peak spawning and consisted of 1 to 3 surveys. If multiple surveys were flown then the survey with the highest count was considered the peak survey.

Data for Chignik aerial surveys and weir counts are available from 1960 to present, but for this document were limited to the 9 years in which surveys were completed for all 12 sites that are typically surveyed in the Chignik River system (1995–2000 and 2006–2008). Similarly, data used from the Alagnak River were limited to years in which all of the 4 major spawning aggregations within the system were assessed (Clark 2005). For the Pilgrim River, data were limited to weir and aerial survey comparisons even though a tower was used to assess escapement prior to switching to a weir. However, only 3 years of paired tower/aerial survey data were available and there were issues with species identification early on in the tower project (Menard et. al. 2011). Aerial survey and weir data for the Kanektok River were also available (Taylor and Elison 2010), but were not included in calculation of the mean expansion factor and CV because of the limited years with acceptable aerial surveys and higher mean expansion factor (6.40) than the other systems (1.94 to 2.99), which suggests that this system is particularly difficult to assess.

An expansion factor of 2.47 with a CV of 0.54 (Table 2) will be used to expand sockeye salmon aerial survey indices for the purposes of estimating escapement within the subregional and regional reporting groups. The CV estimate reflects the between-observation variation in the peak count expansion.

ESCAPEMENT OF SOCKEYE SALMON IN SUBREGIONAL AND REGIONAL REPORTING GROUPS IN THE WASSIP AREA

Chignik Regional Reporting Group

There are 2 sockeye salmon subregional reporting groups within the Chignik regional reporting group—Black Lake and Chignik Lake—that correspond to the early and late runs of sockeye salmon in the Chignik River system (Dann et al. 2012). Escapement of sockeye salmon in the Chignik regional reporting group was estimated based on information available in the annual area management reports (Jackson and Anderson 2009; Stichert 2007; Stichert et al. 2009). While there are a number of other sockeye-producing streams in the Chignik Management Area, these are generally small compared to the Chignik River and are not included in any of the reporting groups for WASSIP, therefore escapements from these systems are not included in the escapement estimates for either of the subregional reporting groups within the Chignik reporting group. Sockeye salmon escapements for the Black Lake (early-run) and Chignik Lake (late-run) subregional reporting groups are assessed with the Chignik River weir using underwater video equipment. Fish passing the weir are identified to species and counted during the first 10 minutes of each hour. The counts are expanded to estimate hourly escapements, which are then summed to estimate daily escapement. July 4 is used as the demarcation date for the early and late runs based on historical scale pattern analysis. This is the date after which the number of early-run sockeye salmon is, on average, about equal to the number of late-run sockeye salmon that have already passed the weir (Jackson and Anderson 2009; Stichert 2007; Stichert et al. 2009). There is an unknown error associated with the assessment of early and late-run escapements. This error is thought to be small relative to the magnitude of the Chignik escapements. The late-run escapement includes the number of sockeye salmon counted passing the weir plus an estimated escapement that occurs after the weir is removed based on time series analysis and forecast. The

CV of the portion of the escapement counted at the weir is assumed to be 0.04 (Table 3). This is the same as other weir projects even though sockeye salmon passing through the Chignik weir are counted for 10 minutes of every hour using a video system like tower projects. While there is sampling error associated with the systematic sampling design as with tower counts (see below), counting errors are likely to be smaller than with tower projects because the video can be reviewed especially during periods of high escapement. Therefore, the CV associated with weir counts rather than tower counts was assumed for Chignik weir. A CV of 0.20 was assumed for the portion of escapement that was estimated after the weir was removed. This CV is 5 times the CV associated with escapement counted at the weir and about half the CV of aerial surveys for sockeye salmon. Therefore, the CVs for the total escapement for Chignik Lake subregional reporting group (i.e., late-run) ranged between 0.04 and 0.05, based upon the relative portions of the escapements each year that were counted at the weir and estimated after the weir was removed (Table 3).

South Peninsula Regional Reporting Group

The South Peninsula reporting group is not subdivided into multiple subregional reporting groups. The area from Kupreanof Point to Scotch Cap comprises the South Peninsula sockeye salmon regional reporting group (Dann et al. 2012). Total escapement of sockeye salmon in the South Peninsula reporting group was estimated based on information available in the annual area management reports (Poetter 2009; Poetter et al. 2007, 2008) and Westward Region aerial survey database. There are several sockeye salmon runs in the South Peninsula regional reporting group that are assessed annually including Middle Lagoon, Mortensens Lagoon, Thin Point Lake, and Orzinski Lake, as well as a number of smaller populations. These smaller populations, plus Middle Lagoon and Mortensens Lagoon (2007 and 2008) are included in the South Peninsula aerial survey index (Table 4). In general, streams in the South Alaska Peninsula are not obscured by brush or trees and visibility of the spawning grounds are outstanding during normal water flow and clear weather (Poetter 2009; Poetter et al. 2007, 2008). Sockeye salmon escapement in Orzinski Lake and Mortensens Lagoon (2006 only) were assessed with weirs. The sockeye salmon run to Orzinski Lake began late in all 3 years of WASSIP (Poetter 2009; Poetter et al. 2007, 2008). In 2006, escapement after the weir project finished was estimated by aerial survey (Poetter et al. 2007). In 2007 and 2008, the weir project was run later into the season so no postweir estimate was made (Poetter 2009; Poetter et al. 2008). Mortensens Lagoon weir was only run in 2006 and operated by the U.S. Fish and Wildlife Service. A video monitoring system was run 24 hours per day and fish were counted with a motion detection system. Paired motion detection counts and counts from continuous video recordings were identical for 84% of the time periods examined and differed by one fish for the remainder (Anderson and Dion 2007). No pre- or postweir escapements were estimated for Mortensens weir because it was assumed very few sockeye entered the system prior to installation of the weir or after the weir was removed, based upon the pattern of escapement while the weir was operational (Anderson and Dion 2007).

