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Estimating Escapement of Western Alaska chum salmon for Western Alaska Salmon Stock Identification Program Reporting Groups, 2007 to 2009

by

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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, and Special Publications. 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. 12-21

ESTIMATING ESCAPEMENT OF WESTERN ALASKA CHUM SALMON FOR WESTERN ALASKA SALMON STOCK IDENTIFICATION PROGRAM REPORTING GROUPS, 2007 TO 2009.

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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 chum salmon. Escapements and associated uncertainties were estimated for each of the WASSIP chum salmon regional reporting groups (Chignik/Kodiak, South Peninsula, Northwest District, Northern District, Coastal Western Alaska, Upper Yukon River, Kotzebue Sound; i.e., stocks). The 2007 to 2009 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 = 0.01), sonar (CV = 0.10), aerial counts (expansion factor = 7.15 and CV = 1.09). 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, chum salmon, *Oncorhynchus keta,* mixed stock analysis, escapement

INTRODUCTION

The Western Alaska Salmon Stock Identification Program (WASSIP) was initiated to identify the stock contributions of sockeye and chum salmon to fisheries in and around western Alaska from Chignik northward to Kotzebue Sound. The WASSIP Memorandum of Understanding (MOU; ADF&G 2006) specifically recognizes the desires of signatories to extend stock contribution estimates, *to the extent possible*, 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 chum salmon. For WASSIP, reporting groups approved by the Advisory Panel (representatives of the signatory groups to the MOU) will serve as "stocks" for estimating stock-specific parameters for chum salmon (Habicht et al. 2012). 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 chum salmon in each of the WASSIP chum salmon reporting groups. The 2007 to 2009 escapement data and coefficient of variation (CV) are presented for each WASSIP chum salmon regional reporting group that will be used in the harvest rate estimation. The information summarized in this document combined with a future technical document on chum 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 the WASSIP fisheries. These harvest rates do not account for fish harvested 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 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.

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):

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

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 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,

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

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

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

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 ($C^{(i)}_{f,y}$), terminal harvests ($T^{(i)}_y$) and reporting group-specific escapement ($E^{(i)}_{f,y}$). 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:

$$N^{(i)}_y = T^{(i)}_y + E^{(i)}_y + \sum_f C^{(i)}_{f,y}$$

$$HR^{(i)}_{f,y} = {C^{(i)}_{f,y}}\Big/{N^{(i)}_y}$$

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

Estimates of escapement CVs are not routinely reported in ADF&G escapement and management reports. CVs for escapement estimated by counts (e.g., tower, weir, 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 count are unknown and problematic. Reasonable approximations, however, 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) is 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 EXPANDED AERIAL COUNTS

For many chum salmon reporting groups within the WASSIP area, escapements are enumerated from aerial counts. This is particularly so for the Chignik, Kodiak, Alaska Peninsula, and Norton Sound areas. Assessments of escapement are based on multiple aerial surveys of a large number of streams that encompass most of the spawning habitat. The index of escapement is the peak count, (i.e., the largest count 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 (cf., Dangel and Jones 1988; Fried et al. 1998) the number of fish present in the stream at any given time is below the actual 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 (cf., Dangel and Jones 1988). Other factors such as observer bias and poor visibility further increase 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 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 chum 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 ($\hat{x}$).

The available studies where aerial counts of chum salmon were compared to absolute estimates of chum salmon escapement are summarized in Table 1. There were 10 years of chum salmon observations in Southeast Alaska, 8 years of chum salmon observations in Goodnews River, 13 years of chum salmon observations in Kwiniuk River, and 8 years of chum salmon observations in East Fork Andreafsky River (Yukon). Note that escapement indices used in the published comparative studies in Southeast Alaska include mouth counts, as well as counts of live and dead fish instream. The counts in the Southeast Alaska chum studies were adjusted to include only counts of live instream fish (count data obtained from the ADF&G Division of Commercial Fisheries' database *Alexander: the integrated fisheries database for Southeast Alaska and Yakutat*). Escapement indices used in the comparative studies in the Kuskokwim and Prince William Sound Areas include only counts of live instream fish.

An expansion factor for the peak count was estimated for each year and system of observation. Mean expansion factors and CV reflecting the between observation variation in the peak count expansion were calculated (Table 1). There was clear bias in the peak count as escapement estimator, with mean expansion faction ranging from 4.20 to 9.85. In the following sections, the expansion factor applied to chum salmon assessed with surveys was 7.15 with CV = 1.09. This is the average weighted by number of observations over chum salmon studies in Southeast Alaska, Kuskokwim Bay, Yukon River, and Norton Sound.

Table 1.–Summary of historical data comparing aerial survey counts to independent estimates of escapement for chum salmon in Alaska.

System	Escapement enumeration method	Expansion based on peak aerial or peak foot count			References
		Mean	CV	No. of Obs.	
Southeast Alaska					
Disappearance Creek	Weir count - M-R	9.85	0.10	3	Piston and Heinl (2010a, 2010b), Piston and Brunette (2011)
Traitors Creek	Mark-recapture	6.73	0.67	7	Unpublished data from Steve Heinl, Fishery Biologist, ADF&G, Ketchikan, AK
Kuskokwim					
Middle Fork Goodnews River	Weir count	4.20	0.92	8	Taylor and Clark (2010a)
Norton Sound					
Kwiniuk River	Tower count	7.62	1.47	13	Clark (2001a)
Yukon River					
East Fork Andreafsky River	Weir, tower, or sonar counts	8.69	1.38	8	JTC (2012)
Weighted mean[a]		7.15	1.09	39	

[a] Mean weighted by number of observations and includes southeast Alaska, Kuskokwim River, Yukon River, and Norton Sound and escapement indices include only counts of live fish inriver from a single survey.

ESCAPEMENT BASED ON WEIR COUNTS

Chum salmon escapements enumerated using weirs make up components of total escapement for several of the reporting groups within the WASSIP area. Weirs are deployed on the Chignik River, 7 rivers in the North and South Alaska Peninsula, 2 Kuskokwim Bay rivers, several tributaries on the Kuskokwim River, several tributaries on the Yukon River, and 5 rivers within the area encompassed by the Norton Sound reporting group. A few chum salmon are counted in weir projects in the Chignik and Kodiak areas. Although these projects are designed to count sockeye salmon, the few chum salmon counted are included. Generally, for each salmon species, all individuals that pass through the weir are counted and the count is considered absolute. 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 (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 are 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 weather conditions, observer variability, and incomplete counting of the escapement because the weir project was started before the beginning of the migration, ended before migration was complete, or the weir was inoperable during the main part of the run.

Because passage of fish is controlled through the use of gates or traps, 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.

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 typically compose a small percentage of the entire run.

Additional downward bias 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. 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.

In the following sections, 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. This CV is based on input and consensus of the Advisory Panel and represents counting (observation error) and additional uncertainty not explicitly accounted for.

ESCAPEMENT BASED ON TOWER COUNTS

For most 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). Towers are used to count chum salmon on 3 river systems in Norton Sound, where a single tower provides sufficient coverage of the migratory corridor. These projects include Kwiniuk, Niukluk, and North rivers. For the Kwiniuk Tower, a 20 minute period is counted each hour.

Counting towers do not provide error-free estimates of escapement (Woody 2007). Weather, water conditions, characteristics of the migration, observer variability, and the systematic sampling design all affect the accuracy and precision of counts (Becker 1962; 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. This bias, however, 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 appear to be random and probably do not bias the escapement estimate because these differences tend to cancel out when total counts for the season are considered (Becker 1962; Cousens et al. 1982; Woody 2007). Studies that have investigated observer variability found the total error of paired tower counts to be 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 2).

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 (2007–2009), estimated sampling error using historical count data for sockeye salmon from 9 Bristol Bay tower projects were available (unpublished data obtained from Tim Baker, Commercial Fisheries Biologist, ADF&G, Anchorage). Using the V5 estimator, the average CV of total escapement for the 9 tower projects in 2004 and 2005 was estimated to be 0.02 (range: 0.01–0.03). These estimates of sampling error are considered indicative of sampling errors in tower counting of chum salmon.

