Regional Information Report No. 1J19-12

Stock Status and Review of Factors Affecting Coho Salmon Returns and Escapements in Southeast Alaska

by

Leon D. Shaul

Julie A. Bednarski

Jeffery T. Williams

and

Brian W. Elliott

December 2019

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

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, 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

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By

Leon D. Shaul and Julie A Bednarski,
Alaska Department of Fish and Game, Division of Commercial Fisheries, Douglas

Jeffery T. Williams,
Alaska Department of Fish and Game, Division of Sport Fish, Douglas

and

Brian W. Elliott
Alaska Department of Fish and Game, Division of Sport Fish, Haines

Alaska Department of Fish and Game
Division of Commercial Fisheries, Publications Section
802 3rd Street, Douglas, Alaska 99824

December 2019

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Leon D. Shaul and Julie A. Bednarski,
Alaska Department of Fish and Game, Division of Commercial Fisheries,
802 3rd St., Douglas, AK 99824 USA

Jeffery T. Williams,
Alaska Department of Fish and Game, Division of Sport Fish
802 3rd St., Douglas, AK 99824, USA

and

Brian W. Elliott
Alaska Department of Fish and Game, Division of Sport Fish,
Mile 1 Haines Highway, Haines, AK 99827-0330, USA

This document should be cited as follows:
Shaul, L. D., J. A. Bednarski, J. T. Williams, and B. W. Elliott. 2019. Stock status and review of factors affecting coho salmon returns and escapements in Southeast Alaska. Alaska Department of Fish and Game, Regional Information Report No. 1J19-12, Douglas.

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ABSTRACT

The status of coho salmon stocks in Southeast Alaska was assessed from information on escapement, smolt abundance, marine survival, and total abundance from coded-wire-tagged indicator stocks and from stocks returning to streams that were surveyed for escapement. Monitored escapements have remained mostly within or above escapement goal ranges—we identified no stocks of concern. Runs to Lynn Canal rivers decreased sharply after 2004 and have remained low. A rebound in smolt production under recent climatic warming was offset by a decrease in marine survival to historic lows in 2016 and 2017, and a record low Auke Creek jack return points to continued poor survival in 2018. Circumstances surrounding the decline in survival in inside waters appear consistent with an increase in predation rather than food limitation. The total abundance of wild coho salmon available to the troll fishery has remained high despite declines in important inside stocks, pointing to changes in stock composition of the catch. The Alaska troll exploitation rate index trended lower from an average of 41% during 1989–1998 to 28% during 2008–2017, while recent average all-fishery exploitation rates were moderate (39–51%) for all indicators except Ford Arm Creek (67%). A forecast model based on climatic and top-down controls on offshore squid prey has continued to provide accurate forecasts of adult size during a recent period of unprecedented warming in the northeast Pacific, explaining 67% of variation in dressed weight over a 49-year period. Growth and size-at-maturity are directly related to abundance of distinct even- and odd-year squid populations that are in turn positively influenced by warmer ocean temperature and negatively influenced by the biomass of maturing pink salmon in the Gulf of Alaska. Late marine growth has important effects on survival (particularly of females), per-capita reproductive capacity of spawners, and harvest allocation among fisheries.

Key words: coho salmon, *Oncorhynchus kisutch*, escapement, escapement goals, smolts, nomads, marine survival, exploitation rates, weight, length, Auke Creek, Berners River, Taku River, Ford Arm Creek, Hugh Smith Lake, Chilkat River, Tsiu River, Situk River, Lost River.

INTRODUCTION

Coho salmon (*Oncorhynchus kisutch*) are important to a variety of commercial, sport, and subsistence users in Southeast Alaska. Trollers have accounted for over 60% of the commercial harvest, on average, but coho salmon are also important to purse seine, drift gillnet, and set gillnet fisheries. Recreational fisheries occur in both freshwater and saltwater areas and have constituted an increasing component of the harvest in recent years. Directed subsistence fisheries have been very limited, but regulations allowing directed subsistence fishing for coho salmon have been expanded under federal rules in many freshwater areas. This report updates an earlier assessment (Shaul et al. 2011) of the stocks that support these fisheries through the 2017 return. In addition, we will provide an overview of trends in abundance, smolt production, marine survival rates, adult size, harvest, and exploitation rates. We will compare and contrast trends in these variables across the region and relate this information to factors/conditions that drive stock productivity. We will also provide information on escapement goal analysis methods that are more compatible with the life history and productivity of coho salmon compared with the commonly applied Ricker model.

Full development of a troll fishery targeting coho salmon occurred around 1940, and the commercial harvest (Figure 1) provides an indication of the trend in coho salmon abundance after that time. Stocks recovered in the early 1980s from a prolonged period of low abundance that extended for over 2½ decades. Whereas low marine survival was likely a major factor driving poor harvests from 1956 to 1981, improved marine survival has been an important factor influencing larger wild stock harvests since 1982. The commercial harvest reached a peak during 1990–1996 at an average of 2.86 million wild fish (3.46 million total fish), before following a lower but relatively level trend during the most recent two decades (1998–2017) around an average of approximately 1.9 million wild fish and 2.5 million total fish. After 2005, harvests in most years varied between 1.4–2.0 wild fish and 1.8–2.4 million total fish, with the exception of 2013 and 2014, when total harvests of 3.59 and 3.36 million fish ranked as the second and fifth largest commercial harvests in history and 7th and 11th highest for wild fish (2.59 and 2.46 million fish). In 2017, the commercial harvest of 2.31 million wild fish (2.75 million total) was also high, and a record 76% of the wild harvest (and 78% of the total harvest) was taken by the troll fishery.

Excellent coho salmon habitat occurs throughout Southeast Alaska (Figure 2). Coho salmon are produced in over 2,500 primary anadromous streams within the region, most of which are small producers about which little is known. In addition to wild stocks within Southeast Alaska, important contributions to the region's total harvest are made by 13 hatcheries in Southeast Alaska, several transboundary rivers (Alsek, Taku, and Stikine), and by streams on the northern British Columbia coast.

From 2011 to 2015, hatcheries contributed an average of 27% (range 24–28%) of the Southeast Alaska commercial harvest. This represented an increase from the prior two decades (1991–2010) when the hatchery component of the commercial harvest remained level at an average 19% (range 13–22%) despite tripling of coho salmon non-fry hatchery releases in the region. However, the hatchery component subsequently dropped sharply to 21% in 2016 and 16% in 2017. During recent years, more than 99% of the hatchery contribution to the Southeast Alaska harvest was produced by Alaska facilities.

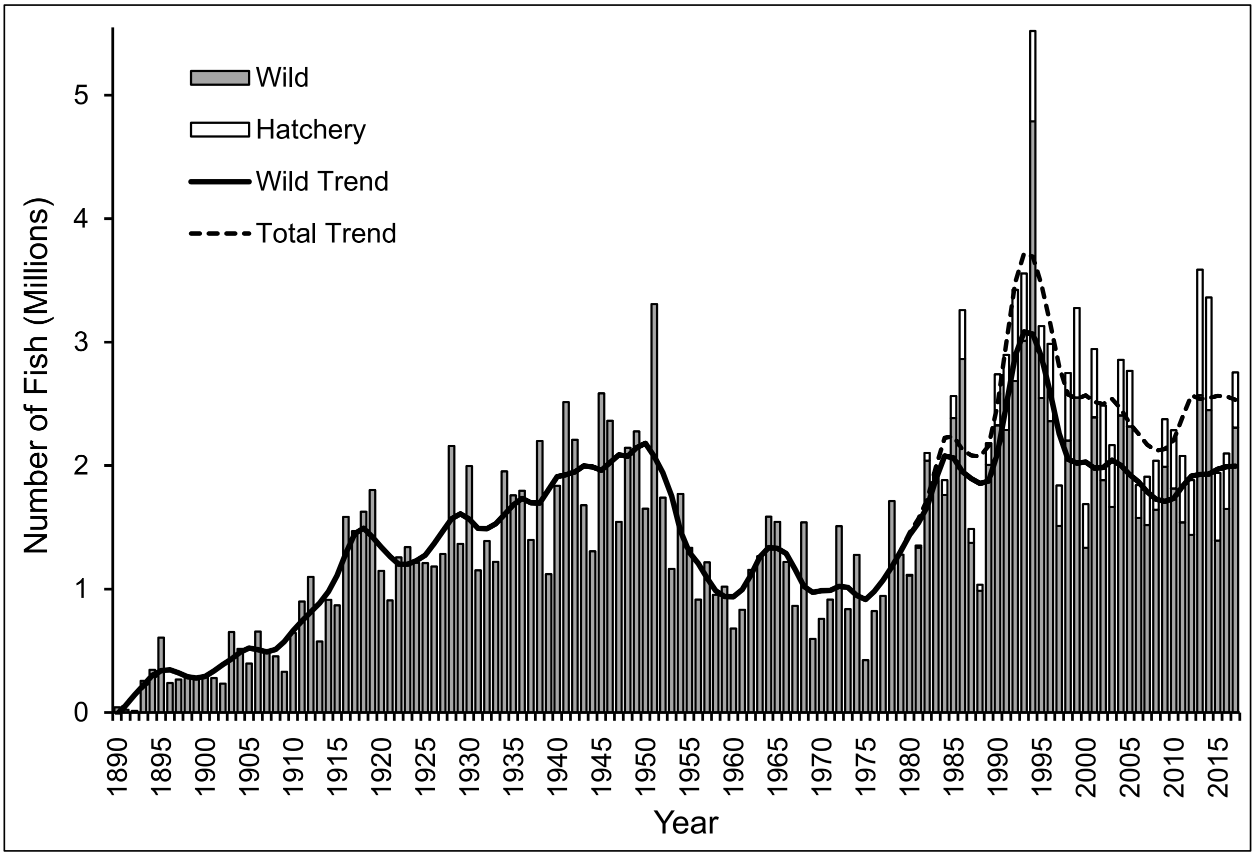

Figure 1.–Commercial harvest of wild and hatchery coho salmon in Southeast Alaska, 1890–2017, with a 9-point LOESS trend.

The Alaska Department of Fish and Game (ADF&G) implemented an improved stock assessment program in the early 1980s to better understand and manage coho salmon stocks. New assessment projects were implemented to monitor population and fishery parameters for selected indicator stocks (Shaul 1994; Shaul and Crabtree 1998). In addition, a systematic escapement survey program was developed to augment information provided from the more intensive indicator stock projects. These programs have bettered the understanding among fishery researchers and managers of the status of Southeast Alaska coho salmon stocks and have formed the basis for improved management (Shaul et al. 2008, 2009, 2011, 2014, 2017).

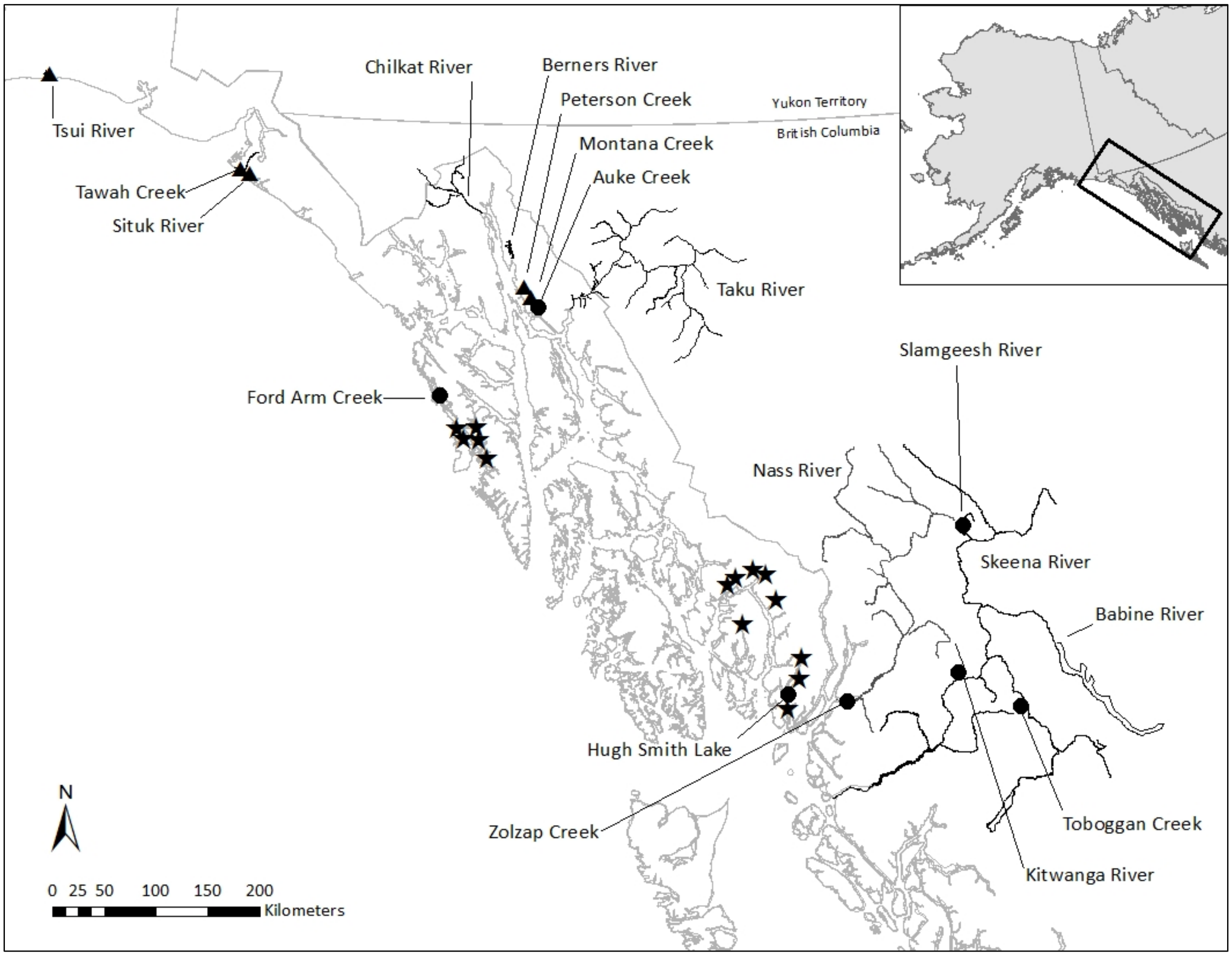

Figure 2.–Map of Southeast Alaska and northern British Columbia, showing the locations of recent coho salmon full indicator stock assessment projects. Stars mark area index streams and triangles mark surveyed streams with independent escapement goals.

The principal management objective for Southeast Alaska fisheries for coho salmon is to achieve *maximum sustained yield (MSY)* from wild stocks. Hatchery contributions and natural production are identified inseason in key fisheries using coded wire tags (CWTs). Fisheries directed primarily at coho salmon are managed based on wild stock fishery performance to achieve adequate escapement while harvesting the surplus. Escapement goal ranges have been established for a number of wild indicator stocks and surveyed systems. A secondary management objective is to achieve long-term commercial gear-type allocations that were established by the Alaska Board of Fisheries (board) in 1989. These allocations preserve a 1969 to 1988 historical base distribution of 61% for troll gear, 19% for purse seine gear, 13% for drift gillnet gear, and 7% for set gillnet gear.

The broad distribution of coho salmon production across thousands of small stream systems necessitates that much of the harvest occur in highly mixed stock fisheries where the stocks intermingle. Except for years of strong deviations from average abundance, commercial trollers fish a relatively stable season and harvest a relatively stable proportion of the total runs. This pattern of fishing has resulted in a more even distribution of the troll harvest across all stocks in the region, thereby realizing some harvest from all stocks and ensuring that more heavily exploited inside stocks are able to support some harvest in inside fisheries while still maintaining escapement. Most active management to harvest surpluses and achieve escapement goals is conducted in gillnet fisheries, based on returns to single major systems or local concentrations of productive systems. Nearly all of the harvest of many small to medium stocks on the outer coast and along inside passages occurs in the commercial troll and marine sport fisheries, and a small incidental harvest occurs in commercial purse seine fisheries that are managed primarily to harvest pink salmon (*O. gorbuscha*).

The commercial fisheries are managed under specific management plans for each fishery. The Southeast Alaska and Yakutat area plan *Management of Coho Salmon Troll Fishery* (5 AAC 29.110) contains several decision points that potentially trigger early or midseason closures for conservation and allocation, and/or an extension of the troll coho season for up to 10 days after the regulatory closing date of 20 September. Some provisions of the plan were written in the late 1970s and 1980s when direct information on coho salmon abundance was limited to fishery catch and effort statistics. In recent years, fishery managers have tried to balance the specific provisions of the management plan with increasing capability to assess monitored stocks and their escapement needs. Inseason management has increasingly focused on escapement goals that produce *MSY* as a specific priority objective.

In addition to provisions specified in state management plans, the Pacific Salmon Treaty (PST) contains provisions for the conservation of northern British Columbia coho salmon stocks. The PST provisions are essentially the same as board management plan provisions for potential early and midseason troll fishery closures. However, the PST also contains provisions that trigger a closure of the troll fishery in boundary areas of southern Southeast Alaska and in northern British Columbia when abundance of northern British Columbia stocks is indicated to be low based on fishery performance thresholds.

The sport fishery has accounted for a small, but generally increasing, component of the coho salmon harvest (Figure 3). Marine sport fisheries, which accounted for an average of 88% of the total recreational harvest over the past decade, are managed primarily under a 6-fish bag limit. The same bag limit applies in most freshwater systems, except for some more accessible streams where the bag limit is 2 fish. Concurrent with expansion of the sport charter industry, sport harvest accounted for an increasing share of the all-fishery harvest from the mid-1970s until the early 2000s and has averaged 9–13% of the annual total coho salmon harvest since 2000. The sport harvest reached a peak estimated harvest of 409.3 thousand fish in 2005 (Figure 3), decreased to an average of 226.6 thousand fish during 2006–2012, then increased again to 232.7–339.6 (average 299.8) thousand fish during 2013–2017. Although emergency inseason management actions have been less frequent in the recreational fisheries, seasons have been closed or bag limits reduced in both marine and freshwater fisheries in response to inseason indicators of low abundance. Bag limits were increased in some locations to harvest the very large 1994 return.

Directed subsistence fishing for coho salmon occurs in a few streams in the region, and small numbers are also harvested incidentally in both subsistence and personal use fisheries directed at sockeye salmon (*O. nerka*). The 10-year (2008–2017) average combined subsistence and personal use harvest, as reported on returned permits, averaged only 2,700 fish.

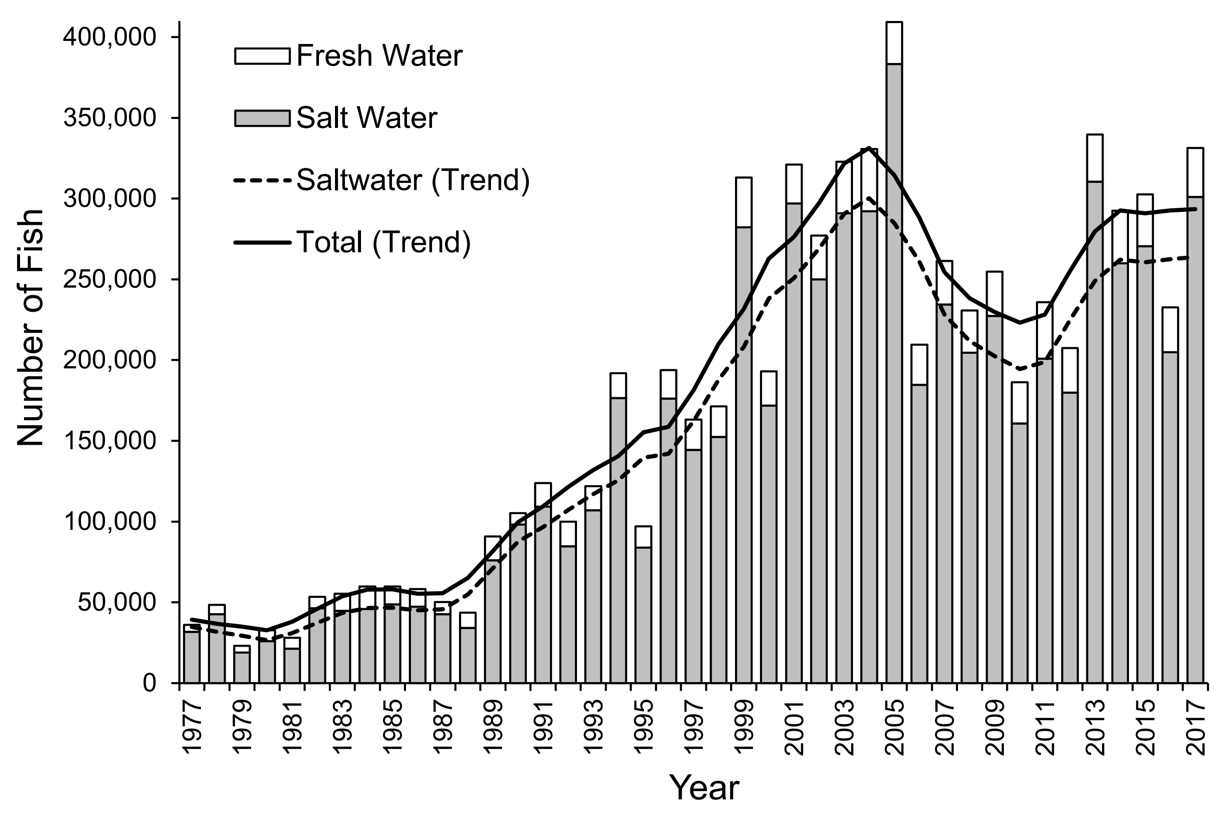

Figure 3.–Sport harvest of coho salmon in saltwater and freshwater in Southeast Alaska, 1977–2017 (and 8 pt LOESS trends), based on the state-wide harvest survey.

STOCK STATUS

Status of coho salmon stocks in the Southeast Region was judged by trends in abundance and escapement of indicator stocks relative to established goals. Overall, 14 systems or groups of systems have goals, including 11 with biological escapement goals (*BEG*), and three with sustainable escapement goals (*SEG*) (Table 1).

Escapement goal classifications are defined in the *Policy for the Management of Sustainable Salmon Fisheries* (5 AAC 39.222) under Section (f):

"(3) "*biological* escapement goal" or "(*BEG*)" means the escapement that provides the greatest potential for maximum sustained yield;" and

"(36) "*sustainable* escapement goal" or "(*SEG*)" means a level of escapement, indicated by an index or an escapement estimate, that is known to provide for sustained yield over a 5- to 10-year period, used in situations where a *BEG* cannot be estimated or managed for."

Table 1.–Estimated coho salmon escapements for systems with formal escapement goals in Southeast Alaska, 2012–2017[a].

System	Assessment Method	Type	Escapement Goal	Year Established	Escapement					
					2012	2013	2014	2015	2016	2017
Hugh Smith Lake	Weir	BEG	500–1,600	2009	1,908	3,048	4,110	956	948	1,266
Klawock River	Weir	SEG	4,000–9,000	2013	7,507	8,323	7,698	12,780	24,242	7,412
Taku River	MR	BEG	50,000–90,000	2015	70,775	68,117	124,171	60,178	87,704	57,868
Auke Creek	Weir	BEG	200–500	1994	837	736	1,533	517	204	283
Montana Creek	FS, IE	SEG	400–1,200	2006	394	367	911	1,204	717	634
Peterson Creek	FS, IE	SEG	100–250	2006	190	126	284	202	52	20
Ketchikan Survey Index	HS	BEG	4,250–8,500	2006	11,960	11,295	16,675	10,128	13,420	11,557
Sitka Survey Index	FS, IE	BEG	400–800	2006	1,157	1,414	2,161	2,244	2,943	1,280
Ford Arm Creek	Weir	BEG	1,300–2,900	1994	2,282	1,573	3,025	3,281	NA	NA
Berners River	FS, HS, IE	BEG	4,000–9,200	1994	5,480	6,280	15,480	9,940	6,733	7,040
Chilkat River Escapement	AS/FS, MR, IE	BEG	30,000–70,000	2006	36,961	51,324	130,200	47,372	26,280	34,482
Tawah Creek (Lost River)	BS, IE	SEG	1,400–4,200	2015	NA	2,593	3,555	2,015	746	1,455
Situk River	BS, IE	BEG	3,300–9,800	1994	3,007	14,853	8,226	7,062	6,177	4,122
Tsiu/Tsivat Rivers	AS, IE	SEG	10,000–29,000	1994	10,500	47,000	27,000	19,500	31,000	38,000

Note: AS = peak aerial survey, FS = foot survey, BS = boat survey, HS = helicopter survey, IE = index escapement, MR = mark–recapture, BEG = biological escapement goal, SEG = sustainable escapement goal, NA = not available.

[a] Changes to Berners River and Tsiu/Tsivat river goals in 2018 (Heinl et al. 2017) are not reflected in this table.

Coho salmon stocks are very widely distributed and are believed to be present in over 2,500 primary anadromous streams; however, it is practical and feasible to conduct stock assessment projects on only a small fraction of those streams. Most direct assessment of the stocks occurs at two levels: full indicator stock and escapement indicator.

FULL INDICATOR STOCKS

Full indicator stocks are marked as smolts or presmolts with CWTs, which makes it possible to estimate their smolt production (from the marked rate-at-return) and contribution to the fisheries by systematically sampling fishery harvests and escapements. These programs were expanded in the 1990s and 2000s (Shaul et al. 2011) but were subsequently reduced to six systems by 2015, including Auke Creek, Berners River, Ford Arm Creek, Hugh Smith Lake, Chilkat River, and Taku River (Figure 2). The Ford Arm Creek project was discontinued after 2015.

Full indicator stock programs provide detailed population information needed to establish and manage for *BEG*s. Specific parameters that are estimated for these stocks include total adult abundance, spawning escapement (including age, size, and sex), smolt production (abundance, age, and size), marine survival, fishery contributions by area, gear type, and time, and exploitation rates. Over time, these parameters are used to evaluate the relationship between spawning escapement and production and to establish *BEG*s that produce *MSY*. One major advantage of the smolt estimation programs associated with coho salmon indicator stocks is that they make it possible to filter out variation in return abundance caused by variation in marine survival and to improve resolution of the relationship between escapement and brood-year production (Shaul et al. 2007).

In 1994, *BEG*s were established for four long-term indicator stocks (Hugh Smith Lake, Ford Arm Creek, Auke Creek, Berners River) based on Ricker stock-recruit relationships (Clark et al. 1994). The goal established for the Hugh Smith Lake stock of 500–1,100 spawners was later revised to 500–1,600 spawners (Shaul et al. 2009). A review of the Ford Arm stock based on many more years of data, more appropriate spawner-recruit models, and more informed scale aging concluded that the original goal of 1,300–2,900 spawners remained appropriate (Shaul et al. 2014). The original goal for Auke Creek has not been revised, while the *BEG* for the Berners River has been reduced from 4,000–9,200 spawners (based on the unexpanded survey count) to 3,600–8,100 spawners (Shaul et al. 2017). A *BEG* of 30,000–70,000 spawners was developed for the Chilkat River based on Ricker analysis (Ericksen and Fleischman 2006). Surveys are conducted on four tributaries of the Chilkat River and the combined count is expanded to total system escapement using an average expansion factor based on 5 years of paired counts and mark–recapture estimates. Also, for the Taku River, a minimum inriver abundance goal of 38,000 spawners specified in the 1999 Pacific Salmon Treaty (PST) was replaced with a *BEG* of 50,000 to 90,000 fish, with a *MSY* point goal of 70,000 fish (Pestal and Johnston 2015).

ESCAPEMENT INDICATORS

Foot or helicopter surveys have been systematically carried out on sets of streams in the Juneau, Haines, Sitka, Ketchikan, and Yakutat areas. These projects provide greater coverage at a much lower level of resolution compared with full indicator stocks. Freshets resulting from high and variable rainfall in the fall months make it difficult to obtain consistent surveys. In the Juneau area, repetitive foot surveys are conducted on Montana and Peterson creeks, which have individual *SEG*s (Clark 2005). In the Sitka area, five local streams have been surveyed on foot most years since 1985. In the Ketchikan area, surveys have been conducted by helicopter on 14 streams since 1987. *BEG*s for the aggregate survey counts in the Ketchikan and Sitka areas were developed by Shaul and Tydingco (2006). Goals for the Situk, Lost, and Tsiu rivers near Yakutat were developed by Clark and Clark (1994). In 2015, the Lost River goal was changed to an *SEG* to include only Tawah Creek, the tributary that has been most consistently surveyed (Heinl et al. 2014).

Only peak survey counts that met standards for timing, survey conditions, and completeness were included in the Ketchikan and Sitka indices. 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), must be used since the sums change as missing counts are filled in at each step. Most of the consistent indicators of coho salmon escapement were established in the early to mid-1980s (Table 2).

Northern Inside Stocks

Escapements to Auke Creek, a stream with a weir on the Juneau road system, have been consistently within or above the *BEG* range since the early 1980s (Figure 4, Appendix A1). In the Juneau roadside area, Clark (2005) recommended the current *SEG*s of 400–1,200 spawners for Montana Creek and 100–250 spawners for Peterson Creek. The goal for Peterson Creek was met or exceeded annually for 35 consecutive years, 1981–2015, but peak counts then fell sharply under goal to 52 fish in 2016 and 20 fish in 2017. The lower bound of the goal for Montana Creek was not met in only 9 years out of 37 but has been consistently met in the four most recent years (2014–2017). All three Juneau roadside stocks are harvested primarily in highly mixed stock troll, purse seine, and sport fisheries, with some additional exploitation in inside drift gillnet fisheries.

The Berners River in lower Lynn Canal, the Chilkat River in upper Lynn Canal, and the Taku River south of Juneau all had relatively strong escapements near or above respective upper goal bounds during 2000–2004 (Figure 4; Appendix A1). More recent escapements in those systems have averaged lower but have fallen below current *BEG*s in only two cases (Chilkat River in 2007 and 2016). All three of these systems have similar mainland valley rearing habitat, including wetlands, ponds, and sloughs, and their coho salmon returns are targeted by drift gillnet fisheries in addition to the troll fishery.

The Berners River is a compact system with concentrated high-quality coho salmon spawning and rearing habitat. Although a substantially smaller producer than the Taku and Chilkat rivers, it is an important contributor to the fisheries in northern Southeast Alaska. Average adult production was 60% lower during 2005–2014 compared to the previous 15-year period (1990–2004), as a result of proportionately equal decreases in smolt production and marine survival (Shaul et al. 2017). However, despite substantially lower returns, escapement fell below the prior *BEG* only once since 2005, and the goal was achieved nine times and exceeded twice. A recent analysis led to a 10–12% reduction in the *BEG* (based on the unexpanded survey count) from 4,000–9,200 spawners to 3,600–8,100 spawners (Shaul et al. 2017; Figure 4; Appendix A1).

For the escapement goal analysis for the Berners River population (Shaul et al. 2017), annual spawning escapement was standardized to a constant per capital egg biomass, based on the sex ratio and average egg biomass of female spawners. "Effective" spawning escapement was more variable than nominal escapement because per-capita egg biomass tended to be lower in years of poor growth and survival and vice versa (Shaul and Geiger 2016). Estimated "effective" escapement fell slightly under the current goal in 2007 and 2009, while nominal escapement did not (see Escapement Goal Development section).

The Taku River may be the single largest coho salmon-producing system in the region. Escapement estimates were first made in 1987 and run reconstruction estimates are available since 1992 (Elliott and Bernard 1994; McPherson et al. 1994, 1997, 1998; McPherson and Bernard 1995, 1996; Yanusz et al. 1999, 2000; Jones et al. 2006; Jones et al. 2012). The inriver run past Canyon Island near the U.S./Canada boundary is estimated using a mark–recapture technique. Marking is done at research fish wheel sites in the canyon, while recovery sampling is done in test and Canadian commercial fisheries. Results of a 1991 radio-telemetry study indicated that the fish wheel mark–recapture estimate represented about 78% of the total Taku River escapement, namely because about 22% of spawning in Alaska waters occurs below Canyon Island (Eiler et al. *unpublished*[1]). The current *BEG* of 50,000–90,000 spawners in the Taku River above Canyon Island was consistently met or exceeded during the most recent 20-year period (1998–2017; Figure 4)

The Chilkat River has produced nearly as many returning coho salmon as the Taku River, on average. Mark–recapture estimates obtained in 5 years (1990, 1998, 2002, 2003, and 2005) were used to calibrate a standardized peak survey count in spawning areas. Escapement estimates peaked at 204,805 spawners in 2002 and have met or exceeded the *BEG* of 30,000–70,000 spawners in nearly all years since it was established in 2006, with exceptions in 2007 and 2016 when escapement estimates fell short of the lower goal bound by 17% and 12%, respectively (Table 2).