Aggregate escapement for the South Peninsula reporting group was estimated by adding the weir count(s) and the expanded aerial survey index. It was noted that some of the aerial survey indices in the annual management reports included mouth counts or were applied inappropriately (i.e., taking peaks from multiple days from systems with multiple stream numbers, e.g., Thin Point system). Therefore, the aerial survey indices used in this study are derived from the Westward Region aerial survey database and only include the largest count of live fish observed during a single survey of a system and do not include mouth counts. An expansion factor of 2.47 was used for the aerial survey index (Table 4). CVs for the aggregate escapements were calculated based on methods described above and assumed CVs of 0.54 for expanded aerial counts and 0.04 for portions of runs actually counted with weir projects (Table 4). For Orzinski Lake the postweir escapement estimate was assumed to have a CV of 0.54 because it was based on an aerial survey; however, the estimated number of fish was assumed to be in terms of total number of fish and not an escapement index. The CV for the total sockeye escapement for Orzinski Lake was estimated to be 0.46 based upon the relative portions of the run that were counted at the weir and estimated by aerial survey.

North Peninsula Regional Reporting Group

The North Peninsula regional reporting group is comprised of 7 sockeye salmon subregional reporting groups for WASSIP and includes: Northwestern District/Black Hills, Nelson, Bear, Sandy, Ilnik, Meshik, and Cinder (Dann et al. 2012). Total escapement of sockeye salmon in the North Peninsula reporting group was estimated based on information available in the annual area management reports (Murphy and Hartill 2009, Murphy et al. 2008, Murphy and Tschersich 2007). The Northwestern District/Black Hills subregional reporting group includes McLees Lake (located on Unalaska Island), several small systems in the Aleutian Islands, Urilia Bay (including Christianson and Peterson lagoons), Swanson Lagoon, Bechevin Bay, Izembek–Moffet Bay and Caribou Flats–Black Hills (including North Creek). Escapements are a 2.47 expansion of the peak aerial survey indices with an assumed escapement CV of 0.54 (Table 5). McLees Lake is an exception in that sockeye salmon escapement is assessed by weir; therefore, there is no expansion of the escapement estimates. In 2006, there was a breach in the weir for 10 days early in the run when few sockeye salmon were migrating (Edwards 2006). In 2007 there was an 8-hour breach in June during which a small number of fish were assumed to have passed (Anderson and Edwards 2008). And in 2008, there were 2 breaches/mechanical failures—the first early in the migration when numbers of migrating fish were low and the second was a hole in the trap box that was caught before the gate was opened (Hildreth 2009). In all 3 years the weir was operational before sockeye salmon were first observed at the weir and it was assumed escapement after the weir was removed was minor (Edwards 2006; Anderson and Edwards 2008; Hildreth 2009). Therefore, the escapement CV is assumed to be 0.04 for all 3 years. The aggregate escapement for the Northwestern District/Black Hills subregional reporting group is a sum of the expanded escapements and the McLees Lake weir escapement with an aggregate escapement CV calculated using the methods above. The Nelson subregional reporting group includes Nelson River weir counts and aerial survey indices in the Nelson Lagoon, Herendeen Bay and Moller Bay areas (Table 6). Total escapement for the Nelson subregional reporting group is the sum of the weir counts, a postweir escapement estimate (see below), and a 2.47 expansion of the aerial survey counts. Escapement CV is a composite of the weir count CV, postweir estimate CV, and expanded aerial count CV (Table 6). The Bear subregional reporting group includes the Bear River weir counts, plus postweir escapement estimate, and the Sandy subregional reporting group includes the Sandy River weir counts and postweir escapement estimate (Table 6). CV for both subregional reporting groups is a combination of the weir count CV and the postweir escapement CV. Total escapement for the Ilnik subregional reporting group is the sum of the Ilnik River weir counts, a postweir escapement estimate and the 2.47 expanded aerial survey index of Ocean River and several streams in the Three Hills area (Table 7). The escapement CV is a composite of weir count CV, postweir escapement CV and aerial index CV. The Meshik and Cinder subregional reporting groups are both assessed using aerial surveys;

therefore the total escapement estimates are the 2.47 expansion of the respective aerial survey indices for these systems with an estimated CV of 0.54 (Table 7).

Escapements after the weirs were removed on the Nelson, Bear, Sandy, and Ilnik rivers were estimated and reported in the area management reports. These postweir estimates are based on aerial surveys, commercial fisheries performance, run timing indicators, effort levels and weather conditions (Murphy and Hartill 2009; Murphy et al. 2008; Murphy and Tschersich 2007). Because aerial surveys likely had the largest influence on postweir escapement estimates, it was assumed the CVs associated with these estimates were similar to that of aerial surveys (0.54). These postweir escapement estimates, however, were also assumed to be in terms of total number of fish and not an index since they were typically a small proportion of the escapement. Taking into account the combined uncertainty associated with actual weir counts and postweir estimates, the aggregate CVs for the total escapement for these weir projects ranged between 0.04 and 0.06 for Nelson River weir, 0.06 and 0.08 for Bear River weir, 0.04 and 0.18 for Sandy River weir, and between 0.04 and 0.05 for Ilnik River weir.

Bristol Bay Regional Reporting Group

The Bristol Bay regional reporting group is comprised of 9 sockeye salmon subregional reporting groups for WASSIP (Dann et al. 2012). Escapement of sockeye salmon in the Bristol Bay regional reporting group was based on information available in the annual area management report (Jones et al. 2009). The escapements are by subregional reporting group and include Ugashik, Egegik, Naknek, Alagnak, Kvichak, Nushagak, Wood, Igushik, and Togiak (Table 8). Escapements are based on tower counts for each subregional reporting group except Nushagak, which are based on sonar counts. The CV for tower counts is assumed to be 0.05 and the CV of the Nushagak sonar counts of sockeye salmon is assumed to be 0.10. Neither tower nor sonar escapement estimates were adjusted for potential bias.

Kuskokwim Bay Regional Reporting Group

The Kuskokwim Bay regional reporting group is comprised of 3 sockeye salmon subregional reporting groups for WASSIP, including Goodnews, Kanektok, and Kuskokwim River (Dann et al. 2012). Escapements of sockeye salmon in the Kuskokwim Bay regional reporting group were estimated based on information available in monitoring and assessment reports for the Goodnews River (Taylor and Clark 2010a), Kanektok River (Clark and Linderman 2009; Taylor and Clark 2010b; Taylor and Elison 2010), Kuskokwim River (Schaberg et al. 2010) and Kogrukluk River (Bavilla et al. 2010).

