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Escapement Goals for Coho Salmon Counted in Aggregate Surveys in the Ketchikan and Sitka Areas

by

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and

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Alaska Department of Fish and Game

Divisions of Sport Fish and Commercial Fisheries

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

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

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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ABSTRACT

We examined coho salmon escapement survey counts for groups of streams in the Ketchikan management area (14 streams) and the Sitka management area (5 streams). Although escapement goals for these aggregate escapement indexes would be useful for fishery management, information on age, total escapement and harvest was inadequate for conventional spawner-recruit analysis. We recommend Biological Escapement Goals (BEGs) for these index streams based on estimates of smolt production from brood years with high escapement counts as an indicator of carrying capacity, combined with estimates of average productivity (smolts/spawner) from literature. Smolt production associated with index counts was estimated by incorporating marine survival and exploitation rate estimates from established coded-wire tagged wild indicator stocks at Hugh Smith Lake near Ketchikan area and the Nakwasina River near Sitka. Brood years with lower escapement counts were excluded to insure that estimates of habitat capacity for smolt production were based on a sufficient number of spawners to fully seed available habitat. Recommended point goals were based on average coho salmon stock productivity (smolts/spawner at Maximum Sustained Yield (MSY)) from 17 studies in literature. Optimum escapements were estimated by dividing the estimated smolt production capability (associated with each escapement index) by average productivity at MSY (42.4 smolts/spawner from literature, assuming 12% marine survival). We recommend target range counts based on the estimated smolt production capacity divided by 50.8 smolts/spawner (lower escapement bound) and 25.4 smolts/spawner (upper escapement bound). Resultant ranges are of appropriate breadth for management and are predicted to produce 84% or more of maximum sustained yield based on a hockey stick relationship. Based on these estimates, we recommend a point goal of 5,100 counted spawners with a range of 4,250–8,500 spawners for the Ketchikan index and a point goal of 500 counted spawners with a range of 400–800 for the Sitka index.

Key words: coho salmon, *Oncorhynchus kisutch*, Hugh Smith Lake, Nakwasina River, spawning escapement, smolt abundance, escapement goal, spawner-recruit, carrying capacity, habitat capability, Ketchikan, Sitka, Southeast Alaska

INTRODUCTION

Coho salmon escapements in local systems near Ketchikan and Sitka have been indexed using aerial and foot surveys since the mid-1980s. The purpose of these surveys has been to obtain a representative index of overall escapement in each area. Survey counts provide greater coverage than other methods of escapement assessment but, due to several sources of error, are less complete and have a lower level of resolution compared with weir and mark-recapture methods. Fall months in Southeast Alaska are characterized by high average rainfall and highly variable weather and stream conditions. These factors, combined with variation in run timing and surveyor efficiency, make obtaining comparable surveys and interpreting results between years difficult.

Surveys are most useful for evaluating trends in escapement (Shaul et al. 2004). However, their utility as a fishery management tool has been limited by the absence of a biological escapement objective. Conventionally, escapement goals for salmon populations are developed by fitting a Ricker or Beverton-Holt model to paired data sets of spawners and returns. However, available data on surveyed systems near Ketchikan and Sitka is inadequate to directly estimate a stock-recruitment relationship because of a lack of harvest estimates and age composition samples associated with the counts.

In similar cases, goals have been established based on rearing habitat measurements combined with target spawner densities from literature (Nickelson 1998; Holtby 2002; Bocking and Peacock 2004). We rejected the habitat-based approach for estimating optimum escapement to these systems for two reasons. First, the method requires calibration of survey counts to total escapement. Among the systems under consideration, this calibration has been done only for the Nakwasina River.

A second drawback of the habitat-based method is its dependence on a correlation between habitat measurements and smolt production capability. Coho salmon habitat has typically been quantified based on stream and shoreline length, and sometimes area (Marshall and Britton 1990; Holtby et al. 1990; Nickelson 1998). Based on a sample of 86 streams, Bradford et al. (1997) found that only stream length and, to a lesser extent, latitude was useful in predicting average smolt abundance. They concluded that forecasting smolt yield from stream length and latitude is feasible at the watershed or regional level, but that the precision of predictions for individual streams was poor. Shaul and Van Alen (2001) also found average smolt production per km of stream and lakeshore to vary widely from 213 to 4,140 smolts/km among a group of wild coho salmon indicator stocks in Southeast Alaska and northern British Columbia.

A current study relating detailed habitat measurements with observed fish production for systems in Southeast Alaska (Brian Frenette, Alaska Department of Fish and Game (ADF&G), Sport Fish Division, personal communication) will help evaluate the habitat-based approach to setting escapement goals in this region. However, based on currently available information on variation in coho salmon density and habitat features we elected not to incorporate habitat-based predictors of smolt production capability.

METHODS

We employed an approach for developing escapement goals that assumes recent average smolt production during a period of relatively strong runs and escapements represents the capability of habitat to produce smolts. Direct smolt yield estimates are unavailable for most surveyed systems (with the exception of the Nakwasina River for 2000–2004 returns). However, intensively monitored wild indicator stocks have been evaluated for a period of years in both management areas. In the Ketchikan area, studies of the Hugh Smith Lake stock have been conducted since 1982 (Shaul et al. 2004). In the Sitka area, smolt and adult production from the Salmon Lake stock was estimated from 1985–1990 (Elliott et al. 1989; Schmidt 1986, 1987, 1988, and 1990; Schmidt and DerHovanisian 1991) and again in 1994–1995 (smolt production only; Schmidt 1996) and from the Nakwasina River during 2000–2004 (Brookover et al. 2001, 2003; Tydingco 2003, 2005a, 2005b and *In prep*).

We applied marine survival and exploitation rate estimates from the indicator stocks in the respective areas to the aggregate escapement survey counts to estimate smolt yield. This approach implies that marine survival and exploitation rates apply evenly to stocks within each area. While variation in these rates likely exists within each area, we believe the potential error in this assumption is lower than error in habitat-based predictions of smolt production capacity among highly varied local habitats.

A second advantage of this approach is that the method allows goals to be established based on smolt production associated with the summed peak survey counts without the need to expand survey counts to total escapement. This feature avoids another problematic assumption inherent in the habitat-based approach.