Sitka Area Stocks

Ford Arm Creek was the only indicator stock in the Sitka area that had a long-term escapement data record and an established *BEG* (Figure 5; Tables 2 and 4). However, monitoring of this population was discontinued after 2015. The Ford Arm Creek stock is available to fisheries in coastal waters from early July through early September and is harvested intensively by local directed commercial troll and marine sport fisheries, and incidentally to pink salmon in the Khaz Bay commercial purse seine fishery. The goal range of 1,300–2,900 spawners was achieved in 18 years and exceeded in 15 years during the 33-year history of the project (Figure 5).

The sum of peak escapement survey counts for the five small streams in the Sitka survey index trended downward in the late 1980s, then increased sharply in the early 1990s (Figure 5; Table 2; Appendix A2). The counts declined again from 1997 to 2000, but then trended higher, reaching a record count in 2016. Shaul and Tydingco (2006) recommended a goal of 400–800 spawners for the aggregate count in the five streams based on an analysis that assumes productivity (smolts per spawner at *MSY*) for Sitka Sound stocks to be average for coho salmon stocks that have been studied. Escapements exceeded the lower goal bound in every year except one (1987), and exceeded the upper goal bound in all of the 10 most recent years by an average of 112%.

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[1] Eiler, J. H., M. M. Masuda, and H. R. Carlson. Unpublished. Stock composition, timing, and movement patterns of adult coho salmon in the Taku River drainage, 1992. National Marine Fisheries Service report, Juneau.

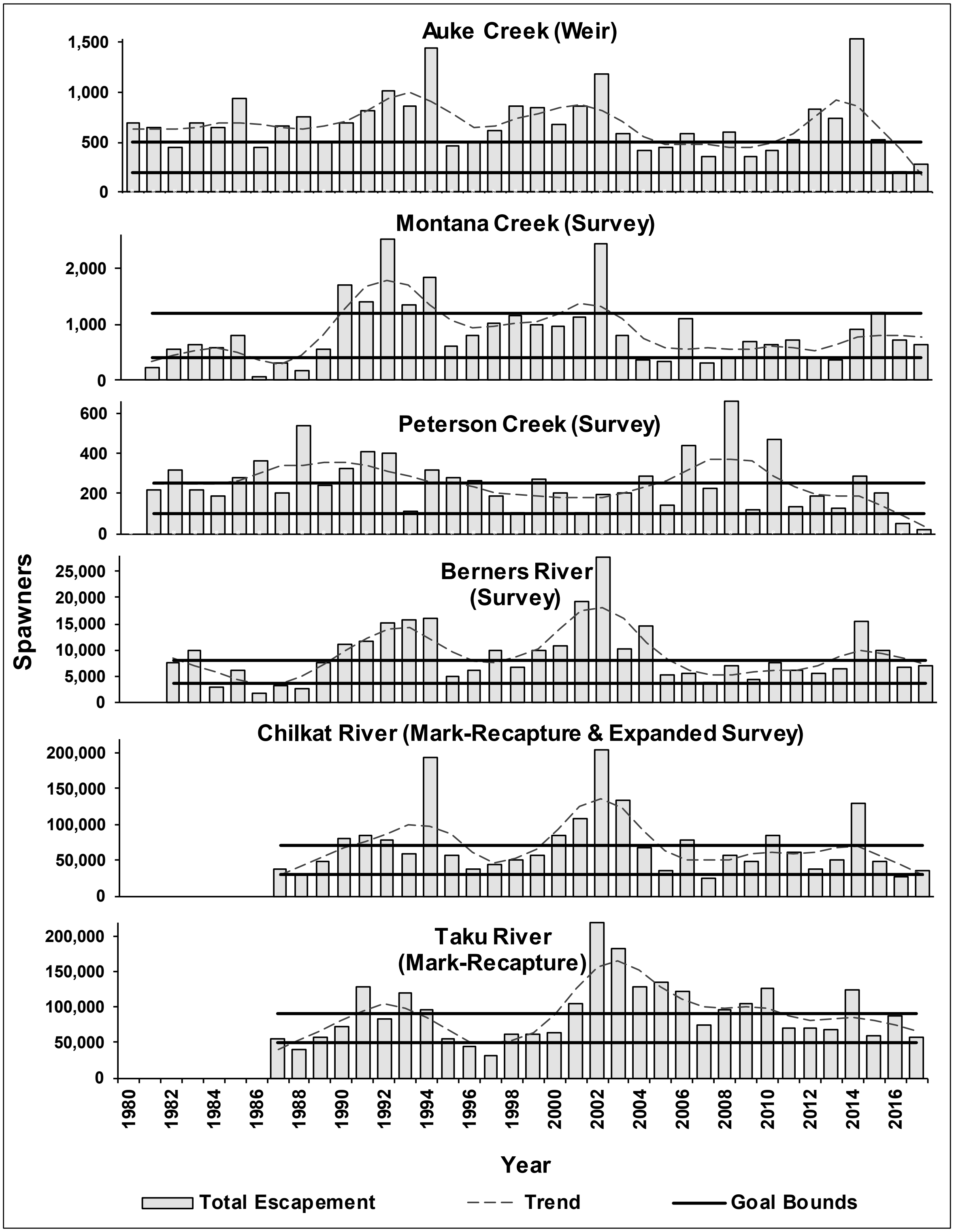

Figure 4.–Coho salmon escapement estimates and indices for streams in the Northern Inside area (Districts 111 and 115) with escapement goal bounds and 7-point LOESS trends, 1980–2017.

Table 2.–Southeast Alaska age-.1 adult coho salmon escapement estimates and index counts, 1980–2017.

Year	Auke Creek	Montana Creek	Peterson Creek	Berners River[a]	Chilkat River	Taku River	Ford Arm Creek[b]	Sitka Survey Index[c]	Hugh Smith Lake	Ketchikan Survey Index[d]
1980	698	-	-	-	-	-	-	-	-	-
1981	646	227	219	-	-	-	-	-	-	-
1982	447	545	320	7,505	-	-	2,655	1,545	2,144	-
1983	694	636	219	9,840	-	-	1,931	457	1,487	-
1984	651	581	189	2,825	-	-	-	2,063	1,407	-
1985	942	810	276	6,169	-	-	2,324	1,246	903	-
1986	454	60	363	1,752	-	-	1,552	702	1,782	-
1987	668	314	204	3,260	37,432	55,457	1,694	293	1,117	4,792
1988	756	164	542	2,724	29,495	39,450	3,119	403	513	5,007
1989	502	566	242	7,509	48,833	56,808	2,176	576	433	6,761
1990	697	1,711	324	11,050	79,807	72,196	2,192	566	870	3,444
1991	808	1,415	410	11,530	84,517	127,484	2,761	1,510	1,836	5,721
1992	1,020	2,512	403	15,300	77,588	83,729	3,866	1,899	1,426	7,017
1993	859	1,352	112	15,670	58,217	119,330	4,202	1,716	832	7,270
1994	1,437	1,829	318	15,920	194,425	96,343	3,227	1,965	1,753	8,690
1995	460	600	277	4,945	56,737	55,710	2,446	1,487	1,781	8,627
1996	515	798	263	6,050	37,331	44,635	2,500	1,451	950	8,831
1997	609	1,018	186	10,050	43,519	32,345	4,718	809	732	5,025
1998	862	1,160	102	6,802	50,758	61,382	7,049	1,242	983	7,095
1999	845	1,000	272	9,920	57,140	60,768	3,800	776	1,246	8,038
2000	683	961	202	10,650	84,843	64,700	2,304	803	600	8,634
2001	865	1,119	106	19,290	107,697	104,394	2,209	1,515	1,580	11,267
2002	1,176	2,448	195	27,700	204,805	219,360	7,109	1,868	3,291	12,223
2003	585	808	203	10,110	133,045	183,112	6,789	1,101	1,510	11,899
2004	416	364	284	14,450	67,053	129,327	3,539	1,124	840	9,904
2005	450	351	139	5,220	34,575	135,558	4,257	1,668	1,732	14,840
2006	581	1,110	439	5,470	79,050	122,384	4,737	2,647	891	6,901
2007	352	324	226	3,915	24,770	74,246	2,567	1,066	1,244	4,316
2008	600	405	660	6,870	56,369	95,226	5,173	1,117	1,741	16,752
2009	360	698	123	4,230	47,911	103,950	2,181	1,156	2,281	8,710
2010	417	630	467	7,520	84,909	126,830	1,610	1,273	2,878	4,563
2011	517	709	138	6,050	61,099	70,871	1,908	2,222	2,137	5,098
2012	837	394	190	5,480	36,961	70,775	2,282	1,157	1,908	11,960
2013	736	367	126	6,280	51,324	68,117	1,573	1,414	3,048	11,295
2014	1,533	911	284	15,480	130,200	124,171	3,025	2,161	4,110	16,675
2015	517	1,204	202	9,940	47,372	60,178	3,281	2,244	956	10,128
2016	204	717	52	6,733	26,280	87,704	-	2,943	948	13,420
2017	283	634	20	7,040	34,482	57,868	-	1,280	1,266	11,557
Goal Range										
Lower	200	400	100	3,600	30,000	50,000	1,300	400	500	4,250
Upper	500	1,200	250	8,100	70,000	90,000	2,900	800	1,600	8,500

[a] The Berners River index is the unexpanded survey count.

[b] Ford Arm Creek project discontinued after 2015.

[c] The Sitka survey index is the sum of peak survey counts on five streams.

[d] The Ketchikan survey index is the sum of peak survey counts on 14 streams.

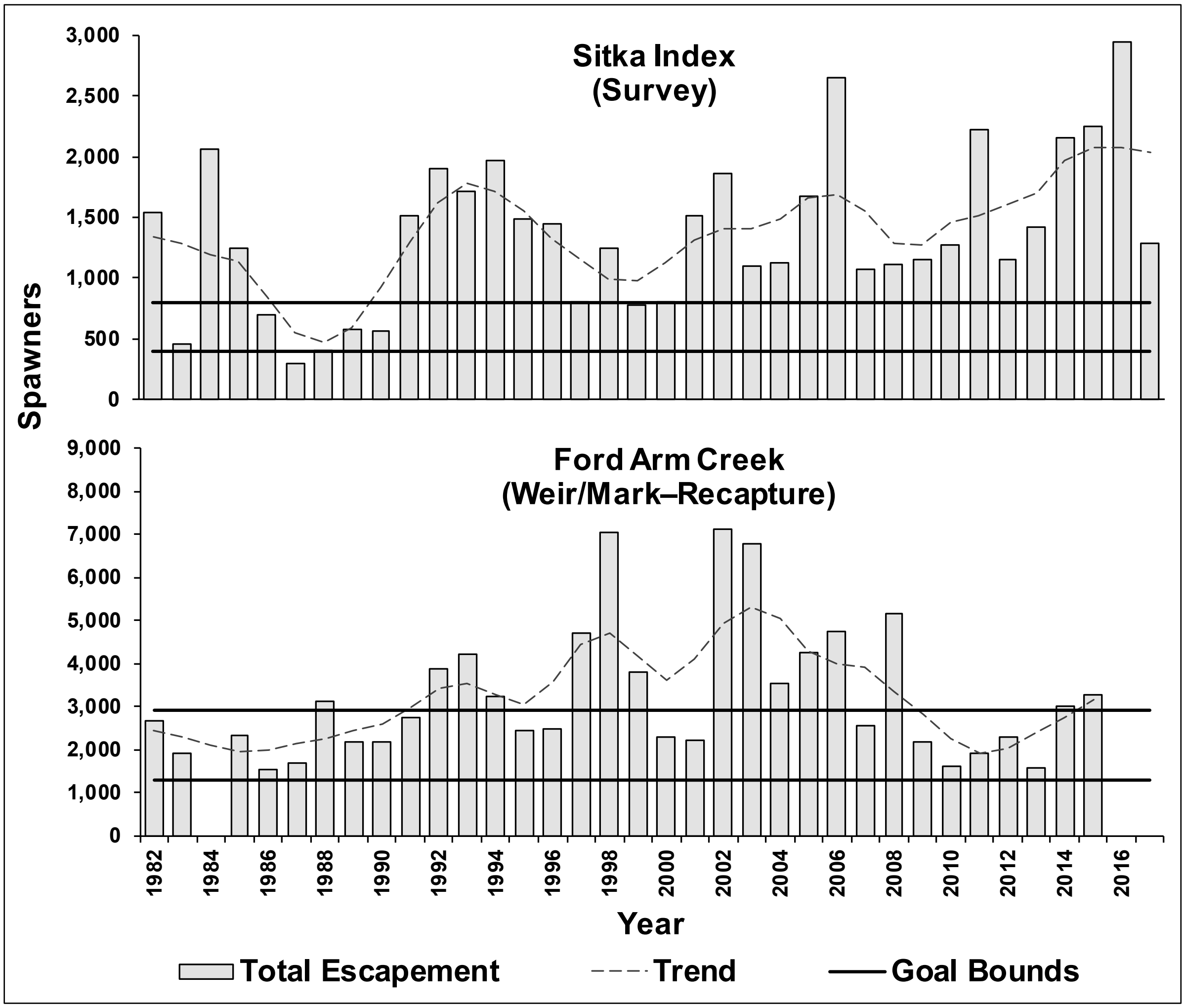

Figure 5.–Coho salmon escapement estimates and indices for streams in the Sitka area (District 113) with 7-point LOESS trends, 1982–2017. The Ford Arm Creek project was discontinued after 2015.

Southern Southeast Stocks

Hugh Smith Lake is the only full indicator stock in southern Southeast Alaska that has a long-term data series and an established *BEG* (Figure 6; Table 2). Over the past 36 years, escapements have been below the current *BEG* range of 500–1,600 spawners only once (1989), above it in 14 years, and within the goal range in 21 years. The *BEG* was consistently exceeded during 2008–2014 as a result of smolt production and marine survival rates that averaged 7% and 26% higher than pre-2008 averages, respectively. In addition, all-fishery exploitation rates during the latter period averaged only 50% compared to the pre-2008 average of 65%. Escapements fell back within the *BEG* range during 2015–2017, primarily as a result of a decrease in the marine survival rate to 6–7%, compared with a previous (1982–2014) average of 13%, while smolt production remained above-average and the exploitation rate ranged from 48–62% in 2015–2017 (average 53%, same as the 2000–2014 average but below the 1990s average of 75%).

The Ketchikan area survey index of peak helicopter counts for 14 streams followed a generally upward trend from 1987 to the early to mid-2000s, with highly variable counts occurring during 2006–2012 followed by consistently high counts during 2013–2017 (Figure 6; Table 2; Appendix

A3). A *BEG* of 4,250 to 8,500 spawners was established in 2006 based on the recommendation of Shaul and Tydingco (2006). During the past 31 years (1987–2017), escapements have fallen short of the *BEG* only once (in 1990), were within the goal range in 13 years, and were above the upper bound of the goal over half of the time (17 years).

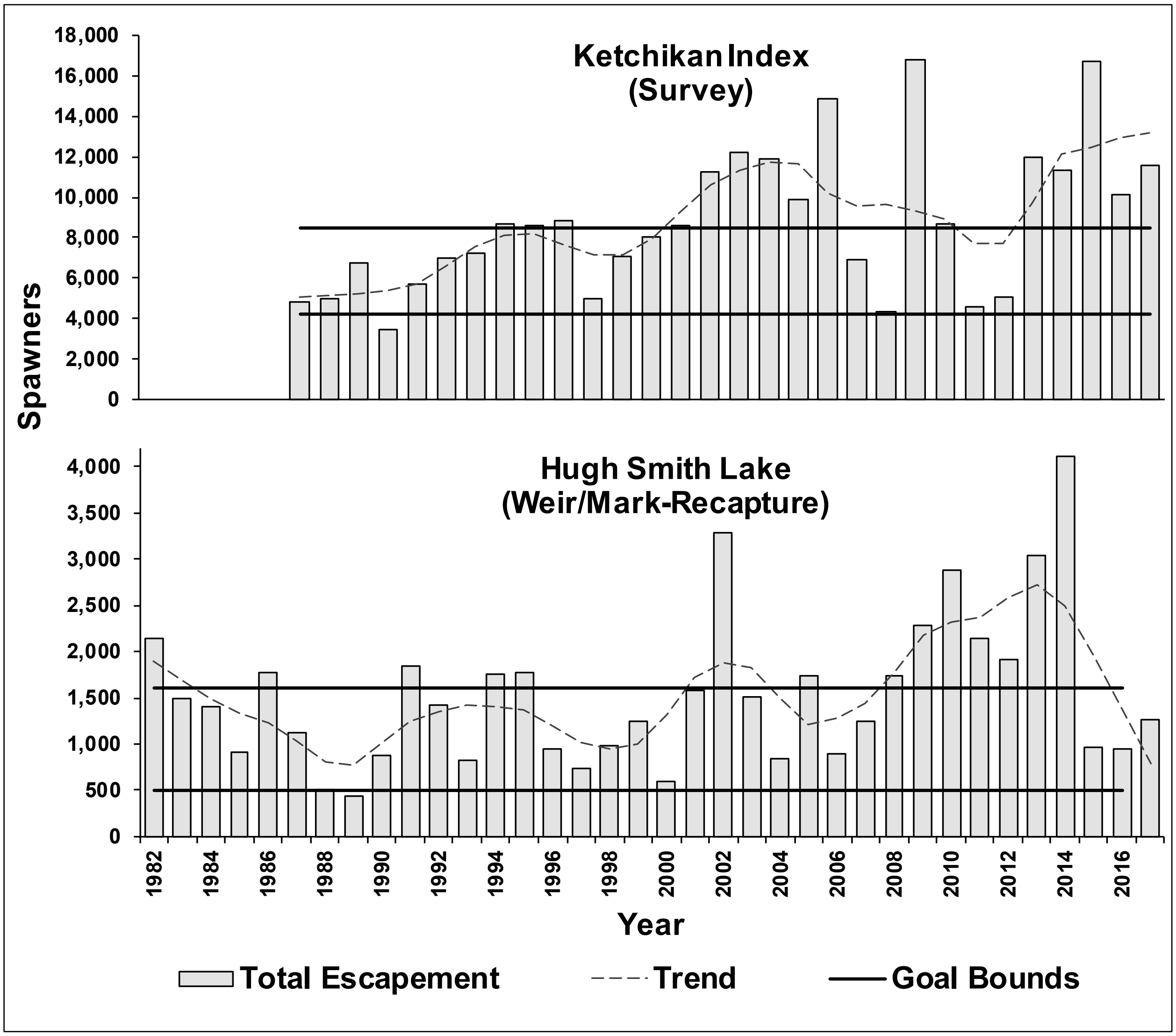

Figure 6.–Sum of peak coho salmon escapement survey counts for 14 index streams in the Ketchikan area (top graph) and coho salmon escapement counts and estimates for Hugh Smith Lake (bottom graph) with 7-point LOESS trends, 1982–2017.

Yakutat Stocks

Yakutat stocks are harvested primarily in commercial set gillnet and sport fisheries that target runs in terminal areas to discrete systems, but trollers and sport charter operators that fish on mixed stocks off the coast also account for some of the harvest. The marine (troll and sport) exploitation rate for the Situk River return was estimated at only 4–5% in 2005 and 2006 (Shaul et al. 2010). *BEG*s were initially established for seven stocks in this area (Clark and Clark 1994), but several goals have been dropped because peak escapement surveys have been conducted relatively consistently in recent years on only three systems, Tawah Creek and the Situk and Tsiu rivers.

Although the escapement data series starts in 1972, the quality and comparability of peak survey counts in the Yakutat area are somewhat lower than is the case in other areas of the Southeast Region (Figure 7; Appendix A4). Most aerial and foot surveys on these systems have been conducted early in the run to support inseason management of the set gillnet fisheries. Utility of the peak survey counts in assessing historical escapement is limited by decreasing survey effort near the peak of spawner abundance at the end of the fishery, and by frequently deteriorating weather conditions after mid-September. Mark–recapture studies were conducted to estimate escapements of coho salmon at the Situk River from 2004 to 2006 (Waltemyer et al. 2005; Eggers and Tracy 2007; Shaul et al. 2010) and the Lost River in 2003 and 2004 (Clark et al. 2005, 2006) in hopes of providing a calibration of the index counts; however, mark–recapture estimates were not consistent with peak survey counts. Index counts were substantially lower than estimated total escapement in all years and accounted for minor and variable portions of the total escapement. As a result, meaningful expansion factors could not be estimated.

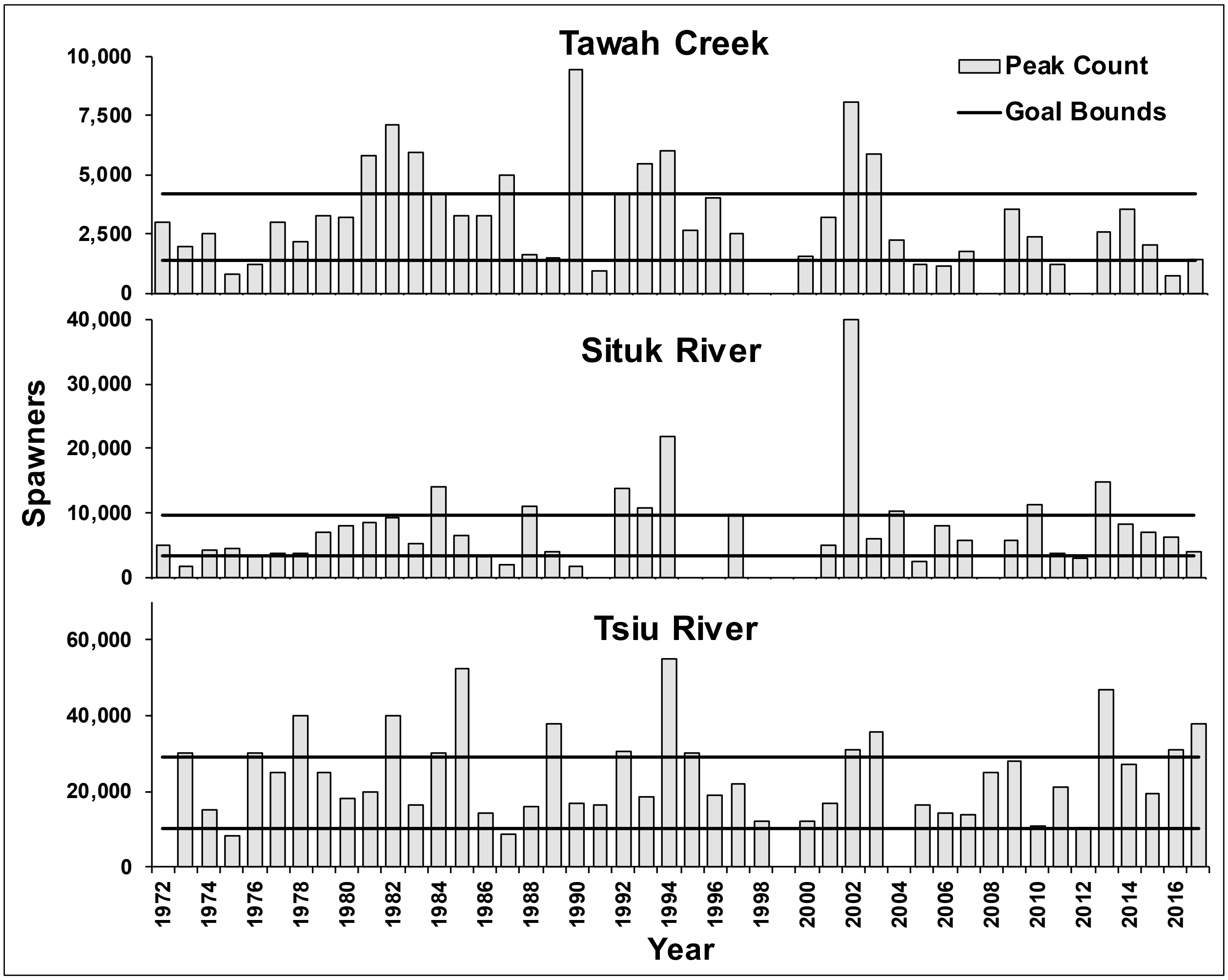

Figure 7.–Peak coho salmon escapement survey counts for 3 systems in the Yakutat area, 1972–2017, and escapement goal bounds.

During 2008–2017, an effective peak survey was conducted on Tawah Creek in 8 years during which the count fell below the current sustainable escapement goal (*SEG*) range in 3 years and met or exceeded it in 5 years. During the same period, the goal in the nearby Situk River was met or exceeded in 8 out of 9 years when peak counts were available. Effective peak counts are available for the Tsiu River in all years during 2008–2017 and all counts met or exceeded the escapement goal range.

ESCAPEMENT GOAL DEVELOPMENT

Most escapement goals for coho salmon were established based on a Ricker relationship between spawners and recruits (Ricker 1975), but other models have proven more appropriate for coho salmon, including Beverton-Holt (Beverton and Holt 1957; Barrowman et al. 2003), hockey stick (Barrowman and Myers 2000), and bent hockey stick (Shaul et al. 2013) models. The primary shortcoming of the widely used Ricker model when applied to coho salmon populations is the over-compensation feature that is uncharacteristic of the species.

Although features typical of the coho salmon spawner-recruit response (including absence of over compensation) are reasonably encompassed in the Beverton-Holt Model (Beverton and Holt 1957), Shaul et al. (2013) proposed a modification of the hockey stock (HS) model called the bent hockey stick (BHS) model which also encompasses the positive relationship between spawners and recruits above S_{msy} without the assumption of very high intrinsic productivity inherent in the Beverton-Holt model (Figure 8). Shaul et al. (2013) hypothesized that this positive relationship represents the contribution by marine-rearing nomad fry that are surplus to freshwater rearing capacity (Chapman 1962, 1966; Koski 2009), suggesting that a small but relatively constant fraction of these “surplus” fry survive and grow in marine waters where density dependence is presumed to be lower. They appear to provide a buffer against population shocks and enable populations to produce yield near *MSY* over a broader range, including from larger spawning escapements.

Shaul et al. (2009) used Beverton-Holt analysis to revise the *BEG* for Hugh Smith Lake to 500–1,600 spawners. Shaul et al. (2014) reviewed the *BEG* of 2,050 (range 1,300–2,900) spawners for Ford Arm Creek based on a variety of conventional spawner-recruit models, including one that incorporated pink salmon escapement. Their analyses resulted in estimates similar to the Ford Arm Creek goal initially established in 1994 (Clark et al. 1994) and they concluded that no change was warranted. Spawner-recruit analysis for both of these two long-term indicator stocks indicated a significant ($p = 0.05$) positive relationship between brood year escapement and production over the range of observations, with no evidence of the over-compensation feature prominent in the widely employed Ricker spawner-recruit model (Figure 8).

The *BEG* for the Berners River was recently revised 10–12% lower (Shaul et al. 2017). The analysis was based on estimated escapements and returns for the 1989–2010 brood years. The analysis was limited to this later period because escapement survey efficiency appeared to have stabilized after 1988 and because a transition from coded-wire tagging of presmolts (with over 10 months of freshwater residence remaining) to tagging of migrating smolts after 1988 resulted in dramatic improvement in the precision of harvest estimates and a clearer delineation between freshwater and marine effects. Adult runs to the Berners River have been highly variable, decreasing sharply from a 15-year period of high smolt production coincident with high marine survival during 1990–2004 to a post-2004 period when both smolt abundance and marine survival averaged substantially lower. Brood year production during both periods appeared largely unaffected by variation in escapement.

Marine survival was standardized to a constant rate for all brood years in the Berners River analysis under the assumption that marine survival is independent of spawner abundance, a common assumption for coho salmon but not for all species. A hockey stick production model (Bradford et al. 2000) was fit to both freshwater "regimes" including an earlier warm period (1989–1999) and a later cool period (2000–2010), as well as the full series, at constant marine survival rates that simulate varying ocean regimes including low marine survival (bottom quintile: 9.5%), high marine survival (top quintile: 25.4%), and average marine survival (16.3%).

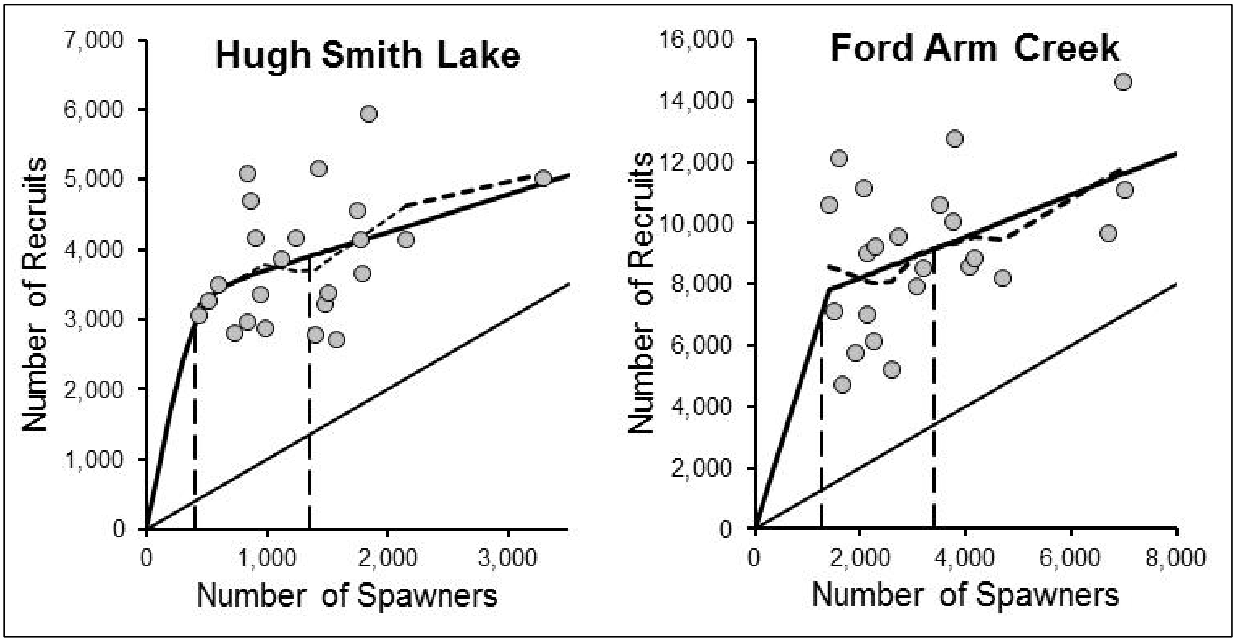

Figure 8.–Bent hockey stock (BHS) spawner–recruit relationships for Hugh Smith Lake coho salmon (1982–2004 brood years) and Ford Arm Creek coho salmon (1982, 1983, and 1985–2005 brood years) showing a 0.75 LOESS trend (dashed line), the replacement line (thin black solid) and the escapement range estimated to produce 90% or more of maximum sustained yield (black dashed lines; from Shaul et al. 2013).

Annual estimates of the number of Berners River spawners (i.e., nominal escapement) were standardized to a constant average per capita reproductive capacity in order to estimate "effective escapement" for each brood year. Per capita egg biomass was used to represent per capita reproductive potential and was computed as a function of (a) the proportion of females in the spawning escapement and (b) their average egg biomass (a function of female size). Per capita reproductive potential of spawners has been highly variable and positively correlated with marine survival, leading to greater variation in effective spawning escapement compared with nominal escapement (Shaul and Geiger 2016; Shaul et al. 2017).

Although the intent was to compare only unadjusted nominal estimates of Berners River escapement against the *BEG*, the recommended lower goal bound was increased by 26% to account for a pattern of lower per capita egg biomass in years when returns (and potential escapements) were low. The recommended upper goal bound was based on analysis for a period of favorable freshwater conditions (1989–1999 brood years) combined with assumed high marine survival (average for the upper quintile) to ensure that the biological escapement goal would encompass optimal escapement during a period of favorable conditions. The recommended *BEG* for the expanded survey count was 4,500–10,000 spawners. After adjusting for the survey expansion factor, the *BEG* for the unexpanded survey count was 3,600–8,100 spawners.