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 2). The CV for just the projects that counted chum salmon averaged 0.18 (range: 0.16–0.21). Although the sample size (2) for chum is small, the CV is substantially higher than for the 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 two 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 2). 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.

Table 2.–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	10.60	19.40	35,938	23,240	0.161
Kwiniuk River	1965	Pink	35	1,356	1,249	8.60	14.40	9,417	436	0.084
Igushik River	1965	Sockeye	12	1,758	2,700	-34.90	1.50	117,200	30,848	0.057
Kvichak River - left bank	1965	Sockeye	36	558,180	585,700	-4.70	2.40	23,257,500	3,884	0.002
Kvichak River - right bank	1965	Sockeye	22	375,870	387,950	-3.10	1.60	23,491,875	19,934	0.005
Egegik - left bank	1965	Sockeye	24	28,146	24,820	13.40	1.70	1,655,647	116,571	0.006
Egegik - right bank	1965	Sockeye	23	43,824	43,281	1.30	3.00	1,460,800	1,285,282	0.021
Coghill River	1965	Mixed species	80	13,468	14,874	-9.50	29.60	45,500	8,438	0.004
Kwiniuk River	1966	Chum	36	6,906	7,295	-5.30	22.00	31,391	29,389	0.207
Kwiniuk River	1966	Pink	36	5,172	5,213	-0.80	48.00	10,775	7,559	0.306
Togiak River	1966	Sockeye	15	1,446	1,305	10.80	1.30	111,231	629	0.009
Nuyakuk River	1966	Sockeye	24	16,596	16,494	0.60	10.20	162,706	147,063	0.089
Nuyakuk River	1966	Pink	32	14,382	12,361	16.30	0.90	1,598,000	61,547	0.006
Nushagak River	1966	Pink	14	33,666	34,028	-1.10	0.90	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.

In the following sections, a CV of 0.1 was used as an estimate of uncertainty for tower counts when estimating escapement of chum salmon within the regional reporting groups and no adjustments for bias were made. The estimated CV for chum salmon tower escapement estimates is substantially higher than that assumed for sockeye consistent with the higher CVs observed for chum salmon in the Seibel study. This CV reasonably accounts for sampling error, observer error, and for uncertainties that are difficult to measure (e.g., weather, water conditions, etc.). This estimate of uncertainty in tower counts for chum salmon is similar to 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 (Cousens et al. 1982). These references, however, did not provide specific details regarding how these estimates were derived. Given the information detailed above, it is believed that a CV of 0.10 is a reasonable estimate of uncertainty for chum salmon escapements assessed by tower count projects within the WASSIP area and for the years of that the project encompasses.

ESCAPEMENT BASED ON SONAR COUNTS

Chum salmon are enumerated with sonar projects on the Nushagak River, on the Aniak River within the Kuskokwim River system, at Pilot Station on the lower mainstem Yukon River, and on the Anvik River within the Yukon River system. The variance of the Nushagak sonar escapement estimates are routinely provided in project reports (e.g., Brazil and Buck 2011). The estimated CV for the Nushagak River chum salmon escapement was 0.067 in 2007, 0.039 in 2008, and 0.031 in 2009 (unpublished data obtained from Tim Baker, Commercial Fisheries Biologist, ADF&G, Anchorage). The errors (bias and precision) of the Nushagak sonar counts are due to errors in species apportionment as well as 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, and the published CVs are likely underestimates of the true uncertainty. In the following, a CV of 0.1 was assumed for the Nushagak River sonar chum 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. The CV for the Arctic-Yukon-Kuskokwim DIDSON sonar projects are not explicitly estimated but are probably at least as precise as those of the Nushagak sonar project. This is because chum salmon are the dominant species counted in the Arctic-Yukon-Kuskokwim projects. Reasonable CVs that are higher than those estimated in the Nushagak sonar counts (0.1 for DIDSON, 0.15 for split beam, and 0.2 for Bendix systems) are explicitly considered in the run reconstruction models applied to Yukon River summer chum salmon and Yukon River fall chum salmon (Fleischman and Evenson 2010; Fleischman and Borba 2009).

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). Measures, however, are taken to minimize these biases, such as using newer sonar technology (i.e. DIDSON), as is the case with the Nushagak River, Aniak River, and Anvik River sonar project. As with weir and tower projects, biases can also be introduced if the project is not operational for the full run. No information is available to correct escapement estimates for the small portion of the migration that may have occurred after the projects were terminated for the season. It is believed, as with weir and tower projects, that bias due to uncounted late fish in WASSIP sonar projects to estimate chum salmon escapement is small.

ESCAPEMENT BASED ON CATCH EXPANDED BY HARVEST RATE

Assessment of escapement for most chum salmon stocks in Bristol Bay is not available. Aerial surveys are conducted on Bristol Bay river systems that support chum salmon; however these surveys are directed at assessing Chinook salmon escapement. Chum salmon counts are available from these surveys and demonstrate substantial spawning populations in the Ugashik, Egegik, and Alagnak rivers, as well as several river systems in the Togiak District. The timing of these surveys is too early to effectively assess chum salmon, and surveys were not conducted for each river system during the WASSIP years. Chum salmon escapement estimates are only available for the Nushagak River, which is the primary chum salmon spawning area in the Nushagak District. To assess chum salmon escapements for the other districts, the harvest rates estimated for sockeye salmon were used to expand the district chum salmon catch to chum salmon escapements in the respective district. The harvest rate of Ugashik River, Egegik River, Alagnak River, Nushagak River, and Togiak River chum salmon in the Ugashik, Egegik, Naknek/Kvichak, Nushagak, and Togiak districts were assumed to be the same as sockeye salmon from these same systems. Here,

$$E_i = C_i \left({(1 - U_i)} / {U_i} \right) (1 - B)$$

where E_i is the estimated escapement of chum salmon terminal to district i, C_i is the harvest of chum salmon in district i, U_i is the district i harvest rate on the sockeye salmon stock assumed to be surrogate for the terminal chum salmon stock, and B is the relative bias. The CV and relative bias were estimated from paired Nushagak sonar counts and escapements estimated by expanding chum catch by sockeye harvest rate. These paired observations are available from 1990 to 2009 (Table 3). Over the years with paired escapement estimates, the expanded catch escapements were much lower than the Nushagak sonar counts with a relative bias of –46.6%. To correct for this bias the expanded catch estimates were multiplied by the bias correction. The bias correction (B) is the average relative bias $((\hat{E} - E)/\hat{E})$ weighted by the estimated escapement.

The means of the hind-casted escapement corrected for bias were equal to the mean of the Nushagak River sonar counts. The CV based on the errors in the expanded escapements over the year of paired observations was 0.39. Note, that in estimating the expanded chum salmon catch, the assumed sockeye harvest rates were estimated using the traditional method of catch allocation (West et al. 2012) based on equal exploitation by age class (Table 3). These harvest rates are known to be biased based on comparisons with independent estimates made with genetic stock identification (Dann et al. 2009). Estimates of unbiased harvest rates for Bristol Bay sockeye based on genetic stock identification methods are not available for all years with comparative estimates of chum salmon escapements based on the Nushagak sonar counts.

Table 3.–Statistics relevant to estimating method of expanding chum salmon catch to escapement (Escape.) based on district-specific harvest rates on sockeye salmon. Catch numbers are in thousands of fish.