The observed production and habitat-based approaches both require an assumed value for the productivity parameter (α) of a stock and an assumed form of spawner-recruit relationship. In developing habitat-based models, Bocking and Peacock (2004) applied average freshwater survival values for coho salmon from the literature to estimate the number of smolts/spawner at replacement. Based on average fecundity estimates of 2,500 eggs/female for the Nass system and 3,000 eggs/female for coastal systems and average published egg to fry survival of 19.8% and fry to smolt survival of 7.6% (Bradford 1995), their model assumed productivity of 18.8 to 22.6 smolts/spawner. These productivity values are likely conservative. Average freshwater survival rates may be substantially lower than the survival rate associated with maximum sustained yield (MSY) because freshwater survival increases as spawner density declines in streams that are fully seeded. Accurate estimates of productivity require estimates of smolts produced per spawner at MSY.

We used literature-based estimates of productivity for coho salmon and scaled them to the estimated smolt production potential associated with the survey indexes. For stocks reviewed in literature, estimated smolt production capacity was divided by estimated spawning escapement at MSY (assuming a constant 12% marine survival rate). We calibrated average estimates of smolts/spawner with estimates of average smolt production associated with higher brood year counts (assuming returning adults were age 3 and 4), under the assumption of full habitat seeding by spawners. We calibrated estimates of average stock productivity from detailed studies with estimated habitat capability associated with the survey counts.

Current escapement goals for the four long-term indicator stocks in the region have upper goal bounds that range from 2.2 to 2.5 times the lower bound (Clark et al. 1994). These bounds have provided a meaningful management target, considering inseason management capability, variation in run size, and uncertainty in the point goal estimates. Based on a decade of experience with these goals, we conclude that the ratio of the upper to lower goal bound around the MSY estimate should be at least 2 but probably no more than 2.5. In this study we initially set goal bounds based on a range estimated to produce 90% or more of MSY, based on the average from 15 published studies. In cases where we believed the range was narrower than desired as a management target, we broadened the goal so that the upper bound was double the lower bound while maintaining a constant fraction of MSY at both bounds.

SURVEY INDEX

The strategy for counting spawning coho salmon in the Ketchikan and Sitka areas was to survey when the peak number of fish was visible in survey areas. Local staff in each area timed their survey efforts to the peak of the run, based on experience, and during periods of favorable weather conditions and good visibility. Peak counts for individual streams were summed to obtain a total index of escapement for each area. Interpolations (described below) were made in cases where counts for individual streams were missing to obtain a comparable total index for each area.

Ketchikan Area

Escapement counts in the Ketchikan area were conducted by helicopter on 14 streams (Figure 1). Two surveys were scheduled for different periods: a pre-peak period during about September 28–October 1 and a peak period during October 15–20. If conditions prevented an effective survey during the pre-peak target period, the survey was conducted at the first good opportunity after that date. In cases in which the first survey had to be delayed until the peak period, only one survey was conducted. Surveys were not conducted after October 31. Spawners were often more concentrated in pools during the early period. There were likely more fish present during the later peak survey but they were often more scattered throughout the survey area and more difficult to thoroughly count.

Helicopter surveys were usually conducted from an altitude of 30–50 m with the sun at the observer's back when possible. The observer wore polarized sunglasses and the passenger door on the observer's side was usually removed to improve visibility. The observer directed the pilot through an intercom with headsets. The helicopter was flown slowly along the stream course to the side of the channel to provide the observer with optimal visibility into the stream. The helicopter was slowed or stopped when necessary to provide the observer time to count larger aggregations of fish.

Each of two staff members in the Ketchikan office was responsible for a different group of streams. One biologist surveyed streams in Behm Canal and Portland Canal (Tombstone River, Blossum River, Keta River, Marten River and Humpback Creek). The other surveyed Chickamin River tributaries (Indian, Barrier, King and Choca Creeks), Burroughs Bay streams (Herman Creek, Grant Creek, Klahini River, Eulachon River) and Carroll Creek on Revillagigedo Island. All streams in each circuit were usually flown in the same day, but individual streams with poor visibility conditions were sometimes skipped and surveyed on a later flight.

The Ketchikan escapement survey index is the sum of counts for all 14 streams, including interpolations (Table 1).

Sitka Area

Five streams have been routinely surveyed in and around Sitka Sound since the mid-1980s. The Sitka survey index is the sum of counts for the five streams (Table 2), including interpolated values for missing counts using a procedure described in the next section. Comparable peak counts were obtained from Starrigavan Creek (Figure 2) every year since 1982. St. John's Creek, Sinitsin Creek and the Nakwasina River have been surveyed in most years since 1983. Peak survey counts were obtained from the Eagle River on Kruzof Island from 1986–2004, with exceptions being 1988, 1989 and 1999.

Access was by road and boat and surveys were conducted by two or three observers who walked from tidewater to the uppermost reaches of coho salmon spawning. The crew walked on the bank or instream as conditions warranted and attempted to observe as many coho salmon as possible. Spawners were often prodded from cover for counting with rocks or long sticks. In some years, one observer counted from within the stream, wearing a wetsuit or drysuit, snorkel and face mask. This method has been used annually in Eagle River since 1990 and occasionally in the other systems.

Surveys in the Sitka area were targeted for late September and October and scheduled on days when weather and visibility conditions were favorable.