During 1990–2013, the Berners River population followed a very significant odd-year dominant pattern in female size, the ratio of females to males, and per capita egg biomass in age 1-ocean spawners (Shaul et al. 2017; Figure 9). This relationship changed, however, for 2014–2017 returns. The 2014–2016 returns were influenced by the warm water "Blob" in the northeast Pacific (Bond et al. 2015). The 2017 return was impacted by pink salmon runs that produced the two largest North American harvests on record (in 2013 and 2015), and which were expected to exert maximum influence on coho salmon growth in 2017 through impact on primary prey populations (odd-year squid) (Shaul and Geiger 2016). Female size rebounded in 2014–2016 from historic lows for both odd- and even-year cycle phases in 2011–2013 (Figure 9A), largely in line with the model forecast based on the PDO index and pink salmon biomass in the Gulf of Alaska (See Causes of Variation in Size; Figures 37 and 38).

The ratio of females to males declined substantially after 2013 (Figure 9B), however, despite the improvement in growth. We hypothesize that the disproportionate decrease in females may have been in part a sex-specific response to increased metabolic stress from elevated ocean temperatures during the "Blob". However, female size declined yet again in 2017, and the sex ratio reached a record low 0.44 females per male. In, 2017, the combination of small female size, (in line with the model forecast) and a record low sex ratio resulted in record low per capita egg biomass among Berners River spawners (Figure 9C). Although the warm water Blob had largely abated by early 2017, sea surface temperature maps indicated that anomalously high surface temperatures remained over much of the Gulf of Alaska, which may have added some level of continued metabolic stress at a time when availability of offshore squid prey was impacted by back-to-back record pink salmon returns.

The decrease to record low per capita egg biomass occurred as overall marine survival for both sexes continued a pattern of decline from an early 1990s peak, reaching a new low of 4.9% in 2017 (Figure 9D). Fortunately, the record low marine survival rate experienced by 2016 smolts (which returned as adults in 2017) was substantially offset in adult returns by a record 2016 smolt migration, that was positively influenced by record summer-fall rainfall in 2015 (Figure 9) followed by an exceptionally mild winter in 2015–2016. The expanded escapement count of 7,040 spawners was above the mid-point of the *BEG* (4,500–10,000 spawners), while the effective spawning escapement estimated at 5,410 spawners (adjusted for low per capita egg biomass) was in the lower portion of the goal range (Figure 10).

Adjusting nominal escapement (number of fish) to effective escapement (based on constant per capita reproductive potential) can be useful when there is evidence of growth-related and sex-specific mortality, as in populations like the Berners River coho salmon stock and other coho and Chinook (*O. tshawytscha*) salmon populations in the region. The combined effect of adult female size and differential late-ocean mortality in females can increase variation in total effective spawning escapement because lower survival rates tend to produce both a smaller number of returning salmon and fewer surviving spawners. Females returning under these conditions are typically smaller on average (with lower egg biomass) and comprise a smaller proportion of the spawning population compared with males than when growth and survival are high.

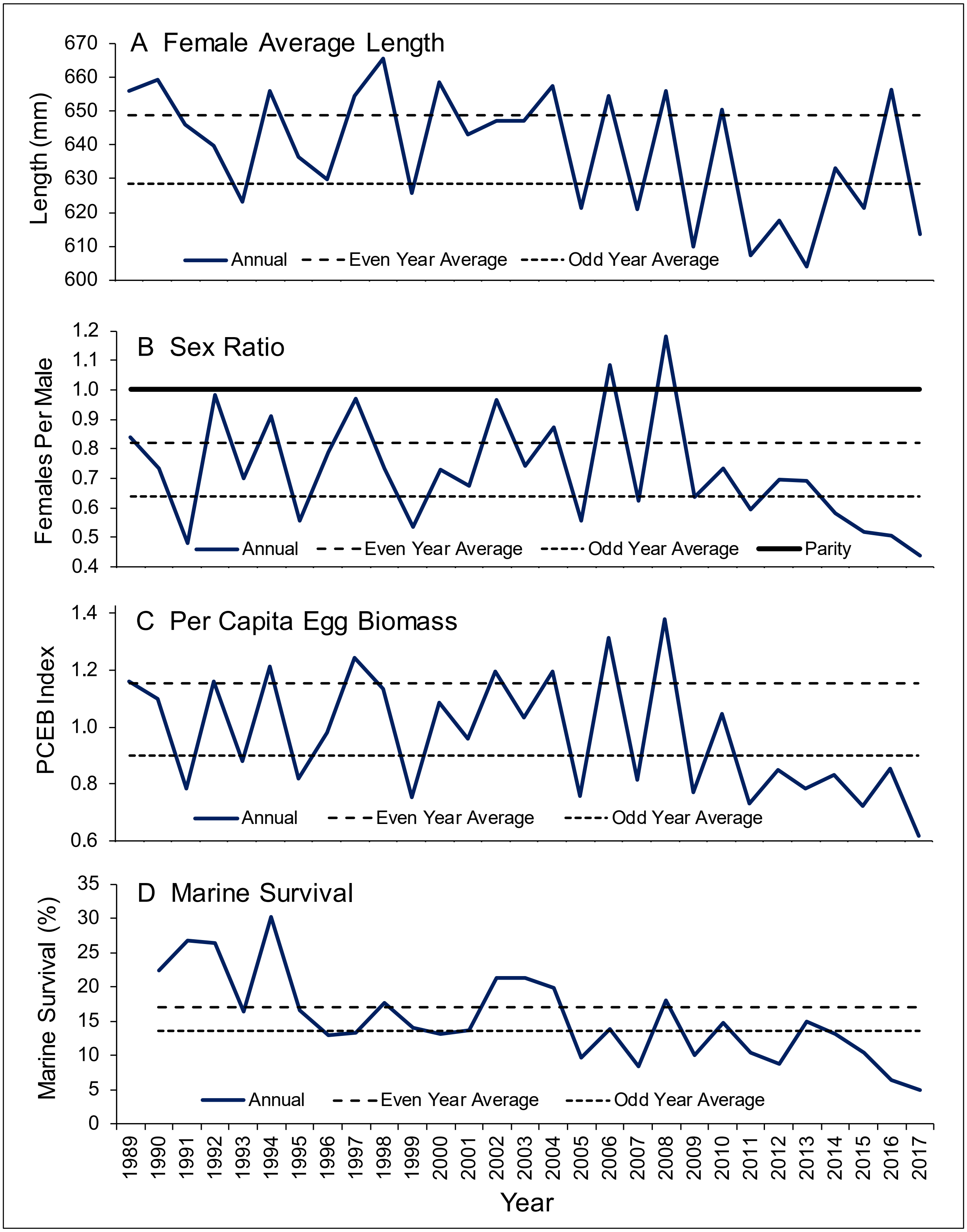

Figure 9.–Average female spawner length (A), ratio of female spawners to males (B), per capita egg biomass index for spawners (C), and marine survival from smolt to age 1-ocean returning adult for the coho salmon population in the Berners River, 1989–2017.

However, evidence of a possible shift in the spatial and temporal occurrence of marine mortality may justify revisiting the lower *BEG* bound for the Berners River stock. While there appears to have been an increase in early marine mortality beginning in the 2015 smolt year (reflected in both jack and adult returns to Auke Creek), recovery in adult size appears likely to continue in the near term. Unpublished age-sex-length data for the 2018 Berners River return indicates that females were large and survived well relative to males, whereas coho size forecasts point to a probable increase in size for both odd- and even-year lines in 2019 and 2020. An inshore shift in marine mortality means that female growth, late-ocean survival, and per capita egg biomass may remain favorable (as in 2018) even in years when returns and escapements are constrained by high early marine mortality. If this recent pattern persists, the 26% positive adjustment in the lower *BEG* bound to compensate for low per capita reproductive capacity (Shaul et al. 2017) may be unjustified.

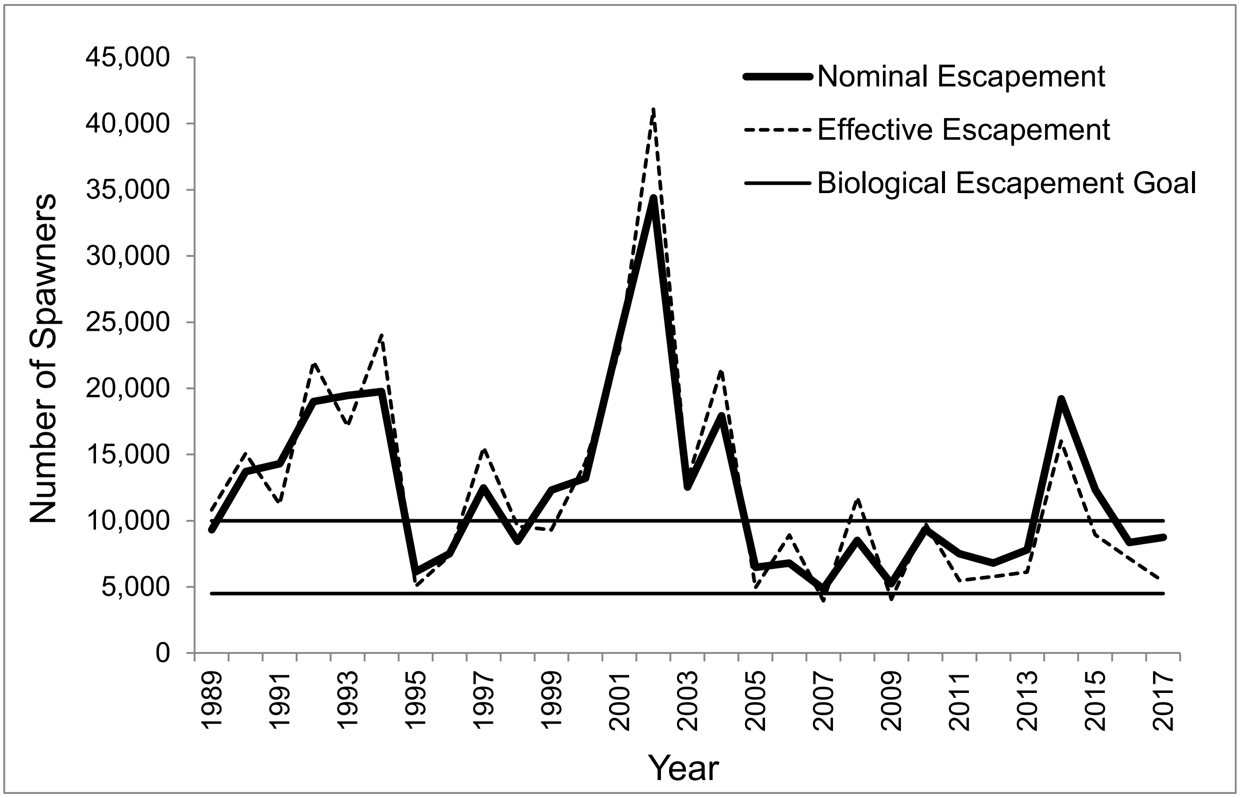

Figure 10.–Nominal number of coho salmon spawners in the Berners River and estimated effective spawning escapement adjusted to constant average per capita reproductive potential. Effective escapement is calculated by multiplying the escapement estimate by the per-capita egg biomass index standardized to a 1989–2014 average (Shaul et al. 2017).

SMOLT AND PRESMOLT PRODUCTION

Recent smolt production estimates are available through 2017 for five systems (Auke Creek, Berners River, Chilkat River, Taku River, Hugh Smith Lake), and presmolt estimates in the summer prior to smolt emigration are available for Ford Arm Creek through the 2015 return year (Table 3). Estimates in Table 3 are listed by adult return year for the smolt emigration in the previous year.

Auke Creek:

Shaul et al. (2005) noted a long-term linear decline in Auke Creek smolt production that appeared unrelated to brood year spawning escapement but were unable to offer a likely explanation for the trend, although Shaul et al. (2011) observed a marked recovery in 2010 and 2011. Overall, the trend in Auke Creek smolt production from the inception of the project in 1979 through an inflection point in 2008 is best described by a rate of decline of 2.4% per year, for a total decrease of 50% over the 30-year period. Smolt production rebounded dramatically after the 2008 sea-entry year, and since 2011 has ranged from 4,178 to 10,333 smolts and averaged 7,433 smolts, only 8% below the average of 8,044 smolts during the first 5-years of the project (1979–1983; Figure 11).

The dramatic reversal in smolt production began in spring 2009, immediately following construction of a handicapped accessible trail around Auke Lake, including sections of floating walkway, in summer 2008. We hypothesize that the decline may have been caused by gradual loss of habitat structure for rearing fry and juveniles such as woody debris from fallen trees as well as aquatic vegetation, and the reversal may have resulted from addition of habitat structure associated with floating sections of the trail. However, the 2018 migration of only 4,178 smolts was the lowest since 2008, so it remains unclear if recovery has been sustained. Smolts sampled and tagged in 2017 appeared to be in poorer condition and carried a substantial parasite load which may have affected freshwater survival (Scott Vulstek, National Marine Fisheries Service, Juneau, personal communication).

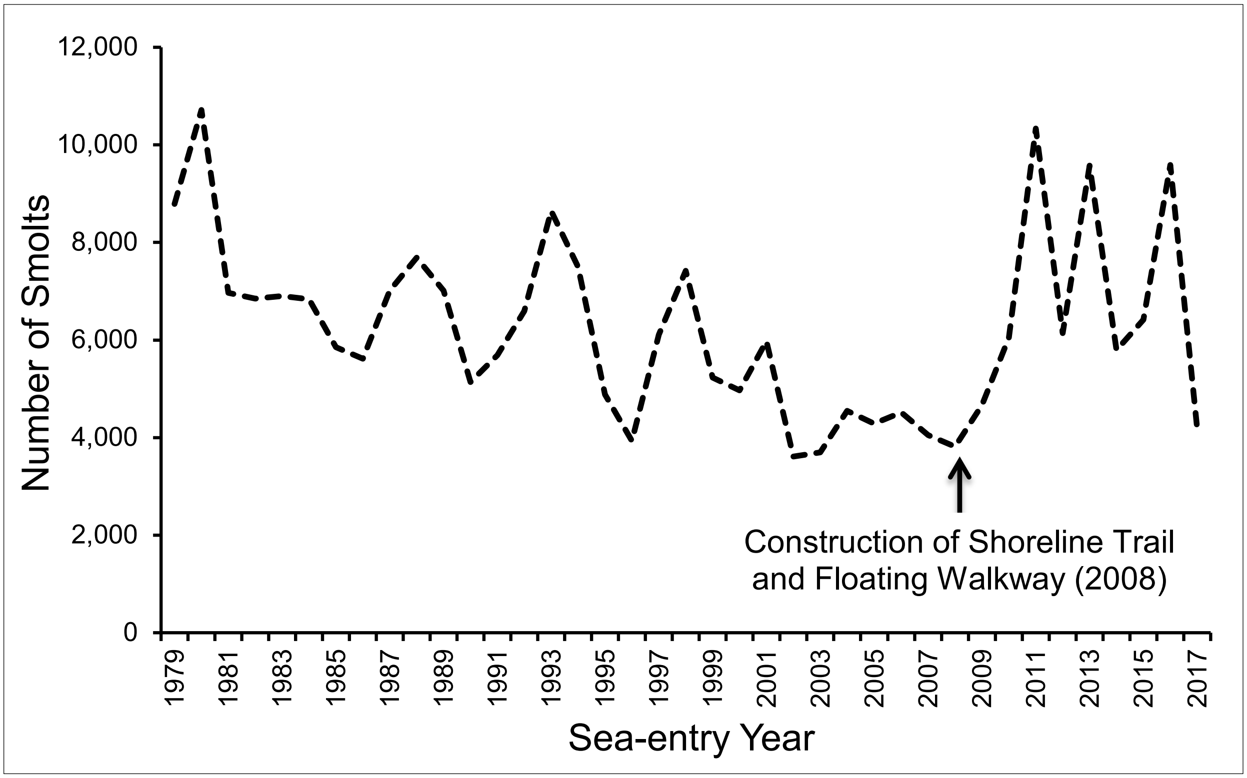

Figure 11.–Auke Creek coho salmon smolt production by sea-entry year, showing timing of construction of a handicapped accessible trail around the perimeter of Auke Lake.

Berners River:

During the initial 17-year period of smolt estimates for the Berners River (1989–2005 sea-entry years; 1990–2006 adult return years), the number of smolts was strongly correlated with July–November precipitation at the Juneau airport in the year prior to sea-entry ($R^2 = 0.725$, $p<0.0001$). During this period, smolt production averaged 193.8 thousand (range 124.1–326.3 thousand) fish (Figure 12; Shaul et al. 2017). However, the number of smolts subsequently declined, even while levels of precipitation remained favorable, and reached a low of 89.2 thousansd smolts in spring 2007. Although on-site physical monitoring has not been conducted in the Berners River drainage on a year-round basis, we suspect that the decrease in smolt production may have been related to a trend toward colder spring temperatures beginning in the mid-2000s, with probable longer annual periods of snow-on-ice coverage on off-channel habitats (Shaul et al. 2017). The low point in smolt production in 2007 (Figure 12) followed a winter of record snowfall that resulted in major winter-spring mortality and reduction in populations of moose (*Alces alces*) and mountain goats (*Oreamnos americanus*) in Berners Bay (White et al. 2012a, 2012b). Smolt production recovered to an average of 228.5 thousand fish from 2013 to 2016 (above the pre-2006 average) during a recent transition to warmer conditions. In the 2016 smolt year, production rebounded to a record high 327.9 thousand smolts, coincident with record high summer-fall precipitation (Figure 12) followed by exceptionally mild winter-spring weather.

Hugh Smith Lake:

Smolt production from Hugh Smith Lake has followed a relatively stable long-term trend and has shown the least variability among indicator stocks, perhaps because most freshwater rearing in the system occurs in a lake environment that is hydrologically, thermally, and structurally more stable compared with systems in which a higher proportion of rearing habitat occurs in streams, sloughs and ponds. An average of 39.2 thousand smolts migrated from Hugh Smith Lake during the most recent 5-year period with available final estimates (2013–2017 adult return years), a level of freshwater production 25% higher than the previous 30-year (1983–2012) average of 31.5 thousand smolts.

Ford Arm Creek:

Smolt population estimates are unavailable for Ford Arm Creek but the number of presmolts was estimated based on CWT marking of presmolts in the system in summer and recovery sampling of returning adults two years later (Table 3; Figure 13). Presmolt estimates increased markedly from an average of 60.7 thousand fish during earlier years of the project from 1980 to 1991 (1982–1993 adult return years) to 95.3 thousand fish during 1992–2013. This increase in freshwater coho salmon production coincided with a relatively steady increase in the peak number of spawning pink salmon observed in Ford Arm Creek from very low levels in the early 1980s (Figure 13).

Shaul et al. (2014) examined brood year coho salmon returns as a function of the combined biomass density of all pink, chum (*O. keta*), coho, and sockeye salmon in Ford Arm Creek. They observed a strong positive effect by freshwater coho salmon production at low-to-moderate levels of marine-derived nutrients (MDN), with an evident saturation effect as MDN levels increased above 1.30–1.93 pink salmon equivalents per m^2. The best predictive model for freshwater production of coho salmon from Ford Arm Creek indicated that spawner density was approximately equally important in both of the two years preceding migration of smolts to sea, whereas studies in Puget Sound rivers (Michael 1995; Zimmerman 2011) have shown a concentrated response to spawning pink salmon in the year following the common brood year, which for age-1 coho salmon smolts is also the year prior to smolt migration. The analysis was complicated by autocorrelation in both data series (spawning salmon biomass and coho salmon abundance), and by the absence of a strong biennial cycle in the Ford Arm Creek pink salmon population.

However, indications of a nutrient response in more than one year is consistent with studies indicating persistence of a nutrient legacy into the next growing season in periphyton (Verspoor et al. 2011), generalist macro invertebrates and Dolly Varden (Rinella et al. 2013), and density of juvenile coho salmon (Nelson and Reynolds 2014). In addition to being retained in biota, nutrients may be stored in the streambed and re-suspended (Rex and Petticrew 2008) or re-enter the main channel following deposition on the floodplain (Fellman et al. 2008). Reisinger et al. (2013) found evidence at two trophic levels (epilithon and juvenile coho salmon) that the size of the salmon run in one year can influence the isotopic signature of stream-resident biota prior to the salmon run in the following year.

The indicated strong initial response to increasing salmon spawner biomass by freshwater coho salmon production, followed by a saturation effect as spawner biomass increased above a density of 1–2 pink salmon equivalents per m^2, was consistent with the growth response observed in juvenile coho salmon in a controlled experiment in Southeast Alaska (Wipfli et al. 2003). Other studies have suggested that stream ecosystems can become saturated with salmon-derived material and do not respond to further increases in spawner density beyond a saturation threshold (Bilby et al. 2001; Chaloner et al. 2002a). Based on a bent hockey stick spawner-recruit model (Shaul et al. 2013) that incorporated pink salmon escapement, Shaul et al. (2014) estimated that the nutrient subsidy from pink salmon explained 57% of the variation in coho salmon abundance compared with 5% explained by parent coho escapement.

Despite nutrient benefits to presmolt production up to moderate levels, increasing pink salmon escapements began (by 1995) to tax dissolved oxygen (DO) levels in Ford Arm Creek to the point of causing substantial pre-spawn mortality in adult salmon in some years (Shaul et al. 2014), similar to the mortality event observed on Etolin Island by Davidson (1933). These events typically occurred after a period of days without rainfall and proved particularly lethal for larger fish, commonly resulting in 100% mortality in coho, chum, and sockeye salmon in the outlet stream. Juvenile salmon mortality has been more difficult to evaluate; however, a severe oxygen-depletion event on 30 August 2013 resulted in both high mortality among adult salmon and widespread mortality of large juvenile coho salmon that had a high potential to survive to smolthood and adulthood (Figure 14). The weir crew estimated that 40,000 fish out of 109,000 adult pink salmon counted in the stream died during this event, along with all adult coho and chum salmon observed below the weir. They also observed several dead trout. Juvenile coho salmon mortality was concentrated in the quieter section below the weir and appeared less extensive farther downstream, possibly because of aeration caused by turbulence from riffles and small falls in lower sections. Unlike adult mortality in coho salmon, which has likely had little effect on subsequent returns, mortality of large juveniles in late summer and fall likely reduces smolt production the following spring and adult returns 2-years after the mortality event.

Table 3.–Total coho salmon smolt and presmolt production estimates for six wild coho salmon-producing systems in Southeast Alaska by age-.1 return year, 1980–2017.

Return Year	Auke Creek Smolts	Berners River Smolts	Chilkat River Smolts	Taku River Smolts	Hugh Smith Lake Smolts	Ford Arm Creek Pre-smolts
1980	8,789	-	-	-	-	-
1981	10,714	-	-	-	-	-
1982	6,967	-	-	-	-	79,059
1983	6,849	-	-	-	29,117	63,686
1984	6,901	-	-	-	53,227	-
1985	6,838	-	-	-	32,283	38,509
1986	5,852	-	-	-	23,572	45,748
1987	5,617	-	-	-	21,878	70,322
1988	7,014	-	-	-	36,218	88,983
1989	7,685	-	-	-	27,904	51,658
1990	7,011	163,998	-	-	26,620	54,851
1991	5,137	141,291	-	-	33,101	56,284
1992	5,690	187,688	-	1,080,551	23,373	61,728
1993	6,596	326,312	-	1,510,032	32,657	57,401
1994	8,647	255,519	-	1,475,874	48,434	82,893
1995	7,495	181,503	-	1,525,330	49,516	134,640
1996	4,884	194,019	-	986,489	22,267	91,605
1997	3,934	133,629	-	759,763	32,294	66,772
1998	6,111	139,959	-	853,662	37,436	80,517
1999	7,420	252,168	-	1,184,195	29,875	132,655
2000	5,233	183,023	1,237,056	1,691,411	19,902	62,444
2001	4,969	268,777	1,185,804	1,811,038	23,327	102,610
2002	5,980	264,599	2,970,458	2,741,593	36,487	102,918
2003	3,616	148,513	1,696,212	2,737,851	26,841	77,081
2004	3,695	185,125	1,938,322	2,961,344	22,997	101,579
2005	4,549	144,778	776,934	3,755,274	39,924	120,632
2006	4,287	124,070	1,807,837	2,149,673	28,184	98,470
2007	4,515	114,648	875,478	3,035,547	37,267	84,017
2008	4,053	89,169	893,032	2,021,243	28,793	72,315
2009	3,815	102,318	716,689	2,803,021	24,006	96,180
2010	4,667	160,627	872,829	2,270,500	25,813	64,349
2011	6,053	130,727	1,026,314	1,526,065	37,742	86,994
2012	10,333	112,305	1,229,468	1,463,444	32,482	86,174
2013	6,143	151,016	788,387	1,338,435	41,093	99,144
2014	9,575	232,019	875,312	1,155,192	47,247	149,090
2015	5,793	172,588	639,750	670,139	33,860	104,490
2016	6,418	181,735	688,274	1,874,546	38,808	-
2017	9,590	308,612	666,396	2,731,997	33,756	-
Average	6,246	175,634	1,189,303	1,815,288	32,487	83,812

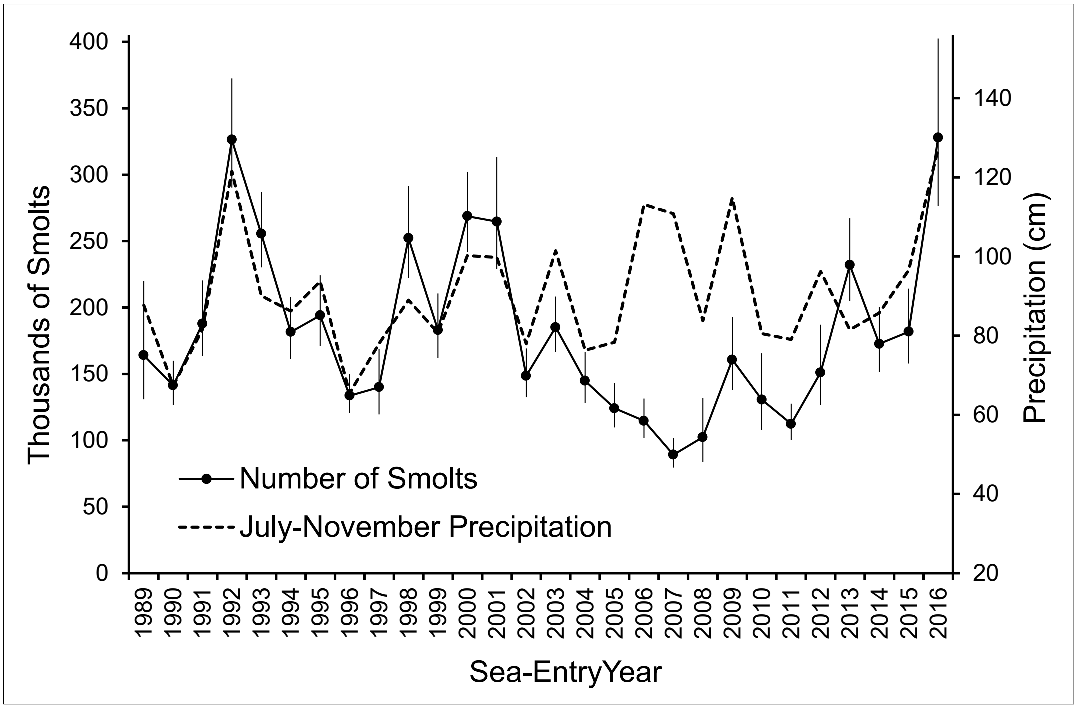

Figure 12.–Berners River coho salmon smolt estimates (with 95% confidence bounds) and total July-November precipitation at the Juneau Airport in the prior year.

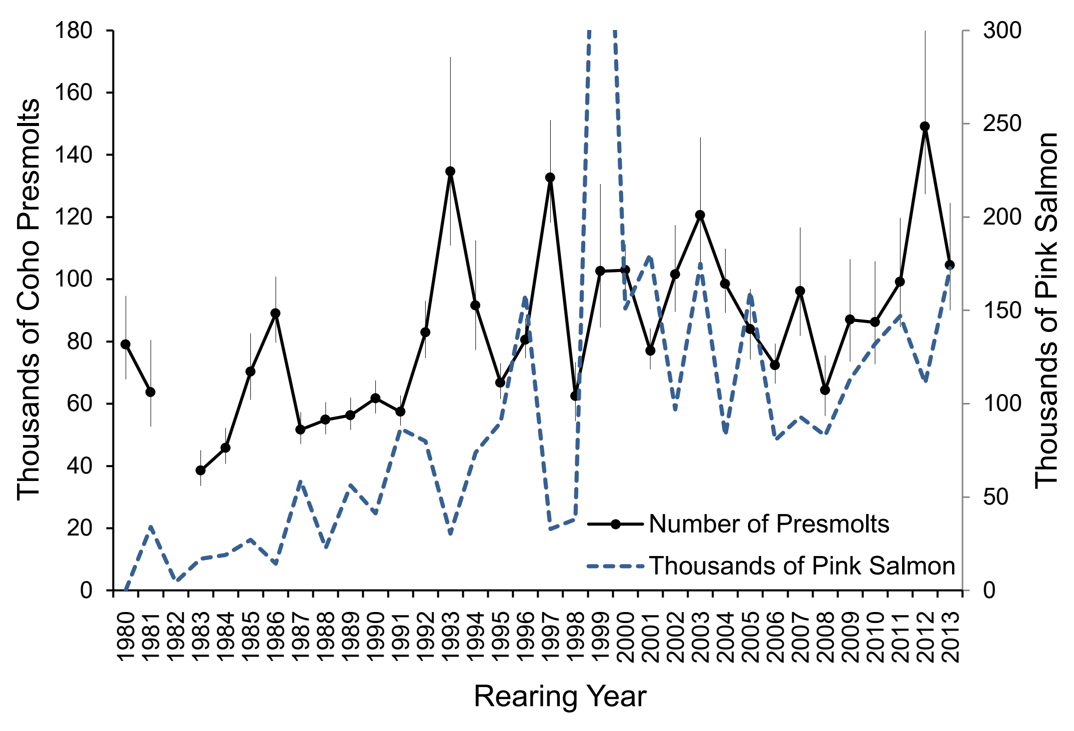

Figure 13.–Estimated population of rearing coho salmon presmolts in the Ford Arm Creek system and the peak survey count of spawing pink salmon in the creek in the same summer.

Although we have not analyzed physical data associated with pre-spawn mortality in detail, we developed a perception in the years following the first observed mortality event in 1995, that the thresholds of risk factors required to trigger these events had decreased; i.e., fewer breathing salmon and fewer consecutive days without rain were required to trigger pre-spawn mortality. The documented increase in salmon-derived nutrients in the Ford Arm Creek system (Shaul et al. 2014) would be expected to increase DO demand related to bacterial decomposition. However, further study would be needed to accurately isolate this factor from climatic risk factors (including late-summer air temperature and precipitation) when examining the relationship between spawner abundance and pre-spawn mortality. The impacts of enhanced ecosystem respiration due to high densities of spawning salmon, elevated stream temperature, and reduced aeration stemming from low streamflow are likely additive in terms of reducing DO (Fellman et al. 2019).

Figure 14.–Pre-spawn adult salmon mortality from oxygen depletion in Ford Arm Creek on 30 August 2013 (left) and resultant mortality of large juvenile coho salmon (right). (©2013 ADF&G/Photos by Amy Hemenway).

MARINE SURVIVAL

Marine survival estimates are available beginning in the early 1980s, near the end of a period of low harvests of coho salmon (Figure 1) and other salmon species that began in the early to mid-1950s. Marine survival rates for wild indicator stocks increased after the early 1980s and reached a peak in the early to mid-1990s before declining to more moderate levels from 1995 to 2004 (Figure 15; Table 4). Smolt–adult survival rates at Auke Creek increased from 9–10% in 1980 and 1981, the first returns with estimates, to an average of 19% during 1985–1989, and peaked at an average of 27% (range 21–35%) during 1990–1994 (Figure 15). Average survival for Auke Creek decreased moderately during subsequent decades to 21% (1995–2004) and 17% (2005–2014), then decreased sharply to 12% in 2015 and only 4% in 2016 and 5% in 2017. Marine survival for adults returning to Auke Creek in 2018 is forecast at 4% with a 95% prediction interval of 2–7% (see Marine Survival Forecasting section below).