Escapements of sockeye salmon for the Goodnews subregional reporting group include the weir counts on the Middle Fork of the Goodnews River and estimated escapement for the North Fork of the Goodnews River (Table 9). The weir was breached or not operational for 1 day in 2006, and 6 days in 2007, for which escapements of sockeye salmon were estimated. In 2006, 38 sockeye salmon (0.03% of total escapement) were estimated to have passed the weir during the breach (Pawluk and Jones 2007), while in 2007, 845 sockeye salmon (1.17% of total escapement) were estimated to have passed the weir during breaches and periods when the weir was not operational (Clark and Linderman 2009). Because the fractions of escapements that were estimated were small for these two years, the CVs associated with these escapements were assumed to be 0.04. In 2008, a total of 14,771 sockeye salmon were estimated to have passed uncounted during breach events and periods when the weir was not operational (Taylor and Clark 2010a). For this study it was assumed that the CV for these estimated escapements was

0.10 (Toshihide Hamazaki, Division of Commercial Fisheries Biometrician, ADF&G, Anchorage, personal communication); therefore the overall CV for the sockeye salmon escapement on the Middle Fork of the Goodnews River was estimated to be 0.05. North Fork escapement estimates were based on the Middle Fork escapement (weir counts) multiplied by the average of the relative magnitude of paired aerial survey counts (x = 1.07, CV = 0.70, n = 12, range = 0.30–2.37) in the Middle and North forks from 1983 to 2008 (Taylor and Clark 2010a).

Escapement for the Kanektok subregional reporting group is based on the Kanektok River weir counts (Clark and Linderman 2009; Taylor and Clark 2010b; Table 9). The weir was not operational in 2006, but a peak aerial survey count was available (Taylor and Elison 2010) and several paired observations of aerial counts and weir counts for the Kanektok River are available. The average ratio of weir counts to aerial counts (i.e., expansion factor) was estimated to be 6.40 (CV = 0.77, n = 4, range = 2.19–13.12), which is much higher and more variable than the estimated expansion factor for sockeye salmon aerial surveys for the Goodnews River and elsewhere (Table 2). Expansion of the 2006 Kanektok River aerial survey index by the general expansion factor used in other systems or the Kanektok River-specific expansion factor would result in an unrealistically high escapement estimate for 2006. Therefore, escapement in 2006 was taken to be the unexpanded aerial count with an assumed CV of 0.54 (i.e., the CV associated with aerial survey expansions for sockeye salmon). The 2006 Kanektok River escapement should be considered a minimum estimate. Escapements for Kanektok River sockeye salmon for 2007 and 2008 include estimates of escapement below the weir, which is located 42 miles upriver from the mouth. These below-weir escapements were estimated with aerial surveys and a CV of 0.54 was assumed for this portion of the total escapement. It was also assumed that these estimates were in terms of total number of fish and not an index. In addition, in 2008 high water delayed the start of weir operations by 3 weeks on the Kanektok River and issues with the boat gate further delayed full operation by an additional 10 days (Taylor and Clark 2010b). As a result 72,359 sockeye salmon (51% of the escapement) were estimated to have passed the weir site before the weir was fully operational. A CV of 0.20 was assumed for this portion of the total escapement. This CV is 5 times the CV associated with escapement counted at the weir and about half the CV of aerial surveys for sockeye salmon. Given these various sources of additional uncertainty in the total sockeye salmon escapement for 2007 and 2008 in the Kanektok River, the estimated CVs for the total escapement was 0.05 in 2007 and 0.15 in 2008 (Table 9).

A basin-wide sockeye escapement estimate was only available for the Kuskokwim River subregional reporting group for 2006, which was based on a mark–recapture experiment at Kalskag (Schaberg et al. 2010; Table 9). Because the mark recapture estimate did not include escapement downriver of Kalskag, sockeye salmon escapement to the lower river, based on weir counts for Kwethluk and Tuluksak rivers (Schaberg et al. 2010), was added to the mark–recapture estimate. Long term estimates of sockeye salmon escapement from the Kogrukluk River weir (a tributary of the Kuskokwim River) are available and were paired with mark–recapture estimates of escapement at Kalskag plus downriver escapement from 2002 to 2006 in Schaberg et al. (2010) to estimate an expansion factor for Kogrukluk River weir counts for an estimate of total sockeye salmon escapement in the Kuskokwim River. Therefore, estimates of total of sockeye salmon escapement in the Kuskokwim River subregional reporting group for 2007 and 2008 were based on expansion of the Kogrukluk River weir counts using an expansion factor of 30.72 with an estimated CV of 0.56 (Table 9). It should be noted that the CV of the expanded escapement estimate is the same as the CV of the expansion factor, using the same error propagation rules that were used for the expanded aerial survey data.

Norton Sound Regional Reporting Group

The Norton Sound regional reporting group for sockeye salmon is represented by the Norton Sound subregional reporting group. The Norton Sound subregional reporting group extends from Point Romanzof to Cape of Prince of Wales (Dann et al. 2012). Aggregate escapement of sockeye salmon in the Norton Sound subregional reporting group for 2006 to 2008 was estimated based on information available in the annual area management reports (Menard et al. 2010; Soong et al. 2008a, b). River systems within this area that are assessed for sockeye salmon escapements include Glacial Lake (Sinuk River), Pilgrim River (Salmon Lake), and Nome, Snake, and Eldorado rivers. Sockeye salmon escapements in all of these systems are assessed using weirs and a CV of 0.04 was assumed for all escapements counted at the weir (Table 10). In 2006 and 2007, Glacial Lake weir was only operated for 2 weeks during peak escapement (Soong et al. 2008a, b). Based on historical daily counts at the weir (unpublished ADF&G data obtained from James Menard, Fishery Biologist, years 2002–2010), it was estimated that, on average, 60% (CV = 0.36) of the run passed the weir during the 2-week operational periods in 2006 and 2007. Using this information, the uncounted portion of the run (before and after weir operation) was estimated and added to the portion that was counted (Table 10) and the estimated CV is a composite of the CV of the counted (0.04) and uncounted (0.64) portions.