	Ugashik District			Egegik District			Naknek/Kvichak District			Nushagak District				Togiak District		
Year	Chum Salmon Catch	Ugashik Sockeye Harvest Rate	Ugashik Escape. based on Expanded Catch	Chum Salmon Catch	Egegik Sockeye Harvest Rate	Egegik Escape. based on Expanded Catch	Chum Salmon Catch	Alagnak Sockeye Harvest Rate	Alagnak Escape. based on Expanded Catch	Chum Salmon Catch	Nushagak River Sockeye Harvest Rate	Nushagak Escape. based on Expanded Catch	Nushagak Sonar Count	Chum Salmon Catch	Togiak Sockeye Harvest Rate	Togiak Escape. based on Expanded Catch
1990										375.63	0.61	347.90	329.79			
1991										463.78	0.72	269.42	287.28			
1992										398.69	0.61	367.20	302.68			
1993										505.80	0.68	350.49	217.23			
1994										328.26	0.67	237.03	378.93			
1995										390.16	0.63	338.77	212.61			
1996										331.41	0.71	194.85	225.33			
1997										185.64	0.57	206.97	61.46			
1998										208.55	0.47	341.91	299.44			
1999										170.80	0.67	122.01	242.31			
2000										114.45	0.72	64.22	141.32			
2001										526.60	0.62	481.39	564.37			
2002										276.78	0.51	393.88	419.97			
2003										740.31	0.74	380.81	295.41			
2004										458.90	0.79	177.11	283.81			
2005										966.05	0.70	611.38	448.06			
2006										1,240.17	0.83	370.62	661.00			
2007	242.03	0.66	183.48	157.99	0.82	51.08	383.93	0.42	766.42	953.28	0.80	351.45	161.48	202.49	0.75	98.03
2008	135.29	0.80	50.69	92.90	0.85	23.17	237.26	0.63	203.58	492.33	0.70	308.37	326.30	301.97	0.76	139.81
2009	64.44	0.65	50.44	124.13	0.91	18.10	258.14	0.63	222.28	775.34	0.75	381.50	438.48	143.42	0.64	118.00

ESCAPEMENT OF CHUM SALMON BY REGIONAL REPORTING GROUPS IN THE WASSIP AREA

Chignik/Kodiak Reporting Group

The Chignik/Kodiak chum salmon reporting group includes streams in the Chignik Area, Kodiak Mainland Area, and the Kodiak Archipelago (Habicht et al. 2012). Chum salmon escapements to the two management areas are indexed by the sum of peak aerial or foot surveys of streams and rivers throughout the Chignik and Kodiak management areas where escapement is monitored.

The overall annual escapement index for the Chignik/Kodiak reporting group is the sum of indices for each management area. Chum salmon escapement index numbers for 2007 to 2009 are available from the annual area management reports (AMR) for Chignik (Stichert et al. 2009; Jackson and Anderson 2009; Anderson 2011) and for Kodiak (Dinnocenzo 2010; Dinnocenzo et al. 2010; Dinnocenzo and Caldenty 2008). Note that chum salmon escapement indices published in the Chignik AMRs include stream mouth counts as well as *ad hoc* adjustments in situations where the time between aerial surveys exceeds the stream life. The aerial counts used here are the peak live instream count obtained from the ADF&G regional database, and are slightly lower than the published aerial counts, which maintain consistency with the method used to estimate total escapement. Total escapement for the reporting group was approximated as a 7.15 expansion of the summed aerial survey index with CV of 1.09 (Table 4). There is a small number of chum salmon counted through the Chignik weir and various Kodiak area weir projects and these counts are included in escapement for this reporting group (Table 4).

Table 4.–Escapement (thousands of fish) and CV of chum salmon in the Chignik/Kodiak reporting group, 2007–2009.

	Chignik/Kodiak					
	Chignik Area		Kodiak Area			
Year	Aerial survey index[a]	Chignik weir[b]	Aerial survey index	Weirs	Region escapement	CV
2007	236.98	0.12	248.66	4.43	3,476.75	1.09
2008	197.14	0.12	158.08	1.91	2,541.70	1.09
2009	215.15	0.11	268.61	1.70	3,460.53	1.09

[a] Expansion factor = 7.15 and CV = 1.09 assumed for all Chignik and Kodiak aerial survey indices.

[b] CV = 0.04 is assumed for weir escapement estimates.

South Peninsula Reporting Group

The area from Kupreanof Point to Scotch Cap comprises the South Peninsula reporting group (Habicht et al. 2012); which is also the South Peninsula Management Area. The annual escapement index for the South Peninsula reporting group is the sum of peak aerial counts in the various streams and rivers in the South Unimak, Southwestern, South Central, and Southeastern districts where chum salmon escapement is monitored. Chum salmon escapement index numbers for districts and sections of the South Peninsula management area for 2007 to 2009 are found in AMRs reports (Poetter 2009; Poetter et al. 2008, 2009). Note that chum salmon escapement indices published in the South Alaska Peninsula AMRs include stream mouth counts as well as *ad hoc* adjustments in situations where the time between aerial surveys exceeds the stream life.

The aerial counts used here are the peak live instream counts obtained from the ADF&G regional database, and are slightly lower than the published aerial counts, which maintain consistency with the method used to estimate total escapement. Total escapement for the reporting group was approximated as a 7.15 expansion of the aggregate escapement index with CV of 1.09 (Table 5).

Table 5.–Escapement (thousands of fish) and CV of chum salmon in the South Peninsula reporting group, 2007–2009.

	South Peninsula[a]					
Year	S. Unimak District Aerial survey index	Southwestern District Aerial survey index	South Central District Aerial survey index	Southeastern District Aerial survey index	Region escapement	CV
2007	1.20	315.11	115.70	177.55	4,358.20	1.09
2008	1.40	128.70	107.85	182.05	3,002.89	1.09
2009	1.40	255.56	18.60	105.50	2,724.48	1.09

[a] Peak aerial counts of live fish in stream; Expansion factor = 7.15 and CV = 1.09 assumed for all South Peninsula aerial survey indices.

Northwest District and Northern District Reporting Groups of North Alaska Peninsula Area

The Northwest District reporting group is represented by waters between Cape Sarichef and Moffett Point in the North Alaska Peninsula Management Area. The annual escapement index for the Northwest district is the sum of peak aerial survey counts in a suite of rivers, creeks and bays in four sections (Urilia Bay, Swanson Lagoon, Bechevin Bay, and Izembek-Moffett Bay). Chum salmon escapement index numbers for district sections and totals for 2007 to 2009 are found in area management reports (Hartill and Murphy 2010; Murphy and Hartill 2009; Murphy et al. 2008). Note that chum salmon escapement indices published in the North Alaska Peninsula AMRs include stream mouth counts as well as *ad hoc* adjustments in situations where the time between aerial surveys exceeds the stream life. The aerial counts used here are the peak live instream count obtained from the ADF&G regional database, and are slightly lower than the published aerial counts, which maintain consistency with the method used to estimate total escapement. Total chum salmon escapement for the reporting group was approximated as a 7.15 expansion of the total escapement index for the district with CV of 1.09 (Table 6).

Table 6.–Escapement (thousands of fish) and CV of chum salmon in the Northwest District and Northern District reporting groups, 2007–2009.

	Northwestern District			Northern District		
Year	Aerial survey index	Region escapement	CV	Aerial survey index	Region escapement	CV
2007	277.25	1,982.27	1.09	121.75	870.48	1.09
2008	250.75	1,792.80	1.09	174.71	1,249.13	1.09
2009	78.44	560.83	1.09	153.00	1,093.91	1.09

[a] Peak aerial counts of live fish in stream; Expansion factor = 7.15 and CV = 1.09 assumed for all North Peninsula aerial survey indices.

The Northern District reporting group is represented by waters between Moffett Point and Cape Menshikof in the North Alaska Peninsula Management Area. The annual escapement index for the Northern District is the sum of aerial survey counts from a suite of rivers, creeks and bays in nine sections (Black Hills, Nelson Lagoon, Herendeen-Moller Bay, Bear River, Three Hills, Ilnik, Inner Port Heiden, Outer Port Heiden, and Cinder River). Chum salmon escapement index numbers for district sections and totals for 2007 to 2009 are found in AMRs (Hartill and Murphy 2010; Murphy and Hartill 2009; Murphy et al. 2008). Note that chum salmon escapement indices published in the North Alaska Peninsula AMRs include stream mouth counts as well as *ad hoc* adjustments in situations where the time between aerial surveys exceeds the stream life. The aerial counts used here are the peak live instream count obtained from the ADF&G regional database, and are slightly lower than the published aerial counts, which maintain consistency with the method used to estimate total escapement. Total chum salmon escapement for the reporting group was approximated as a 7.15 expansion of the total escapement index for the district with CV of 1.09 (Table 6).