Combined survival for Auke Creek smolts returning as both jacks and adults increased from 12–14% for the 1980 and 1981 smolt years to a peak of 46% in 1993 (Figure 16). Survival reached a later peak at 32% in 2001 and began to trend lower before plummeting from 17–24% in 2012–2014 to 5–8% in 2015–2016, with a forecast of 4% for the 2017 smolt year.

During the 1989–2016 smolt years, smolt–adult survival rates for the nearby Berners River population were lower in most years, averaging 15.3% compared with 19.3% at Auke Creek, despite the fact that a substantial proportion of Auke Creek males return a year earlier as age 0-ocean jacks, which are rare in the Berners River. Never-the-less, marine survival between the two systems shows a strong positive correlation ($R^2 = 0.67$ for adult returns and 0.66 when jacks are included).

Prior to the 2009 return, marine survival was typically lower for Hugh Smith Lake coho salmon (a southern Southeast Alaska stock) compared with northern inside indicator stocks. Smolt–adult survival at Hugh Smith Lake averaged 13.3% during 1990–2008, or two-thirds of the mean-average rate for Auke Creek and the Berners River (20.0%) during that same period. Marine survival rates showed a strong positive correlation between northern and southern indicator systems during this period ($R^2 = 0.57$; $p < 0.001$).

The relationship changed abruptly, however, in the 2008 sea-entry year (2009 adult return year) when marine survival decreased in the north relative to the south (Figure 17). This shift in favor of the south occurred during a period of cold climatic conditions in the northeast Pacific as indicated by the Pacific Decadal Oscillation (PDO) Index. The ratio of marine survival rates between the Berners River and Hugh Smith Lake was positively correlated with the September–August PDO index (ending in the sea-entry year) for the 1990–2014 return years (Shaul et al. 2017).

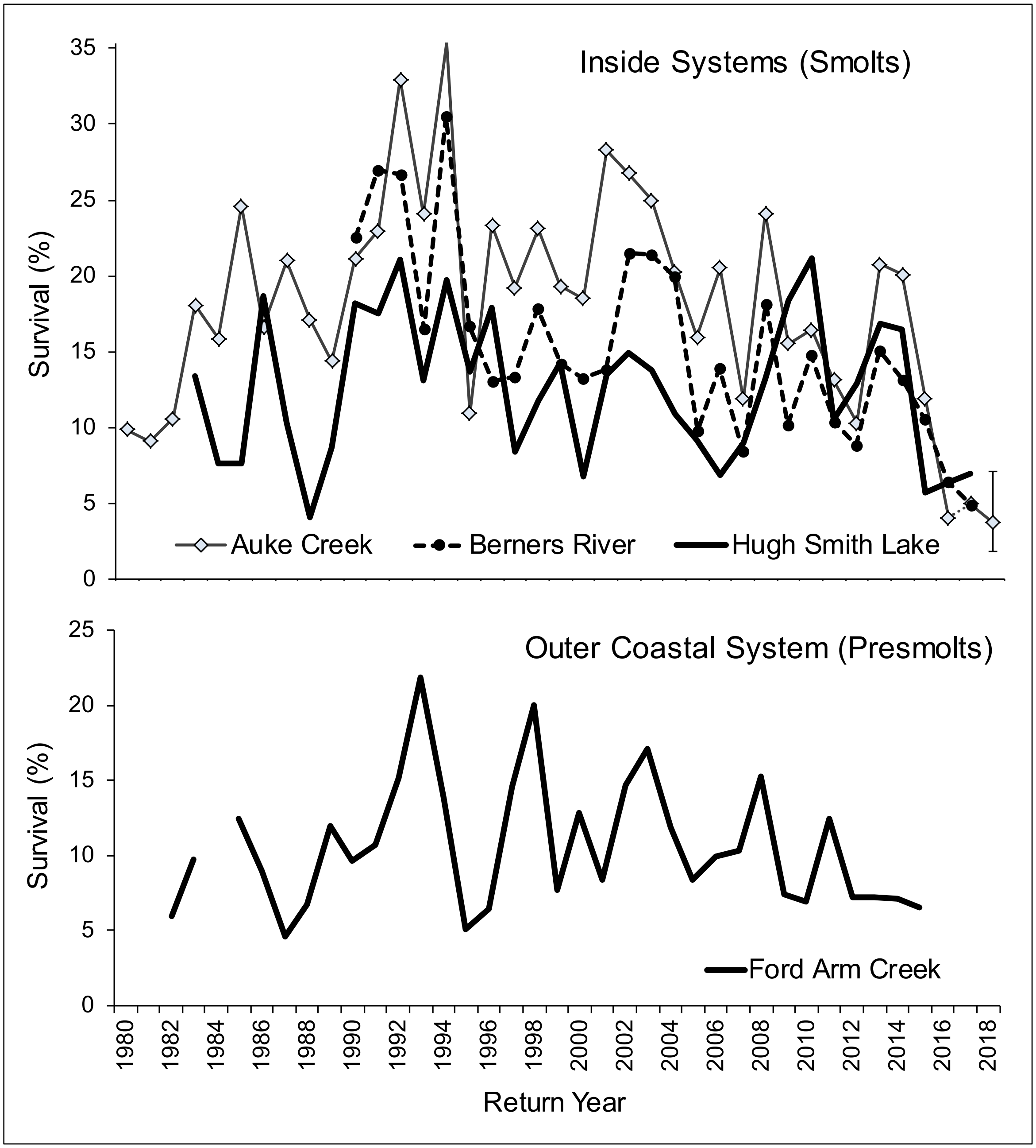

Figure 15.–Estimated marine (smolt–adult) survival rates of wild coho salmon from three systems in inside areas of Southeast Alaska (upper graph) and presmolts from one system on the outer coast of Southeast Alaska (lower graph), 1980–2017, with a 2018 forecast for Auke Creek (with 95% prediction interval). Survival rate estimates for Ford Arm Creek presmolts include approximately 10 months of freshwater mortality from July to May.

Table 4.–Estimated survival rates (percent) of coho salmon smolts and presmolts from six wild Southeast Alaska indicator stocks from the time of tagging until return as age 1-ocean adults to the fisheries, 1980–2017.

Return Year	Auke Creek Smolts	Berners River Smolts	Chilkat River Smolts	Taku River Smolts	Hugh Smith Lake Smolts	Ford Arm Creek Pre-smolts
1980	9.9	-	-	-	-	-
1981	9.1	-	-	-	-	-
1982	10.6	-	-	-	-	5.9
1983	18.1	-	-	-	13.3	9.7
1984	15.9	-	-	-	7.6	-
1985	24.6	-	-	-	7.6	12.5
1986	16.6	-	-	-	18.5	9.0
1987	21.0	-	-	-	10.3	4.6
1988	17.1	-	-	-	4.1	6.8
1989	14.4	-	-	-	8.6	11.9
1990	21.1	22.3	-	-	18.0	9.6
1991	23.0	26.7	-	-	17.4	10.7
1992	33.0	26.5	-	19.7	20.9	15.1
1993	24.1	16.4	-	16.5	13.0	21.9
1994	35.3	30.2	-	23.0	19.5	13.9
1995	10.9	16.5	-	11.9	13.5	5.0
1996	23.4	12.9	-	9.6	17.7	6.4
1997	19.2	13.3	-	6.7	8.3	14.6
1998	23.1	17.7	-	14.0	11.7	20.0
1999	19.3	14.1	-	9.9	14.1	7.7
2000	18.5	13.1	10.1	6.5	6.8	12.9
2001	28.3	13.7	13.1	9.0	13.4	8.4
2002	26.8	21.4	11.4	11.1	14.8	14.7
2003	25.0	21.2	12.9	9.7	13.7	17.1
2004	20.2	19.8	10.1	8.5	10.8	11.9
2005	16.0	9.7	8.4	5.9	9.1	8.4
2006	20.5	13.8	8.0	10.5	6.8	10.0
2007	11.9	8.4	4.4	4.4	8.9	10.3
2008	24.1	18.0	12.1	8.6	13.1	15.3
2009	15.5	10.1	10.9	8.0	18.3	7.4
2010	16.4	14.7	17.7	10.9	21.0	6.9
2011	13.1	10.3	9.5	8.5	10.4	12.5
2012	10.3	8.8	5.3	7.7	12.8	7.2
2013	20.8	15.0	15.4	10.7	16.7	7.2
2014	20.1	10.1	17.9	16.4	16.3	7.2
2015	12.0	8.2	11.2	15.5	5.7	6.6
2016	4.1	6.4	5.9	6.7	6.4	-
2017	5.0	4.9	7.8	4.6	6.9	-
Average	18.4	15.3	10.7	10.7	12.5	10.6

Marine survival at Hugh Smith Lake increased during 2009–2014 to an average of 15.9% that was similar to the peak 10-year period in the series from 1990 to 1999 (15.4%; Figure 12). However, this increase did not persist during the period spanned by the recent warm-water "Blob" in the North Pacific beginning in summer 2014 (Bond et al. 2015). There was an initial shift back in favor of northern stocks in 2015 (2014 sea-entry year; Figure 17), in line with an increasing PDO index, and survival for the Hugh Smith Lake population decreased to 5.7%, well-below average survival for the northern indicators (11.2%; range 10.5–12.0%). However, during subsequent continued warm conditions during sea-entry years, smolt–adult survival reverted in favor of Hugh Smith Lake (6.4–6.9%) over the two northern indicators (average 4.9–5.2%). Smolt–adult survival declined further in both areas of the region, with Auke Creek dropping from 12.0% in 2015 to 4.1% in 2016 and 5.0% in 2017. Berners River survival decreased from 10.5% in 2015 to 6.4% in 2016 and 4.9% in 2017.

Marine survival rates for inside stocks at both ends of the region were at or near historic lows for returns in both 2016 and 2017, and continued poor survival rates are expected in 2018 based on the record low percentage (0.5%) of Auke Creek smolts that returned as jacks in 2017. Overall, between the periods 1983–2008 and 2009–2017 (adult years) there was a shift in the multiplier between Auke-Berners average survival and Hugh Smith Lake survival from 0.64 during the former period to 1.07 during the latter period (Figure 17).

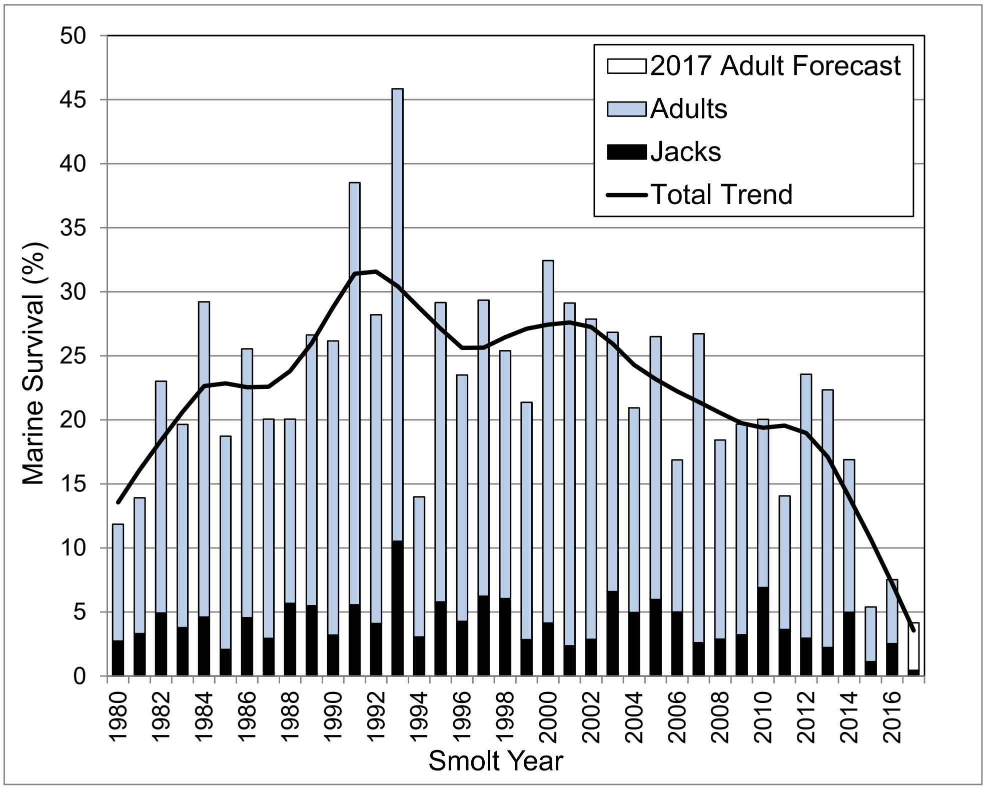

Figure 16.–Estimated marine survival rates of wild Auke Creek coho salmon smolts by age 0-ocean jacks and age 1-ocean adults,1980–2016, with a forecast for 2017 and a 0.25 LOESS trend (black line) for total survival.

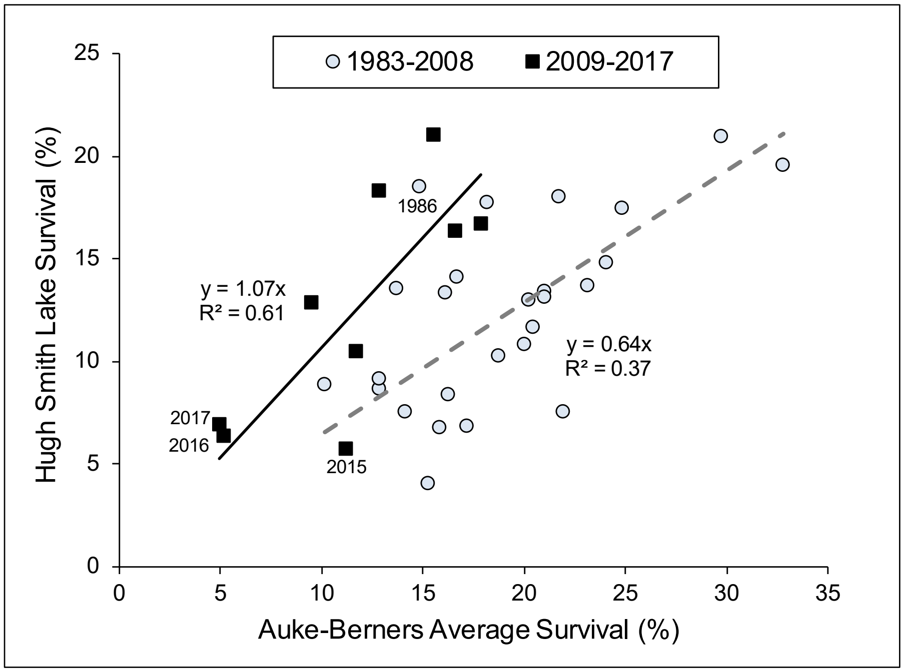

Figure 17.–Relationships in smolt–adult survival rates between the southern indicator stock (Hugh Smith Lake) and the average for two northern indicator stocks (Auke Creek and Berners River) during 1983–2008 and 2009–2017 returns years (linear relationships are forced through the origin). Berners River marine survival prior to 1990 was interpolated from the relationship with Auke Creek during 1990–2017 using the method described by Brown (1974).

Aside from 2015, the other primary outlier from this pattern was in 1986 (1985 smolt year) when there was a coast-wide reversal in the prevailing post-1976 trend in marine survival that favored northern stocks. Coho salmon returns to the Yakutat area, including the Situk River, were very weak in 1986 (as indicated by the Situk-Ahrnklin set gillnet catch) while returns to the south were very strong from southern Southeast Alaska to the Oregon coast. Oregon Production Index hatchery (OPIH) coho salmon survival was higher in 1986 (7.4%) than in any other year during the 57-year period from 1961 to 2017 outside of the 1965–1976 peak, when survival remained consistently above 5% and averaged 7.8% (Figure 18). The relationship between Situk River coho salmon harvest and OPIH marine survival shows a strong inverse relationship consistent with the "Inverse Production Hypothesis" (Hare et al. 1999) during 1961–2000, although the relationship has since been less consistent.

Outer coastal stocks in northern Southeast Alaska, represented by Ford Arm Creek, have shown a somewhat different pattern. Ford Arm Creek presmolts returning from 1982 to 2015 survived at an average rate of 10.6% and increased from an average of 8.1% during 1982–1988 to a peak 10-year average of 12.9% during 1989–1998 (Figure 15; Table 4). Survival rates subsequently decreased and remained stable near 7% during the final four years of the Ford Arm Creek project (2012–2015). Survival rate estimates for Ford Arm Creek include about 10 months of freshwater mortality and, therefore, are not a pure indicator of marine survival.

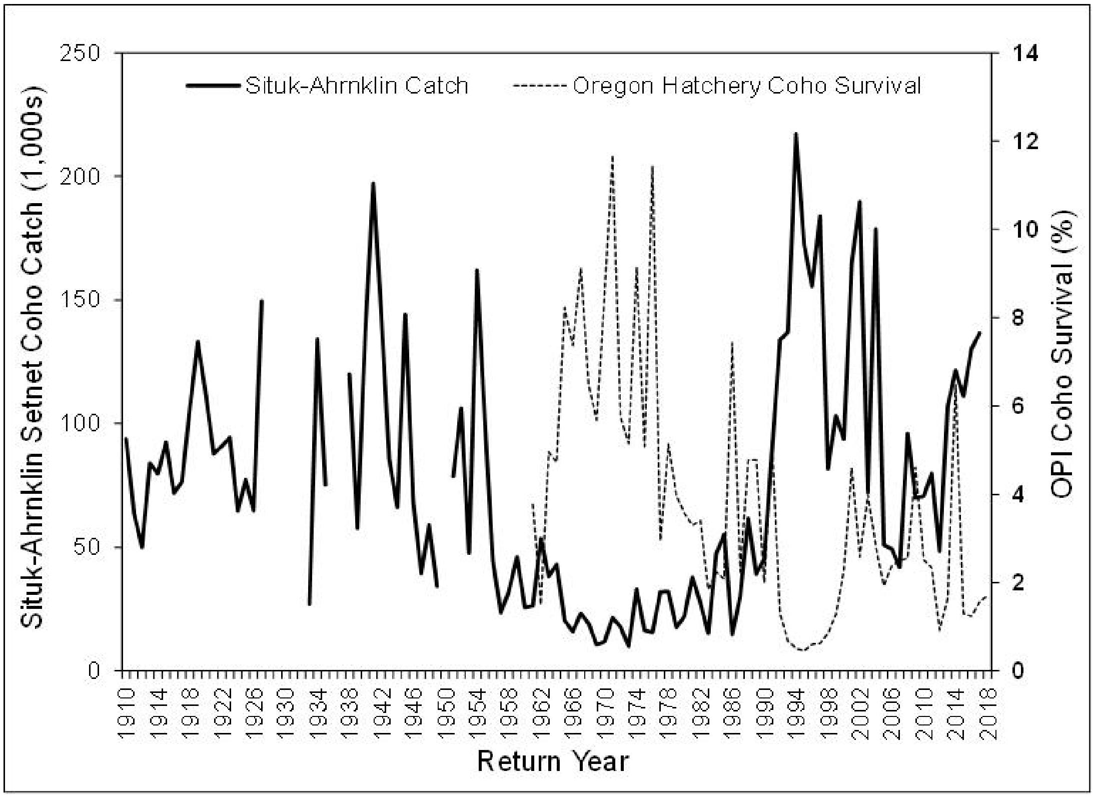

Figure 18.–Coho salmon harvest in the Situk-Ahrnklin set gillnet fishery compared with marine survival of hatchery coho salmon in the Oregon Production Index (OPI) area.

Marine Survival Forecasting

Although the jack-versus-adult relationship alone is a poor predictor of smolt–adult survival, except at extremes, incorporating average jack length adds useful information (Figure 19). Larger jack size appears to be a strong predictor of early maturity in males, and vice versa. Although some jacks escape uncounted between the pickets of most remote adult salmon weirs, the Auke Creek weir provides a census of returning jacks that can be compared with a census of smolts migrating to sea in the same year and an estimate (combined escapement count and CWT-based harvest estimate) of adults returning the following year. Auke Creek smolt–adult survival for the 2017 sea-entry year (2018 adult return) is forecast at only 3.7% (95% prediction interval of 1.8–7.2%) based on the proportion of smolts that returned as jacks and a linear relationship between average jack size and proportion of smolts returning as jacks (versus adults; Figure 19). However, a 0.4 LOESS trend fitted to the data suggests that the relationship may not be linear, particularly at smaller average jack lengths, where the early maturity in males may drop off more rapidly than indicated by the linear relationship. A non-linear (polynomial) relationship fits the data slightly better (R^2 of 0.52 versus 0.48 for the linear relationship) and forecasts a higher smolt-to-adult survival (4.9% versus 3.7%) for 2017 smolts.

Smolt–adult survival at Auke Creek has shown no relationship with early marine growth, as indicated by the average length of juveniles sampled in 21 years of trawl surveys conducted in Icy and Chatham straits on 24 July by the NOAA Southeast Alaska Coastal Monitoring Project (Figure 20; R^2 = 0.03; data provided by Emily Fergusson, National Marine Fisheries Service, Juneau). Juveniles sampled in those trawl surveys were at record average length in 2016, and tied with 1997 for second largest in 2015, but had the fourth smallest average length on record in 2017. However, marine survival was historically poor for all three sea-entry years. This comparison suggests that the recent apparent decrease in early marine survival in the 2015–2017 smolt years, as reflected in returns of both jacks and adults to Auke Creek, has been caused by a factor unrelated to growth, such as an increase in predation pressure.

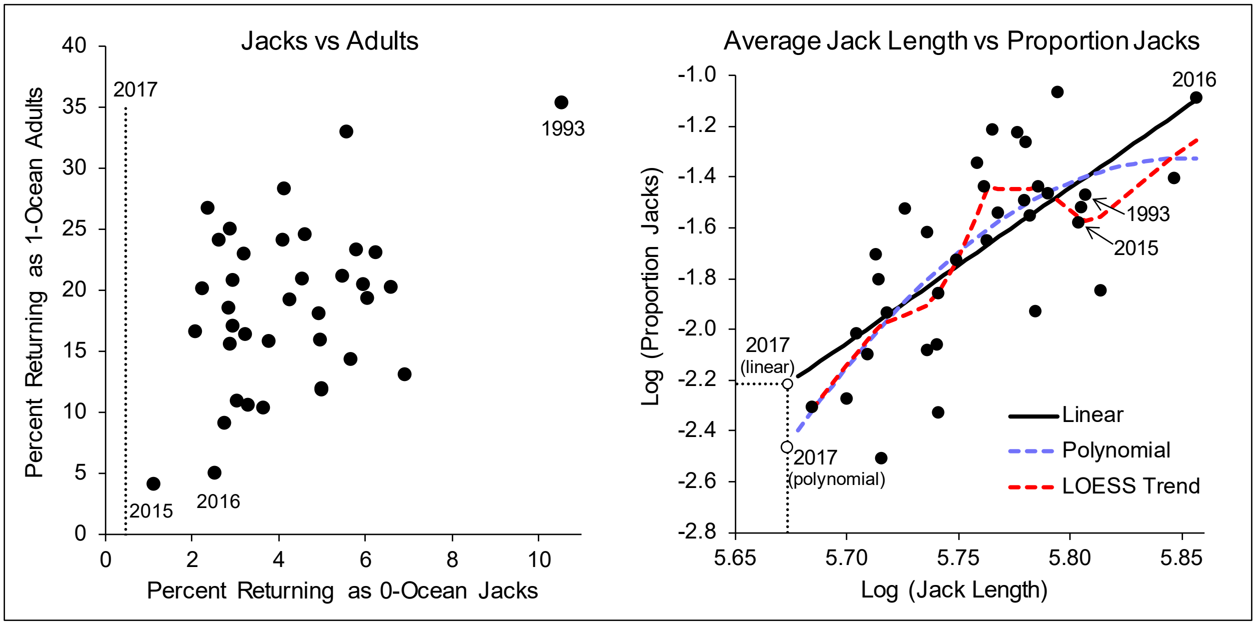

Figure 19.–Relationship between the rate of return of Auke Creek coho salmon as adults versus as jacks (left graph) and log-log relationships between the average age-0 jack length and the jack proportion of combined jack and adult return by sea-entry year (right graph) for the 1980–2016 smolt years. Percent of smolts returning as jacks and average jack length are shown for 2017 with point forecasts for the proportion of smolts returning as jacks. Forecast survival of 2017 smolts to adult return is 3.7% (95% prediction interval 1.8–7.2%) based on the linear relationship, but a polynomial relationship predicts a higher survival rate of 4.9%.

Late-Ocean, Growth-Related Effects

A number of studies from Oregon to southern British Columbia have pointed to an early marine critical period for survival of coho salmon within the first weeks or months of marine residence (e.g., Holtby et al. 1990; Pearcy 1992; Beamish et al. 2004). However, several studies in northern Southeast Alaska have generally failed to support the controlling importance of an early-marine critical period for growth and survival of coho salmon in that region and have instead pointed toward an important late-marine period after juveniles leave coastal waters late in their first summer at sea (Hobday and Boehlert 200l; Briscoe 2004; LaCroix et al. 2009; Orsi et al. 2013; Shaul and Geiger 2016). Research on coho salmon scale growth (Briscoe 2004) has indicated that the size of Auke Creek adults is also influenced primarily by conditions encountered in offshore waters of the Gulf of Alaska.

Shaul and Geiger (2016) observed a moderately strong positive correlation between marine survival of Berners River coho salmon and the size (length) of adults prior to harvest in the near terminal commercial gillnet fishery in Lynn Canal; a relationship that is consistent with the hypothesis that overall survival in the ocean is influenced by late-marine growth (Figure 21). They suggested that a decrease in variation in survival at smaller adult sizes may indicate that slower late-marine growth reduces both average survival and the potential range of survival rates. In other words, as the rate of growth slows in the offshore environment, growth-related late-marine mortality may become a proportionately more important influence on marine survival compared with other factors.

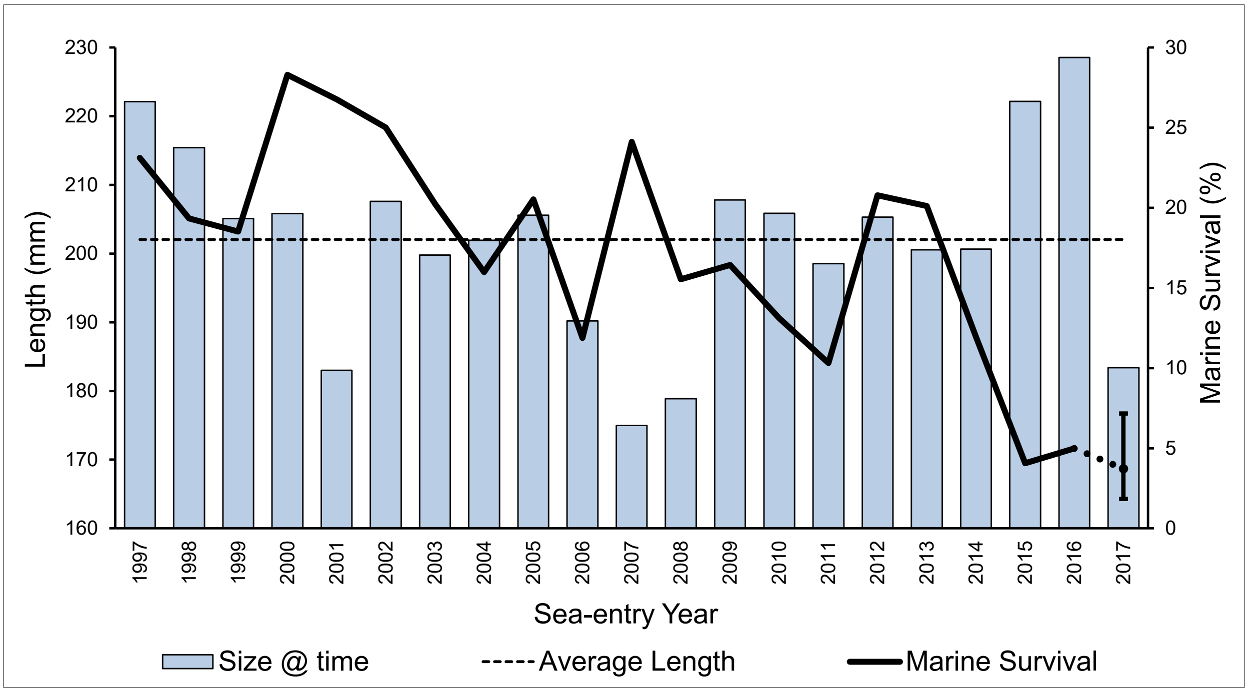

Figure 20.–Smolt-adult survival rates of Auke Creek coho salmon and average fork length of juvenile coho salmon caught on 24 July in NOAA trawl surveys in northern Southeast Alaska, by sea-entry year (average length data provided by Emily Fergusson, National Marine Fisheries Service, Juneau). The marine survival rate for the 2017 sea-entry year is a preliminary estimate (with 95% predication interval) based on the return rate of smolts as jacks and the average length of jacks.

Shaul and Geiger (2016) fit pink salmon biomass and PDO variables (that explained about two-thirds of variation in adult coho salmon weight) to survival-related response variables and found that only the lagged pink salmon biomass variable showed a consistent statistically significant influence. A strong even-year dominant pattern in sex ratio indicates that growth-related late-ocean mortality falls most heavily on females. The pink salmon biomass variable explained much of the year-to-year change in marine survival, sex ratio, and per-capita egg biomass index (with acceptable model diagnostics) suggesting that while trends in marine survival may be influenced by other factors, the biomass of pink salmon has an important effect on year-to-year variation in survival of coho salmon, likely through control of squid prey populations (which, like pink salmon, also have a 2-year life cycle; Jorgenson 2011).

Deterioration of model diagnostics when transitioning from forecasts of adult size to smolt–adult survival (Shaul and Geiger 2016) likely reflects influence of patterns in early-marine survival that are unrelated to offshore growth. These early-marine factors may be increasing in influence. Recent 2016 and 2017 negative outliers in the relationship between adult size and marine survival (Figure 21) suggest that the relative influence of late-ocean growth on overall marine survival may have changed with the recent decline in marine survival. The recent sharp decrease in marine survival beginning in the 2015 sea-entry year has been accurately indicated by Auke Creek jack returns (Figures 16 and 19), suggesting that an increase in early marine mortality has occurred in local inside waters where age 0-ocean jacks are believed to remain throughout their time at sea. However, low survival relative to adult size in 2016 (Figure 21) may have also been influenced by late-ocean mortality factors, as a very low female-to-male ratio (Figure 9B) suggests that some of the decrease in marine survival in that year may have been related to late-ocean mortality that fell disproportionately on females. One potential cause may be increased physiological stress in relation to elevated ocean temperatures during the warm water "Blob". Another potential factor may have been increased exposure by individual salmon to offshore predators because of reduced buffering as a consequence of the very low return of pink salmon throughout the Gulf of Alaska in 2016. We noticed a higher-than-usual incidence of mostly-healed predator scars on 685 spawners sampled for age-length-sex in the Berners River in 2016.