Escapements in Salmon Lake/Grand Central River and Glacial Lake are also assessed using aerial surveys, but because escapements of both systems are also assessed by weirs, only the weir counts will be used for estimating the escapement of sockeye salmon in these systems.

Escapement and CV of regional reporting groups

Total escapement and CV for each reporting group was calculated using the same methods used for the subregional reporting groups. The estimated sockeye salmon escapement and CV for each regional reporting group in WASSIP for the years 2006 to 2008 are summarized in Table 11.

ACKNOWLEDGMENTS

The Technical Document series, upon which this report is based, served as a record of communication between the Alaska Department of Fish and Game Commercial Fisheries Division and the Western Alaska Salmon Stock Identification Program (WASSIP) Technical Committee during the implementation of the program. The authors would like to thank the WASSIP Technical Committee and Advisory Panel for their constructive input on each of the documents throughout the project which led to this report. The authors would also like to thank Erica Chenoweth who coordinated and prepared the Technical Document series for publication and Publication Specialists Amy Carroll and Joanne MacClellan for implementing them into the ADF&G report series.

REFERENCES CITED

ADF&G (Alaska Department of Fish and Game). 2006. Western Alaska Salmon Stock Identification Program Memorandum of Understanding. http://www.adfg.alaska.gov/static/fishing/pdfs/research/wassip/documents/WASSIPSignedMOU2006.pdf (Accessed April 30, 2012).

Adkison, M. D. and Z. Su. 2001. A comparison of salmon escapement estimates using a hierarchical Bayesian approach versus separate maximum likelihood estimation of each year's return. Canadian Journal of Fisheries and Aquatic Science 58:1663 01501671.

Anderson, C. J. 2000. Counting tower projects in the Bristol Bay Area, 1955-1999. Alaska Department of Fish and Game, Regional Information Report 2A00-08, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/RIR.2A.2000.08.pdf (Accessed October 12, 2012).

Anderson, J. L., and C. A. Dion. 2007. Estimation of sockeye salmon escapement in Mortensens Creek, Izembek National Wildlife Refuge, 2006; and 2001 to 2006 run comparisons. U.S. Fish and Wildlife Service, Alaska Fisheries Data Series No. 2007-7.

Anderson, J. L., and M. R. Edwards. 2008. Estimation of sockeye salmon escapement into McLees Lake, Unalaska Island, Alaska, 2007. U.S. Fish and Wildlife Service, Alaska Fisheries Data Series No. 2008-9.

Anderson, T. J. 2011. Chignik Management Area salmon and herring annual management report, 2009. Alaska Department of Fish and Game, Fishery Management Report No. 11-31 Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FMR11-31.pdf (Accessed October 12, 2012).

Banducci A., E. L. Brennan, W. Jones, and J. Menard. 2003. Annual management report, 2002 Norton Sound - Port Clarence - Kotzebue. Alaska Department of Fish and Game, Regional Information Report 3A03-30, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/RIR.3A.2003.30.pdf (Accessed October 23, 2012).

Banducci, A., T. Kohler, J. Soong, and J. Menard. 2007. 2005 annual management report Norton Sound, Port Clarence, and Kotzebue. Alaska Department of Fish and Game, Fishery Management Report No. 07-32, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fmr07-32.pdf (Accessed October 23, 2012).

Bavilla, J., D. Bue, H. Carroll, T. Elison, D. Taylor, J. Estensen, and C. Brazil. 2010. 2009 Kuskokwim Area Management Report. Alaska Department of Fish and Game, Fishery Management Report No. 10-56, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FMR10-56.pdf (Accessed October 23, 2012).

Becker, C. D. 1962. Estimating red salmon escapements by sample counts from observation towers. U.S. Fish and Wildlife Service Fishery Bulletin 61:355–369.

Brazil, C., and G. B. Buck. 2011. Sonar enumeration of Pacific salmon escapement into the Nushagak River, 2006. Alaska Department of Fish and Game, Fishery Data Series No. 11-14, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS11-14.pdf (Accessed October 12, 2012).

Bue, B. G., S. M. Fried, S. Sharr, D. G. Sharp, J. A. Wilcock, and H. J. Geiger. 1998. Estimating salmon escapement using area–under-the-curve, aerial observer efficiency, and stream-life estimates: the Prince William Sound pink salmon example. North Pacific Anadromous Fish Commission Bulletin 1:240–250.

Clark, J. H. 2005. Abundance of sockeye salmon in the Alagnak River system of Bristol Bay Alaska. Alaska Department of Fish and Game, Fishery Manuscript No. 05-01, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fms05-01.pdf (Accessed October 12, 2012).

Clark, J. H., and J. C. Linderman, Jr. 2008. Goodnews River salmon monitoring and assessment, 2007. Alaska Department of Fish and Game, Fishery Data Series No. 08-66, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS08-66.pdf (Accessed October 12, 2012).

Clark, K. J., and J. C. Linderman, Jr. 2009. Kanektok River salmon monitoring and assessment, 2007. Alaska Department of Fish and Game, Fishery Data Series No. 09-11, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS09-11.pdf (Accessed October 12, 2012).

Cousens, N. B. F., G. A. Thomas, C. G. Swann, and M. C. Healy. 1982. A review of salmon escapement estimation techniques. Canadian Technical Report of Fisheries and Aquatic Science 1108.

REFERENCES CITED (Continued)

Dangel, J. R., and J. D. Jones. 1988. Southeast Alaska pink salmon total escapement and stream life studies, 1987. Alaska Department of Fish and Game, Regional Information Report 1J88-24, Juneau. http://www.adfg.alaska.gov/FedAidPDFs/rir.1j.1988.24.pdf (Accessed October 12, 2012).

Dann, T. H., C. Habicht, J. R. Jasper, L. Fox, H. A. Hoyt, H. Hildebrand, E. Lardizabal, P. Kuriscak, Z. Grauvogel, and W. Templin. 2012d. Western Alaska Salmon Stock Identification Program Technical Document 14: Sockeye salmon baseline based upon 96 SNPs. Alaska Department of Fish and Game, Regional Information Report No. 5J12-19, Anchorage.

Edwards, M. R. 2006. Estimation of sockeye salmon escapement into McLees Lake, Unalaska Island, Alaska, 2006. U.S. Fish and Wildlife Service, Alaska Fisheries Data Series No. 2006-12.