Coastal Western Alaska Reporting Group

The Coastal Western Alaska Chum Salmon reporting group consists of all chum salmon stocks in the Bristol Bay, Kuskokwim, and Norton Sound management areas, as well as the summer-run chum salmon in the Yukon River. Escapement and escapement CV is presented for the aggregate stocks of the Coastal Western Alaska reporting group (Table 7). Details of source of escapement and escapement CV estimates are provided by management area and for the summer-run chum salmon in the Yukon River in subsequent tables.

Table 7.–Escapement (thousands of fish) and CV of chum salmon in the Coastal Western Alaska Reporting, 2007–2009.

	Bristol Bay Area		Kuskokwim Area		Yukon Summer-Run		Norton Sound Area		Coastal Western Alaska Reporting Group	
Year	Aggregate Escapement	CV	Aggregate Escapement	CV	Aggregate Escapement	CV	Aggregate Escapement	CV	Aggregate Escapement	CV
2007	1,260.50	0.38	2,827.38	0.35	1,613.23	0.19	479.77	0.90	6,180.88	0.35
2008	743.54	0.25	1,642.28	0.37	1,691.90	0.19	173.94	0.47	4,251.67	0.29
2009	847.30	0.21	1,738.06	0.37	1,213.82	0.19	189.84	0.52	3,989.01	0.31

Bristol Bay Area Chum Salmon

Although aerial surveys in Bristol Bay are not designed to assess chum salmon escapements, they demonstrate that chum salmon occur in rivers terminal to each of the Bristol Bay districts. Escapements to the river systems in these districts were estimated based on expanding the chum salmon catch by the appropriate sockeye salmon harvest rate, which are assumed to be an appropriate proxy for chum salmon harvest rates. Harvest rates assumed for sockeye salmon were based on the traditional catch allocation method (cf. West et al. 2012; harvest rates for WASSIP years currently from Fred W. West, Fishery Biologist, ADF&G, Anchorage, personal communication).

Escapement of chum salmon to the Ugashik River was based on the observed Ugashik District chum salmon catch and the estimated harvest rate of Ugashik River sockeye salmon in the Ugashik District (Table 3); to the Egegik River based on observed chum salmon catch in the

Egegik District and harvest rate of Egegik sockeye salmon; to the Alagnak River based on observed chum salmon catch the Naknek/Kvichak District and harvest rate of Alagnak sockeye salmon in the Naknek/Kvichak District; and to the Togiak River based on observed chum salmon catch in the Togiak District and harvest rate of Togiak sockeye salmon in the Togiak District (Table 3). Escapement of chum salmon to the Nushagak District was estimated from the Nushagak River sonar counts (Morstad et al. 2010).

The estimated total escapement of chum salmon in Bristol Bay is the Nushagak River sonar count plus chum salmon escapement to the other districts that were estimated by expanding the chum salmon catch by the respective district sockeye salmon harvest rate (Table 8). The CVs for aggregate Bristol Bay chum salmon escapement were calculated based on methods above and assuming CV of 0.1 for Nushagak River chum salmon sonar counts for 2007 to 2009, and a CV of 0.39 estimated for each expanded district chum salmon catches (Table 8).

Table 8.–Escapement (thousands of fish) and CV of chum salmon in the Bristol Bay Management Area, 2007–2009.

Year	Ugashik River estimate[a]	CV	Egegik River estimate[b]	CV	Alagnak River estimate[c]	CV	Nushagak River estimate	CV	Togiak River estimate[d]	CV	Aggregate escapement estimate	CV
2007	183.48	0.39	51.08	0.39	766.42	0.39	161.48	0.10	98.03	0.39	1,260.50	0.38
2008	50.69	0.39	23.17	0.39	203.58	0.39	326.30	0.10	139.81	0.39	743.54	0.25
2009	50.44	0.39	18.10	0.39	222.28	0.39	438.48	0.10	118.00	0.39	847.30	0.21

[a] District catch of chum salmon expanded by harvest rate on Ugashik sockeye salmon.

[b] District catch of chum salmon expanded by harvest rate on Egegik sockeye salmon.

[c] District catch of chum salmon expanded by harvest rate on Alagnak sockeye salmon.

[d] District catch of chum salmon expanded by harvest rate on Togiak sockeye salmon.

Kuskokwim Area Chum Salmon

Total escapement of chum salmon in the Kuskokwim area was estimated based on information available in the annual area management report (Bavilla et al. 2010), monitoring and assessment reports for the Kanektok River (Clark and Linderman 2009; Taylor and Clark 2010b; Taylor and Elison 2010a) and Goodnews River (Clark and Linderman 2009; Taylor and Clark 2010a; Taylor and Elison 2010b). The stocks of chum salmon in the Kuskokwim area include Goodnews Bay (District 5), Kanektok River (District 4), and the Kuskokwim River.

Escapement estimates of chum salmon in Kuskokwim Bay include weir counts on the Middle Fork of the Goodnews River, aerial survey estimates for the North Fork of the Goodnews River, and weir counts for the Kanektok River (Table 9). The Middle Fork weir had periods during the season when it was breached or not operational because of high water or holes in the weir. Escapements of chum salmon during these periods were estimated. In 2007, 312 chum salmon (<1% of total escapement) were estimated; in 2008, 9,349 (17%) chum salmon were estimated, and in 2009, 3,273 (21%) chum salmon were estimated. Because the fraction of escapements that was estimated was small for 2007, the CV associated with the estimated escapement was assumed to be 0.04. However, for 2008 and 2009 where the portion of estimated escapement was much greater, it was assumed that the CV for these estimated escapement estimates was 0.10

(Toshihide Hamazaki, Division of Commercial Fisheries Biometrician, ADF&G, Anchorage, personal communication)—similar to escapement of sockeye salmon during inoperable periods of the same weir. North Fork Goodnews River escapements were estimated as Middle Fork weir counts multiplied by the average relative magnitude of paired aerial survey counts ($x = 1.48$, CV = 0.37, $n = 8$, range = 0.76–2.55) in the Middle and North forks from 1982 to 2008 (Taylor and Clark 2010a, Appendix C1). Chum salmon escapement assessment for the Kanektok River is based on a weir located 42 river-miles upriver from the mouth (about halfway). Spawning also occurs below the weir, but there are no quantitative estimates of the proportion that spawn in the lower river because it is low-gradient and heavily braided—making it difficult to accurately survey (John Linderman, Commercial Fisheries Biologist, ADF&G, Anchorage, personal communication). It is suspected that at least 50% of the total spawning in the Kanektok River occurs below the weir (Clark and Linderman 2009; Taylor and Elison 2010a; Taylor and Clark 2010b). Because no data are available on which to base an expansion factor, best professional judgment was used to come up with the assumption that total chum salmon escapement is between 2 and 3 times the weir count, with equal probability that the expansion factor is any value between these two end points. Therefore, to estimate total escapement for chum salmon in the Kanektok River, 100,000 expansion factors between 2 and 3 were randomly drawn from a uniform distribution and applied to 100,000 random samples of weir counts drawn from a lognormal distribution with a mean equal to the weir count for each year (2007–2009) and a CV of 0.04 for all years.