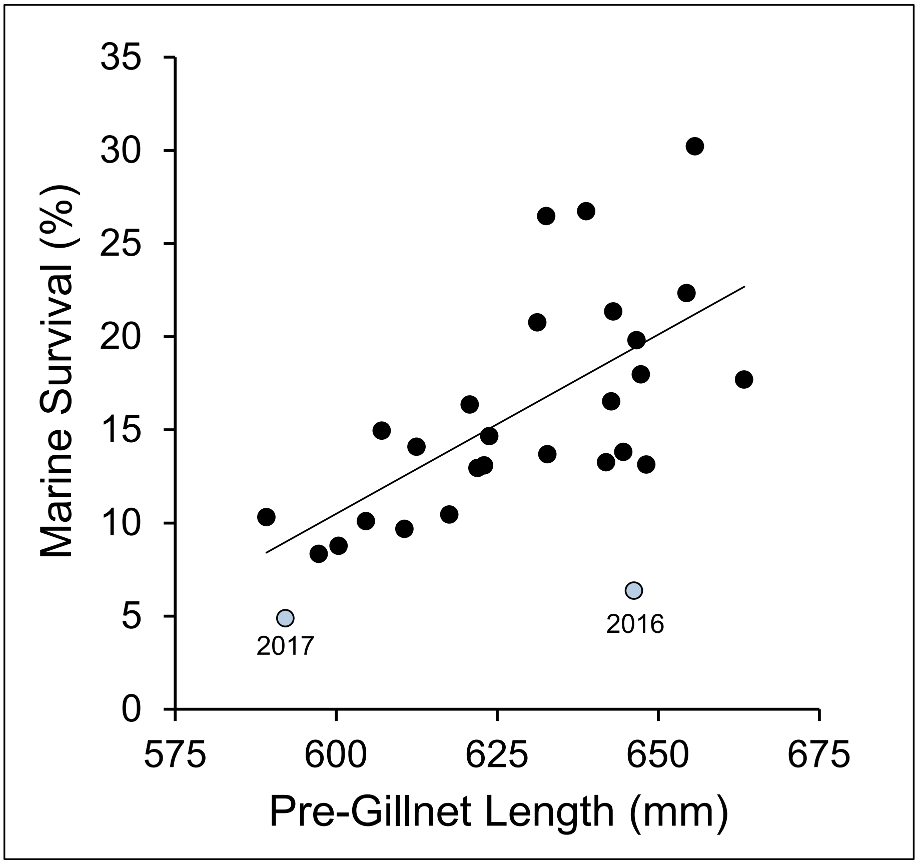

Figure 21.–Relationship between mean-average pre-gillnet length of returning Berners River coho salmon marine survival and smolt–adult survival by return year (1990–2015), with 2016 and 2017 outliers excluded.

Hatchery Production and Survival

Releases of coho salmon from Southeast Alaska hatcheries have increased steadily over the past 3 1/2 decades, from fewer than 1 million fish in 1980 to nearly 24 million fish in 2016 (Figure 22). The aggregate contribution by hatcheries to common property fisheries, however, has not shown a commensurate increase. The number of hatchery coho salmon that contributed to the all-gear commercial harvest reached a 1991–1995, 5-year average harvest of 641.4 thousand fish produced from an average release of 11.8 million fish (Figure 1). However, during the most recent 5-year period (2012–2017), the average harvest of hatchery fish increased only slightly (5%) to 674.4 thousand fish despite the near doubling of hatchery production to an average of 22.7 million fish released.

Shaul et al. (2011) found that marine survival rates of hatchery fish at individual release sites were near parity with wild stocks in initial release years, but quickly decreased relative to wild indicators in subsequent years. The poor production from increased smolt releases appeared to be attributed to a combination of progressive underperformance in marine survival by longer-term hatchery releases from mainline facilities (compared with nearby natural systems) combined with spectacularly poor success by some major new programs.

Shaul et al. (2011) hypothesized that the decrease in marine survival of hatchery fish relative to wild stocks over time resulted from development of predator fields attracted to large point sources of smolts entering marine waters (Beamish et al. 1992; Nickelson 2003). Development of predator fields affecting marine survival around larger annual point sources of salmon smolts may not be unique to hatcheries in the region. Shaul et al. (2003) noted a strong inverse relationship between total salmon production and average marine survival for wild stocks in both the northern inside area (Auke Creek, Berners River, and Taku River) and in the southern boundary area (Hugh Smith Lake, Lachmach River, and Nass River) based on estimates reported by the Joint Northern Boundary Technical Committee (2002). The broad dispersion of point sources of wild coho salmon smolts in Southeast Alaska, because of the region's high rainfall, extensive shoreline, and large number of small primary streams, may be an advantage to their marine survival.

Although hatchery smolt production more than doubled between the 1990 and 2016 release years, the resulting harvest of hatchery-produced coho salmon by the troll fishery declined during 1991–2010, and the hatchery proportion of the total troll catch remained flat at 20% (Shaul et al. 2011). Since 2010, the smolt releases continued to increase, while the average proportion of hatchery fish in the troll catch increased to 26% (range 18–31%) during 2011–2017 (Figure 22). In the past 20 years (1998–2017), smolt releases have followed a remarkably steady increasing linear trend ($R^2 = 0.92$), with facilities collectively adding an additional 596 thousand smolts per year to releases.

In absolute terms, the linear trend in the number of hatchery-produced coho salmon harvested by trollers increased by 4.1% during 1991–2017, although the trend in the percentage of coho salmon of hatchery origin declined for the first 20-years of the period (Shaul et al. 2011). A major factor in the post-2010 increase has been a large increase in returns to Klawock Hatchery, located on the outer coast of Prince of Wales Island. The Klawock Hatchery contributed an average of 108.5 thousand coho salmon to the troll catch during 2011–2017, a nearly 5-fold increase from its average contribution of only 18.8 thousand fish during the prior two decades (1991–2010), even though the average smolt release associated with those returns increased by only 1.5 fold.

At the opposite extreme is the Hidden Falls Hatchery, on Baranof Island, in Chatham Strait. The average contribution of Hidden Falls Hatchery coho salmon to the troll harvest declined from 53.7 thousand fish during 1991–2010 to 29.8 thousand fish during 2011–2017, even as the number of smolts released at the central incubation facility increased by nearly an order of magnitude from fewer than 0.5 million smolts released annually prior to 1994 to over 3.3 million smolts released in 2016 (Figure 23). The trend in the number of hatchery smolts released appears as a near mirror image to the trend in marine survival rates for these releases, which declined from an average of 22% (range 16–29%) during 1991–1994 to only 1% during 2016–2017—a pattern similar to

Georgia Strait hatchery coho salmon releases and survival rates that peaked early in hatchery development in the 1970s before entering a long-term decline toward very low levels approaching zero in recent years (Beamish et al. 2010).

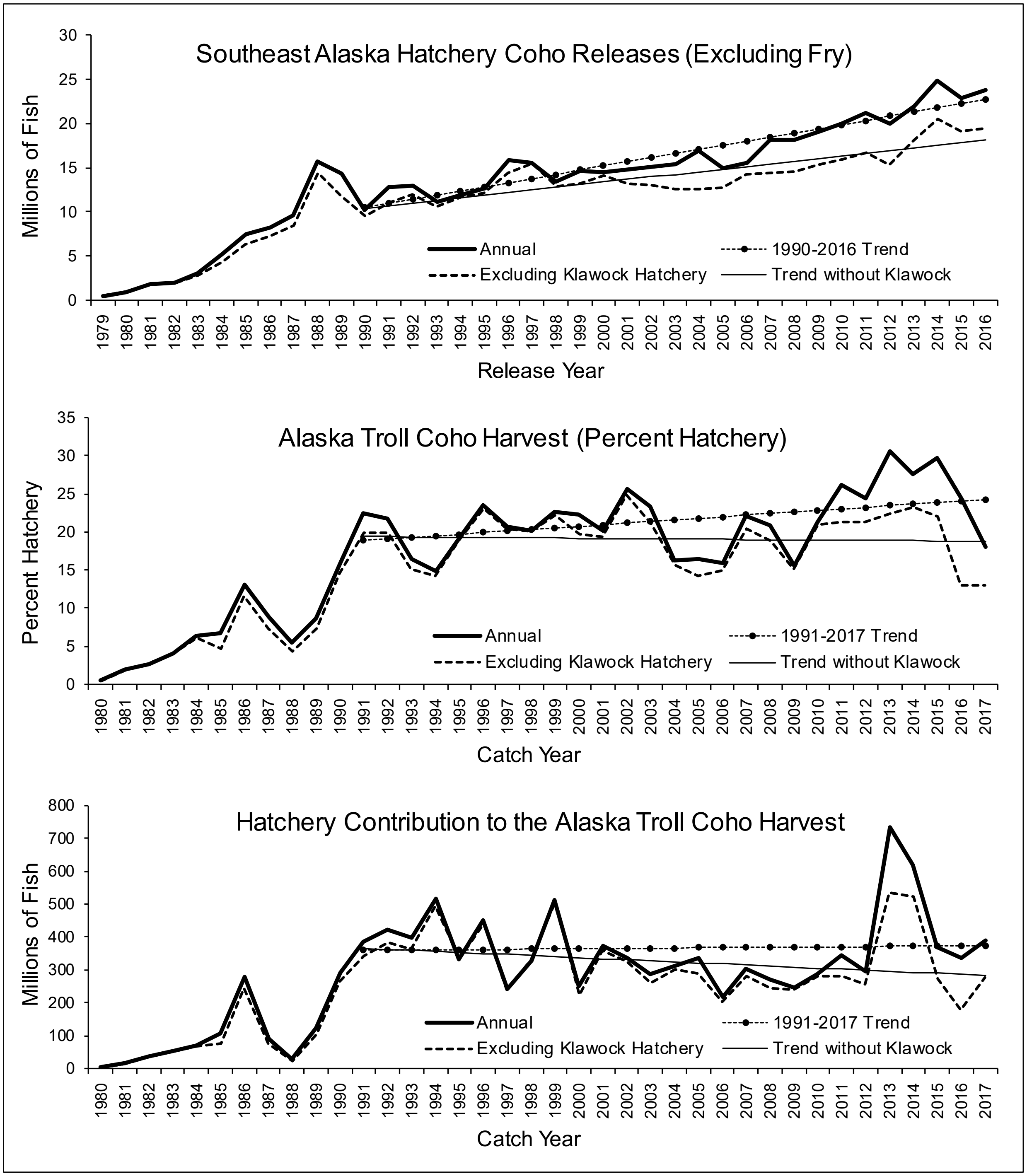

Figure 22.–Releases of coho salmon (excluding fry) from Southeast Alaska hatcheries, the percent of the troll catch comprised of fish of hatchery origin, and the number of hatchery fish contributed to the Alaska troll coho salmon catch, 1980–2017. Estimates are shown both with and without releases and contributions from the Klawock Hatchery.

In Georgia Strait, most research attention has been placed on bottom-up trophic effects on marine survival (e.g., Irvine et al. 2013; Beamish et al. 2018); however, an intensifying predator field at hatchery release locations may also be important (Beamish et al. 1992; Thomas et al. 2017; Allegue 2017). In Southeast Alaska, the humpback whale (*Megaptera novaeangliae*) is one of many species that has been reported to be visually evident feeding on both chum and coho salmon releases near some facilities including Hidden Falls Hatchery (Chenoweth et al. 2017). Observed whale depredation alone contributed to significantly lower survival of coho salmon, resulting in an estimated loss in fishing revenue from coho salmon from the Hidden Falls, Mist Cove and Port Armstrong release sites of approximately US$1 million per year (Chenoweth and Criddle 2019).

After substantial initial success during their early development prior to the early 1990s, hatchery program efforts to further increase the common property harvest of coho salmon through steadily increasing smolt releases have shown little additional gain in either absolute terms (numerical contribution to the catch) or proportionate terms (percent of the catch). Even this assessment is generous since it presumes that the number of hatchery fish documented in the harvest has been strictly additive to (rather than replacing) wild harvest that would have occurred in the absence of supplementation, a historically common assumption that (when tested) has typically failed to find support (e.g., Nickelsen et al. 1986; Hillborn and Eggers 2000; Wertheimer et al. 2005; Amoroso et al. 2017).

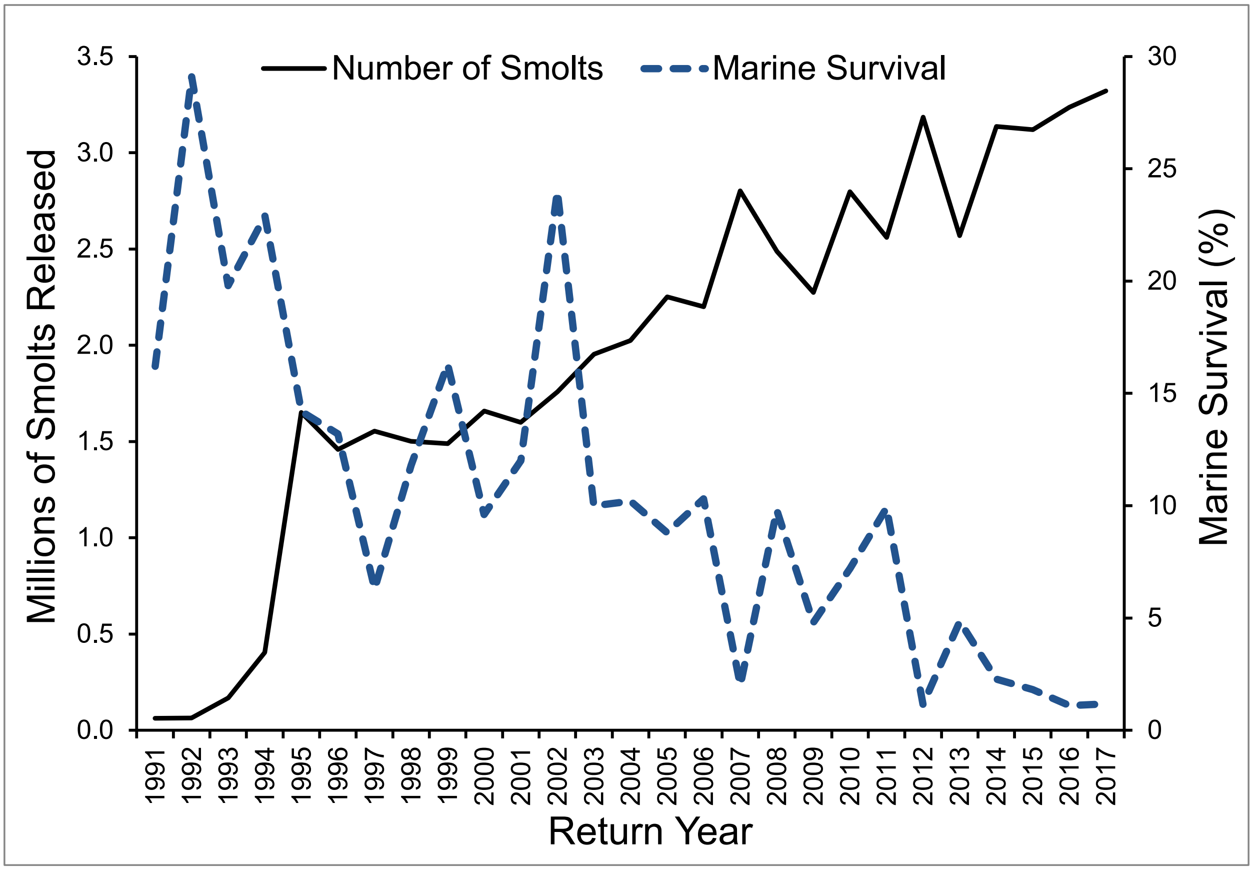

Figure 23.–Number of coho salmon smolts released from the Hidden Falls Hatchery into Kasnyku Bay, and their subsequent marine survival by adult return year.

TOTAL STOCK ABUNDANCE

Total return abundance, including harvest and escapement, is the product of smolt production and marine survival. For the full indicator stocks, estimates of total escapement and harvest are shown in Figures 24 and 25 and Appendices B1–B7.

The longest studied indicator stocks in inside areas of Southeast Alaska show similar patterns in abundance from the early 1980s until the mid-2000s. The Auke Creek, Berners River, Taku River, and Hugh Smith Lake stocks all showed relatively consistent long-term trends during this period, with high abundance in the early 1990s and a spectacular peak in 1994 (Figures 24 and 25) that coincided with a similar peak in the commercial harvest of wild coho salmon (Figure 1). A second lower peak occurred in 2002 that, in combination with low exploitation rates, resulted in very large escapements in those systems.

Estimated adult returns to the Berners and Chilkat rivers were closely synchronized over the 18-year period 2000–2017 ($R^2 = 0.87$). Returns to both systems decreased dramatically beginning in 2005 compared with the previous 15-year period (1990–2004) of high average production. In the Berners River, this decline was about equally attributed to decreases in smolt production and marine survival (Shaul et al. 2017). In contrast, returns to Hugh Smith Lake increased due to a combination of high marine survival during 2009–2014 and more stable smolt production, and returns in 2013 and 2014 were near the previous peak in 1994–1995 (Figure 24).

A period of strong positive correlation between returns to the Berners River and Hugh Smith Lake during 1982–2006 ($R^2 = 0.58$; $p < 0.001$) was followed by a marked divergence after 2006, when Hugh Smith Lake returns increased relative to those in the Berners and Chilkat rivers (Figure 26). However, annual returns to the Berners River and Hugh Smith Lake again maintained a strong positive correlation during the period of maximum divergence in favor of the southern indicator during 2007–2014 ($R^2 = 0.80$; $p = 0.003$). Marine survival rates and adult returns to Hugh Smith Lake decreased dramatically from 2015 to 2017, while smolt production remained above average. Overall, although shifts in scale have occurred between northern and southern stocks, adult returns have exhibited remarkable synchrony between the Berners River and Hugh Smith Lake across the length of the Southeast Alaska region (490 km), and across the shorter 67 km distance (within Lynn Canal) between the Berners and Chilkat rivers.

Estimates of total coho salmon returns to the transboundary Taku River show a similar overall pattern compared with mainland rivers in Lynn Canal (Berners and Chilkat rivers), with peaks in 1994 and 2002. However, estimates for the Taku River were comparatively lower during 1996–2000 and higher during 2003–2010 in relation to the Lynn Canal rivers (Figure 25).

The total return to Ford Arm Creek, on the outer coast, showed only weak positive correlations with most inside systems during 1982–2007 (Shaul et al. 2009). This pattern continued with the updated (1982–2015) data series, with R^2 values of only 0.31, 0.10, and 0.02, for linear relationships with Auke Creek, Berners River, and Hugh Smith Lake, respectively. Estimated returns to Ford Arm Creek increased dramatically from an average of 5,164 adults during 1982–1991 to 10,524 adults during 1992–2008, with peaks of 16,124 adults in 1998 and 15,118 adults in 2002 (Figure 24; Appendix B4). However, returns averaged lower in most years since 2009 (average 7,616 fish), and the 2010 return of only 4,463 adults was the lowest since 1987 and the third lowest return in the 33-year time series.

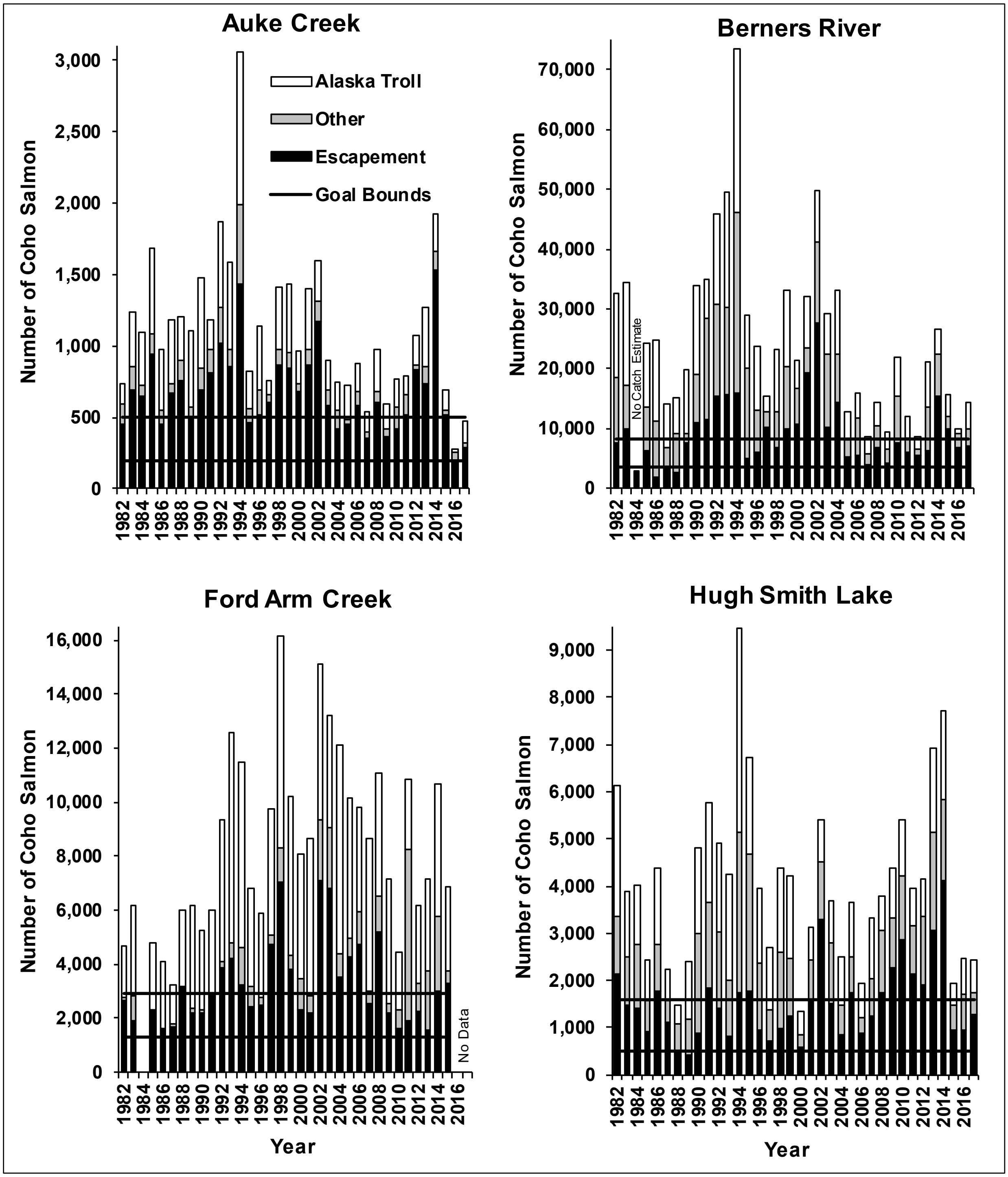

Figure 24.–Total estimated run size, harvest, and escapement, and biological escapement goal ranges for four wild Southeast Alaska coho salmon indicator stocks, 1982–2017 (the Ford Arm Creek project was discontinued after 2015). Escapement to the Berners River is represented by the unexpanded survey count.

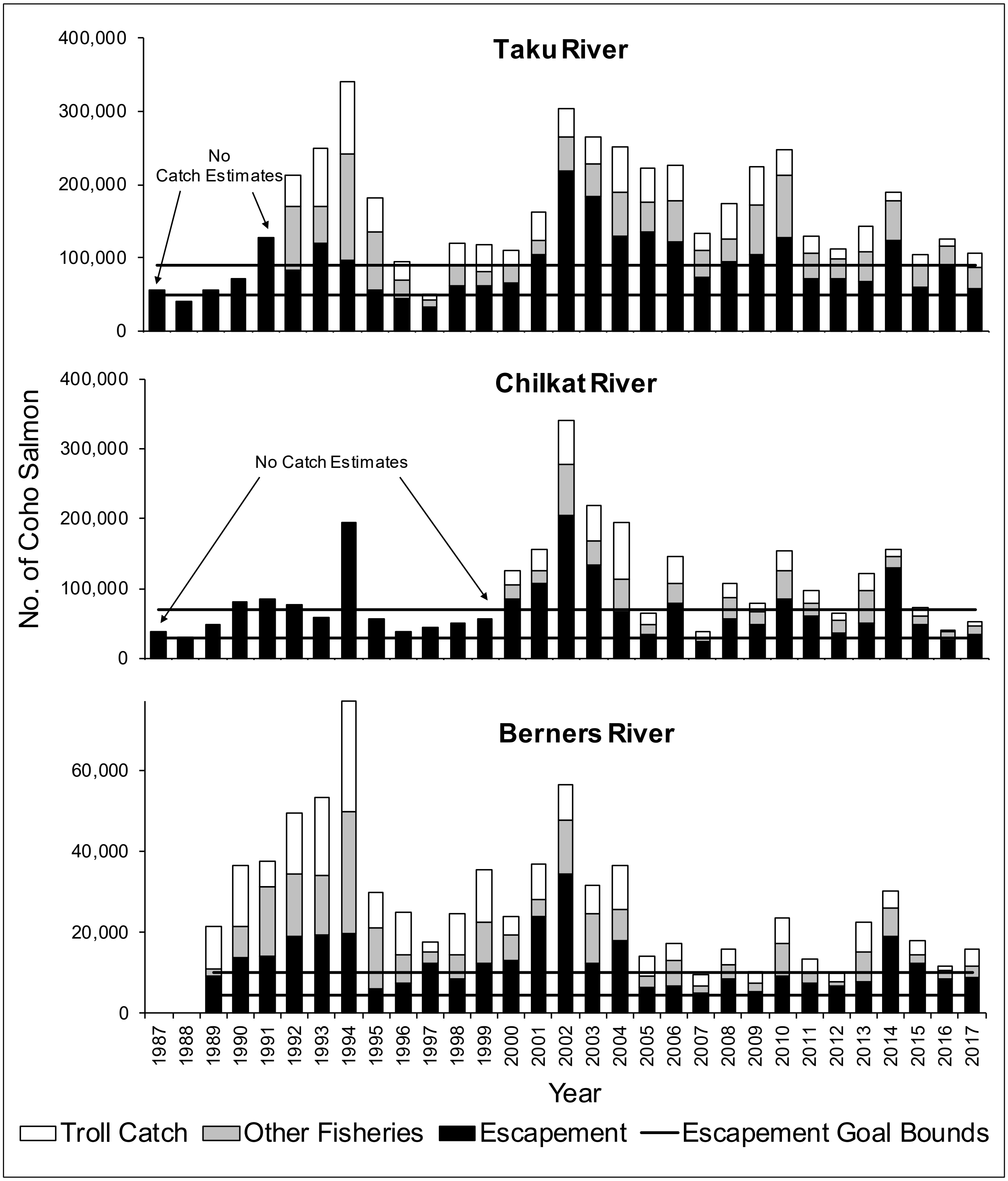

Figure 25.–Total estimated run size, harvest, and escapement, and biological escapement goal ranges for Taku (above Canyon Island), Chilkat, and Berners river coho salmon, 1987–2017. The Berners River escapement and escapement goal bounds are based on an estimated survey expansion factor of 1.241.

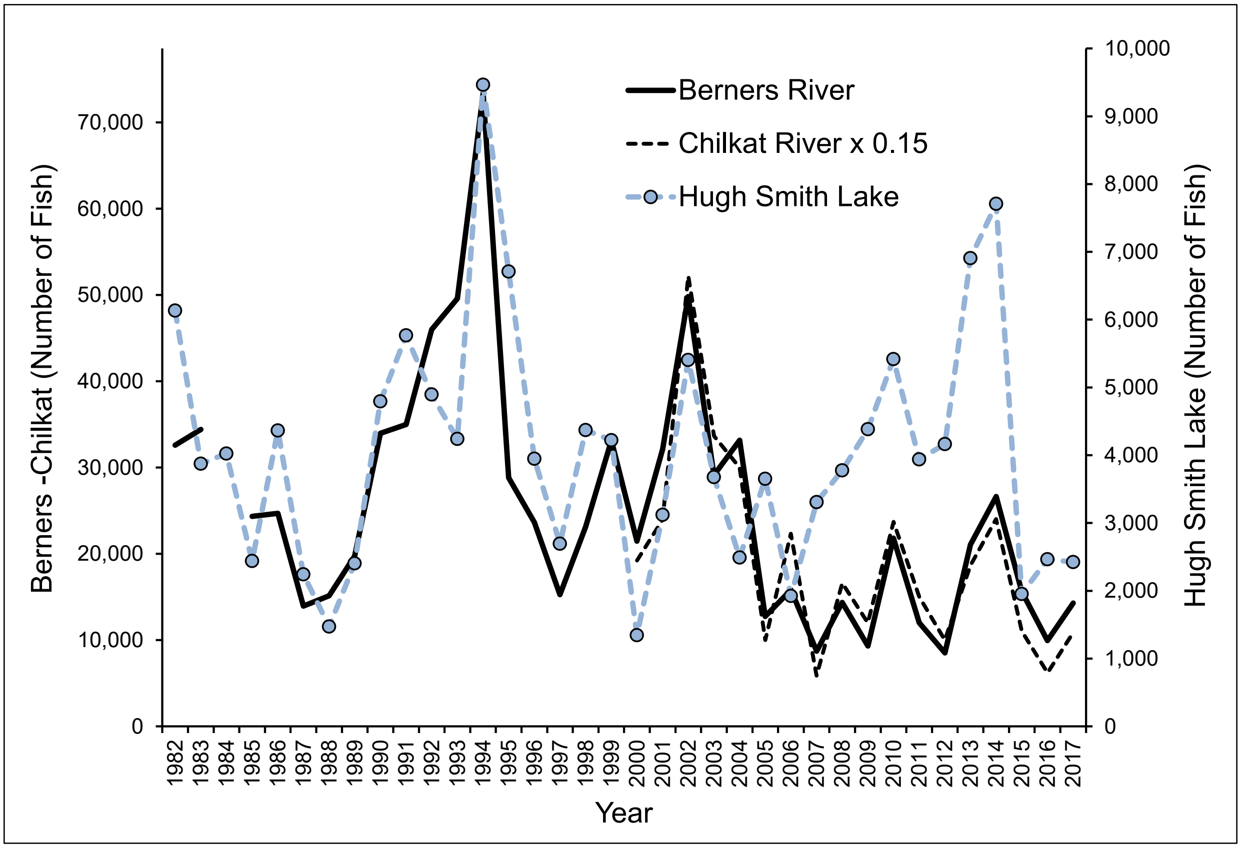

Figure 26.–Total estimated run size of coho salmon returns to the Berners and Chilkat rivers in Lynn Canal and Hugh Smith Lake in Boca de Quadra, southeast of Ketchikan. Berners River returns are based on unexpanded escapement survey counts.

Trends in Wild Stock Abundance in the Taku Inlet Fall Drift Gillnet Fishery

The focus of the fall drift gillnet fishery in Taku Inlet has changed dramatically over the past five decades, away from an earlier emphasis on harvest of fall chum salmon during 1969–1981, to a directed fishery on coho salmon since 1990. During 1969–1981, fall chum salmon CPUE during peak weeks (statistical weeks 35–38) averaged 70 fish/boat-day or more than double average coho salmon CPUE (33 fish/boat-day) during that same period (Figure 27; Appendix B8). In 1981, Joe Muir (Assistant Area Management Biologist, ADF&G, Juneau, personal communication) described the coho salmon resource in the Taku River to the principal author as being an important but secondary consideration to chum salmon in management of the fall Taku-Snettisham drift gillnet fishery. However, wild coho salmon began to increase in abundance in subsequent years, and were approximately equal in CPUE with chum salmon, on average, during 1982–1990. Wild coho salmon CPUE reached a peak average of 81 fish/boat-day during 1989–1994 that was nearly 2.5 times the 1969–1981 average, then declined to a level during 2000–2017 that was intermediate between the 1969–1981 and 1982–1990 averages. After 1990, however, fall chum salmon CPUE plunged to a 2000–2017 mean-average of <5 fish/boat-day, only 10% of average wild coho salmon CPUE and 7% of pre-1991 chum salmon CPUE. The decrease in fall chum CPUE occurred in close concurrence with development of major summer chum salmon hatchery production involving releases of fed fry at locations along both shoreline approaches from Taku Inlet (Figure 27).