Evans, M., N. Hastings, and B. Peacock. 1993. Statistical distributions, 2nd ed. Wiley-Interscience. New York.

Fried, S. M., B. G. Bue, D. Sharp, and S. Sharr. 1998. Injury to spawning areas and an evaluation of spawning escapement enumeration of pink salmon in Prince William Sound, Alaska. Alaska Department of Fish and Game, Regional Information Report No. 2A98-42, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/RIR.2A.1998.42.pdf (Accessed October 12, 2012).

Hilborn, R., B. G. Bue, and S. Sharr. 1999. Estimating spawning escapement from periodic counts: a comparison of methods. Canadian Journal of Fisheries and Aquatic Science. 56:888–896.

Hildreth, D. R. 2009. Estimation of sockeye salmon escapement into McLees Lake, Unalaska Island, Alaska, 2008. U.S. Fish and Wildlife Service, Alaska Fisheries Data Series No. 2009-7.

Jackson, J. V., and T. J. Anderson. 2009. Chignik Management Area salmon and herring annual management report, 2008. Alaska Department of Fish and Game, Fishery Management Report No. 09-59, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FMR09-59.pdf (Accessed October 12, 2012).

Jones, M., T. Sands, S. Morstad, P. Salomone, T. Baker, G. Buck, and F. West. 2009. 2008 Bristol Bay area annual management report. Alaska Department of Fish and Game, Fishery Management Report No. 09-30, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FMR09-30.pdf (Accessed October 12, 2012).

Kohler, T. 2002. Norton Sound and Kotzebue Sound Management Area salmon catch and escapement report, 2001. Alaska Department of Fish and Game, Regional Information Report 3A02-51, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/RIR.3A.2002.51.pdf

Kohler, T., A. Banducci, E. Brennan, J. Menard. 2004. Annual Management Report 2003 Norton Sound-Port Clarence-Kotzebue. Alaska Department of Fish and Game, Regional Information Report 3A04-19, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/RIR.3A.2004.19.pdf (Accessed October 23, 2012).

Kohler, T., A. Banducci, J. Soong, and J. Menard. 2005. Annual management report, 2004, Norton Sound – Port Clarence, Kotzebue. Alaska Department of Fish and Game, Regional Information Report 3A05-04, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/RIR.3A.2005.04.pdf (Accessed October 23, 2012).

Menard, J., J. Soong, and S. Kent. 2010. 2008 annual management report Norton Sound, Port Clarence, and Kotzebue. Alaska Department of Fish and Game, Fishery Management Report No. 10-49, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FMR10-49.pdf (Accessed October 12, 2012).

Menard, J., J. Soong, and S. Kent. 2011. 2009 Annual Management Report Norton Sound, Port Clarence, and Kotzebue. Alaska Department of Fish & Game, Fishery Management Report, No. 11-46, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FMR11-46.pdf (Accessed October 12, 2012).

Murphy, R. L., and T. G. Hartill. 2009. North Alaska Peninsula commercial salmon annual management report, 2008. Alaska Department of Fish and Game, Fishery Management Report No. 09-36, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FMR09-36.pdf (Accessed October 12, 2012).

Murphy, R. L., and P. Tschersich. 2007. North Alaska Peninsula commercial salmon annual management report, 2006. Alaska Department of Fish and Game, Fishery Management Report No. 07-30, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fmr07-30.pdf (Accessed October 12, 2012).

REFERENCES CITED (Continued)

Murphy, R. L., P. Tschersich, and E. A. Russ. 2008. North Alaska Peninsula commercial salmon annual management report, 2007. Alaska Department of Fish and Game, Fishery Management Report No. 08-23, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fmr08-23.pdf (Accessed October 12, 2012).

Pawluk, J. A., and P. W. Jones. 2007. Goodnews River salmon monitoring and assessment, 2006. Alaska Department of Fish and Game, Fishery Data Series No. 07-51, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS07-51.pdf (Accessed October 12, 2012).

Poetter, A. D. 2009. South Alaska Peninsula salmon annual management report, 2008. Alaska Department of Fish and Game, Fishery Management Report No. 09-10, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FMR09-10.pdf (Accessed October 12, 2012).

Poetter, A. D., J. V. Jackson, and D. F. Doolittle. 2007. South Alaska Peninsula salmon annual management report, 2006. Alaska Department of Fish and Game, Fishery Management Report No. 07-31, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fmr07-31.pdf (Accessed October 12, 2012).

Poetter, A. D., J. V. Jackson, and E. A. Russ. 2008. South Alaska Peninsula salmon annual management report, 2007. Alaska Department of Fish and Game, Fishery Management Report No. 08-15, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fmr08-15.pdf (Accessed October 12, 2012).

Quinn, T. J., and R. Gates. 1997. Estimation of salmon escapement models with entry, mortality, and stochasticity. Natural Resources Modeling 10:217–250.

Reynolds, J. H., C. A. Woody, N. E. Gove, and L. F. Fair. 2007. Efficiently estimating salmon escapement uncertainty using systematically sampled data. American Fisheries Society Symposium 54:121–129.

Schaberg, K. L., Z. W. Liller, and D. B. Molyneaux. 2010. A mark–recapture study of Kuskokwim River coho, chum, sockeye, and Chinook salmon, 2001–2006. Alaska Department of Fish and Game, Fishery Data Series No. 10-32, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS10-32.pdf (Accessed October 12, 2012).

Seibel, M.C. 1967. The use of expanded ten-minute counts as estimates of hourly salmon migration past counting towers on Alaskan rivers. Alaska Department of Fish and Game, Informational Leaflet 101, Juneau. http://www.adfg.alaska.gov/FedAidPDFs/afrbil.101.pdf (Accessed October 12, 2012).

Soong, J., S. Kent, and J. Menard. 2008a. 2006 annual management report Norton Sound, Port Clarence, and Kotzebue. Alaska Department of Fish and Game, Fishery Management Report No. 08-32, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fmr08-32.pdf (Accessed October 12, 2012).

Soong, J., A. Banducci, S. Kent, and J. Menard. 2008b. 2007 annual management report Norton Sound, Port Clarence, and Kotzebue. Alaska Department of Fish and Game, Fishery Management Report No. 08-39, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fmr08-39.pdf (Accessed October 12, 2012).