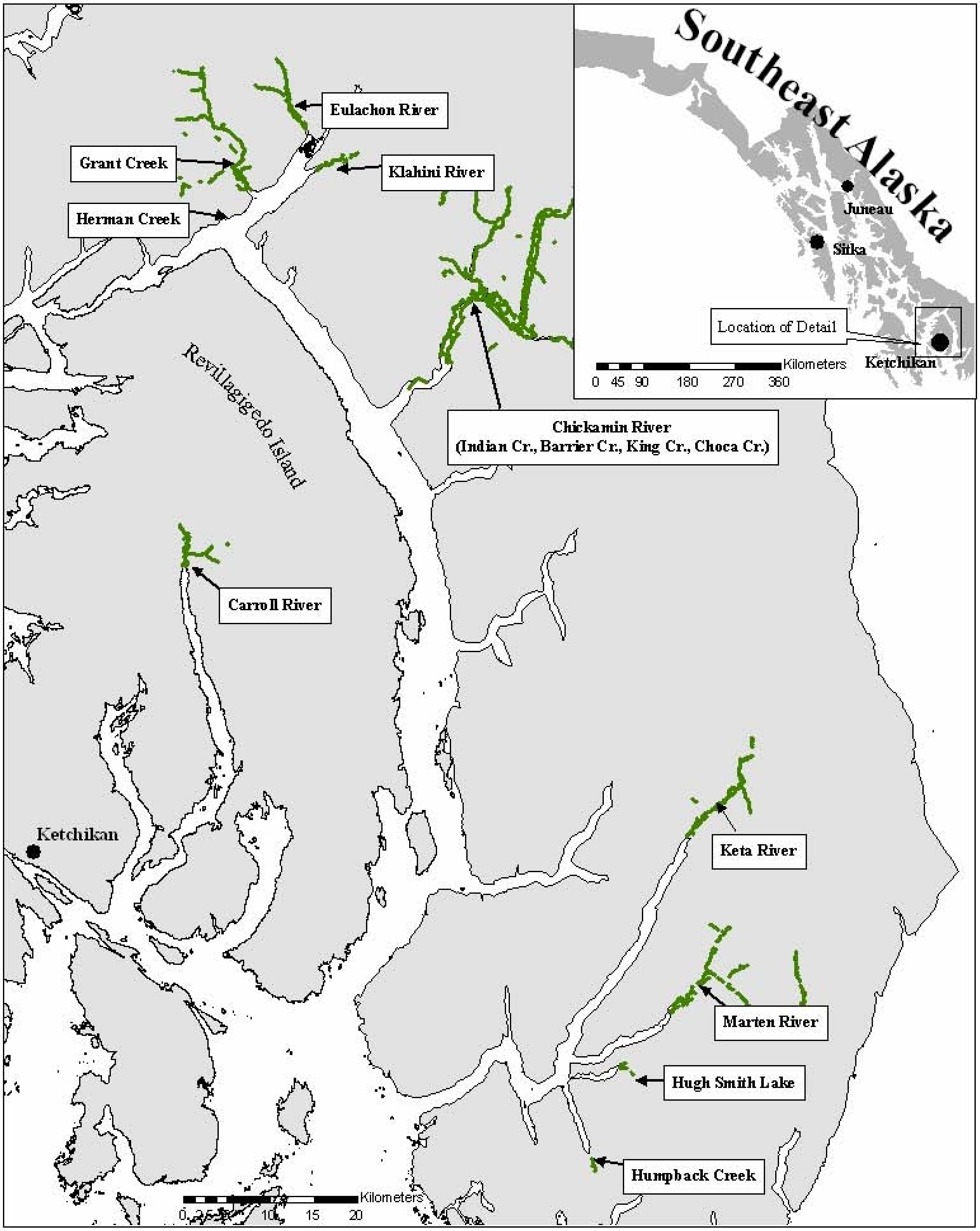

Figure 1.–Hugh Smith Lake and streams surveyed by helicopter for coho salmon escapement in the Ketchikan area.

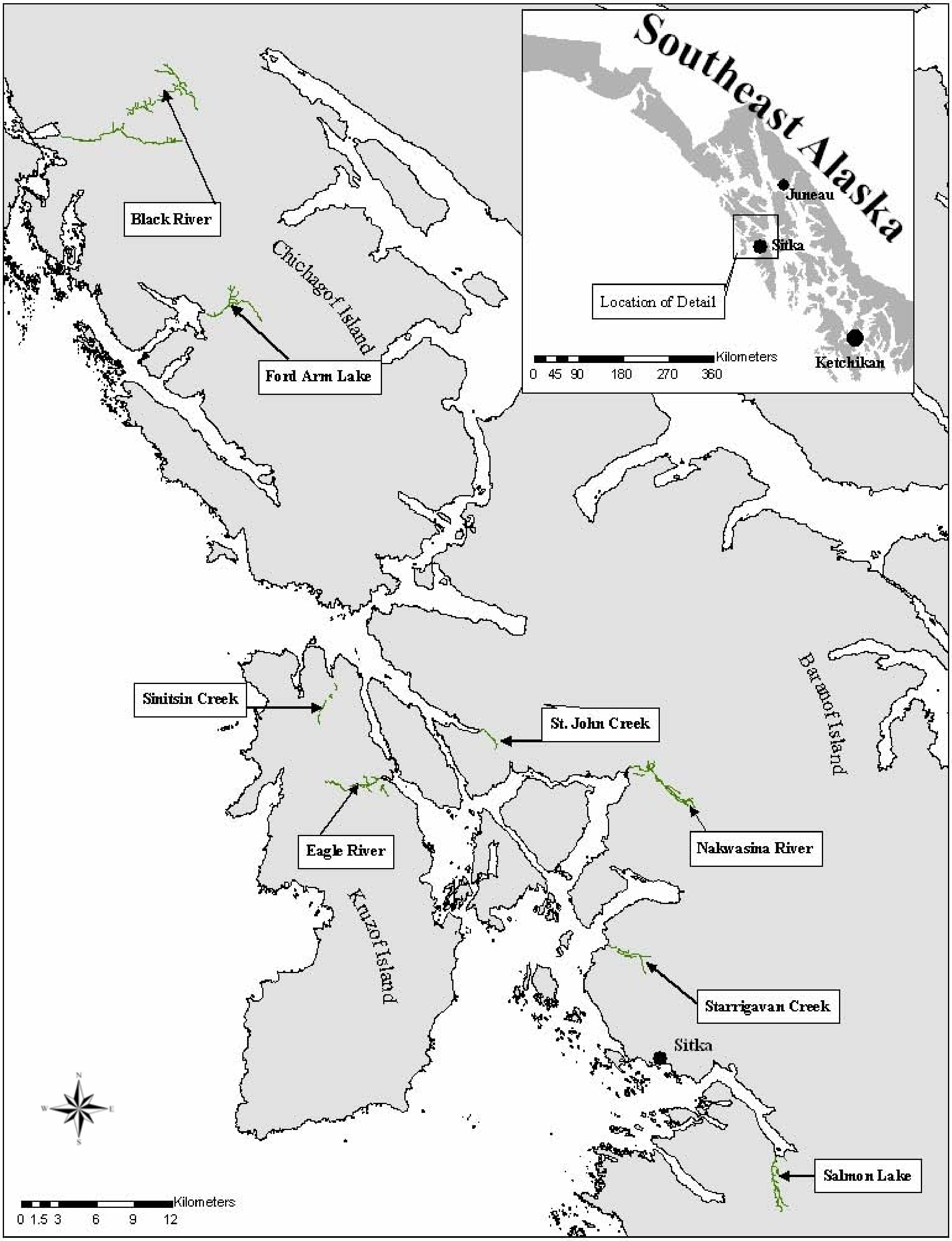

Figure 2.–Ford Arm Lake, Salmon Lake and streams surveyed for coho salmon escapement in the Sitka area.