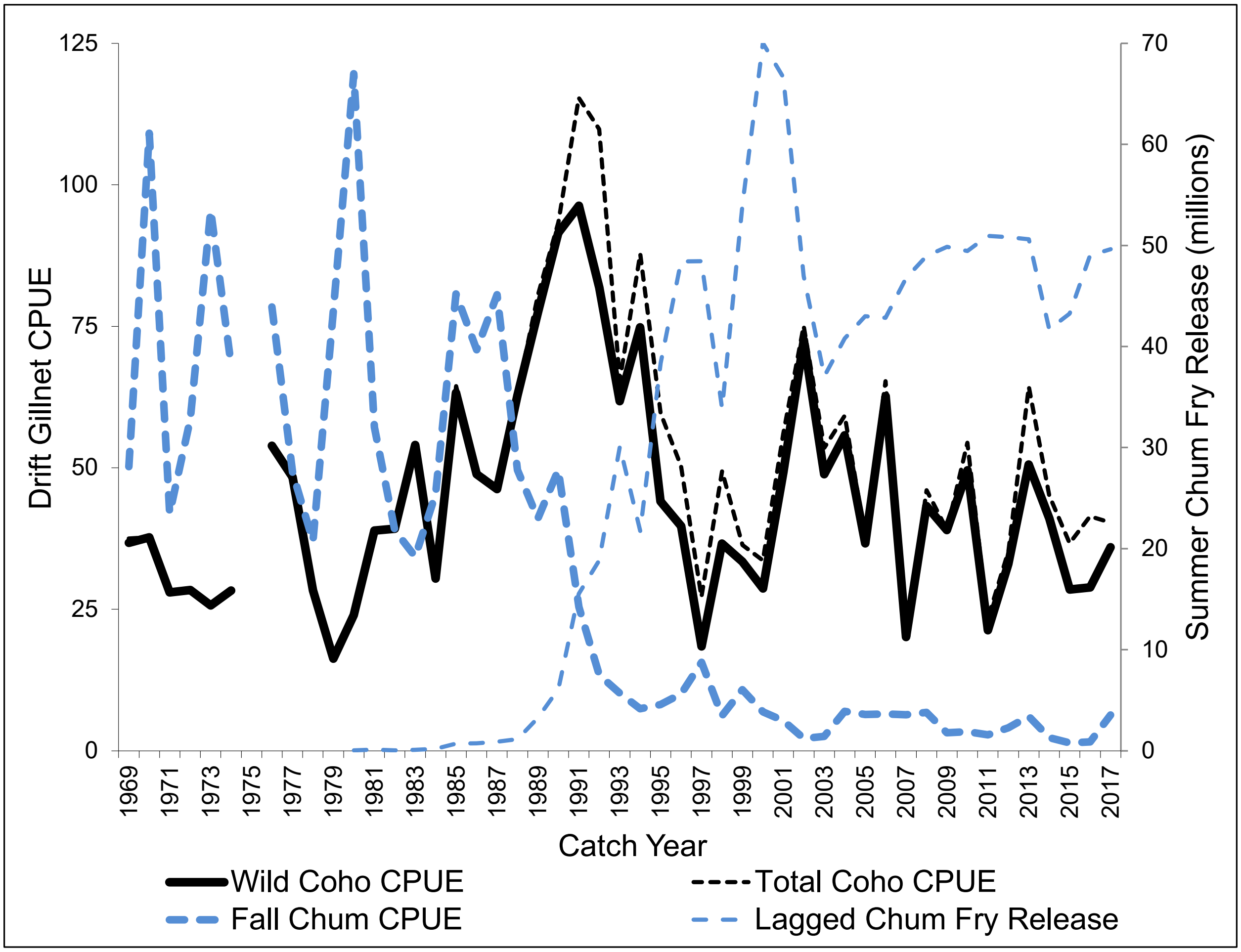

Figure 27.–Mean-average catch-per-boat-day (CPUE) in the Taku Inlet drift gillnet fishery for wild and total fall coho salmon and fall chum salmon in statistical weeks 35–38 compared with the number of summer chum salmon fry released in Gastineau Channel and Limestone Inlet lagged by fall chum salmon ocean ages of 3 years (67%) and 4 years (33%).

A similar but far less severe decrease in harvest and CPUE of fall chum salmon occurred during the same period in the Lynn Canal drift gillnet fishery, where harvested stocks are primarily from the Chilkat River. That decline also resulted in a shift in species targeted in the fall drift gillnet fishery, with an increased emphasis on coho salmon (Shaul et al. 2017).

In 1997, the coho salmon return to the Transboundary Taku River reached a post-1991 low level estimated at only 50,900 fish, prompting early closure of the Taku-Snettisham drift gillnet fishery and imposition of area closures in the troll fishery beginning in the last week of August. Mean-average wild coho salmon CPUE in the Taku Inlet fishery during the subsequent 20-year period (1998–2017) averaged 41 fish/boat-day, only slightly higher than the early (1969–1988) 20-year average (39 fish/boat-day).

REGIONAL WILD ABUNDANCE

The projected commercial harvest of wild coho salmon was established in the 1980s as a proxy for total abundance in determining the need for an early-season troll fishery closure under Alaska regulatory statute (5 AAC 29.110). Specifically, the department may close the coho salmon troll fishery in the Southeast Alaska-Yakutat Area for up to 7 days, on or after 25 July, if the total projected commercial harvest of wild coho salmon is less than 1.1 million fish. When this regulation was established, the commercial harvest of wild fish was considered the best available proxy for aggregate wild coho salmon abundance returning to the region.

A weakness in using commercial harvest as a proxy for abundance, however, is the assumption of a stable total exploitation rate, while exploitation rates have, in fact, varied substantially. Therefore, a more stable index of total abundance was developed based on the estimated troll harvest of wild coho salmon and an index of the troll exploitation rate using estimates for four wild indicator stocks distributed across the region (Auke Creek, Berners River, Ford Arm Creek, and Hugh Smith Lake; Shaul et al. 2011). These indicator stock projects were selected because of their precise accounting of escapement, their long-term history of exploitation rate estimates, and their geographic distribution. Auke Creek and Berners River appear to be suitable representatives for major stock aggregates in inside production areas of northern Southeast Alaska, while Hugh Smith Lake appears representative of southern inside stocks near Ketchikan. Auke Creek was given a 40% weighting prior to 1989, when expanded escapement estimates became available for the Berners River, after which each of those stocks was given a 20% weighting. Ford Arm Creek appears representative of more heavily exploited milling-type stocks on the outer coast. The Ford Arm Creek stock receives less weight (20%) in the index compared with Hugh Smith Lake (40%) and the combined weight of 40% for the two northern inside stocks (Auke Creek and Berners River) out of concern that it is not as broadly representative and is exploited by the troll fishery at rates that are far above average for indicator stocks in the region. For example, the nearby Nakwasina River stock in Sitka Sound, also on the outer coast, is more migratory and has been exploited by the troll fishery at a far lower rate (average 26% during 2000–2007, compared with 52% for Ford Arm Creek; Shaul et al. 2008). Exploitation rate values were interpolated (Brown 1974) based on the relationship in exploitation rates across all stocks and years to fill in missing values for Ford Arm Creek for 1984 and 2016–2017 (following discontinuation of the Ford Arm Creek assessment project).

Total wild coho salmon abundance available to the troll fishery (Table 5; Figure 28) was estimated by dividing the estimated Alaska troll fishery harvest of wild coho salmon by the Alaska troll fishery exploitation rate index, based on the above-described weighted average for the indicator stocks. We also examined the season total (statistical weeks 28–38) mean-average catch-per-boat-day (CPUE) by power trollers in relation to the total wild abundance, as well as wild commercial harvest (Figures 28 and 29). Since power troll CPUE is a primary inseason indicator used to assess aggregate abundance, it is important to account for its historical relationship.

The relationship between estimates of wild abundance and power troll wild CPUE has varied. The average abundance-to-CPUE ratio declined by 27% from the period 1982–1995 to the period 1996–2007 (during which the ratio was also substantially less variable) then increased in both average magnitude (by 24%) as well as variability during the most recent 10-year period (2008–2017; Figure 29). While technological improvements and increased average experience among participants in the fishery have likely played a role, much of the decline in the mid-1990s was likely related to increasing cost pressures that resulted in decreasing troll effort (in power troll equivalent boat-days; Table 5), as fishermen became more selective in expending effort only in areas and at times when catch rates were relatively high. Our discussions with trollers suggested that an increase in cooperation within the fleet in sharing information on fishing success may also have played a role. The increase in the trend and greater variability in the past decade likely reflects several factors, including variation in the number of Chinook salmon retention days in the summer troll fishery, increased interest (combined with high inter-annual variation in success) in targeting hatchery chum salmon beginning in 2009, changes in the geographic distribution of stock abundance, substantial climatic variation, and increased uncertainty in the abundance estimates associated with a decline in the average indicator stock troll exploitation rate (and increased inter-stock variation in estimates) used to estimate wild coho salmon abundance.

Troll effort during the primary coho salmon targeting period (statistical weeks 28–40) decreased by over half (53%) in the mid-to-late 1990s from an average of 46,000 (power troll equivalent) boat-days during 1982–1994 to only 21,400 boat-days during 2000–2009, due in part to a period of very low fish prices in the early 2000s. Average effort during 2010–2017 rebounded by 9% to 23,400 boat-days.

The all-gear wild commercial harvest also fell as a fraction of the abundance index, from an average of 64% during 1982–1999 to only 49% during 2000–2009, and 42% during 2010–2017, as all-gear commercial exploitation rates declined. The troll exploitation rate used to calculate the index decreased from an average of 40% during 1982–1999 to 32% during 2000–2009 and 27% during 2010–2017.

The upward trend in estimated wild coho salmon abundance (Figure 28) stands in contrast with lower recent returns to northern inside systems including Auke Creek, Berners River, Chilkat River, and Taku River and with the decrease in the return to Hugh Smith Lake after 2014 (Figures 24 and 25). These contrasting patterns likely reflect a geographic change in marine survival and adult production that is related to a decline in northern inside stocks in the mid-2000s and more recently to an apparent sharp decrease in marine survival and returns throughout inside waters of Southeast Alaska (as far south as Hugh Smith Lake) beginning in the 2016 adult return year.

A change has also recently occurred in the temporal pattern of wild coho salmon abundance (indicated by wild CPUE) in the Alaska troll fishery. The CPUE peaked earlier (mid-July) during 2013–2017 compared with the average pattern in the prior 20 years (Figure 30). This pattern was particularly evident in 2016 and 2017, when CPUE was far above average in mid-July but decreased to well below average from mid-August to mid-September. This pattern is consistent with other indicators of reduced marine survival and weak returns for late-migrating stocks to inside systems, in contrast with relatively strong runs to systems on the outer coast and in northern British Columbia that are available to the troll fishery earlier in the season. The strongest returns to inside systems in recent years occurred in 2014 (Figure 21) when CPUE increased to a second peak near 100 wild coho salmon per boat-day in early-to-mid September that matched the much earlier peak in mid-July (Figure 30). An apparent change in stock composition in favor of stocks that appear in the fishery early has resulted in overly optimistic early abundance assessments, based on July troll CPUE indicators, particularly concerning core inside mainland river stocks.

EXPLOITATION RATES

Most Southeast Alaska coho salmon stocks accumulate substantial exploitation rates in mixed stock fisheries. Some inside stocks run a gauntlet of fisheries, from outer coastal troll and marine sport fisheries through net, sport, and troll fisheries in migration corridors, followed by intensive inside gillnet fisheries concentrated near some estuaries. In some cases, there are significant freshwater sport and subsistence harvests as well.

Compared with the 1980s and 1990s, more recent all-fishery exploitation rates have trended lower for inside stocks (Auke Creek, Berners River and Hugh Smith Lake) but were historically high for the outer coastal Ford Arm Creek stock during 2009–2014 (Figures 31 and 32; Appendixes C1–C7).

Table 5.–Estimates of wild and hatchery commercial harvest and troll harvest, troll exploitation rate index, mean-average power troll wild coho salmon CPUE, total troll effort, and total wild coho salmon abundance available to the Alaska troll fishery, in millions of fish, 1982–2017.

	Troll Harvest (Millions of Fish)			Alaska Troll Exploitation	Estimated Total Wild	Mean-Avg. Power Troll	Troll Effort (Power Troll	Commercial Catch (Millions of Fish)		
Year	Total	Hatchery	Wild	Rate Index[a]	Abundance	Wild CPUE[b]	Boat-Days)[c]	Total	Hatchery	Wild
1982	1.322	0.036	1.286	34.27%	3.752	46.6	61,795	2.103	0.036	2.041
1983	1.280	0.053	1.227	37.42%	3.280	42.4	47,675	1.943	0.053	1.868
1984	1.134	0.071	1.062	36.96%	2.874	37.2	46,474	1.881	0.071	1.760
1985	1.606	0.107	1.500	38.67%	3.878	39.6	53,287	2.562	0.107	2.385
1986	2.130	0.280	1.850	44.05%	4.200	45.8	56,529	3.259	0.280	2.865
1987	1.042	0.091	0.951	35.60%	2.671	25.0	47,708	1.487	0.091	1.374
1988	0.500	0.028	0.472	30.58%	1.544	21.7	36,768	1.036	0.028	0.987
1989	1.370	0.122	1.248	52.03%	2.399	51.6	45,047	2.182	0.122	2.007
1990	1.851	0.292	1.560	43.12%	3.617	42.9	43,526	2.740	0.292	2.327
1991	1.721	0.384	1.337	32.04%	4.172	49.3	35,028	2.897	0.384	2.289
1992	1.929	0.420	1.509	38.99%	3.871	50.3	37,724	3.424	0.420	2.685
1993	2.408	0.394	2.014	48.26%	4.173	62.8	43,084	3.556	0.394	3.012
1994	3.462	0.515	2.947	44.30%	6.652	84.8	43,503	5.520	0.515	4.788
1995	1.750	0.336	1.414	34.87%	4.055	54.5	29,660	3.130	0.336	2.547
1996	1.907	0.449	1.458	42.78%	3.408	57.9	26,204	2.986	0.449	2.360
1997	1.170	0.242	0.928	34.49%	2.692	40.5	24,068	1.839	0.242	1.512
1998	1.636	0.329	1.307	40.53%	3.225	60.1	22,574	2.751	0.329	2.204
1999	2.273	0.514	1.758	42.21%	4.165	70.7	25,059	3.277	0.514	2.552
2000	1.125	0.249	0.876	34.66%	2.526	41.0	20,875	1.688	0.249	1.334
2001	1.845	0.365	1.481	33.41%	4.432	78.8	19,971	2.945	0.365	2.391
2002	1.315	0.335	0.980	20.87%	4.696	69.1	19,175	2.487	0.335	1.882
2003	1.223	0.287	0.936	25.01%	3.744	64.1	19,336	2.166	0.287	1.665
2004	1.917	0.312	1.605	40.29%	3.983	83.1	22,972	2.858	0.312	2.407
2005	2.038	0.333	1.705	36.10%	4.723	81.9	24,242	2.767	0.333	2.317
2006	1.363	0.217	1.146	31.69%	3.617	59.2	21,550	1.841	0.217	1.575
2007	1.378	0.309	1.069	39.43%	2.712	51.2	22,903	1.911	0.309	1.519
2008	1.293	0.274	1.019	26.65%	3.825	50.1	20,027	2.040	0.274	1.644
2009	1.592	0.247	1.344	33.96%	3.958	67.9	22,704	2.375	0.247	1.991
2010	1.343	0.285	1.058	29.03%	3.644	50.1	24,799	2.286	0.285	1.815
2011	1.312	0.342	0.970	21.69%	4.472	52.8	25,403	2.077	0.342	1.541
2012	1.201	0.310	0.891	25.30%	3.523	45.7	26,350	1.883	0.310	1.440
2013	2.394	0.733	1.661	32.79%	5.065	87.7	25,218	3.588	0.733	2.570
2014	2.245	0.620	1.625	24.53%	6.626	78.2	21,892	3.361	0.620	2.449
2015	1.241	0.384	0.857	26.58%	3.224	61.0	19,057	1.940	0.384	1.394
2016	1.387	0.338	1.049	22.54%	4.653	53.6	21,778	2.098	0.338	1.649
2017	2.149	0.388	1.762	34.16%	5.157	71.6	22,313	2.754	0.388	2.307
Total	1.635	0.305	1.330	34.72%	3.867	56.4	31,285	2.545	0.305	2.096

[a] Index of the exploitation rate on available wild coho salmon stocks by the Alaska troll fishery based on a weighted average for four wild indicator stocks (Auke Creek, Berners River, Ford Arm Creek, and Hugh Smith Lake; see text).

[b] Average of estimates of wild coho salmon CPUE by power trollers during statistical weeks 28–38.

[c] Total troll effort in boat-days during statistical weeks 28-40, with hand troll effort converted to power troll equivalents.

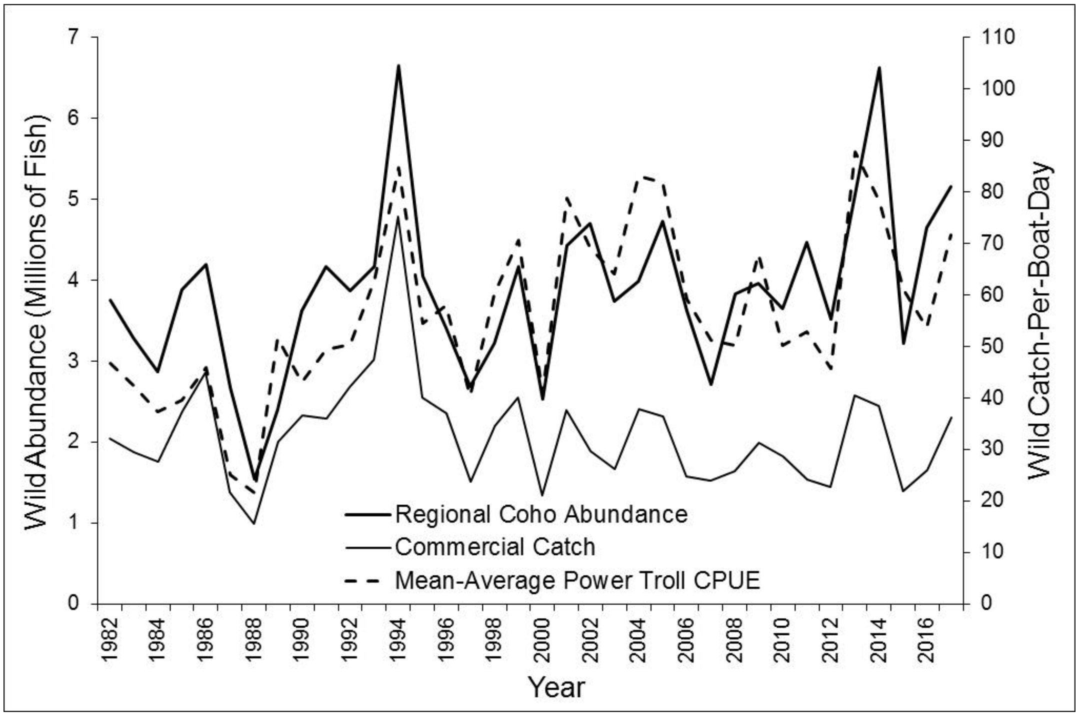

Figure 28.–Estimates of Southeast Alaska wild coho salmon commercial harvest, total wild abundance available to the Alaska troll fishery, and mean-average power troll wild CPUE in statistical weeks 28–38, 1982–2017.

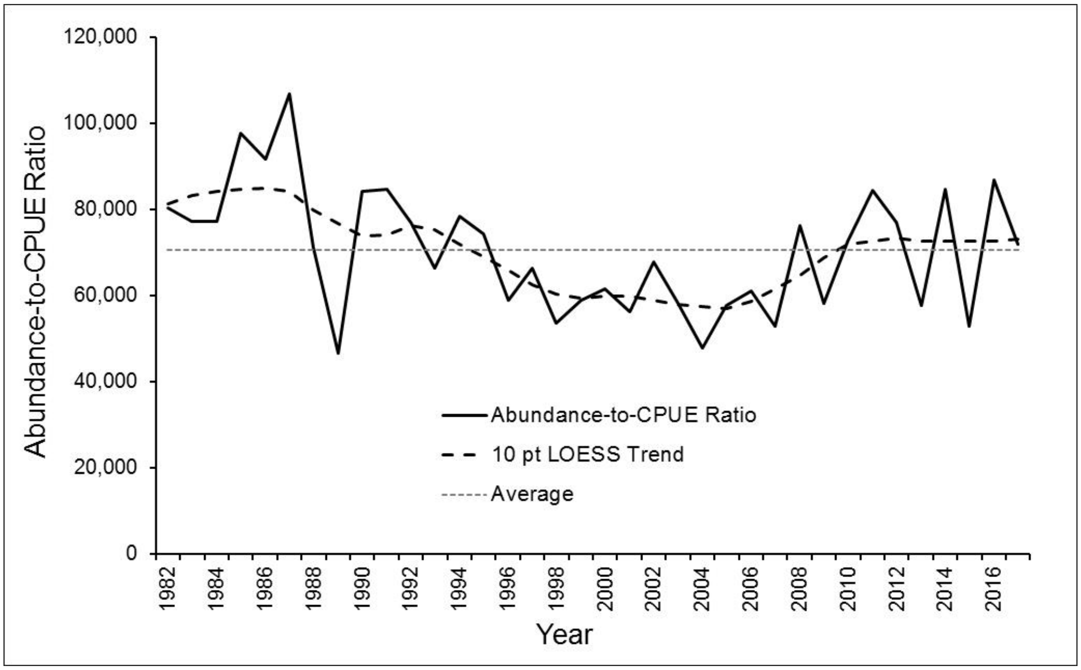

Figure 29.–Ratio of the estimated total abundance of wild coho salmon available to the Alaska troll fishery and mean-average power troll wild coho salmon CPUE (catch-per-boat-day) during statistical weeks 28–38.

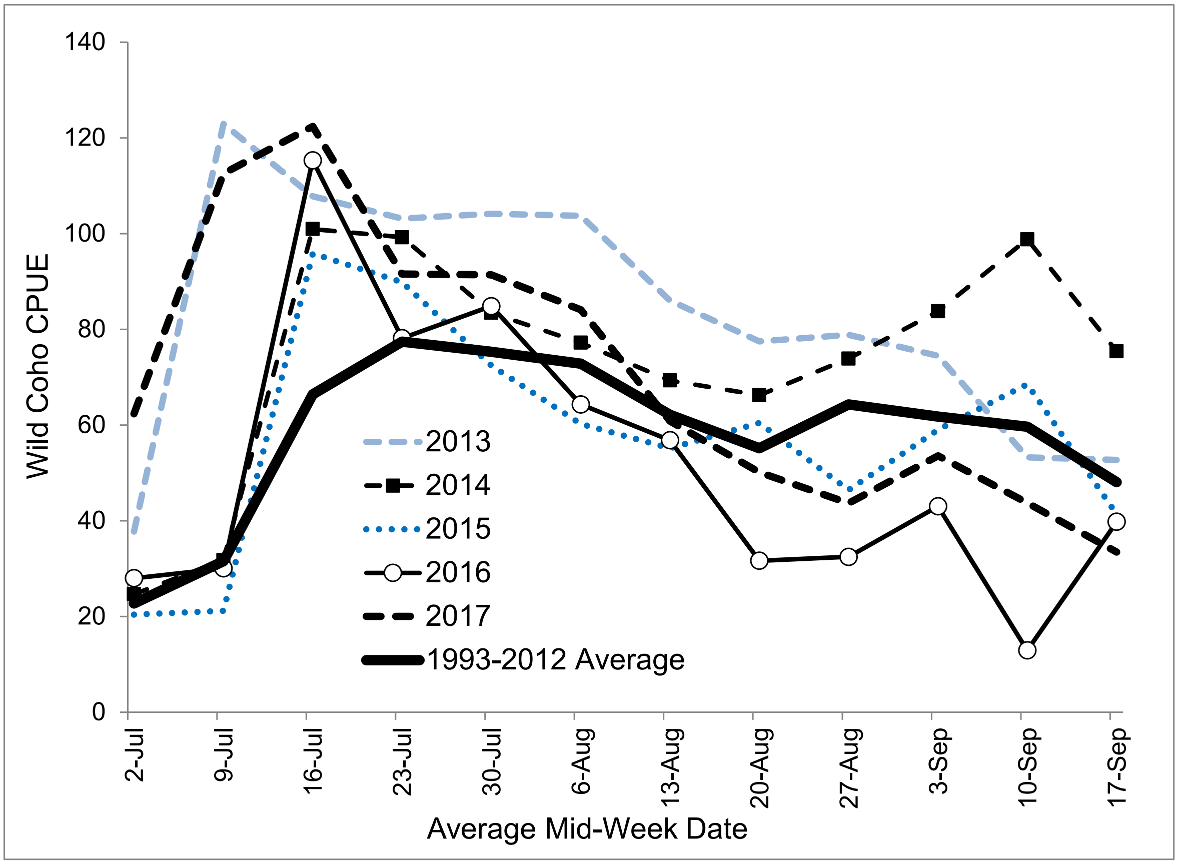

Figure 30.–Region-wide power troll weekly wild coho salmon catch-per-unit-of-effort (CPUE) during 2013–2017 compared with the prior 20-year average (1993–2012).

The Auke Creek stock has been exploited at a relatively low average rate of 38% (range 20–55%) during 1980 to 2017, owing primarily to lack of intensive net fishing within its primary migratory pathway (Figures 31 and 32; Appendix C1). The lowest all-fishery exploitation rate estimate (19.6%) occurred in the first year in the series (1980) when the troll fishery had recently been placed under severe restrictions to protect coho salmon returns, primarily to northern inside systems (Appendix C1). These restrictions included a 10-day region-wide closure, closure of section 11A to commercial trolling, and imposition of an 8-days-on-and-6-days-off fishing schedule in inside waters from Lynn Canal and upper Chatham Strait to outer Cross Sound. The latter restriction was reduced over the following decade and is no longer in effect, while the duration of region-wide closures has been substantially reduced since the early 1990s.

The troll fishery has accounted for the majority of the harvest of Auke Creek coho salmon, exploiting the stock at an average rate of 28% (range 7–48%). Other fisheries exploit the stock at much lower average rates (purse seine 1%, drift gillnet 6%, marine sport 3%). Restrictions on trolling in northern inside waters were incrementally relaxed during the 1980s, and the troll exploitation rate on the Auke Creek stock reached a peak 10-year average of 35% during 1985–1994 then trended lower to an average of only 14% during 2014–2016. In 2016, coincident with the smallest adult return on record, the Auke Creek stock was exploited at the lowest rate on record in the troll fishery (7%) but the highest rate on record in the drift gillnet fishery (18%). Trolling success was relatively poor along the migration route of returning Auke Creek fish in 2016, including in northern inside waters and in outside waters from Cross Sound to Cape Fairweather, a factor that likely accounted for much of the reduction. The pattern reversed in the following year: mid-to-late season catch rates were good in northern inside waters despite generally weak returns to northern inside systems, as fish appeared to mill and feed throughout the area. As a result, the estimated troll exploitation rate on Auke Creek coho salmon jumped sharply to 34% in 2017.

Total all-gear exploitation rate estimates for Berners River coho salmon during 1989–2017 (based on an expanded escapement count) ranged from 28% (2016) to 80% (1995) and averaged 53% (Figure 32; Appendix C3). During this period, the troll fishery was typically the largest harvester of the stock with an average troll exploitation rate of 28% (range 8–49%) compared to 23% (range 8–50%) for the drift gillnet fishery. However, when the drift gillnet harvest is calculated as a removal rate (i.e., harvest as a proportion of only those fish available to the fishery; Shaul et al. 2017), the drift gillnet fishery had a greater influence on spawning escapement with an average removal rate of 34% compared with the troll fishery (28%), which was assumed to have access to the entire return to coastal waters. Purse seine and marine sport fisheries were a minor influence in most years, with each exerting an average exploitation rate of about 1% on the Berners River stock. Similar to Auke Creek, the Berners River stock showed a sharp decrease in troll exploitation during 2014–2016, followed by a marked rebound in 2017. The troll exploitation rate on the Berners River stock was significantly higher in odd years compared with even years during a recent period (1999–2017) when maturing coho salmon averaged substantially larger in even years (see Size Effects on Resource Exploitation and Allocation). Estimates of the total all-fishery exploitation rate for the Berners River decreased from an average of 63% in the 1990s to 44% in the most recent 10-year period (2008–2017) and reached a low of 28% in 2016. The 31% decrease in average all-fishery exploitation between the periods occurred in conjunction with a 56% decrease in the average adult return. The reduction in the average exploitation rate was shared by the primary harvesting fisheries, including the troll fishery (29% decrease) and the drift gillnet fishery (37% decrease).

Total all-gear exploitation rate estimates for Taku River coho salmon during 1992–2017 ranged from 28% (2002) to 72% (1994) and averaged 46% (Appendix C6). The troll fishery accounted for 20% (range 6–31%) of the run, on average, while the drift gillnet fishery accounted for 15% (range 3–37%). The low estimate of 3% occurred in 1997 when the District 111 drift gillnet fishery was closed for the season in late August because of a very weak coho salmon return. Purse seine, marine sport, and inriver fisheries accounted for an average of 2%, 3%, and 6% of the run, respectively.

Total all-gear exploitation rate estimates for Chilkat River coho salmon during 2000–2017 ranged from 17% (2014) to 66% (2004) and averaged 40% (Appendix C7). The troll fishery accounted for 19% (range 6–42%) of the run, on average, while the drift gillnet fishery accounted for 18% (range 9–34%), and marine sport and inriver fisheries accounted for 1% and 2%, respectively. Exploitation rates for this stock likely averaged substantially higher in the 1970s and 1980s, when a much larger drift gillnet fleet targeted abundant Chilkat River chum salmon runs in Lynn Canal during the fall (Shaul et al. 2017).

The Ford Arm Creek stock has been harvested at moderate to high exploitation rates, primarily in the regional troll fishery, which is most intensive in coastal waters near this system. The exploitation rate by the troll fishery averaged 51% (range 24–68%) during 1982–2015 (Figure 31; Appendix C4), and intermittent purse seine harvests and increasing marine sport fishing brought the long-term average exploitation rate by all fisheries up to 61% (range 43–82%).

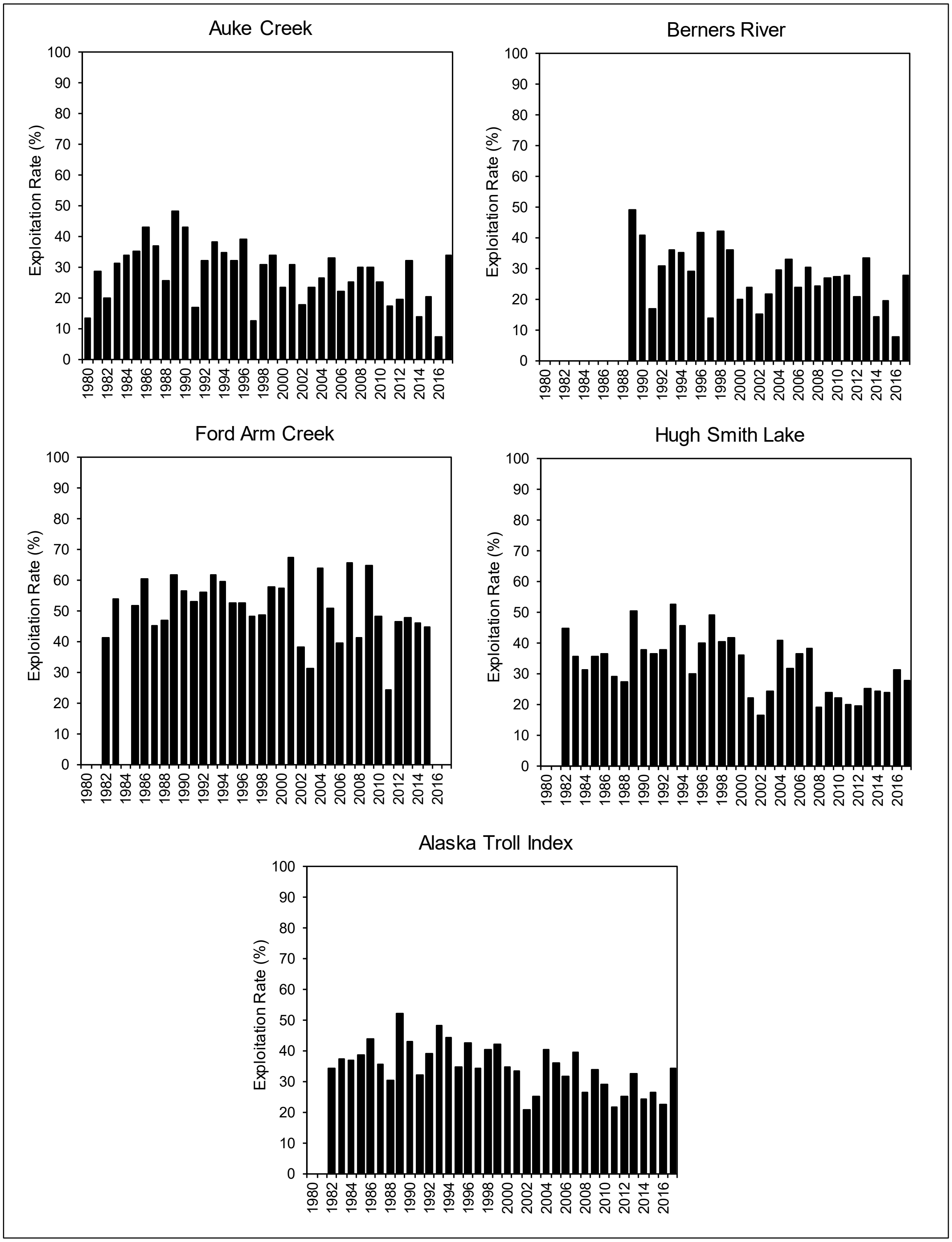

Figure 31.–Estimated exploitation rates by the Alaska troll fishery for four coded-wire-tagged Southeast Alaska coho salmon stocks, 1980–2017. Weightings given to individual stocks in the Alaska troll index are 20% each for Auke Creek, Berners River (based on expanded escapement counts), and Ford Arm Creek and 40% for Hugh Smith Lake (prior to 1989, Auke Creek was given a 40% weighting and Berners River 0%). Interpolations were made in computing the Alaska Troll Index based on Brown (1974) for years when estimates were unavailable.