Stichert, M. A. 2007. Chignik Management Area salmon and herring annual management report, 2006. Alaska Department of Fish and Game, Fishery Management Report No. 07-56, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fmr07-56.pdf (Accessed October 12, 2012).

Stichert, M. A., T. J. Anderson, and T. H. Dann. 2009. Chignik Management Area salmon and herring annual management report, 2007. Alaska Department of Fish and Game, Fishery Management Report No. 09-09, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FMR09-09.pdf (Accessed October 12, 2012).

Su, Z., M. D. Adkison, and B. W. Van Alen. 2001. A hierarchical Bayesian model for estimating historical salmon escapement and escapement timing. Canadian Journal of Fisheries and Aquatic Science. 58:1648–1662.

Taylor, D., and K. J. Clark. 2010a. Goodnews River salmon monitoring and assessment, 2008. Alaska Department of Fish and Game, Fishery Data Series No. 10-08, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS10-08.pdf (Accessed October 12, 2012).

Taylor, D., and K. J. Clark. 2010b. Kanektok River salmon monitoring and assessment, 2008. Alaska Department of Fish and Game, Fishery Data Series No. 10-09, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS10-09.pdf (Accessed October 12, 2012).

REFERENCES CITED (Continued)

Taylor, D. V., and T. B. Elison. 2010. Kanektok River salmon monitoring and assessment, 2009. Alaska Department of Fish and Game, Fishery Data Series No. 10-57, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS10-57.pdf (Accessed October 12, 2012).

Wolter, K. M. 1984. An investigation of some estimators of variance for systematic sampling. Journal of the American Statistical Association. 79:781–790.

Wolter, K. M. 1985. Introduction to variance estimation. Springer-Verlag. New York.

Woody, C. A. 2007. Tower counts. Pages 363–384 [*In*] D.H. Johnson, editor. Salmonid Field Protocols Handbook: Techniques for Assessing Status and Trends in Salmon and Trout Populations. American Fisheries Society, Bethesda, MD, USA.

TABLES

Table 1.–Summary of 1965 and 1966 counting tower data and analysis from Seibel (1967).

Tower Site	Year	Species	Number of hours counted	Estimated Count (Expanded 10-min)	Actual count (total hourly)	% Relative error	% Total migration counted	Total escapement[a]	Variance of error[b]	CV
Kwiniuk River	1965	Chum	53	6,972	6,302	10.6%	19.4%	35,938	23,240	0.161
Kwiniuk River	1965	Pink	35	1,356	1,249	8.6%	14.4%	9,417	436	0.084
Igushik River	1965	Sockeye	12	1,758	2,700	-34.9%	1.5%	117,200	30,848	0.057
Kvichak River - left bank	1965	Sockeye	36	558,180	585,700	-4.7%	2.4%	23,257,500	3,884	0.002
Kvichak River - right bank	1965	Sockeye	22	375,870	387,950	-3.1%	1.6%	23,491,875	19,934	0.005
Egegik - left bank	1965	Sockeye	24	28,146	24,820	13.4%	1.7%	1,655,647	116,571	0.006
Egegik - right bank	1965	Sockeye	23	43,824	43,281	1.3%	3.0%	1,460,800	1,285,282	0.021
Coghill River	1965	Mixed species	80	13,468	14,874	-9.5%	29.6%	45,500	8,438	0.004
Kwiniuk River	1966	Chum	36	6,906	7,295	-5.3%	22.0%	31,391	29,389	0.207
Kwiniuk River	1966	Pink	36	5,172	5,213	-0.8%	48.0%	10,775	7,559	0.306
Togiak River	1966	Sockeye	15	1,446	1,305	10.8%	1.3%	111,231	629	0.009
Nuyakuk River	1966	Sockeye	24	16,596	16,494	0.6%	10.2%	162,706	147,063	0.089
Nuyakuk River	1966	Pink	32	14,382	12,361	16.3%	0.9%	1,598,000	61,547	0.006
Nushagak River	1966	Pink	14	33,666	34,028	-1.1%	0.9%	3,740,667	1,145,555	0.011

[a] Total escapement was calculated from percent of total migration that estimated count represents.
[b] Variance of error is the variance of the differences between the estimated and actual counts.

Table 2.–Summary of historical data comparing aerial survey counts to independent estimates of escapement for sockeye salmon in WASSIP area.

		Expansion based on peak aerial count			
System	Escapement enumeration method	Mean	CV	No. of obs.	References
Chignik					
Chignik River (early & late-run)	Weir count	1.94	0.71	9	Anderson (2011)
Bristol Bay					
Alagnak River	Tower count	2.55	0.40	9	Clark (2005)
Kuskokwim Bay					
Middle Fork Goodnews River	Weir or tower count	2.48	0.41	12	Taylor and Clark (2010a)
Kanektok River[a]	Weir count	6.40	0.77	4	Taylor and Elison (2010)
Norton Sound					
Glacial Lake[b]	Weir count	2.99	0.66	8	Menard et al. (2011), Banducci et al. (2003, 2007), Kohler (2002), Kohler et al. (2004, 2005)
Pilgrim River	Weir count	2.42	0.57	7	Menard et al. (2011)
Weighted mean[a]		2.47	0.54	45	

[a] Kanektok River data not included in calculation of overall mean expansion factor and CV because of limited years with acceptable aerial surveys and higher mean expansion and CV than other systems.

[b] Glacial Lake expansion factor includes paired observations from 2006 and 2007 in which the weir was only operated for 2 weeks of the run and biased low. Removing these data has minimal impact on overall mean expansion factor or CV (2.49 and 0.53, respectively).

Table 3.–Escapement (thousands of fish) and CV of sockeye salmon in the Black Lake and Chignik Lake subregional reporting groups of the Chignik regional reporting group from 2006 to 2008.

	Black Lake		Chignik Lake			
Year	Chignik weir (early-run)	CV	Chignik weir (late-run)	Post-weir estimate[a]	Subregion escapement	CV
2006	366.50	0.04	310.05	58.94	369.00	0.05
2007	361.09	0.04	265.33	28.55	293.88	0.05
2008	377.58	0.04	300.65	27.83	328.48	0.04

[a] Chignik Lake (late-run) escapement includes an estimate of escapement in September, after the weir is removed; CV = 0.20 assumed postweir escapement. CV = 0.04 for portion of late-run that was counted at the weir.