Table 1.–Peak coho salmon survey counts for 14 streams in the Ketchikan area and total adult coho salmon escapement to Hugh Smith Lake, 1987–2004. Total index is the sum of counts and interpolated values. Interpolated values are shown in shaded bold italic print.

Year	Herman Creek	Grant Creek	Eulachon River	Klahini River	Indian River	Barrier Creek	King Creek	Choca Creek
1987	92	***88***	154	***62***	***387***	***98***	***304***	***145***
1988	72	150	205	20	300	50	175	150
1989	75	101	290	15	925	450	510	200
1990	150	30	235	150	***282***	***72***	35	***105***
1991	245	50	285	50	550	100	300	220
1992	115	270	860	90	675	100	250	150
1993	90	175	460	50	475	325	110	300
1994	265	220	755	200	560	175	325	225
1995	250	94	435	165	600	220	415	180
1996	94	92	383	40	570	230	457	220
1997	75	***85***	420	60	***371***	***94***	***292***	175
1998	94	130	460	120	304	50	411	190
1999	75	127	657	150	356	25	627	225
2000	135	94	600	110	380	72	620	180
2001	80	110	929	151	1,140	***212***	891	450
2002	88	138	1,105	20	940	70	700	220
2003	242	***197***	875	39	690	57	1,140	380
2004	150	230	801	170	935	250	640	180
Average	133	132	551	92	580	147	456	216

Year	Carroll River	Blossum River	Keta River	Marten River	Humpback Creek	Tombstone River	Combined Count	Hugh Smith L. (Weir)
1987	180	700	800	740	650	532	4,933	1,118
1988	193	790	850	600	52	1,400	5,007	513
1989	70	1,000	650	1,175	350	950	6,761	433
1990	***139***	800	550	575	135	275	3,533	870
1991	375	725	800	575	671	775	5,721	1,826
1992	360	650	627	1,285	550	1,035	7,017	1,426
1993	310	850	725	1,525	600	1,275	7,270	830
1994	475	775	1,100	2,205	560	850	8,690	1,753
1995	400	800	1,155	1,385	82	2,446	8,627	1,781
1996	240	829	1,506	1,924	440	1,806	8,831	958
1997	140	1,143	571	759	32	847	5,063	732
1998	***255***	1,004	1,169	1,961	256	666	7,070	983
1999	425	598	1,895	1,518	520	840	8,038	1,246
2000	275	1,354	1,619	1,421	102	1,672	8,634	600
2001	173	1,561	***1,612***	1,956	506	***1,704***	11,475	1,580
2002	270	1,359	1,368	2,302	2,004	1,639	12,223	3,291
2003	***427***	1,940	1,934	1,980	214	1,745	11,859	1,510
2004	455	1,005	1,200	1,835	1,230	823	9,904	840
Average	287	994	1,118	1,429	497	1,182	7,814	1,238

Table 2.–Peak escapement counts in five surveyed streams in the Sitka survey index and in the Black River, and total escapement estimates for Ford Arm Lake and the Nakwasina River. The Sitka survey index is the sum of counts and interpolated values. Interpolated values are shown in shaded bold italic print.

Year	Starrigavan Creek	Sinitsin Creek	St. John's Creek	Nakwasina River	Eagle River	Sitka Survey Index	Nakwasina River M/R Estimate	Black R. Survey Count	Ford Arm Lake (Weir-M/R)
1982	317	46	***116***	***580***	***486***	1,545			2,662
1983	45	31	12	217	***144***	457			1,938
1984	385	160	154	715	***649***	2,063		425	
1985	193	144	109	408	***392***	1,246		1,628	2,324
1986	57	***72***	***53***	275	687	702		312	1,546
1987	36	21	***22***	47	167	293		262	1,694
1988	45	56	71	104	***127***	403		280	3,028
1989	101	76	89	129	***181***	576		181	2,177
1990	39	80	38	195	214	566		842	2,190
1991	142	186	107	621	454	1,510		690	2,761
1992	241	265	110	654	629	1,899		866	3,847
1993	256	213	90	***644***	513	1,716		764	4,202
1994	304	313	227	404	717	1,965		758	3,228
1995	274	152	99	626	336	1,487		1,265	2,445
1996	59	150	201	553	488	1,451		385	2,500
1997	55	90	68	300	296	809		686	4,965
1998	123	109	57	653	300	1,242		1,520	7,049
1999	167	48	25	291	***245***	778		1,590	3,598
2000	144	62	30	459	108	803	2,000	880	2,287
2001	133	132	80	753	417	1,515	2,992	1,080	2,178
2002	227	169	100	713	659	1,868	3,141	1,194	7,109
2003	95	102	91	440	373	1,101	2,063	1,055	6,789
2004	143	112	79	399	391	1,124	3,867	380	3,539
Average	156	121	89	443	371	1,179	2,813	833	3,358

ACCOUNTING FOR MISSING COUNTS

Only peak survey counts that met standards for timing, survey conditions, and completeness were included in the indexes. Interpolations were made for missing counts under the assumption that the expected value is determined for a given stream and year in a multiplicative way (i.e., counts across streams for a given year are multiples of counts for other years, and counts across years for a stream are multiples of counts for other streams). The estimated expected count for a given stream in a given year is then equal to the sum of all counts for the year times the sum of all counts for the stream divided by the sum of counts over all streams and years. If there is more than one missing value, an iterative procedure, as described by Brown (1974), was used since the sums changed as missing counts were filled in at each step. The interpolated values are shown in bold italics in shaded blocks (Tables 1 and 2).