Long-term estimates of escapement for the Kuskokwim River chum salmon are available only for the Aniak River sonar and Kogrukluk River weir counts (Bavilla et al. 2010). More recently weirs have been installed on several Kuskokwim River tributaries, including the Kwethluk, George, Tatlawiksuk, and Takotna rivers. Mark–recapture experiments have been conducted, 2002 through 2005, with chum salmon marked and released at Kalskag and recovered at an upriver fish wheel and weirs (Schaberg et al. 2010). Estimates of chum salmon escapement at Kalskag were provided for 2002 and 2003; however these estimates were highly biased and lower that the chum salmon counts upriver due to incomplete mixing of tags and unacceptable tagging mortality (Bue et al. 2008). An independent mark–recapture experiment was conducted in 2002 (Chythlook and Evenson 2003) using radio tags deployed at the mouth of the Holitna River providing an estimate of chum salmon escapement to the Holitna Drainage. Though the precision of the estimate was low (CV = 0.5) due to low recoveries at the Kogrukluk weir, the assessment of chum salmon escapement in 2002 was the most complete to date, with the Holitna River mark–recapture estimate, weirs and sonar projects deployed. A rough estimate of total escapement in 2000, 2002, 2003, and 2006 was provided by Bue et al. (2008, Table 6) using several assumptions to expand estimates to the unassessed tributaries. These included: 1) the Eek and Kisaralik/Kasigluk rivers (tributaries downstream from Kalskag) were assumed to be approximately equal to the Kwethluk River weir counts; 2) For 2000, 2003, and 2006, when Holitna mark–recapture estimates were not available, the Holitna River was assumed to be 1.15 times the Aniak sonar count based on the relative magnitude of 2002 mark recapture and Aniak sonar counts; and 3) the Stony River, the Swift River, tributaries upstream of McGrath, and other tributaries were each assumed to be 10% of the Aniak sonar count (Bue et al. 2008). The estimates of Kuskokwim River escapement provided by Bue et al. (2008) are considered low due to the large aerial extent of the unmonitored tributaries. Expansions are of poor quality, based on several assumptions and a single mark–recapture experiment with a relatively high CV.

Total Kuskokwim River escapements were estimated for years not assessed by Bue et al. (2008) by expansion of escapement to assessed tributaries (Aniak River sonar counts and weir counts on the Kogrukluk, Kwethluk, George, Tatlawiksuk, and Takotna rivers). The expansion factor was estimated to be 2.30, the average ratio of paired total river escapement estimates and assessed tributary escapement counts for 2000, 2002, 2003, and 2006 from Bue et al. (2008, Table 9). The CV of the average expansion factor was low (0.05) and reflects the fact that Bue et al. (2008) used an expansion of the Aniak sonar count to approximate escapement in the unassessed tributaries. For the purposes of this study, the CV for Kuskokwim River chum salmon total escapement was assumed to be 0.4 (Table 9). This was based on applying the method of estimating CV of summed components described above applied to the reconstructed Kuskokwim River chum escapement (Bue et al. 2008). The aggregate escapement CV was calculated assuming CVs for the component weir counts (0.04), sonar counts (0.1), mark–recapture (0.5), and unassessed tributaries (0.5).

Table 9.–Escapement (thousands of fish) and CV of chum salmon in the Kuskokwim Area, 2007–2009.

	Kuskokwim Bay Area				Kuskokwim River				Kuskokwim Area	
	Middle Fork Goodnews River	North Fork Goodnews River	Kanektok River[c]		Aniak River	Kogrukluk, Kwethluk, George, Tatlawiksuk, and Takotna				
Year	Weir[a]	Estimate[b]	Weir	Expansion factor	Sonar	Weirs	Aggregate escapement[d]	CV	Aggregate escapement	CV
2007	49.29	72.74	133.22	2-3	696.80	254.72	2,192	0.40	2,827.38	0.35
2008	44.70	65.97	54.02	2-3	44.98	131.59	1,289	0.40	1,642.28	0.37
2009	19.71	29.09	51.65	2-3	20.05	147.37	1,444	0.40	1,738.06	0.37

[a] 2008 and 2009 Middle Fork escapements include chum salmon estimated to have passed weir during inoperable periods (9,349 fish in 2008 and 3,273 fish in 2009) with an assumed CV = 0.10 for this portion of escapement.

[b] North Fork Goodnews River chum salmon escapement is estimated by multiplying escapement at Middle Fork weir by the average ratio of aerial survey indices for North Fork to Middle Fork (1.48). Estimated CV = 0.37.

[c] Kanektok River weir count for chum salmon is at least half of total escapement, but no data are available to estimate true proportion. Total escapement for Kanektok River chum salmon was estimated by assuming CV of 0.04 for Kanektok weir counts sampled from a lognormal distribution and applying an expansion of 2 to 3 sampled from a uniform distribution.

[d] Kuskokwim River chum salmon escapement is estimated by multiplying the sum of the Aniak River sonar count, Kogrukluk, Kwethluk, George, Tatlawiksuk, and Takotna weir counts by 2.30, with a CV = 0.40.

Yukon River Summer-Run Chum Salmon

Total escapement of summer chum salmon in the Yukon River Area (Table 10) was estimated based on information available in the summer chum salmon stock status and Board of Fisheries report (Bergstrom et al. 2009), 2011 U.S. and Canada Yukon River Joint Technical Committee report (JTC 2012), subsistence and personal use harvest reports (Busher et al. 2009; Jallen and Hamazaki 2011; Jallen et al. 2012), annual area management report (Estensen et al. 2012), and the Yukon Summer chum salmon run reconstruction (Fleischman and Evenson 2010). Escapement is monitored at the East Fork Andreafsky River weir, Pilot Station sonar, and the Anvik River sonar. These data provided the basis of the Yukon River summer chum run reconstruction (Fleischman and Evenson 2010) and includes escapement to the Andreafsky

River, the Anvik River, and the Yukon River upriver of Anvik through 2007. The CVs for escapement estimates from the Yukon River run reconstruction are explicitly estimated from the model and assume CV of 0.1 for the weir counts, 0.2 for the Bendix sonar count data, and 0.4 for the preweir expanded aerial counts. Escapement estimates for these summer chum salmon run components in 2008 and 2009 were taken to be: Andreafsky River escapement as a 2-fold expansion of East Fork Andreafsky river weir count, Anvik River escapement as the Anvik River sonar count, and the Yukon River upriver of Anvik as the Pilot Station sonar count minus the Anvik sonar count and estimated utilization upriver of Pilot Station (Table 10). Utilization includes commercial, subsistence, and personal use harvest. Escapement for 2008 and 2009 were taken from JTC (2012). The estimated utilization upriver of Pilot Station was assumed to be one half the District 2 utilization plus utilization in Districts 3 to 6. Subsistence and personal use harvest, by district, was from Busher et al. (2009), Jallen and Hamazaki (2011), and Jallen et al. (2012). Commercial harvest data were from Estensen et al. (2012). The CVs of escapement (Table 10) were taken to be the CV of the 2008 summer run escapement components provided in (Fleischman and Evenson 2010). These CVs were not explicit in the report, but were calculated from the raw posterior distributions (unpublished ADF&G data obtained from Steve Fleischman, Fisheries Scientist, ADF&G, Division of Sport Fish, Anchorage).

Table 10.–Escapement (thousands of fish) and CV of summer-run chum salmon in Yukon Area, 2007–2009.

	Yukon River Summer-Run							
Year	Andreafsky escapement[a]	CV	Anvik escapement[b]	CV	Above Anvik escapement[c]	CV	Aggregate escapement	CV
2007	140.58	0.24	621.65	0.17	851.00	0.20	1613.23	0.19
2008	114.52	0.24	374.93	0.17	1202.46	0.20	1691.90	0.19
2009	17.54	0.24	193.09	0.17	1003.19	0.20	1213.82	0.19

[a] Andreafsky River chum salmon escapement for 2008 and 2009 is 2 times the East Fork Andreafsky River weir count.

[b] Anvik chum salmon escapement for 2008 and 2009 is Anvik River sonar count.

[c] Above Anvik River chum salmon escapement for 2008 and 2009 is Pilot Station Sonar count less half District 2 utilization, above District 2 utilization, and the Anvik River sonar count.