Table 4.– Escapement (thousands of fish) and CV of sockeye salmon in the South Peninsula regional reporting group from 2006 to 2008. There are no subregional reporting groups within the South Peninsula regional reporting group.

	South Peninsula					
			Orzinski Lake			
Year	South Peninsula aerial survey index[a]	Mortensens Lagoon weir[b]	Weir[b,c]	Post-weir[d]	Subregion escapement	CV
2006	48.36	14.79	6.75	11.25	152.14	0.53
2007	60.43	NA	10.64		159.81	0.54
2008	59.95	NA	36.84		184.81	0.52

Note: NA = Mortensens Lagoon weir was not run in 2007 and 2008, Mortensens Lagoon aerial survey index is included as part of South Peninsula aerial survey index for 2007 and 2008.

[a] Expansion factor = 2.47 and CV = 0.54 is assumed for South Peninsula aerial survey index.

[b] CV = 0.04 is assumed for Mortensens Lagoon and Orzinski Lake weir counts.

[c] The number of jacks that migrated through the Orzinski Lake weir were enumerated and included in the escapement numbers: 2006 = 167; 2007 = 4,580; 2008 = 1,429 (Poetter 2009, Poetter et al. 2008, 2007).

[d] Postweir escapement for Orzinski Lake weir was estimated by aerial survey in 2006 (Poetter et al. 2007). A CV = 0.54 was assumed for the postweir portion of the escapement estimate. No postweir estimates in 2007 and 2008 because the weirs were run late into the season (Poetter 2009, Poetter et al. 2008).

Table 5.–Escapement (thousands of fish) and CV of sockeye salmon in the Northwestern District/Black Hills subregional reporting group of the North Peninsula regional reporting group from 2006 to 2008.

	Northwestern District/Black Hills								
Year	McLees Lake weir[a]	Aleutian Islands aerial survey index[b]	Urilia Bay aerial survey index	Swanson Lagoon aerial survey index	Bechevin Bay aerial survey index	Izembek-Moffet Bay aerial survey index	Caribou Flats - Black Hills aerial survey index	Subregion escapement	CV
2006	12.94	0.25	45.06	0.38	7.88	41.20	7.53	265.40	0.54
2007	21.43	0.04	48.08	9.20	2.28	32.60	16.80	290.46	0.54
2008	8.66	0.07	118.60	5.50	3.10	46.60	44.00	546.43	0.54

[a] CV = 0.04 is assumed for McLees Lake weir.

[b] Expansion factor = 2.47 and CV = 0.54 is assumed for aerial survey indices.

Table 6.–Escapement (thousands of fish) and CV of sockeye salmon in the Nelson, Bear, and Sandy subregional reporting groups of the North Peninsula regional reporting group from 2006 to 2008.

	Nelson					Bear				Sandy			
		Nelson River				Bear River				Sandy River			
Year	Nelson Lagoon - Herendeen Bay aerial survey index[a]	Weir[b,c]	Post-weir[d]	Subregion escapement	CV	Weir[b,e]	Post-weir[d]	Subregion escapement	CV	Weir[b,f]	Post-weir[d]	Subregion escapement	CV
2006	14.00	196.27	18.74	249.56	0.11	404.20	40.81	445.00	0.07	35.79	12.21	48.00	0.18
2007	10.10	174.70	5.30	204.93	0.09	396.54	34.46	431.00	0.06	44.33	0.37	44.70	0.04
2008	38.22	135.45	6.15	235.94	0.31	282.58	38.42	321.00	0.08	29.58	2.60	32.18	0.06

[a] Expansion factor = 2.47 and CV = 0.54 is assumed for Nelson Lagoon-Herendeen Bay aerial survey index.

[b] CV = 0.04 is assumed for weir counts on Nelson, Bear, and Sandy rivers.

[c] The number of jacks that migrated through Nelson River weir were enumerated and included in the escapement numbers: 2006 = 3,717; 2007 = 1,056; 2008 = 918 (Murphy and Hartill 2009, Murphy et al. 2008, Murphy and Tschersich 2007).

[d] Escapements after weir removal were estimated for Nelson, Bear, and Sandy rivers as well as a postweir installation escapement estimate of 10,000 sockeye salmon in 2006 for Sandy River; estimates are based on aerial surveys, commercial fisheries performance, run timing indicators, effort levels and weather conditions (Murphy and Hartill 2009, Murphy et al. 2008, Murphy and Tschersich 2007). CV of postweir escapement is assumed to be same as aerial survey (0.54), but escapement estimate is not expanded.

[e] The number of jacks that migrated through Bear River weir were enumerated and included in the escapement numbers: 2006 = 10,198; 2007 = 6,396; 2008 = 6,632 (Murphy and Hartill 2009, Murphy et al. 2008, Murphy and Tschersich 2007).

[f] The number of jacks that migrated through Sandy River weir were enumerated and included in the escapement numbers: 2006 = 329; 2007 = 2,164; 2008 = 351 (Murphy and Hartill 2009, Murphy et al. 2008, Murphy and Tschersich 2007).

Table 7.–Escapement (thousands of fish) and CV of sockeye salmon in the Ilnik, Meshik, and Cinder subregional reporting groups of the North Peninsula regional reporting group from 2006 to 2008.

	Ilnik						Meshik			Cinder		
			Ilnik River									
Year	Three Hills aerial survey index[a]	Ocean River aerial survey index[a]	Weir[b,c]	Post-weir[d]	Subregion escapement	CV	Meshik aerial survey index[a]	Subregion escapement	CV	Cinder aerial survey index[a]	Subregion escapement	CV
2006	1.80	13.00	74.55	0.45	111.53	0.22	142.61	352.00	0.54	101.10	249.55	0.54
2007	1.50	14.00	77.17	1.83	117.26	0.22	58.50	144.40	0.54	142.00	350.50	0.54
2008	2.00	16.00	27.00	1.30	72.73	0.45	86.25	212.89	0.54	129.80	320.39	0.54

[a] Expansion factor = 2.47 and CV = 0.54 is assumed for Three Hills, Ocean River, Meshik, and Cinder aerial survey indices.