ESTIMATING SMOLT PRODUCTION CAPABILITY

We used average estimated smolt numbers associated with the survey counts as a best estimate of habitat capability or carrying capacity (K) based on an assumed hockey stick model (Barrowman and Meyers 2000) in which production was assumed to be independent of spawning escapement above a minimum threshold level or reference point. Since smolt production may have been limited by spawning escapement in some years, we also calculated averages that excluded years with low brood year peak spawner counts and used those numbers if they were higher than the average for all years.

The estimated number of smolts (Ns_i) associated with the escapement index count (E_i) for each area in year i was estimated as follows:

$$\hat{N}s_i = \frac{E_i}{\left[\left(1-\hat{H}_i\right)\hat{S}_i\right]}$$

where H_i is the exploitation rate for the indicator stock in year i

and S_i is the marine survival rate for the indicator stock in year i

The resultant estimates do not account for total system smolt production, but represent only estimates of the number of smolts that resulted in the number of spawners in the combined peak survey count. The smolt estimates were averaged, and averages from higher brood year escapement counts were used to estimate habitat capability associated with the survey index.

RESULTS

SMOLT PRODUCTION CAPACITY

Ketchikan Area

Smolt production associated with the Ketchikan escapement index in 1987–2004 was estimated based on marine survival and exploitation rate estimates for the Hugh Smith Lake indicator stock (Figure 1). Resultant smolt production estimates associated with the survey index during an 18-year period averaged 215,581 smolts (Table 3). Average smolt production associated with 7 brood years in which escapement counts were over 7,000 spawners remained nearly unchanged at 215,755 smolts, suggesting that spawning escapement has likely not been an important factor limiting production in most years.

Table 3.–Estimates of smolt production associated with the Ketchikan coho salmon escapement survey index based on exploitation rate and marine survival rate estimates for local wild indicator stocks. Also shown are escapement reference points based on a target range of 25.4–50.8 smolts/spawner.

	Hugh Smith Lake Indicator Stock		Ketchikan Survey Index		Reference Points based on Smolts/Spawner		
Return Year	**Exploitation Rate**	**Marine Survival**	**Sum. of Counts**	**Associated Smolts**	**Lower (50.8)**	**MSY (42.4)**	**Upper (25.4)**
1987	52.3%	10.7%	4,933	96,529	1,902	2,277	3,806
1988	66.5%	4.2%	5,007	353,495	6,965	8,337	13,937
1989	82.1%	10.4%	6,761	364,381	7,179	8,594	14,366
1990	81.1%	17.3%	3,533	108,103	2,130	2,550	4,262
1991	68.1%	17.4%	5,721	103,156	2,032	2,433	4,067
1992	70.8%	21.0%	7,017	114,805	2,262	2,708	4,526
1993	80.6%	13.0%	7,270	287,757	5,670	6,787	11,345
1994	81.4%	19.4%	8,690	241,910	4,766	5,705	9,537
1995	73.6%	13.7%	8,627	238,732	4,704	5,630	9,412
1996	75.7%	17.9%	8,831	203,404	4,008	4,797	8,019
1997	72.4%	8.2%	5,063	223,470	4,403	5,271	8,810
1998	77.2%	11.4%	7,070	272,573	5,370	6,429	10,746
1999	70.2%	14.0%	8,038	192,690	3,797	4,545	7,597
2000	55.5%	6.6%	8,634	292,917	5,771	6,908	11,548
2001	49.4%	13.5%	11,475	168,385	3,318	3,971	6,639
2002	38.9%	14.7%	12,223	135,564	2,671	3,197	5,345
2003	58.8%	13.7%	11,859	210,767	4,153	4,971	8,310
2004	65.0%	10.4%	9,904	271,817	5,356	6,411	10,716
Average (n = 18)	67.8%	13.2%	7,814	215,581	4,248	5,084	8,499
Average for Returns after 1990 with Both Brood Year Escapements >7,000 Spawners (n = 7)			8,998	215,755	4,251	5,089	8,506

Sitka Area

Smolt production associated with the Sitka escapement index in 2000–2004 (Table 4) was estimated based on marine survival and exploitation rate estimates for the Nakwasina River stock (Brookover et al. 2003; Tydingco 2003, 2005a, 2005b and *In prep*). Estimates for the Salmon Lake stock were available from 1985–1990 (Elliott et al. 1989; Schmidt 1986, 1987, 1988, and 1990; Schmidt and DerHovanisian 1991). However, we elected not to include Salmon Lake estimates in the analysis since most were taken from weir counts made under periodic flood conditions without back-up mark-recapture estimation. Also, Salmon Lake smolts are exceptionally large and their marine survival rate may not be indicative of most stream systems near Sitka.

During the 1999–2003, estimated smolt production from the Nakwasina River averaged 43,134 fish and ranged from 22,472 to 55,424 fish (Brookover et al. 2003; Tydingco 2003, 2005a, 2005b and *In prep*). Brookover et al. 2001 estimated that a substantially larger number of smolts (102,794; standard error = 14,255) migrated in 1998. We elected not to incorporate the 1998 smolt estimate because marine survival and the exploitation rate estimates were not made for the associated 1999 adult return and because available rearing habitat appeared to decrease after 1998. A beaver dam that existed in 1998 later deteriorated and its impoundment was drained (Tom Brookover, ADF&G, Anchorage, personal communication).

Survival and exploitation rate estimates for the Sitka survey index based on the Nakwasina indicator stock are limited to 5 return years, making it difficult to compare average production associated with low and high brood year escapement. Tydingco (*In prep*) estimated an average of 97.6% (range 96.4–98.7%) of adults returning to the Nakwasina River to be age 3. Based on the assumption of only one contributing brood year (age 1), smolt production from three brood year escapement counts ranging from 776–809 spawners averaged 19,013 (range 11,993–25,947) smolts compared with 19,847 (range 16,110–23,583) smolts from two brood year escapement counts ranging from 1,242–1,515 spawners. The slightly (4.4%) greater average smolt production estimate from the higher brood year escapements was used as the best estimate of smolt production capability at full seeding.

SPAWNER PRODUCTIVITY

We reviewed the literature to determine an expected number of smolts per spawner at maximum sustained yield (MSY). Bradford et al. (2000) estimated MSY reference points for 14 coho salmon stocks from Oregon to central British Columbia based on a review of studies that resulted in paired data sets of escapement and smolt production (Table 5). From their hockey stick parameter estimates based on these data sets, we calculated a range of smolts per spawner associated with lower and upper escapements expected to produce 90% or more of MSY, based on a constant marine survival rate of 12%.