Norton Sound Area Chum Salmon

Total escapements of chum salmon in Norton Sound were estimated based on information available in the annual area management report (Menard et al. 2011), stock status and action plan for the Subdistrict 1 chum salmon (Menard and Bergstrom 2009a), and stock status and action plan for Subdistricts 2 and 3 chum salmon (Menard and Bergstrom 2009b). Note that chum salmon escapement indices published in the Norton Sound AMRs include may include counts of dead fish in addition to live fish. The aerial counts used here are the peak live instream count obtained from the ADF&G regional database and may be slightly lower than the published aerial counts, which maintain consistency with the method used to estimate total escapement.

Escapement monitoring in the Unalakleet, Shaktoolik and Norton Bay Subdistricts is limited. In the Unalakleet Subdistrict, escapement monitoring includes the tower on the North River (a tributary of the Unalakleet River). A weir has recently been installed on the mainstem Unalakleet

River, but data are not available for WASSIP years. In addition, a multiple year radio telemetry study based on mark–recapture experiments was conducted on the Unalakleet River, 2004 to 2006 (Estensen et al. 2005; Jeff Estensen, Commercial Fisheries Biologist, ADF&G, Fairbanks, personal communication). Escapement monitoring in the Shaktoolik Subdistrict include aerial surveys on the Shaktoolik River. Escapement monitoring in the Norton Bay Subdistricts include aerial surveys on the Inglutalik River and Ungalik River. Aerial surveys in the Eastern Norton Sound Subdistricts are sporadically conducted because of poor survey conditions and not available for each river during the WASSIP years. Unalakleet River chum salmon escapement estimates are based on expanded North River tower counts. The expansion factor (x = 7.30 with a CV of 0.27) was based on three years of paired tower counts and Unalakleet River mark–recapture estimates (Table 11). Aerial surveys are available for all three years for the Shaktoolik River and escapement estimates are based on expansion of these aerial counts using the assumed expansion factor and CV for chum salmon in this report (x = 7.15; CV = 1.09). For the Inglutalik and Ungalik rivers, the only aerial survey conducted between 2007 and 2009 was on the Inglutalik River in 2007. The escapement for 2007 on the Inglutalik was estimated using the assumed expansion factor and CV for chum salmon in this report. Escapement estimates for the Inglutalik and Ungalik Rivers for years not surveyed are based on expansion of the respective year aerial counts in the Shaktoolik River. The expansion factors based the relative magnitude of aerial counts in these rivers to the aerial counts in the Shaktoolik River (Table 11). These were estimated on paired aerial counts from 1980 to 2007 and were 3.01, CV of 1.38, 6 years for the Inglutalik River and 2.11, CV of 1.54, 10 years for the Ungalik River.

Escapements of chum salmon in the Nome Subdistrict (Table 12) include the estimated escapements for Sinuk, Nome, Bonanza, Snake Solomon, Flambeau and Eldorado rivers. Weir or tower counts are available for the Nome, Snake, and Eldorado rivers from 2007 to 2009 (Table 12). Escapements for Sinuk, Bonanza, Solomon, and Flambeau rivers are based on escapement reconstructions (Clark 2001a). Clark's reconstruction was based on calibrated aerial counts in the rivers with weir projects and expansion of aerial counts in rivers without weirs. The method used by Clark (2001a) was applied to estimate escapement from 2007 to 2009 (Menard et al. 2011, Appendix A.29 footnotes). The CV of the aggregate escapement estimates in Nome Subdistrict (Table 12) were derived using the methods described above assuming a CV of 0.04 for weir and 0.05 for tower count escapement components and a CV of 1.09 for calibrated aerial count escapement components. These are the generic CVs assumed for weir counts, tower counts, and expansions of aerial chum salmon counts (Table 1).

Escapement of chum salmon in the Golovin Subdistrict occurs in the Fish River complex and includes the Fish River, Boston Creek, and Niukluk River. Tower counts of chum salmon escapement to the Niukluk River are available since 1996. Total escapement for the Fish River complex (Table 12) was estimated based on expansion of the Niukluk tower counts (Menard et al. 2011). The expansion factor (x = 3.04, CV of 0.06) is based on paired Niukluk tower counts and Fish River escapements estimates from the 2002 to 2004 mark–recapture and radiotelemetry study (Todd et al. 2005).

Table 11.–Escapement (thousands of fish) and CV of chum salmon in the Eastern Norton Sound Subdistricts, 2007–2009.

	Unalakleet District			Shaktoolik District			Norton Bay Subdistrict						Eastern Norton Sound	
	Unalakleet River			Shaktoolik River			Inglutalik River			Ungalik River				
Year	North River tower	Unalalkeet escapement esimate[a]	CV	Aerial survey index	Escapement estimate[b]	CV	Escapement index[c]	Escapement estimate[b]	CV	Escapement index[d]	Escapement estimate[b]	CV	Aggregate escapement estimate	CV
2007	8.15	59.48	0.27	3.28	23.42	1.09	9.05	64.71	1.09	6.90	49.34	1.89	196.95	1.17
2008	9.50	69.34	0.27	0.42	3.00	1.09	1.27	9.05	1.76	0.88	6.33	1.89	87.72	0.39
2009	9.80	71.50	0.27	0.75	5.34	1.09	2.25	16.10	1.76	1.57	11.25	1.89	104.19	0.55

[a] Unalakleet escapement assumed to be 7.3 times the North River tower count.

[b] 7.15 expansion of escapement index count.

[c] Estimated 2008, 2009 Inglutalik River escapement assumed to be 3.01 times the respective Shaktoolik River index.

[d] Estimated Ungalik River escapement assumed to be 2.11 times the respective Shaktoolik River escapement index.

Table 12.–Escapement (thousands of fish) and CV of chum salmon in the Norton Sound Area, 2007–2009.

	Moses Point Subdistrict				Golovin Subdistrict		
Year	Tubutulik Estimated Escapement[a]	Kwiniuk Tower	Estimated escapement	CV	Niukluk River Tower	Estimated escapement	CV
2007	23.06	27.76	50.81	0.64	50.99	155.07	0.12
2008	7.86	9.46	17.32	0.64	12.08	36.73	0.12
2009	7.26	8.74	16.00	0.64	15.88	48.29	0.12

	Nome Subdistrict							
	Escapement Estimates or Weir/Tower Counts by River System							
Year	Nome River[c]	Bonanza River[b]	Snake River[c]	Solomon River[b]	Flambeau River[b]	Eldorado River[c]	Estimated Escapement	CV
2007	7.03	8.49	8.15	3.47	12.01	21.31	76.94	0.75
2008	2.61	3.64	1.24	0.96	11.62	6.75	32.18	0.96
2009	1.57	6.74	0.89	0.92	4.08	4.94	21.37	0.92

	Eastern Norton Sound Subdistricts		Norton Sound Area	
Year	Estimated escapement	CV	Aggregate escapement	CV
2007	196.95	1.17	479.77	0.90
2008	87.72	0.39	173.94	0.47
2009	104.19	0.55	189.84	0.52

[a] Tubutulik escapement assumed to be 0.83 times the Kwiniuk tower count.

[b] Expanded aerial count.

[c] Weir/tower count.

Escapement of chum salmon in the Moses Point Subdistrict occurs in the Tubutulik and Kwiniuk rivers. Tower counts of chum salmon escapement to the Kwiniuk River are available back to 1965. Chum salmon escapement to the Tubutulik River, 1965 to 2001, was based on calibrated aerial counts taken from Clark's (2001b) run reconstruction. The method that Clark (2001b) used is similar to the method used to estimate North Fork Goodnews River from expansion of the Middle Fork weir counts. Clark developed expansions of the Tubutulik aerial counts based on several years of paired aerial counts and tower counts in the Kwiniuk River. Tubutulik escapements, 2007 to 2009, were based on expansion of Kwiniuk tower counts by a factor of 0.83 with CV of 1.0. The expansions of Kwiniuk tower counts are based on paired tower counts and Clark's (2001b) estimates on Tubutulik escapements, 1965 to 2001. The CVs for the aggregated Moses Point Subdistrict escapements (Table 12) assumed CVs of 0.05 for Kwiniuk River tower counts, and 1.09 for Tubutulik River escapements based on expansion of Kwiniuk River tower counts.