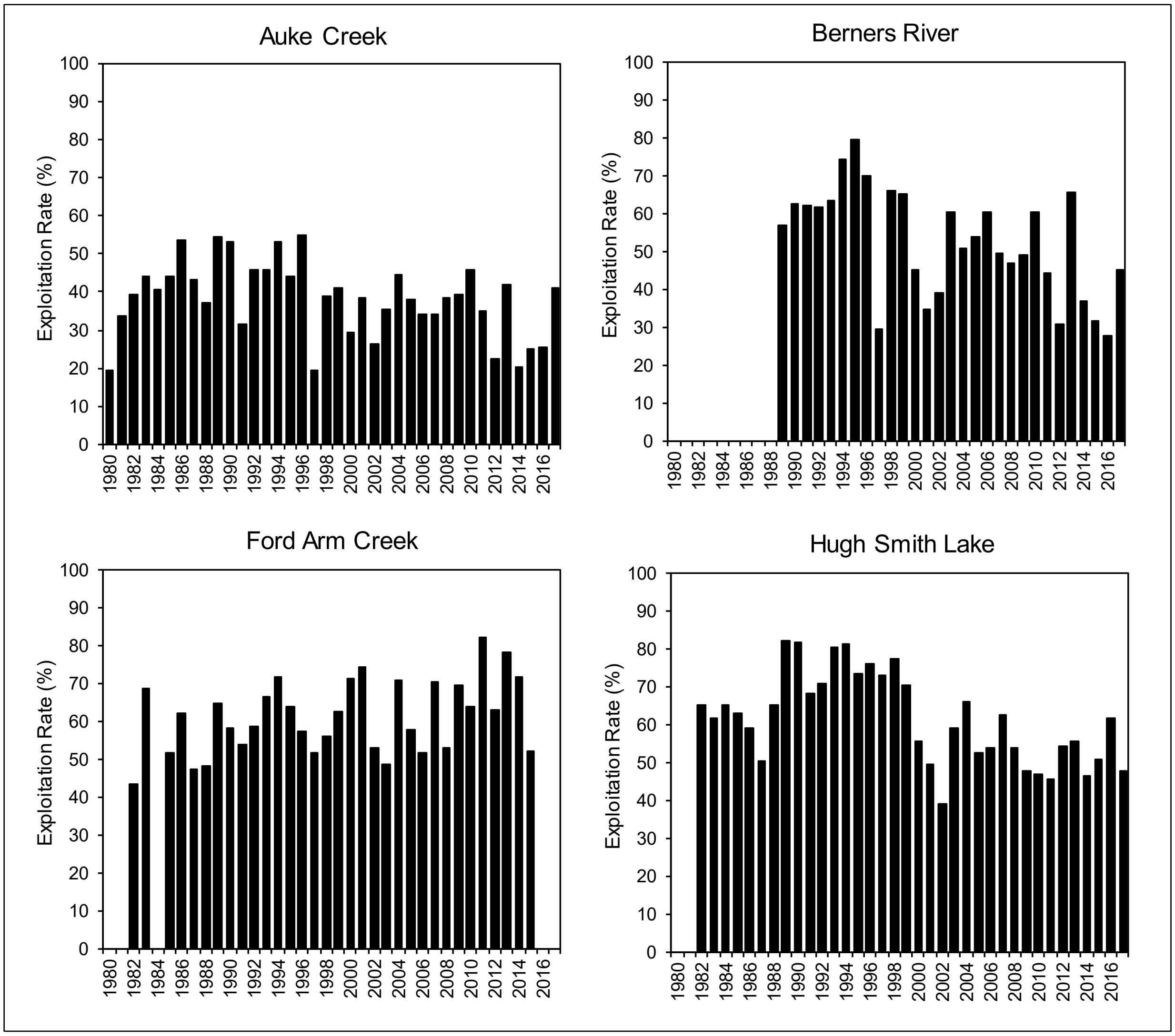

Figure 32.–Estimated total exploitation rates by all fisheries for four coded-wire-tagged Southeast Alaska coho salmon stocks, 1980–2017. Estimates are available only for Auke Creek prior to 1982. Estimates are unavailable for the Berners River prior to 1989 and for Ford Arm Creek in 1984 and 2016–2017. Berners River estimates are based on expanded escapement survey counts.

The Ford Arm Creek stock forages in coastal waters throughout the summer and is, therefore, substantially more available to intensive hook-and-line fisheries in the vicinity of Sitka and Pelican compared with more migratory stocks. The purse seine fishery exploitation rate on the Ford Arm Creek stock was relatively moderate, averaging only 4% (and never exceeding 15%), for most of the monitoring period prior to 2011. In 2011, however, the stock appeared to leave outside marine waters early, resulting in a record low troll exploitation rate of 24%, and entered Khaz Bay during a period of intensive seining for pink salmon. The total harvest of coho salmon (of all stocks) within Slocum Arm reached a record 11.0 thousand fish in 2011. The result was an extremely high purse seine exploitation rate of 58%, and a record all-fishery exploitation rate of 82% (Figure 32). During 2012–2014, intensive purse seining on large pink salmon returns to Khaz Bay streams resulted in continued above-average purse seine exploitation rates (range 14–29%). Earlier-than-average timing may also have contributed to the higher purse seine exploitation rates in those years, particularly in 2012 when the coho salmon run was again observed to be early at the weir site. During 2011–2014, when purse seine exploitation rate estimates were consistently high on the stock, mark–recapture estimates of fish that passed the weir uncounted (primarily before it was installed in the second week of August) amounted to 41% of the escapement in both 2011 and 2012, 20% in 2013, and 31% in 2014. These numbers are substantially above the average of 6% (range 0–21%) that were estimated to have escaped into the system uncounted from 1988 to 2009 (Shaul et al. 2014), though the weir did not appear to be any less operationally effective during 2011–2014 than it was in prior years. In 2015, the purse seine exploitation rate on Ford Arm Creek coho salmon decreased to a more normal 6%, despite another substantial pink salmon harvest of nearly 1.1 million fish.

The Hugh Smith Lake population is an example of a stock that traverses an extensive gauntlet of mixed stock fisheries along the coast and is exposed to fisheries outside of state jurisdiction in Canada and around Annette Island. From 1982 to 1988, the Hugh Smith Lake stock was exploited at moderate rates for coho salmon, averaging 61% (Figure 32; Appendix C5). The total exploitation intensified during 1989–1999 to an average of 76% (range 68–82%), primarily as a result of an increase in the Alaska troll exploitation rate from an average of 34% to an average of 42%, combined with an increase in the Alaska drift gillnet exploitation from an average of 6% to an average of 16%. During 2000–2017, however, the all-fishery exploitation rate decreased sharply to an average of 53% (range 39–66%).

This decrease was distributed across all commercial fisheries: the Alaska troll exploitation rate decreased to an average of 27%, the Alaska drift gillnet rate decreased to an average of 13%, and the Alaska purse seine fishery rate decreased from an average 10% to an average of 7%. The Alaska troll exploitation rate on the Hugh Smith Lake stock was particularly low (average 21%; range 19–24%) during 2008–2012, a series of relatively cold years with low PDO index values during which the stock displayed a more southward approach in returning to the coast that resulted in less exposure to the area of most intensive trolling in northern Southeast Alaska. The average Alaska sport exploitation rate remained about the same at 2% after 1999.

The troll fishery in British Columbia was a substantial factor in total Hugh Smith Lake coho salmon exploitation rates through the mid-1990s. The exploitation rate averaged 7% during 1982–1997, after which Canadian exploitation decreased to zero for several years due to fishing restrictions on coho salmon aimed primarily at conserving upper Skeena River stocks. Although the troll fleet in northern British Columbia was substantially reduced in the late 1990s, relaxation of fishery restrictions during 2008–2017 resulted in an increased Canadian troll exploitation rate on the Hugh Smith Lake stock to an average of 4% in 2008–2017. The Canadian marine sport fishery has become a larger component of exploitation of the Hugh Smith stock since 2008 (average 2–3%), while the average total exploitation rate by all northern British Columbia fisheries decreased slightly from 8% during 1982–1997 (prior to restructuring of Canadian fisheries) to 6% in the most recent decade (2008–2017).

Differing troll exploitation rate trends among indicator stocks may be explained in part by stock-specific migratory behavior. The marked decrease in the Alaska troll exploitation rate on the Hugh Smith Lake stock beginning in 2008 was most pronounced in northern Southeast Alaska, where troll fishery exploitation had increased between 1982–1988 and the 1990s. Ford Arm Creek has shown proportionately less change compared with inside indicator stocks, with Alaska troll exploitation rates averaging 46% during 2012–2015, a substantial (16%) proportionate reduction from the 1990s average of 55%. By comparison Alaska troll exploitation rates decreased between these periods by 32% for Auke Creek and the Berners River and 43% for Hugh Smith Lake. The presence of feeding Ford Arm Creek fish throughout the summer troll season in the area of consistently most intensive fishing from Cross Sound to Sitka Sound likely increases the probability of individual fish being caught even under lower region-wide troll effort or under climatic conditions that affect the return migration and reduce exposure of other, more migratory stocks to the troll fishery.

Alaska Troll Fishery Exploitation Index

Exploitation of coho salmon runs by the Alaska troll fishery has been tracked through a weighted average of troll exploitation rate estimates for wild indicator stocks. The primary purpose of the index has been (when combined with the total troll harvest of wild coho salmon) to provide a tool to estimate total abundance of wild coho salmon available to the troll fishery in Southeast Alaska waters.

The Alaska troll fishery exploitation index averaged 35% during 1982–2017. The index increased from 34–37% during 1982–1984 to a peak 10-year average of 41% (range 32–52%) during 1989–1998, then trended lower to an average of 28% (range 22–34%) during 2008–2017 (Figure 33; Table 5). There appear to be varied reasons for the decrease, including an overall decrease in the number of (power troll equivalent) boat-days fished and climatic changes, including a period of colder years with negative PDO index values that may have resulted in a southward shift in landfall during return migration, resulting in decreased exposure by more southern stocks to the area of most intensive trolling in northern Southeast Alaska. In recent years, the troll fishery has also shifted much of its targeted fishing effort from away from coho salmon in open ocean areas to hatchery chum salmon in more limited inshore fishing areas.

The trend in the troll catch of wild coho salmon has been relatively level during the 40-year period following the 1977 North Pacific regime shift (Figure 33). There has been a declining trend in the Alaska troll exploitation rate index during most of this period, from an average of 38.5% in the first 10-year period (1982–1991) to 27.7% in the most recent period (2008–2017). This decline in troll exploitation appears related to increasing cost pressures on the fishery, resulting in a decrease in troll effort in boat-days.

However, fishery restrictions have not been a factor in the decrease, as coho salmon troll fishery management has generally been liberalized since the mid-1990s. A region-wide troll fishery closure of at least 10 days (23 days total in 1988) was implemented every year during the main summer fishery period (1 July–20 September) during 1982–1991, while the mid-season closure during 2008–2017 has averaged only 3 days (range 0–5 days). In addition, a provision allowing extension of the summer troll season for up to 10 days (during 21–30 September) was established in 1994 and has been implemented in seven of the most recent 10 years, while the earliest date for legal retention of coho salmon was changed from 15 June to 1 June beginning in 2012 (Hagerman et al. 2018). In 2013, 2015 and 2017, coho salmon harvest and retention was allowed in the troll fishery for a full 4-month period from 1 June through 30 September, continuous troll coho salmon seasons that were longer than any since the 1930s.

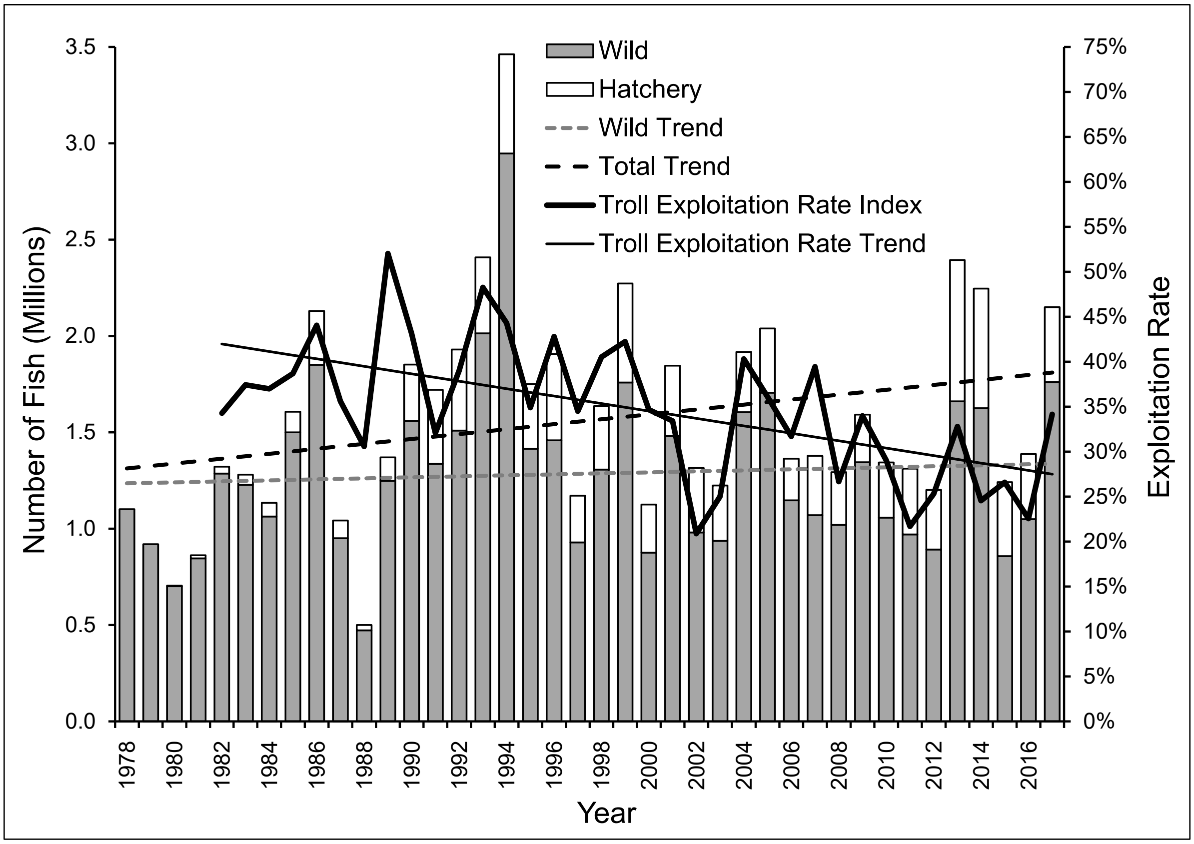

Figure 33.–Alaska troll catch of wild and hatchery coho salmon that entered the sea as smolts following the 1977 regime shift, compared with an index of the Alaska troll fishery exploitation rate based on estimates from three wild indicator stocks.

LENGTH AND WEIGHT TRENDS

Variation in growth and size-at-maturity of returning coho salmon has an economic effect on the total landed weight of the harvest, as well as important effects on survival, reproductive potential, and harvest allocation between hook-and-line and gillnet gear. Shaul et al. (2011) observed a marked change in the seasonal pattern of dressed weight of troll-caught coho salmon in the mid-1990s. Prior to 1997, mean-average weight during the summer fishing season increased at a relatively steady rate of 4.3% per week from early July to late August, followed by a marked decline in the rate of increase in September. During 1997–2010, however, the average rate of increase during early July to mid-August fell by more than half compared to the 1970–1996 average to 2.0% per week; the weekly rate of increase remained similar between the two periods during mid-to-late August, but, in contrast to 1970–1996, weekly mean-average weight increased dramatically in September during 1997–2010.

This change, combined with anecdotal observations of increasing variation in size of commercially caught fish late in the season, appeared consistent with a decline in growth in more local waters, whereas the more rapid weight increase observed later in the season appeared consistent with an influx of more migratory maturing fish that had experienced better growth somewhere on the high seas. This observation, combined with a proportionately greater size decline observed in the least migratory stock (Ford Arm Creek) led Shaul et al. (2011) to hypothesize that there had been a decrease in the quantity or quality of forage in outer coastal waters of Southeast Alaska while forage remained more abundant in more distant offshore feeding areas frequented by more migratory fish that appeared to display better growth.

One substantial challenge to this hypothesis was that the overall biomass of one major prey species of coho salmon in coastal waters, the Pacific herring (*Clupea pallasii*), showed a marked increase from the early 1980s to the 2000s (Hebert 2017), and conversations with veteran salmon trollers tended to support an increase (rather than decrease) in the overall forage fish complex in coastal waters during this period. After reviewing salmon research data from offshore waters of the Gulf of Alaska and the Central North Pacific Ocean (Aydin 2000; Kaeriyama et al. 2004; Davis 2003; and others), Shaul and Geiger (2016) concluded that these patterns were likely explained not by near-shore forage fish but by variation in offshore squid populations, which are the primary driver of the dramatic growth curve in coho salmon in their final season at sea (Aydin 2000; Davis 2003). The richer distant feeding area that produces larger migratory fish likely encompasses waters of the squid-rich Subarctic Current which flows eastward across the North Pacific from Japan toward Vancouver Island at the southern margin of the Western Subarctic Gyre and the Gulf of Alaska (Kaeriyama et al. 2004). Coho salmon that experience poor growth from winter to early summer in offshore waters of the central and northern Alaska Gyre may be unable to compensate with increased growth after their arrival in fish-rich coastal waters. Based on the observed seasonal patterns described by Shaul et al. (2011), we now hypothesize that feeding conditions for coho salmon have declined in the vast offshore Alaska Gyre while remaining more favorable in both the distant Subarctic Current and (at least until recently) in outer coastal waters of Southeast Alaska, although there has been a major decline in herring populations in inside waters since 2012 (Hebert 2017).

Adult Coho Salmon Length

We examined temporal trends in Southeast Alaska in both the dressed weight of troll-caught fish (1970–2017) and the mid-eye to fork (MEF) length of males and females sampled in escapements to four wild systems (1982–2017). Trends in MEF length of male and female age-.1 adult coho salmon from the four long-term wild indicator stocks show a consistent pattern of decreasing size over time (Figure 34; Appendixes D1 and D2). A decline involving a stepped decrease in length following the 1998 regime shift in North Pacific climate (Peterson and Schwing 2003) is evident for Auke Creek, Ford Arm Creek, and Hugh Smith Lake coho salmon. An even-year dominant size pattern is also evident, particularly for the Berners River and Ford Arm Creek stocks. In all cases, size declines were greater in males compared with females (Shaul et al. 2011).

Over the entire series, adult females in the four systems have averaged longer than males, by 1.5% for Auke Creek, 3.4% for Hugh Smith Lake, 5.2% for Berners River, and 5.4% for Ford Arm Creek (mean-average 3.9%). There are substantial differences among systems in the magnitude of degree of inter-annual variation in length. Males and females from the same system tend to show a similar pattern of change that is usually more exaggerated in males.

The most striking example of the difference between the sexes is found at Ford Arm Creek, where males displayed a remarkably steep 15% decrease in mean-average MEF length between the periods 1982–1986 and 2011–2013, while mean-average female length decreased by only 9%. The latter period coincided with historically low average dressed weight for troll-caught coho salmon. When applying a length-to-weight conversion (Gray et al. 1981), males lost an estimated 43% of body mass between these periods, while females lost 29%. Interestingly, the latter period (2011–2013), when age 1-ocean adults reached their minimum size-at-return, also coincided with observations of exceptionally early run timing in Ford Arm Creek and related high purse seine exploitation rates (see Exploitation Rates). Average length of both sexes at Ford Arm Creek subsequently rebounded to near the long-term average in 2014 and 2015. During the early period of good growth (1982–1986), spawners of both sexes were of nearly equal length and females averaged only 0.8% (range 0.3–1.1%) longer than males, compared with a 7.6% (range 4.4–10.5%) difference during a period of much lower growth from 2000 to 2013.

Coincident with the downward trend in average length, some stocks exhibited significant increases in variability in length among age 1-ocean individuals of the same sex (Shaul et al. 2011; Figure 35). In all cases, the average value for the coefficient of variation (CV) of length was higher during 1999–2014 compared with 1982–1998, although the difference was significant ($p = 0.05$) only for males at Ford Arm Creek and both sexes at Hugh Smith Lake. In most cases, variation in length decreased during 2015–2016, a very warm period in the northeast Pacific (Figure 35). This recent decrease in variation in size may reflect greater homogeneity in the distribution of prey during this period. The CV of length increased again in 2017 compared with 2015–2016 for males and females at Auke Creek, Berners River, and Hugh Smith Lake.

Auke Creek and Berners River Comparison

The Berners River and Auke Creek stocks display features described by Holtby and Healey (1990) as typical of Type A and Type B coho salmon populations, respectively. In their conceptual model, males are more risk averse than females within a Type A population, returning at smaller size and higher abundance relative to females when feeding conditions are poor. Age 1-ocean males are smaller and more abundant than females in Type A populations, but about the same size and slightly rarer in Type B populations. Type B populations have a substantial component of age 0-ocean precocious males which are rare in Type A populations. Holtby and Healy (1990) proposed specific conditions leading to size differences based on features of the spawning stream and the degree of competition, based on spawner density. They proposed that conditions leading to Type A populations (in which females average larger and are less abundant than age 1-ocean males) occur in streams where male competition is low (i.e., spawner densities are low) or spawning habitat is structurally complex, giving small and large males similar potential for spawning success. In contrast, they propose that Type B populations, characterized by a more equal sex ratio and smaller size difference between the sexes, occur where competition between males is higher (spawner densities are high) or the spawning habitat is structurally simple, giving large males greater potential for spawning success than small males.

Healey and Prince (1998) suggested that a mixed evolutionarily stable strategy exists involving three distinct reproductive tactics including two variations of the stealth strategy, "sneaker" strategy in 0-ocean jacks and "satellite" strategy in 1-ocean males, in addition to the primary dominance (alpha) strategy used by larger males. Jack returns are virtually nil in the Berners River, so nearly all of the stealth mating is done by 1-ocean males which tend toward a bimodal length distribution in poor growth years (usually odd years), as more of the smaller and mid-size males appear to trade growth, and the chance to be a competitive dominant (alpha) spawner, for improved odds of survival (Shaul et al. 2017). In contrast, the male stealth mating strategy is dominated by 0-ocean jacks in Auke Creek, where 1-ocean males typically return at a ratio that is below parity with females.

Sex-specific differences in average length and variation in length among age 1-ocean fish in the two populations are, for the most part, consistent with relationships proposed by Holtby and

Healey (1990) to be typical of Type A (Berners River) and Type B (Auke Creek) populations. The mean-average MEF length of age 1-ocean male spawners from Auke Creek and the Berners River over a period of 34 years (1982–2017, excluding 1984) was exactly the same (609 mm), but the coefficient of variation (CV) among males returning in the same year was 32% greater for Berners River (Figure 35) and the CV of annual average length of males was 70% greater in the Berners River (Figure 34). Size relationships between females were different over that same period: Berners River females averaged 23 mm (3.7%) longer than Auke Creek females and displayed an average 5% less variation in length among individuals but 21% more inter-annual variation in average length. Mean-average length of Auke Creek females (619 mm) was only 1.6% longer than 1-ocean males, whereas mean-average length of Berners River females (641 mm) was 5.3% longer than 1-ocean males from that system.

However, some differences between these populations suggest that differentiating features may not be limited to the spawning environment, as Holtby and Healy (1990) proposed, but also extended to conditions in the rearing environment that influence the growth of juveniles in each system and their subsequent maturity schedule. Greater size variation among age 1-ocean Berners River males and relatively greater competition among them for females is likely a direct result of the rarity of early-maturing age 0-ocean jacks.

The propensity for nearly all Berners River males to remain at sea and mature at age 1-ocean relieves them from competition by jacks employing a "sneaker" mating strategy. However, increased competition for females among older males results in greater dependence upon stealth among smaller age 1-ocean males. Consequently, age 1-ocean males in the Berners River show far more variation in size as an apparent result of their dual primary mating strategies, compared with Auke Creek 1-ocean males that face less competition for mating and therefore can more broadly employ the dominance mating strategy that favors consistent size. These observations contrast with the hypothesis by Holtby and Healy (1990) that holds that there is less competition among males in Type A populations like the Berners River than in Type B populations like Auke Creek.

Indications that population type may be linked to the incidence of early-maturing males leads to an obvious question: why are jacks very common in Auke Creek but rare in the Berners River? Primary spawning areas within the Auke Creek system, including Lake Creek (the main inlet to Auke Lake), are small and likely confining in space for large spawners. These spatial limitations in spawning habitat likely also explain the smaller average size of females spawning in Auke Creek, and may provide a mobility advantage for age 0-ocean jacks over 1-ocean males of all sizes. However, habitat conditions in Auke Lake that lead to rapid growth and large smolt size may also be important in determining maturity in males. Smolts from the nearby Berners River are divided relatively evenly between ages 1 and 2, and have averaged 105 mm, with only 3% exceeding 125 mm (Shaul et al. 2011). At Auke Creek, however, smolts have averaged 115 mm; during 1993–1997, the largest length class (>125 mm) accounted for 31% of the smolt migration and produced 68% of the total jack return (Lum 2003). Auke Creek smolts are predominantly age-1 but many of the jacks are produced by very large age-2 smolts. At Auke Creek, jacks resulted mostly from the very large (>125 mm) and large (111–125 mm) smolts that emigrated early (Lum 2003). Therefore, we suspect that freshwater growth conditions affecting smolt size may be even more influential than features of the spawning habitat in determining average age-at-maturity of males, and therefore population type.

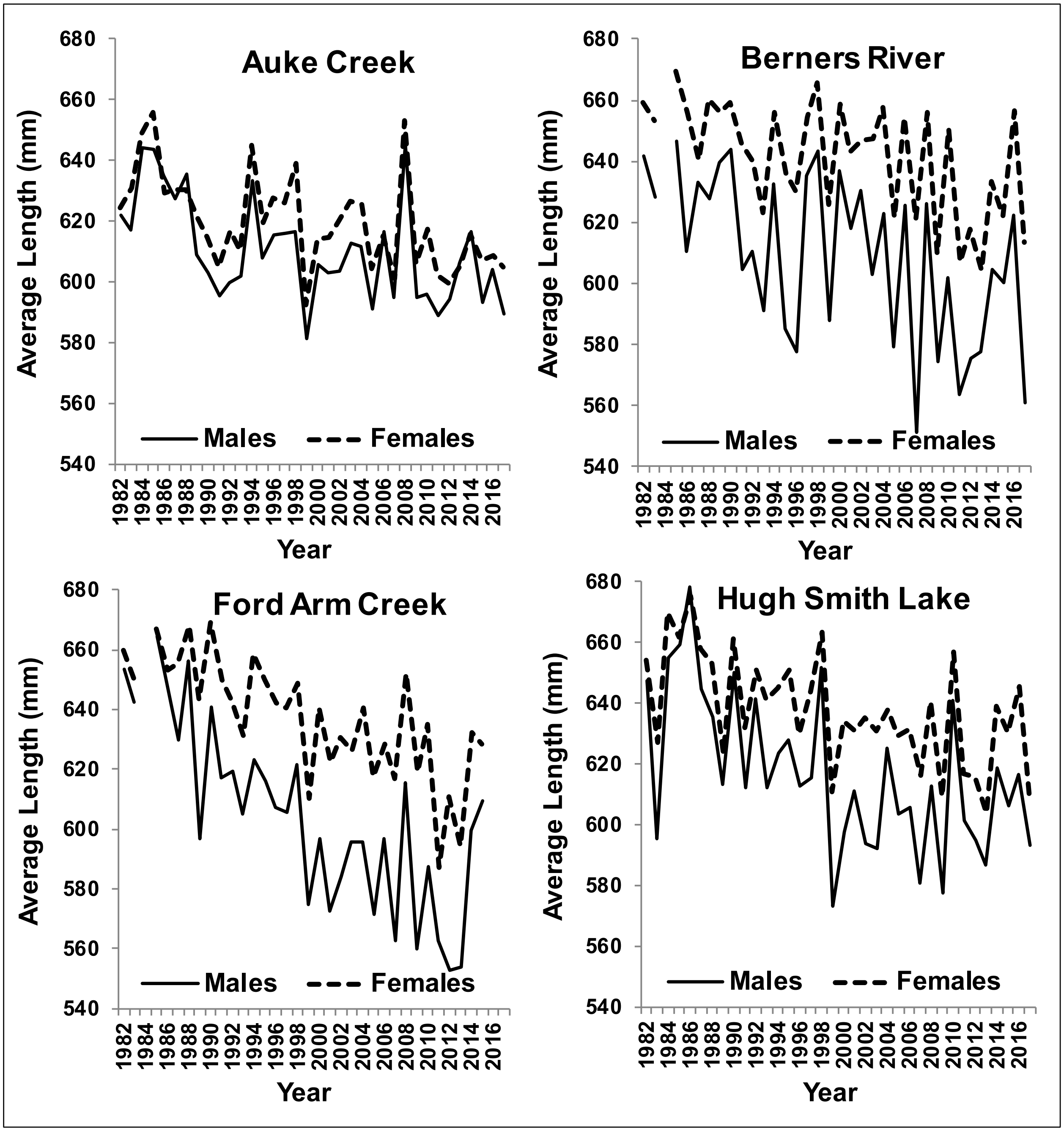

Figure 34.–Annual average mid eye to fork length for age-.1 male and female coho salmon sampled in Auke Creek, Berners River, Ford Arm Creek, and Hugh Smith Lake, 1982–2017.