We followed a similar procedure using a Ricker model fit to paired escapement and smolt production estimates (PMFC 2001) for the Queets River stock on the Washington coast.

Finally, we followed the same procedure for four wild coho salmon indicator stocks in Southeast Alaska (Clark et al. 1994), except that we used average survival rates for each system instead of assuming a constant 12% survival rate. Substantial errors have been found in aging of Southeast Alaska coho salmon after these goals were established, but there is no indication from subsequent returns that they do not reasonably approximate MSY escapement. The Berners

River scale collection has been re-aged based on known-age standards acquired from an aging validation study. An updated spawner-recruit relationship based on expanded survey estimates was fit using a hockey stick model (Shaul and Crabtree *In prep*). Spawner-recruit relationships and escapement goals for Auke Creek, Ford Arm Lake and Hugh Smith Lake have not been updated.

Productivity estimates at MSY for studies reviewed by Bradford et al. (2000) averaged 47 smolts/spawner and ranged from 19 for Hunt's Creek in southern British Columbia to 106 for Minter Creek, Washington. Excluding those two extremes, estimates for the remaining 12 systems ranged from 22 for the Deschutes River to 72 for Carnation Creek and averaged 44 smolts/spawner (Table 5). Excluding Hunt's and Minter Creeks, bounds associated with 90% or more of MSY averaged 30 and 49 smolts/spawner, respectively. MSY for the Queets River was estimated at 37 smolts/spawner by the Ricker model with 90% of MSY bounds of 25-58 smolts/spawner (assuming constant 12% marine survival). Estimates associated with existing MSY goals for the four long-term Southeast Alaska indicator stocks vary from 20 (range 14–34) smolts/spawner for Auke Creek to 41 (range 29–63) smolts/spawner for Hugh Smith Lake. The Auke Creek stock has had a high average marine survival rate of 20% and a low average exploitation rate of 40% (Shaul et al. 2004). The current Auke Creek escapement goal was based on data with relatively little contrast and high average marine survival (natural and fishing-related) and may be substantially higher than actual MSY.

Our recommended goals for Ketchikan and Sitka surveyed systems are based on an average productivity at MSY for twelve of the systems considered by Bradford (excluding Hunt's and Minter Creeks), and the Queets River, Toboggan Creek, Auke Creek, Hugh Smith Lake, and an updated estimate for the Berners River (Shaul and Crabtree *In prep*). On average, at MSY these 17 systems produce an estimated 42.4 smolts/spawner (range of 29.1 to 50.1 smolts/spawner corresponds with 90% or more of MSY). This range is relatively narrow for an escapement goal range given the lack of fine scale in-season assessment information, with the upper bound only 1.72 times the lower bound compared with our desired ratio of no less than 2. Therefore, we set the recommended upper bound at double the lower bound based on a hockey stick model and an MSY reference point of 42.4 smolts/spawner, assuming a marine survival rate of 12%. The resulting range corresponds with 84% or more of MSY at equilibrium exploitation rates of 80% at the upper bound and 67% at the lower bound. The range corresponds with 25.4 to 50.8 smolts/spawner when escapements at the bounds are applied to smolt production at carrying capacity. Note that the hockey stick model predicts actual maximum productivity at only 42.4 smolts/spawner at the lower escapement bound but the higher smolts/spawner number at the lower bound applies to smolts at carrying capacity (instead of predicted production) divided by escapement.

A rough comparison with estimates of smolt production associated with the Ketchikan survey index suggests that Ketchikan area stocks are capable of this level of productivity. If we average age 3 and 4 brood year escapements associated with the Ketchikan survey index (assuming a 50% contribution by each brood year), production has averaged 31 smolts/spawner (range 18–56). If all returning adults are assumed to be age 3, production has also averaged 31 smolts/spawner with a range of 16–81 smolts/spawner. The average of 31 smolts/spawner is likely well above MSY since there is no indication that index counts of over 7,000 spawners (90% or more of average) have resulted in significantly higher production than lower escapements (Table 3).

Table 4.–Estimates of smolt production associated with the Sitka coho salmon escapement survey index based on exploitation rate and marine survival rate estimates for local wild indicator stocks. Also shown are escapement reference points based on a target range of 25.4–50.8 smolts/spawner.

	Indicator Stock Estimates			Sitka Survey Index		Reference Points based on Smolts/Spawner		
Retur Year	**Stock**	**Exploitation Rate**	**Marine Survival**	**Sum. of Counts**	**Smolts**	**Lower (50.8)**	**MSY (42.4)**	**Upper (25.4)**
1982				1,545				
1983				457				
1984				2,063				
1985	Salmon L.	35.2%	13.5%	1,246	14,215	280	335	560
1986	Salmon L.	43.5%	12.7%	702	9,779	193	231	386
1987	Salmon L.	55.1%	9.4%	293	6,948	137	164	274
1988	Salmon L.	48.1%	10.9%	403	7,088	140	167	279
1989	Salmon L.	71.9%	5.6%	576	36,507	719	861	1,439
1990	Salmon L.	73.8%	8.2%	566	26,330	519	621	1,038
1991				1,510				
1992				1,899				
1993				1,716				
1994				1,965				
1995				1,487				
1996				1,451				
1997				809				
1998				1,242				
1999				776				
2000	Nakwasina R.	37.9%	6.8%	803	19,100	376	450	753
2001	Nakwasina R.	32.5%	9.5%	1,515	23,583	465	556	930
2002	Nakwasina R.	18.9%	8.9%	1,868	25,947	511	612	1,023
2003	Nakwasina R.	22.6%	11.9%	1,101	11,993	236	283	473
2004	Nakwasina R.	29.8%	9.9%	1,124	16,110	317	380	635
Average		42.7%	9.8%	1,178	17,964	354	424	708
Salmon L. (Average)		54.6%	10.1%	628	16,811	331	396	663
Nakwasina								
2000–2004 Average		28.3%	9.4%	1,282	19,347	381	456	763
2001, 2004 Average		31.2%	9.7%	1,320	19,847	391	468	782
2000, 2002 and 2003 Average		26.5%	9.2%	1,257	19,013	375	448	750

Table 5.–Coho salmon smolt production per spawner based on estimates of habitat carrying capacity divided by estimates of spawning escapement at MSY and at lower and upper bounds estimated to produce 90% of MSY (assumes a constant 12% marine survival rate).