Upper Yukon River Reporting Group

The Upper Yukon River reporting group includes the fall-run chum salmon in the Yukon River. Escapements (Table 13) were estimated based on information available in the fall chum salmon sock status and Board of Fisheries report (Borba et al. 2009) and the Yukon fall chum salmon run reconstruction (Fleischman and Borba 2009), and the 2011 U.S. and Canada Yukon River Joint Technical Committee report (JTC 2012). The Yukon River fall chum salmon escapement estimates are based on the Yukon River fall chum run reconstruction (Fleischman and Borba 2009). The run reconstruction report only estimated escapements up to 2007. Escapement estimates for 2007 to 2009 were taken from JTC (2012). Measurement error in the escapement data (CV of 0.1 assumed for DIDSON sonar counts, 0.15 assumed for split-beam sonar counts, 0.2 assumed for Bendix sonar counts, 0.2 for foot survey counts, 0.4 for aerial survey counts, and 0.2 for mark-recapture estimates) was explicitly considered in the Yukon River fall run reconstruction (Fleishman and Borba 2009). The CVs of total Yukon River fall chum salmon escapements used in this study (Table 13) were taken from the run reconstruction report. The CV for 2007 was provided in the report, but estimates for 2008 and 2009 used in this study were based on a 5-year average (2003–2007).

Table 13.–Escapement (thousands of fish) and CV of chum salmon in the Upper Yukon River reporting group, 2007–2009.

	Upper Yukon River	
Year	Escapement	CV
2007	910.88	0.06
2008	687.15	0.07
2009	482.41	0.07

Kotzebue Sound Reporting Group

The Kotzebue Sound reporting group includes the Noatak and Kobuk rivers. Escapements (Table 14) of chum salmon in the Kotzebue Sound were based on information available in the annual area management report (Menard et al. 2011) and from Eggers and Clark (2006) reconstruction of the Kotzebue Sound chum salmon runs. The run reconstruction estimated aerial survey expansion factors for the Noatak and Kobuk aerial counts from paired mark–recapture and sonar counts. Several years of missing aerial counts were estimated from expansion of commercial harvest by the harvest rate estimated from the commercial fishery fishing effort (boat days of fishing) and commercial catchability. The parameters of the run reconstruction (expansion factors for Kobuk aerial counts, expansion factors for Noatak aerial counts, and fishery catchability) were estimated by fitting the various run components. The model fits were generally good with CV for expanded escapements of 0.2 and CV for expanded catch of 0.26. Eggers and Clark (2006) provided escapement estimates through 2004. Total escapements from 2007 to 2009 were estimated by expansion of commercial harvest by the harvest rate estimated from the commercial fishery fishing effort (boat days of fishing) and commercial catchability estimated in the Eggers run reconstruction. The model fits and the total run CV (0.26) estimated based on the square root of the mean deviation of the reconstructed total runs from expanded catch is not a realistic estimate of the uncertainty in the run reconstructed escapements, because the run reconstruction assumed the input data were known without error. Most of the uncertainty in the Kotzebue Sound chum salmon run reconstructions was due to the potential errors in the aerial counts A more realistic estimate of the Kotzebue escapement CV of 1.02 was derived as a blend of the expanded catch CV (0.26) and the generic CV assumed for expanded chum salmon aerial counts (1.09) using methods described above. The relative magnitude of catch and escapement is consistent with the average historical commercial harvest rate of 0.28 observed for the stock.

Table 14.–Commercial harvest (thousands of fish), subsistence harvest (thousands of fish), commercial fishing effort (boat days per season), escapement (thousands of fish) and escapement CV of chum salmon in the Kotzebue Sound reporting group, 2007–2009.

	Kotzebue Sound					
Year	Commercial Harvest	Subsistence Harvest[a]	Effort (boat days)	Total Run[b]	Region escapement	CV
2007	147.09	54.32	146.08	1,071.73	870.32	1.02
2008	190.55	54.32	135.83	1,485.66	1,240.79	1.02
2009	187.56	54.32	216.96	952.70	710.82	1.02

[a] Subsistence harvest not available for WASSIP years, based on the average subsistence harvest, 2000–2004, estimated from run reconstruction.

[b] Total Run estimated by expansion of commercial catch and harvest rate. Harvest rate estimated from fishing effort and catchebility (q = 0.001).

Escapement and CV of Reporting Groups

Total escapement and CV for each reporting group in WASSIP for the years 2007 to 2009 are summarized in Table 15.

Table 15.–Escapement (thousands of fish) and CV of chum salmon within the WASSIP area by reporting group, 2007–2009.

	2007		2008		2009	
Regional Reporting Group	Escapement	CV	Escapement	CV	Escapement	CV
Chignik/Kodiak	3,476.75	1.09	2,541.70	1.09	3,460.53	1.09
South Peninsula	4,358.20	1.09	3,002.89	1.09	2,724.48	1.09
Northwestern District	1,982.27	1.09	1,792.80	1.09	560.83	1.09
Northern District	870.48	1.09	1,249.13	1.09	1,093.91	1.09
Upper Yukon River	910.88	0.06	687.15	0.07	482.41	0.07
CWAK	6,180.88	0.35	4,251.67	0.29	3,989.01	0.31
Kotzebue Sound	870.32	1.02	1,240.79	1.02	710.82	1.02

REFERENCES CITED

ADF&G (Alaska Department of Fish and Game). Alexander: The integrated fisheries database for Southeast Alaska and Yakutat. Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau.

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 November 4, 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 Sciences 58:1663–1671.

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 November 4, 2012).

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 November 4, 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 November 4, 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.

Bergstrom, D. J., D. F. Evenson, and E. J. Newland. 2009. Yukon River summer chum stock status, 2009; a report to the Alaska Board of Fisheries. Alaska Department of Fish and Game, Special Publication No. 09-22, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/SP09-22.pdf (Accessed November 4, 2012).

Borba, B. M., D. J. Bergstrom, and F. J. Bue. 2009. Yukon River fall chum stock status and fall season salmon fisheries, 2009; a report to the Alaska Board of Fisheries. Alaska Department of Fish and Game, Special Publication No. 09-24, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/SP09-24.pdf (Accessed November 4, 2012).

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 November 4, 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.

Bue, B. G., D. B. Molyneaux, and K. L. Schaberg. 2008. Kuskokwim River chum salmon run reconstruction. Alaska Department of Fish and Game, Fishery Data Series No. 08-64, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS08-64.pdf (Accessed November 4, 2012).

Busher, W. H., T. Hamazaki, and D. M. Jallen. 2009. Subsistence and personal use salmon harvests in the Alaska portion of the Yukon River drainage, 2008. Alaska Department of Fish and Game, Fishery Data Series No. 09-73, Anchorage. http://www.adfg.alaska.gov/fedaidpdfs/FDS09-73.pdf (Accessed November 4, 2012).

Clark, J. H. 2001a. Biological escapement goal for chum salmon in Subdistrict One of Norton Sound. Alaska Department of Fish and Game, Regional Information Report 3A01-09, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/RIR.3A.2001.09.pdf (Accessed November 4, 2012).

Clark, J. H. 2001b. Biological escapement goal for Kwiniuk and Tubutulik chum salmon. Alaska Department of Fish and Game, Regional Information Report 3A01-08, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/RIR.3A.2001.08.pdf (Accessed November 4, 2012).

Clark K. J., 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 November 4, 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 November 4, 2012).

Chythlook, J. S. and M. J. Evenson. 2003. Assessment of Chinook, chum, and coho salmon escapements in the Holitna River drainage using radiotelemetry, 2002. Alaska Department of Fish and Game, Fishery Data Series No. 03-23, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds03-23.pdf (Accessed November 4, 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.