[b] CV = 0.04 is assumed for Ilnik River weir counts.

[c] The number of jacks that migrated through Ilnik River weir were enumerated and included in the escapement numbers: 2006 = 671; 2007 = 137; 2008 = 88 (Murphy and Hartill 2009, Murphy et al. 2008, Murphy and Tschersich 2007).

[d] Escapements after weir removal were estimated for Ilnik River; 2006 estimate includes a postweir installation escapement estimate of 500 sockeye salmon; estimates are based on aerial surveys, commercial fisheries performance, run timing indicators, effort levels and weather conditions (Murphy and Hartill 2009, Murphy et al. 2008, Murphy and Tschersich 2007). CV of postweir escapement is assumed to be same as aerial survey (0.54), but escapement estimate is not expanded.

Table 8.–Escapement (thousands of fish) and CV estimates of sockeye salmon in the Ugashik, Egegik, Naknek, Alagnak, Kvichak, Nushagak, Wood, Igushik, and Togiak subregional reporting groups of the Bristol Bay regional reporting group from 2006 to 2008.

	Ugashik		Egegik		Naknek		Alagnak		Kvichak	
Year	Tower	CV	Tower	CV	Tower	CV	Tower	CV	Tower	CV
2006	1,003	0.05	1,465	0.05	1,953	0.05	1,774	0.05	3,068	0.05
2007	2,599	0.05	1,433	0.05	2,945	0.05	2,466	0.05	2,810	0.05
2008	596	0.05	1,260	0.05	2,473	0.05	2,181	0.05	2,758	0.05

	Nushagak		Wood		Igushik		Togiak	
Year	Sonar	CV	Tower	CV	Tower	CV	Tower	CV
2006	548.41	0.10	4,008	0.05	305	0.05	312.13	0.05
2007	518.04	0.10	1,528	0.05	415	0.05	269.65	0.05
2008	492.12	0.10	1,725	0.05	1,055	0.05	205.68	0.05

Table 9.–Escapement (thousands of fish) and CV of sockeye salmon in the Goodnews, Kanektok, and Kuskokwim River subregional reporting groups of the Kuskokwim Bay regional reporting group from 2006 to 2008.

	Goodnews				Kanektok		Kuskokwim River		
Year	Middle Fork weir[a]	North Fork estimate[b]	Subregion escapement	CV	Sub-region escapement	CV	Kogrukluk weir	Subregion escapement	CV
2006	126.77	135.14	261.91	0.51	367.30[c]	0.54	60.81	696.21[d]	0.07
2007	72.28	77.05	149.33	0.52	327.74[e]	0.05	16.53[f]	507.60[g]	0.56
2008	50.46	53.79	104.25	0.57	145.76[h]	0.15	19.68	604.33[g]	0.56

[a] CV = 0.04 is assumed for 2006 and 2007 Middle Fork weir counts; CV = 0.05 for 2008 Middle Fork weir counts (29% escapement estimated with CV = 0.10).

[b] North Fork Goodnews River sockeye salmon escapement is estimated by multiplying escapement at Middle Fork weir by the average ratio of aerial survey indices of North Fork to Middle Fork (1.07). Estimated CV = 0.70.

[c] Kanektok River weir not operational in 2006. Escapement is based on unexpanded aerial survey with assumed CV equal to other sockeye salmon aerial survey escapement estimates.

[d] Mark-recapture and CV (0.07) estimate at Kalskag plus 7,717 escapement below Kalskag, based on weir counts for Kwethluk and Tuluksak rivers (CV = 0.04) (see Schaberg et al. 2010).

[e] Includes additional 19,992 sockeye salmon below Kanektok River weir in 2007 estimated by aerial survey (Clark and Linderman 2009); CV = 0.54 for this portion of escapement.

[f] Kogrukluk weir operation incomplete in 2007 and > 20% of total escapement is based on daily passage estimates.

[g] Kuskokwim River sub-region escapement estimate for 2007 and 2008 are based on expansion of Kogrukluk weir escapements using an expansion factor of 30.72.

[h] Includes additional 4,373 sockeye salmon below Kanektok River weir in 2008 (estimated by aerial survey) and 72,359 sockeye salmon estimated to have passed weir during breach events and inoperable periods (Taylor and Clark 2010b). CV = 0.54 lower river escapement estimate and CV = 0.20 for estimated escapement during breach events and inoperable periods.

Table 10.– Escapement (thousands of fish) and CV of sockeye salmon in the Norton Sound regional reporting group from 2006 to 2008. There are no subregional reporting groups in the Norton Sound regional reporting group.

	Norton Sound									
		Glacial Lake[a]								
Year	Pilgrim River weir	Weir count	Pre-/postweir estimate	Total	CV	Snake River weir	Nome River weir	Eldorado River weir	Subregion escapement	CV
2006	52.32	6.85	4.64	11.49	0.36	0.30	0.19	0.00	64.31	0.07
2007	43.43	4.53	3.07	7.61	0.36	1.35	0.53	0.02	52.95	0.06
2008	20.45	1.79			0.04	0.14	0.09	0.00	22.48	0.04

[a] Glacial Lake weir was operated for only two weeks in 2006 and 2007, pre- and postweir estimate is based on expansion of estimate of portion of run counted (60%) with CV = 0.64. For portion of run counted during weir operation CV = 0.04.

Table 11.–Escapement (thousands of fish) and CV of sockeye salmon within the WASSIP area by regional reporting group from 2006 to 2008.

	2006		2007		2008	
Regional reporting group	Escapement	CV	Escapement	CV	Escapement	CV
Chignik	735.49	0.05	654.97	0.04	706.06	0.04
South Peninsula	152.14	0.53	159.81	0.54	184.81	0.52
North Peninsula	1,721.03	0.40	1,583.24	0.39	1,741.56	0.49
Bristol Bay	14,436.54	0.05	14,983.69	0.05	12,745.80	0.05
Kuskokwim Bay	1,325.42	0.28	984.68	0.48	854.33	0.56
Norton Sound	64.31	0.07	52.95	0.06	22.48	0.04