			Smolts Per Spawner		
System	**Source**	**Model**	**MSY**	**Lower**	**Upper**
Big Beef Cr.	[a]Sharma 1998	Hockey Stick	34	37	26
Big Qualicum River	[a]Fraser et al. 1983	"	44	49	31
Bingham Creek	[a]Sharma 1998	"	40	44	29
Black Creek	[a]J. Irvine and K. Simpson, unpublished data	"	39	43	28
Carnation Creek	[a]Anderson and Scrivener 1993; P.Tschaplinski, B.C. Ministry of Forests, unpublished data	"	72	80	41
Deer Creek	[a]Knight 1980	"	54	60	35
Deschutes River	[a]Sharma 1998	"	22	24	19
Flynn Creek	[a]Knight 1980	"	40	44	29
Hooknose Creek	[a]Hunter 1959	"	70	78	40
Hunt's Creek	[a]Fraser et al. 1983	"	19	21	17
Minter Creek	[a]Salo and Bayliff 1958	"	106	118	49
Needle Branch Creek	[a]Knight 1980	"	40	44	29
Skykomish River	[a]Sharma 1998	"	44	48	31
Snow Creek	[a]Johnson and Cooper 1995	"	34	38	26
Average (Bradford et al. 2000)			47	52	31
Average without Hunt's Cr. and Minter Cr.			44	49	30
Queets R.	PMFC 2001	Ricker	37	58	25
Babine River	Shaul and Van Alen (2001)	Ricker	129	205	89
Toboggan Creek	Shaul and Van Alen (2001)	Ricker	39	62	27
Berners River (adj. for survey efficiency)	Estimates through 2004 return	Hockey Stick	28	31	23
Berners River Current Goal	Clark et al. 1994	Ricker	37	58	25
Hugh Smith Lake Current Goal	Clark et al. 1994	Ricker	41	63	29
Auke Creek Current Goal	Clark et al. 1994	Ricker	20	34	14
Ford Arm Lake Current Goal (presmolts)	Clark et al. 1994	Ricker	29	46	21

[a] Cited by Bradford et al. 2000.

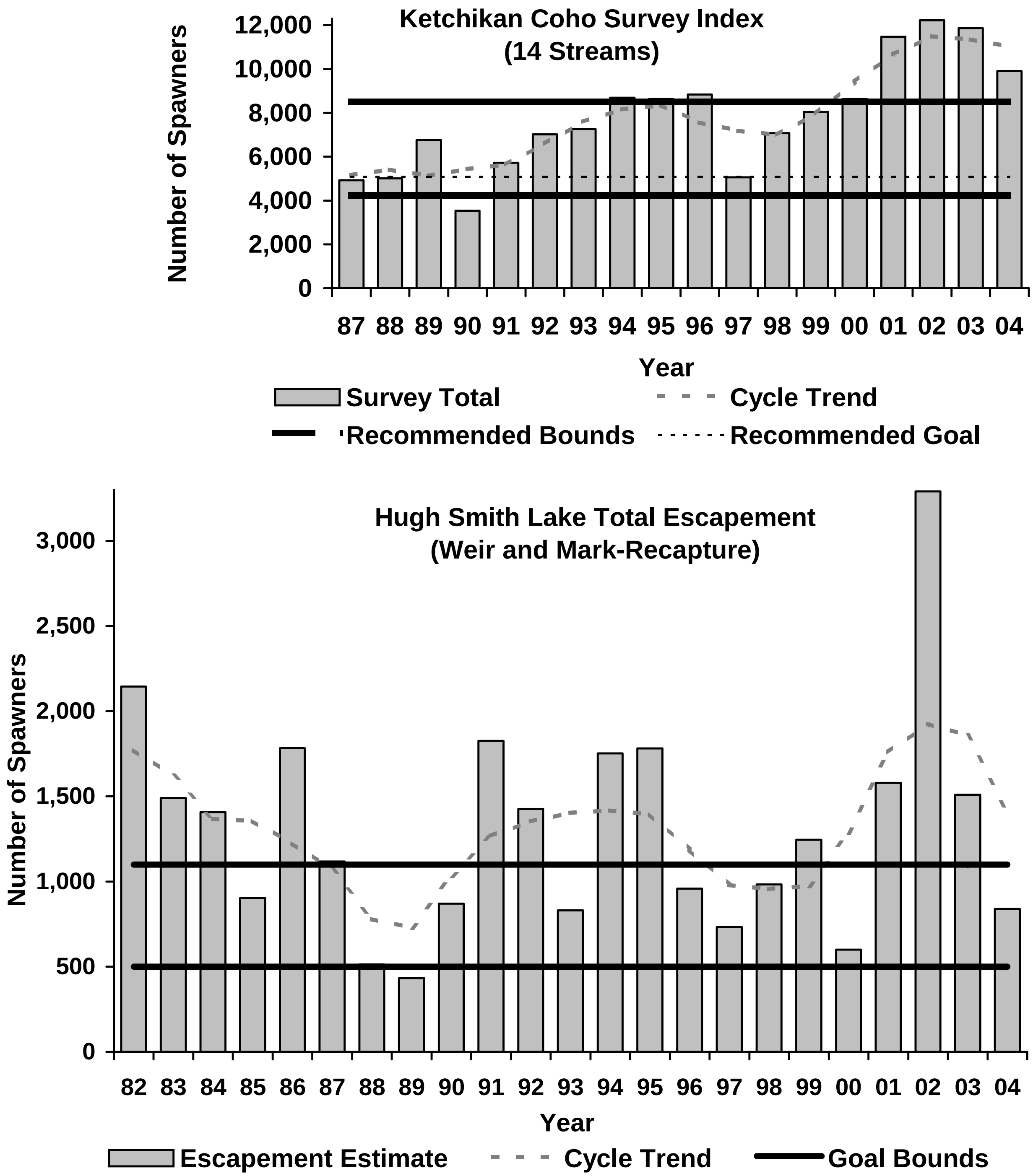

Figure 3.–Sum of peak coho salmon escapement survey counts for 14 streams in the Ketchikan area (top figure) and coho salmon escapement counts and estimates for Hugh Smith Lake (bottom figure). Also shown are 3 1/2 year "cycle" trends, the current escapement goal for Hugh Smith Lake, and a recommended goal (5,100 spawners) and goal range (4,250–8,500 spawners) for Ketchikan surveyed streams.