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 November 4, 2012).

Dann, T. H., C. Habicht, J. R. Jasper, H. A. Hoyt, A. W. Barclay, W. D. Templin, T. T. Baker, F. W. West, and L. F. Fair. 2009. Genetic stock composition of the commercial harvest of sockeye salmon in Bristol Bay, Alaska, 2006–2009. Alaska Department of Fish and Game, Fishery Manuscript Series No. 09-06, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FMS09-06.pdf (Accessed November 4, 2012).

Dinnocenzo, J. 2010. Kodiak Management Area commercial salmon annual management report, 2008. Alaska Department of Fish and Game, Fishery Management Report No. 10-02, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FMR10-02.pdf (Accessed November 4, 2012).

Dinnocenzo, J., and I. O. Caldentey. 2008. Kodiak management area commercial salmon annual management report, 2007. Alaska Department of Fish and Game, Fishery Management Report No. 08-45, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fmr08-45.pdf (Accessed November 4, 2012).

Dinnocenzo, J., G. Spalinger, and I. O. Caldentey. 2010. Kodiak Management Area commercial salmon fishery annual management report, 2009. Alaska Department of Fish and Game, Fishery Management Report No. 10-22, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FMR10-22.pdf (Accessed November 4, 2012).

Eggers, D. M. and J. H. Clark. 2006. Assessment of historical runs and escapement goals for Kotzebue area chum salmon. Alaska Department of Fish and Game, Fishery Manuscript No. 06-01, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fms06-01.pdf (Accessed November 4, 2012).

Estensen, J. L., S. Hayes, S. Buckelew, D. Green and D. L. Bergstrom. 2012. Annual management report for the Yukon and Northern Areas, 2010. Alaska Department of Fish and Game, Fishery Management Report No. 12-23, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FMR12-23.pdf (Accessed November 4, 2012).

Estensen, J. L., G. L. Todd, and C. S. Monsivias. 2005. Estimation and distribution of chum salmon in the Unalakleet River drainage, 2004. Alaska Department of Fish and Game, Fishery Data Series No. 05-52, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds05-52.pdf (Accessed November 4, 2012).

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

Fleischman, S. J., and B. M. Borba. 2009. Escapement estimation, spawner-recruit analysis, and escapement goal recommendation for fall chum salmon in the Yukon River drainage. Alaska Department of Fish and Game, Fishery Manuscript No. 09-08, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FMS09-08.pdf (Accessed November 4, 2012).

Fleischman, S. J., and D. Evenson. 2010. Run reconstruction, spawner-recruit analysis, and escapement goal recommendation for summer chum salmon in the East Fork of the Andreafsky River. Alaska Department of Fish and Game, Fishery Manuscript No. 10-04, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FMS10-04.pdf (Accessed November 4, 2012).

REFERENCES CITED (Continued)

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 2A98-42, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/RIR.2A.1998.42.pdf (Accessed November 4, 2012).

Hartill, T. G., and R. L. Murphy. 2010. North Alaska Peninsula commercial salmon annual management report, 2009. Alaska Department of Fish and Game, Divisions of Sport Fish and Commercial Fisheries. Fishery Management Report No. 10-19, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FMR10-19.pdf (Accessed November 13, 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 Sciences 56:888–896.

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 November 4, 2012).

Jallen, D. M., and T. Hamazaki. 2011. Subsistence and personal use salmon harvests in the Alaska portion of the Yukon River drainage, 2009. Alaska Department of Fish and Game, Fishery Data Series No. 11-07, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS11-07.pdf (Accessed November 4, 2012).

Jallen, D. M., W. H. Busher, and T. Hamazaki. 2012. Subsistence and personal use salmon harvests in the Alaska portion of the Yukon River drainage, 2007. Alaska Department of Fish and Game, Fishery Data Series No. 12-41, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS12-41.pdf (Accessed November 4, 2012).

JTC (Joint Technical Committee of the Yukon River US/ Canada Panel). 2012. Yukon River salmon 2011 season summary and 2012 season outlook. Alaska Department of Fish and Game, Regional Information Report 3A12-01, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/RIR.3A.2012.01.pdf (Accessed November 13, 2012).

Menard, J., and D. J. Bergstrom. 2009a. Norton Sound Subdistrict 1 (Nome) chum salmon stock status and action plan, 2010: A report to the Alaska Board of Fisheries. Alaska Department of Fish and Game, Special Publication No. 09-20, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/SP09-20.pdf (Accessed November 4, 2012).

Menard, J., and D. J. Bergstrom. 2009b. Norton Sound Subdistrict 2 (Golovin) and Subdistrict 3 (Moses Point) chum salmon stock status and action plan, 2010: A report to the Alaska Board of Fisheries. Alaska Department of Fish and Game, Special Publication No. 09-19, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/SP09-19.pdf (Accessed November 4, 2012).

Menard, J., J. Soong, and S. Kent. 2011. 2009 Annual Management Report Norton, Sound, Port Clarence, and Kotzebue. Alaska Department of Fish and Game, Fishery Management Report No. 11-46. http://www.adfg.alaska.gov/FedAidPDFs/FMR11-46.pdf (Accessed November 4, 2012).

Morstad, S., M. Jones, T. Sands, P. Salomone, T. Baker, G. Buck and F. West. 2010. 2009 Bristol Bay area annual management report. Alaska Department of Fish and Game, Fishery Management Report No. 10-25, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FMR10-25.pdf (Accessed November 4, 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 November 4, 2012).

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 November 4, 2012).

Piston, A. W., and S. C. Heinl. 2010a. Disappearance Creek chum salmon weir study, 2008. Alaska Department of Fish and Game, Fishery Data Series No. 10-15, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS10-15.pdf (Accessed November 4, 2012).

REFERENCES CITED (Continued)

Piston, A. W., and S. C. Heinl. 2010b. Disappearance Creek chum salmon weir study, 2009. Alaska Department of Fish and Game, Fishery Data Series No. 10-48, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS10-48.pdf (Accessed November 4, 2012).

Piston, A. W., and M. T. Brunette. 2011. Disappearance Creek chum salmon weir study, 2010. Alaska Department of Fish and Game, Fishery Data Series No. 11-09, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS11-09.pdf (Accessed November 4, 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 November 4, 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 November 4, 2012).

Poetter, A. D., M. D. Keyse, and A. C. Bernard. 2009. South Alaska Peninsula salmon annual management report, 2009. Alaska Department of Fish and Game, Fishery Management Report No. 09-57, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FMR09-57.pdf (Accessed November 4, 2012).

Quinn, T. J., and R. Gates. 1997. Estimation of salmon escapement models with entry, mortality, and stochasticity. Natural Resources Modelling 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 November 4, 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 November 4, 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 November 4, 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 Sciences 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 November 4, 2012).

Taylor, D. V., 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 November 4, 2012).

Taylor, D. V., and T. B. Elison. 2010a. 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 November 4, 2012).

Taylor, D. V., and T. B. Elison. 2010b. Goodnews River salmon monitoring and assessment, 2009. Alaska Department of Fish and Game, Fishery Data Series No. 10-64, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS10-64.pdf (Accessed November 13, 2012).

Todd, G. L., C. S. Monsivais, and D. F. Kaplan. 2005. Estimation of chum salmon abundance, migration timing, and spawning distribution in the Fish River complex, Norton Sound Alaska, 2002–2004. Alaska Department of Fish and Game, Fishery Data Series No. 05-67. http://www.adfg.alaska.gov/FedAidPDFs/fds05-67.pdf (Accessed November 4, 2012).

REFERENCES CITED (Continued)

West, F., T. T. Baker, S. Morstad, K. Weiland, P. Salomone, T. Sands, and C. Westing. 2012. Abundance, age, sex, and size statistics for Pacific salmon in Bristol Bay, 2005. Alaska Department of Fish and Game, Fishery Data Series No. 12-02, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS12-02.pdf (Accessed November 4, 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.