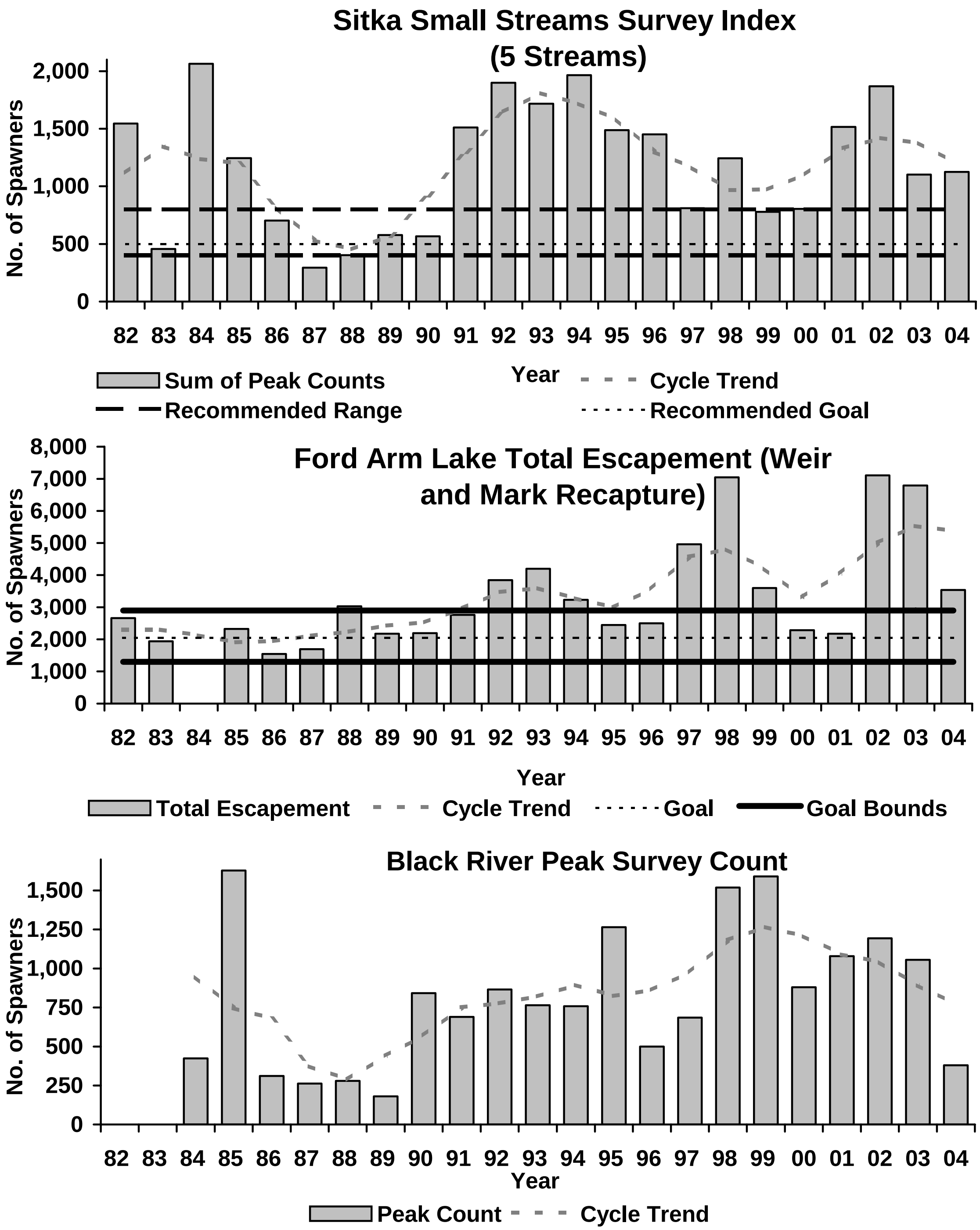

Figure 4.–Sum of peak coho salmon escapement survey counts for 5 streams in the Sitka area (top figure), coho salmon escapement counts and estimates for Ford Arm Lake.(middle figure), and peak survey counts of coho salmon in the Black River (bottom figure). Also shown are 3 1/2 year "cycle" trends, the current escapement goal for Ford Arm Lake, and a recommended aggregate goal (500 spawners) and goal range for streams surveyed streams in the Sitka area (400–800 spawners).

ESCAPEMENT GOAL RECOMMENDATIONS

For the Ketchikan index, an index count point goal of 5,084 is suggested by associated habitat capability estimated at about 215,581 smolts (average for higher brood year escapements) combined with an average MSY estimate of 42.4 smolts/spawner from indicator stock studies. Bounds corresponding with 25.4–50.8 smolts/spawner based on a 2 to 1 ratio between the upper and lower bound indicate an escapement goal range of about 4,251–8,506 spawners (point goal 5,089). We recommend rounding these goals to the nearest 50 spawners for a point goal of 5,100 spawners with a range of 4,250–8,500 spawners (Figure 4).

For the Sitka index, an index count point goal of 468 is suggested by habitat capability estimated at about 19,847 smolts (based on Nakwasina survival and exploitation rates) combined and 42.4 smolts/spawner from indicator stock studies suggests. Bounds corresponding with 25.4–50.8 smolts/spawner indicate an escapement goal range of about 391–782 spawners (point goal 468). We recommend rounding these goals to a point goal of 500 spawners with a range from 400–800 spawners (Figure 5).

The recommended lower and upper goal bounds are 0.83 to 1.67 times the recommended point goal for the Ketchikan index and 0.85 to 1.70 times the recommended point goal for the Sitka index. These ranges are consistent with the recommended range for Pacific salmon stocks by Eggers (1993) of 0.8 to 1.6 times MSY escapement.

We consider these goals to be Biological Escapement Goals as defined in the Sustainable Salmon Fisheries Policy (5 AAC 39.222 (f)(3).[1]

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

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