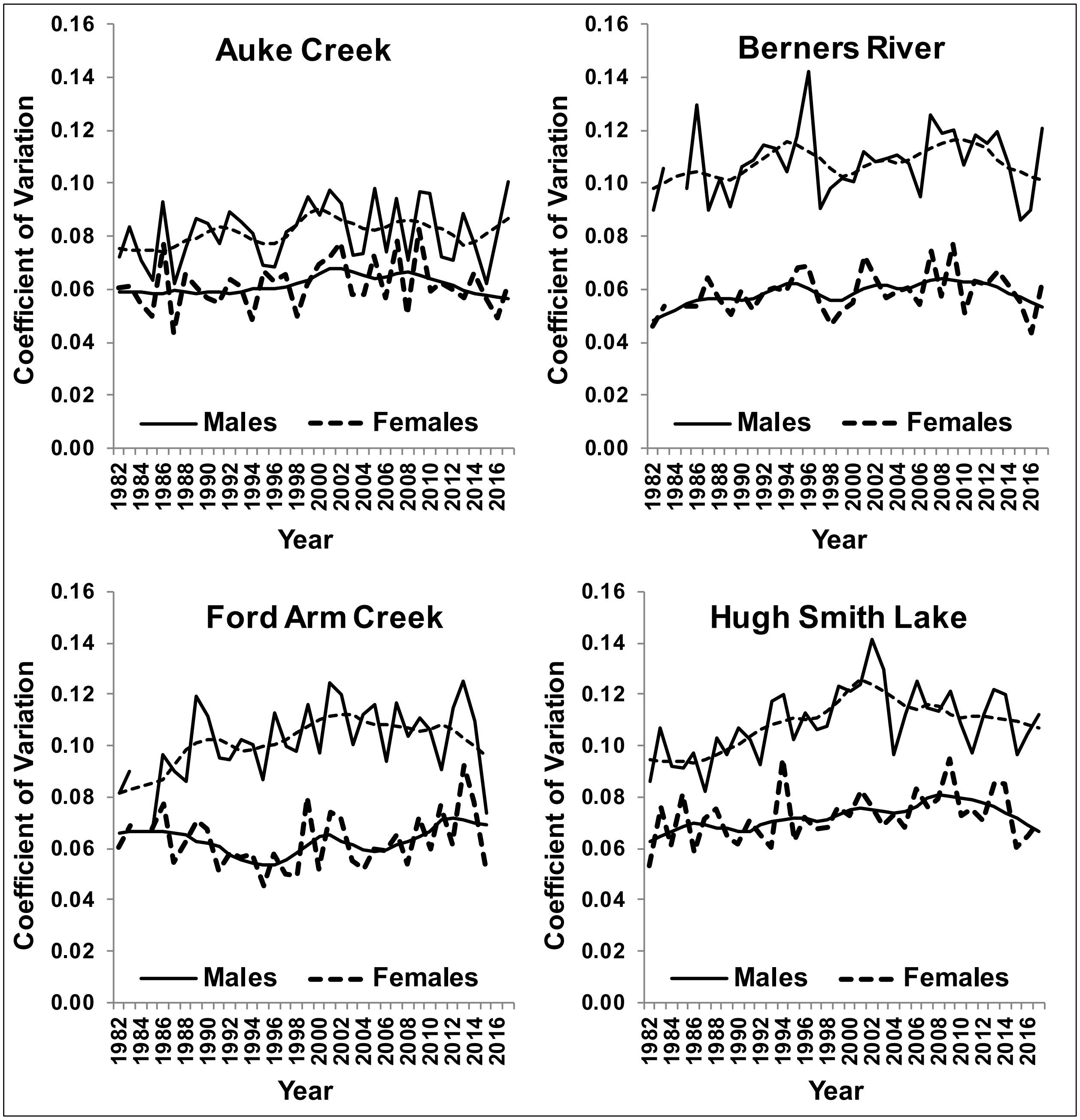

Figure 35.–Coefficient of variation in the mid eye to fork length and 9-pt LOESS trend for age-.1 male and female coho salmon sampled in Auke Creek, Berners River, Ford Arm Creek, and Hugh Smith Lake, 1982–2017.

Our observations for the Berners River population, including a strong biennial pattern in the female-to-male ratio (see Escapement Goal Analysis; and Shaul et al. 2017), are supportive of the hypothesis by Holtby and Healey (1990) that sex-specific mortality in females (particularly in Type A females) occurs primarily through increased risk-taking during the second season at sea, rather than earlier in the life history of females. In Alaska Chinook salmon, an improbable combination of decreasing size-at-age and decreasing length-at-maturity (Lewis et al. 2015) may be explained by a similar risk trade-off response by females of that species, which, on average, mature at an older age compared with males. A decrease in average age, if it occurs concurrent with decreases in both average size-at-age and the female proportion of spawning populations, would appear supportive of a late critical period for marine survival of female chinook salmon (as in female Berners River coho salmon) based on an increase in growth-related risk-taking, rather than "choice" by individual fish to mature early in response to some stimulus such as an increase in early-marine growth (Seigel et al. 2018).

Troll Fishery Average Weight

The average weight of coho salmon caught in the Alaska troll fishery was used as an index of average adult size of maturing coho salmon returning to Southeast Alaska and northern British Columbia. Coho salmon weight was calculated by dividing the weight of head-on, gutted coho salmon landed by the Southeast Alaska troll fishery by the associated number of fish reported on sales slips. There is a seasonal trend of increasing average weight, as well as substantial inter-annual variation in the temporal distribution of the troll catch (Shaul et al. 2011). Therefore, average weight was calculated weekly and averaged across 11 statistical weeks (28–38), spanning a period from early July through mid-September, in order to obtain a temporally stable measure of average coho salmon weight in coastal waters. With the exception of a few years, weight of troll-caught fish tracked closely with mean-average length of male and female spawners returning to the four primary indicator systems in Southeast Alaska (Figure 36). Both data series show an even-year dominant size pattern that became more pronounced and consistent after 1997.

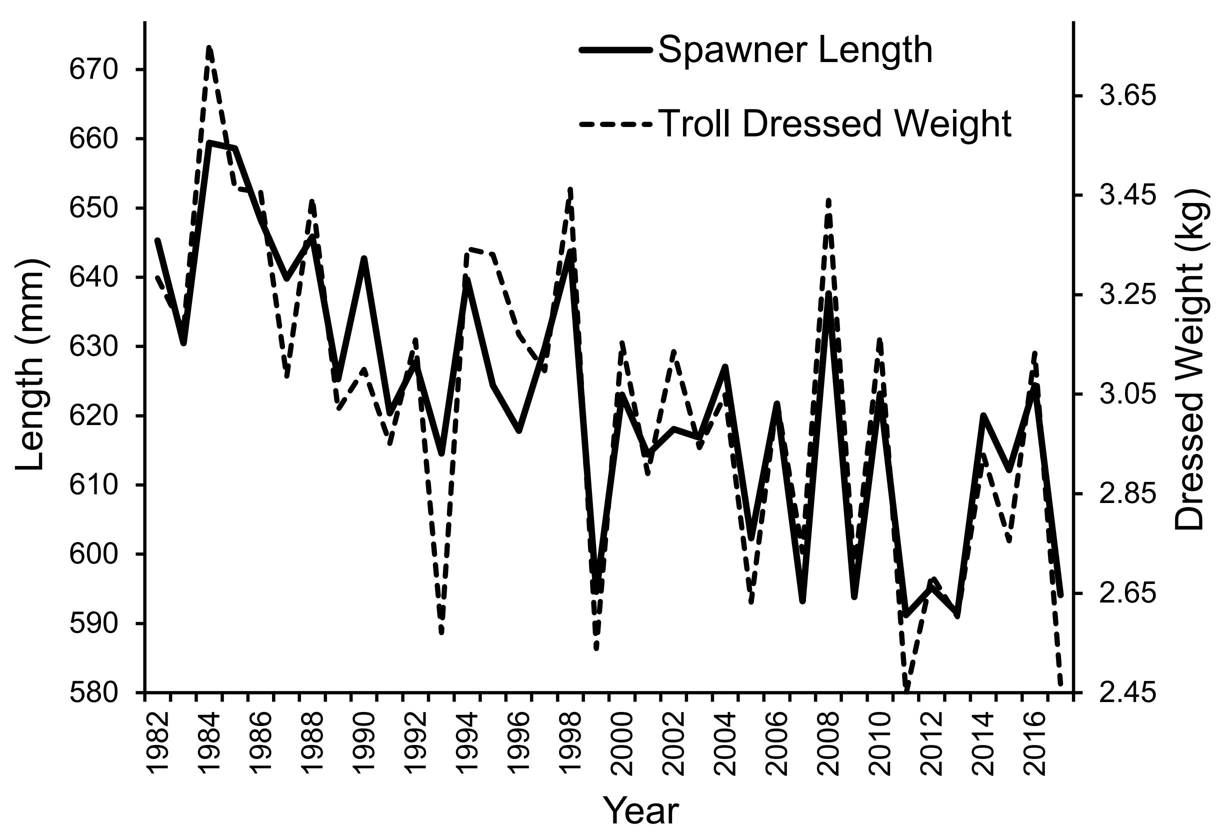

Figure 36.–Mean-Average Length of male and female coho salmon spawners returning to four wild indicator streams compared with the mean-average dressed weight of troll-caught coho salmon in Southeast Alaska during statistical weeks 28-38.

Causes of Variation in Size

A decreasing trend in size and development of a consistent even-year dominant size pattern, particularly after 1997, led us to suspect that these patterns were related to increasing numbers of pink salmon returning to streams and hatcheries in North America, particularly in odd years. We began to suspect that increasing runs of pink salmon, which have a biennial life cycle and are known to exhibit competitive dominance over other salmonids at sea (Ruggerone and Nielsen 2004), were placing increasing pressure on food resources used by returning coho salmon.

Shaul and Geiger (2016) found that about two-thirds of the variation in annual troll-caught coho salmon weight during a 45-year period was explained by two lagged variables, the average harvest biomass of pink salmon in North America (excluding the Bering Sea and Aleutian Islands) averaged at years -2 and -4 and the April–March PDO (Pacific Decadal Oscillation) index averaged across years 0, -2 and -4. The ocean range of maturing Southeast Alaska coho salmon coincides closely with the range of maturing pink salmon returning to streams and hatcheries in the two largest North American pink salmon production areas, Southeast Alaska and Prince William Sound (Myers et al. 1996). Both pink salmon and the primary squid prey species (*Berryteuthis anonychus*) of salmon in offshore waters have 2-year lifespans, resulting in uneven top-down pressure on the two distinct squid lines by pink salmon predators that have exhibited increasing odd-year dominance.

The lack of influence by pink salmon biomass in the current return year appears to result from a relatively late transition from zooplankton to squid prey in the diet of pink salmon in their last year at sea. The lagged relationship with pink salmon biomass arises from the large size required of pink salmon (about 1 kg) to effectively prey upon maturing squid (Davis 2003; Kaeriyama et al. 2004), a size that is not achieved until their final weeks at sea after competing coho salmon have achieved a large portion of their second-season marine growth from feeding on the current-year squid cohort. Therefore, the detectable competitive effect with pink salmon arises from the cumulative impact of predation by pink salmon on prior generations of squid, rather than direct competition among fish for squid in the current-year cohort. The fact that the average monthly PDO index is also influential only at 2-year lags for annual periods covering emergence and development of *B. anonychus* suggests that North Pacific climate influences growth of coho salmon primarily through its effect on squid larval survival and recruitment.

The model developed by Shaul and Geiger (2016) has continued to track observed coho salmon weight with similar annual error through 2018 (Figure 37). Although nearly 5% lower than the forecast of 2.59 kg, observed troll weight in 2017 (2.47 kg) was only slightly above the record low weight of 2.45 kg in 2011. While positively influenced by a recent warm period of high PDO index values, the low average troll-caught coho salmon weight in 2017 was negatively influenced by the two largest pink salmon runs on record in the Gulf of Alaska that preyed upon the parents (2015) and grandparents (2013) of the squid cohort fed upon by coho salmon maturing in 2017. Harvest biomass was used to represent pink salmon in the Gulf of Alaska because the mass of fish landed contains elements of both abundance and average size, and the ability of individual pink salmon to prey on maturing squid is positively dependent upon fish size, beginning at a threshold weight of about 1,000 g (Davis 2003). In addition, landed weight represents a more accurate census of the harvest, because salmon are priced by landed weight, while numerical harvest estimates are based on limited samples for average weight.

Interestingly, inclusion of 2015–2018 data from during and after the warm-water Blob event in the North Pacific produced a slightly improved overall model fit ($R^2 = 0.673$) for the 49-year period (Figure 37) compared with an R^2 value of 0.646 for the period from 1970–2014 (Shaul and Geiger 2016). Residuals were positive (weight greater than predicted by the model) during the years encompassing the Blob event (2014–2016).

The model can be rearranged to express the climate variable as the climate-based capacity of the Gulf of Alaska to pasture pink salmon while achieving a constant target (1970–2014) average coho salmon weight of 3.09 kg (Shaul and Geiger 2016; Figure 38). With the model updated through 2018, capacity at this target coho salmon weight at a constant neutral (0) PDO index value is estimated at 129.1 thousand metric tons of pink salmon harvested from Washington State to the south Alaska Peninsula.

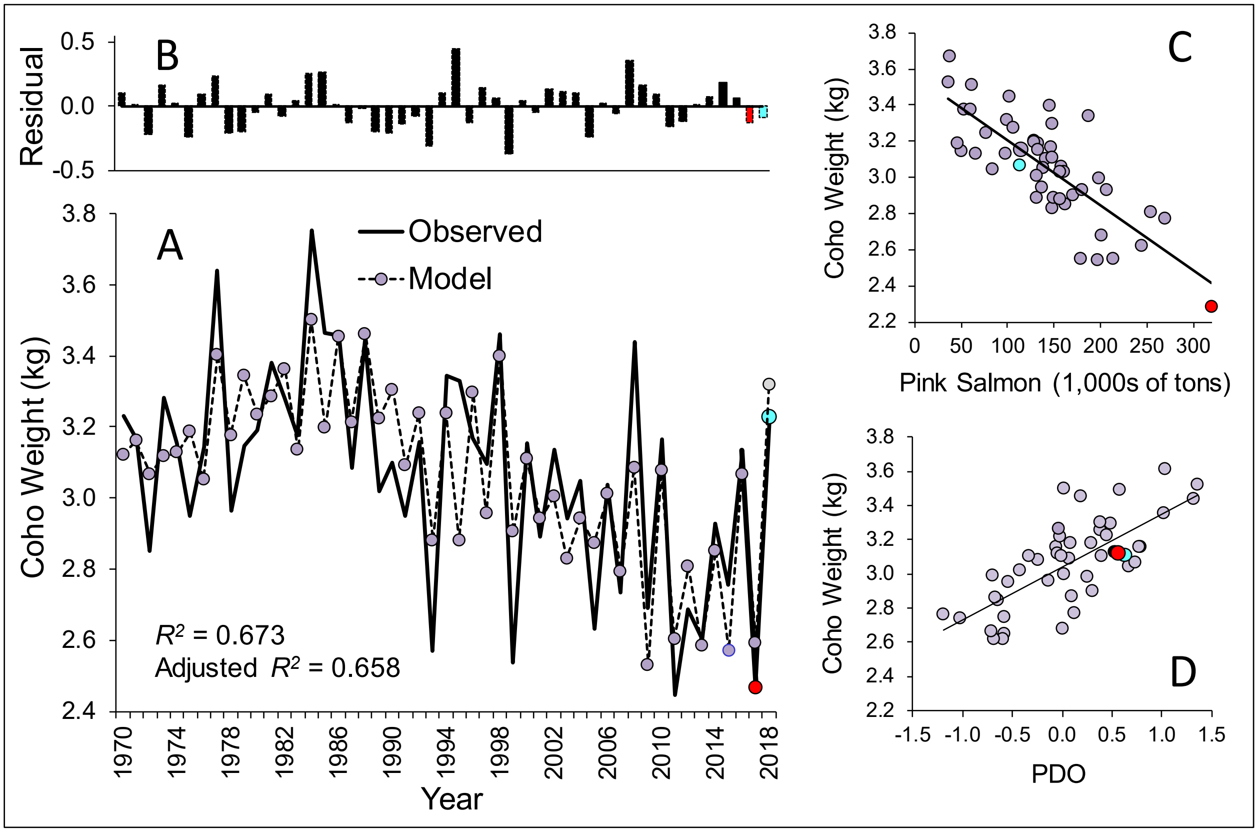

Figure 37.–Southeast Alaska troll-caught coho salmon average dressed weight compared with modeled weight (A) based on a multiple regression model with two variables: the standardized April–March PDO Index (average for lag 0, 2, and 4 years; 0.451 weighting based on the regression coefficient) and the standardized average commercial catch of pink salmon in North America (excluding the Bering Sea and Aleutian Islands) lagged by 2 and 4 years (0.549 weighting). The model residual is shown (B), as well as partial residual plots for pink salmon (C) and the PDO index (D). The model developed by Shaul and Geiger (2016; using 1970–2014 data) is refitted for 1970–2018, with the 2017 and 2018 data points indicated on the partial residual plots by red and blue dots, respectively. The average PDO index used in the model forecast of coho salmon weight in 2019 includes only 6 months of the final 12 months.

Pink salmon biomass tracked below estimated capacity based on variable climate in most years until 1990, but then began to trend higher while capacity decreased, reaching a low in 2009–2013 before rebounding during the very warm period beginning in 2014. The model forecasted a large average coho salmon weight of 3.32 kg in 2018 (Figure 36), when estimated climate-based capacity exceeded the trailing pink salmon harvest biomass variable for the first time since 1998 (Figure 38; Appendix D3). Observed coho weight in 2018 (3.23 kg) was 3% lower than forecasted but still followed the rebounding pattern of the even-year line. Odd-year weight is also forecast to improve from the second lowest weight on record in 2017 (2.47 kg) to 2.88 kg (80% C.I. 2.61–3.14 kg) in 2019 (Figure 39). The forecast improvement over 2017 is a result of continued warming during squid emergence and development, and a 14% decrease in average pink salmon biomass in the parent and grandparent years for the 2019 squid cohort, from the record high for 2017 (Figure 38). The lagged PDO index variable for the preliminary 2019 coho salmon weight forecast includes only the first 6 months of the most recent year at lag-0, and full-year values at the 2- and 4-year lags.

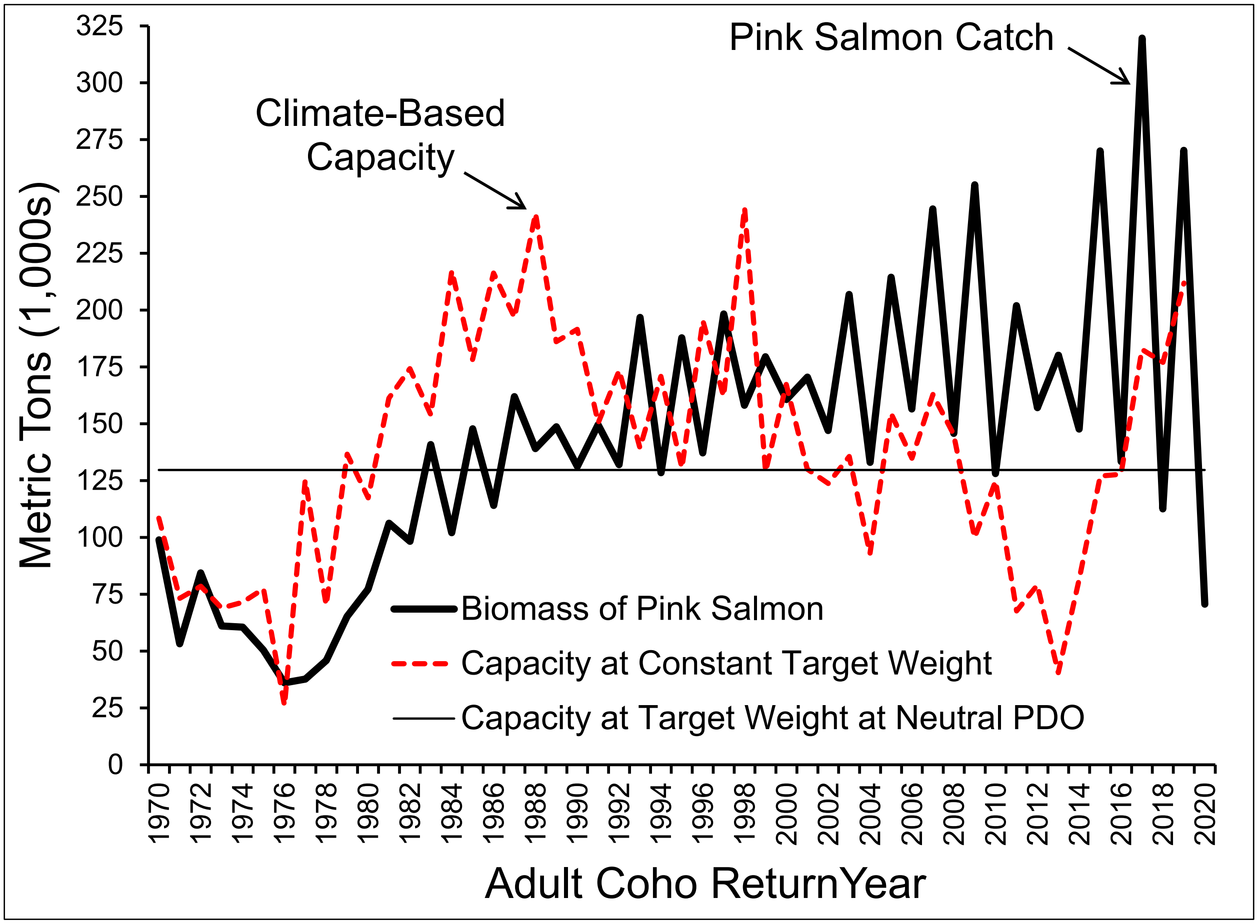

Figure 38.–Average Gulf of Alaska pink salmon catch in the preceding two cycles (lag 2, 4) compared with the estimated catch at a constant target coho salmon weight of 3.09 kg (1970–2014 average) at both the trailing 3-cycle average PDO index (lag 0, 2, 4) and at a constant neutral PDO index. The PDO variable is converted to an estimate of the climate-based capacity of the Gulf of Alaska to produce pink salmon for harvest while also achieving a target coho salmon weight.

With the exception of a couple brief periods, the trend in even-year coho salmon weight has remained substantially more constant compared with odd-year weight since 1970, suggesting that predation pressure on coho salmon prey has usually been sustainable on the even-year squid line. A series of high even-year weights in 1984, 1986, and 1988 (Figure 39) coincided with the 3 years out of 49 when estimated climate-based capacity exceeded the pink salmon harvest variable by the greatest amount, and the record coho salmon weight of 3.75 kg in 1984 coincided with the greatest positive difference between estimated pink salmon capacity and estimated harvest biomass (Figure 38).

A second deviation from a stable even-year trend occurred when coho salmon weight dropped to a record low of 2.69 kg in 2012 (Figure 39) that was only 2% above the mean-average weight of 2.62 kg for the nearest four odd years during 2009–2015. In 2012, the gap between trailing pink salmon biomass and estimated capacity was the largest observed negative difference in an even year and was 6th highest for all years (Figure 38), due primarily to a record harvest of 71.3 million Prince William Sound pink salmon in 2010 (of which 97% were of hatchery origin; Botz et al. 2012), combined with negative PDO index values at all three annual lags (0, 2, 4). The Prince William Sound hatchery contribution alone comprised 62% of the 181.71 thousand metric tons of pink salmon harvested from Washington State to the south Alaska Peninsula in 2010. Although not included in the model, an exceptional 2010 run of 28.3 million sockeye salmon to the Fraser River, the largest run since 1913 (Pacific Salmon Commission 2015), likely placed additional pressure on squid prey populations in the Gulf of Alaska.

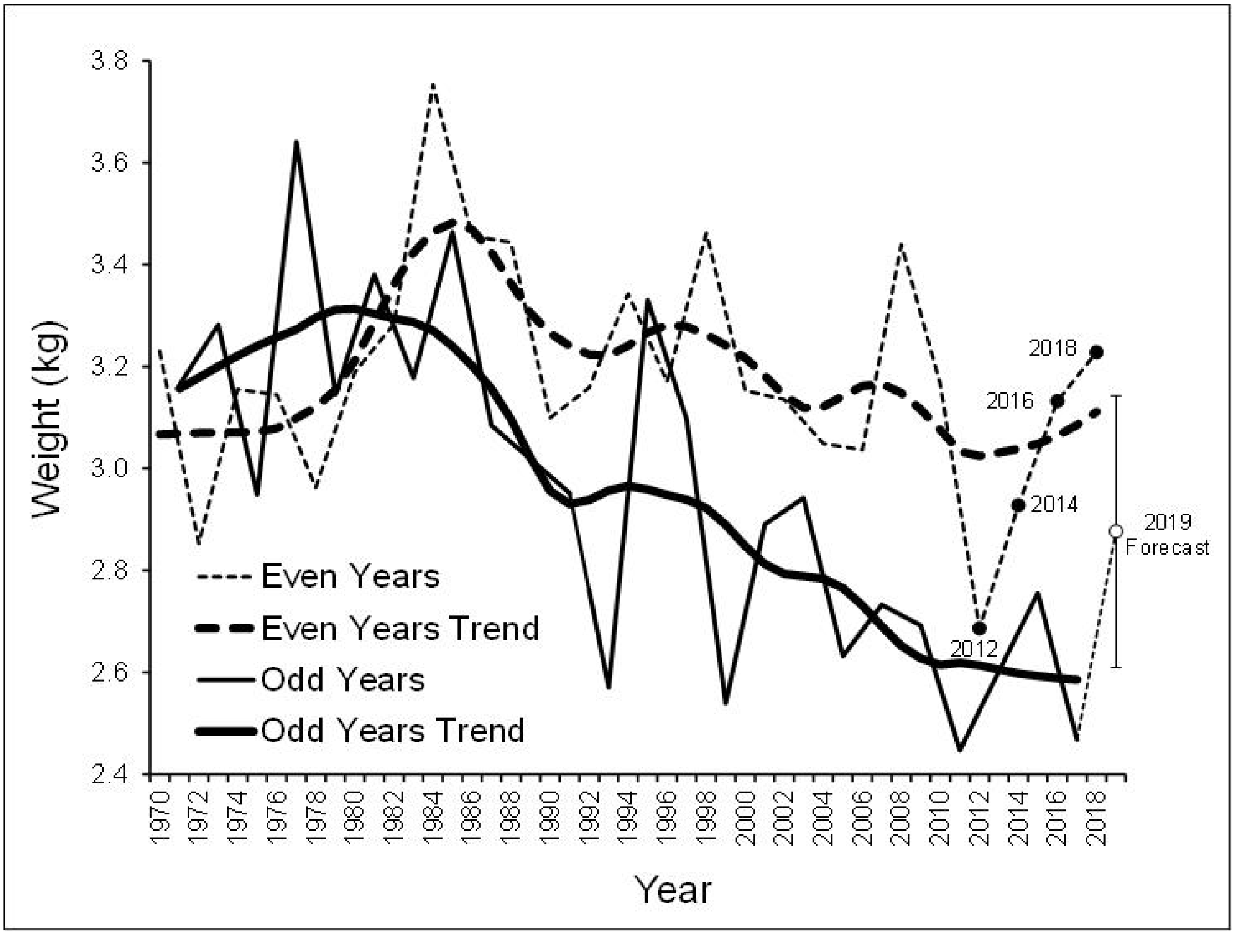

Figure 39.–The dressed weight of troll caught coho salmon in Southeast Alaska in even and odd years with 0.3 LOESS trends and forecast for 2019 (with 80% confidence bounds). The 2019 forecast is based on a model that excludes the PDO index at lag 0. Recent even years are marked with dots to highlight progressive recovery of coho salmon weight on the even-year squid line from a record low in 2012.

Following the abrupt drop in 2012, even-year coho salmon weight increased progressively in 2014 and 2016, and exceeded the 1970–2010 median even-year weight (3.17 kg) in 2018 (3.23 kg), suggesting that the even-year squid line had reached recovery (Figure 39). Even-year coho salmon weight will likely increase further in 2020, with the model point forecast currently (pending the final year's PDO index value) indicating a troll dressed weight of about 3.5 kg (Appendix D3), following sequential even-year pink salmon harvests of only 70–72 tons that were the lowest since 1976 and recent warm conditions associated with high average PDO index values. If troll weight comes in that high in 2020, it will be third heaviest weight on record, after 1984 and 1977.

Standing in sharp contrast with the relatively level trend in even-year weights, is a long-term declining trend in odd-year weight following an annual peak at 3.64 kg in 1977 (and a 1981 peak in the 0.3 LOESS trend of 3.31 kg) to an average of 2.57 kg (range 2.45–2.76 kg) for the most recent odd years (2011, 2013, 2015, and 2017). This represents a decline of 22% in odd-year weight. Average weight of troll-caught coho salmon shifted from odd-year dominance to even-year dominance in 1982–1983 (Figure 39), two cycles after an opposite shift in cyclic dominance of the commercial harvest of pink salmon populations in the Gulf of Alaska (Shaul and Geiger 2016; Beamish et al. 2018). The lagged response by coho salmon weight to pink salmon harvest biomass is remarkably consistent, when the influence of climatic variation is taken into account. Odd-year coho salmon weight is also likely to improve, with a projected 2019 troll weight of 2.88 kg (Figure 39; Appendix D3) that would be near the upper end of the range of mean-average weight (2.45–2.87 kg) in the past 7 odd years (2003–2017).

Size Effects on Resource Exploitation and Allocation

In addition to substantial effects on marine survival, per-capita-reproductive potential, and abundance of maturing adults (Shaul and Geiger 2016), marine growth of coho salmon influences the allocation of returning coho salmon among fishing gear groups. The effect was particularly apparent in the period following the 1998 regime shift, when average size of returning coho salmon has been consistently odd-year dominant (with the possible exception of 2012, when average size was near the odd-year average).

During years when size-at-maturity is large (typically in even years), the commercial harvest in northern inside districts (110–112 and 114–115) in the region has strongly favored the drift gillnet fishery over the troll fishery and vice versa. Since 1999, the ratio of the troll catch to the drift gillnet catch has averaged more than twice as high in even years (3.82) compared with odd years (1.78; $p = 0.003$ based on a 2-tailed t-test; Figure 40A). From a stock specific standpoint, the troll-to-gillnet ratio of the harvest of Berners River coho salmon has averaged 1.71 in odd years, compared with near parity (1.01) in even years (Figure 40B). The ratio of troll to drift gillnet catch in the region-wide commercial harvest was 38% higher in odd years, although the difference was not statistically significant ($p = 0.087$).

Part of the effect is attributed to greater effectiveness by trollers in exploiting coho salmon runs in odd years. The estimated troll exploitation rate on the Berners River stocks averaged 31.0% in odd years compared with 24.9% in even years (Figure 40C). The troll exploitation rate was also proportionately higher in odd years for nearby Auke Creek coho salmon ($p = 0.0028$), but not for the Hugh Smith stock in southern Southeast Alaska ($p = 0.887$), possibly because of other influences on migration and availability of the latter stock (see section on Exploitation Rates in the Discussion).

The reason for greater effectiveness in odd years when fish are smaller is not entirely clear, but may be associated with increased milling behavior by fish that are still actively feeding and growing in coastal waters compared to even years, when typically large, mature fish appear to use coastal waters primarily as a travel corridor during the return migration to their natal stream. Scarcity of prey in offshore waters of the northern gulf in odd years may prompt returning fish to continue their search for energetically profitable concentrations of prey into inshore and inside waters earlier than in even years. Other growth-related factors may also influence hook-and-line exploitation. For example, many coho salmon escape troll gear by tearing free of the hook, sometimes by shearing through the jawbone. Although we have not analyzed data collected on the incidence of hook-torn jaws among Berners River spawners, anecdotally, our impression is that hook-torn jaws tend to be more prevalent on larger individuals that have an advantage of greater mass and body leverage in pulling free from troll gear.

In the Berners River population, drift gillnets appear less effective in odd years because a large proportion of the 1-ocean males (including those likely destined to be subdominant stealth spawners) appear to trade growth for survival, returning at a small size at which many can pass through fall gillnet web (the bimodal pattern fades and more of the males are in the “catch zone” when growth is good; Shaul et al. 2017). Also, smaller fish that are still actively feeding closer to the river may tend to range deeper and more fish escape under drift gillnets, leading to reports of coho salmon catches concentrated in lower gillnet webs. In 1999, fishermen reported that coho salmon caught in the District 111 fishery in September were eating Pacific sandfish (*Trichodon trichodon*), a bottom dweller.

Size Comparison with Chinook Salmon

When feeding in offshore waters, the diet of Chinook salmon is very similar to that of coho salmon and consists primarily of squid, particularly the species *B. anonychus* (Davis 2003; Kaeriyama et al. 2004). Chinook salmon stocks from Alaska and north-migrating stocks to the south have shown a decreasing pattern in both size-at-age (in older fish) and age-at-maturity (Kendall and Quinn 2011; Johnson and Friesen 2013; Lewis et al. 2015; Ohlberger et al. 2018). However, a level or increasing trend in size has been prevalent in younger age 1- and age 2-ocean Chinook salmon.

Age 4-ocean Chinook salmon from mixed stocks that were landed in the traditional Southeast Alaska July troll fishery (statistical weeks 27–29) exhibited a similar but steeper decline in length since 1982 compared with coho salmon, as indicated by mean-average length of male and female spawners in Ford Arm Creek and the Berners River (Figure 41). There has been a divergence during the recent very warm period beginning in 2014, when coho salmon rebounded in size (consistent with the coho salmon weight model) while less thermally tolerant Chinook salmon (Abdul-Aziz et al. 2011) continued to decline in size. Prior to the mid-2000s, declining size was limited primarily to older age 4-ocean Chinook salmon, but age 3-ocean fish have also shown steep declines in size since 2006, particularly after 2010 (Figure 41).

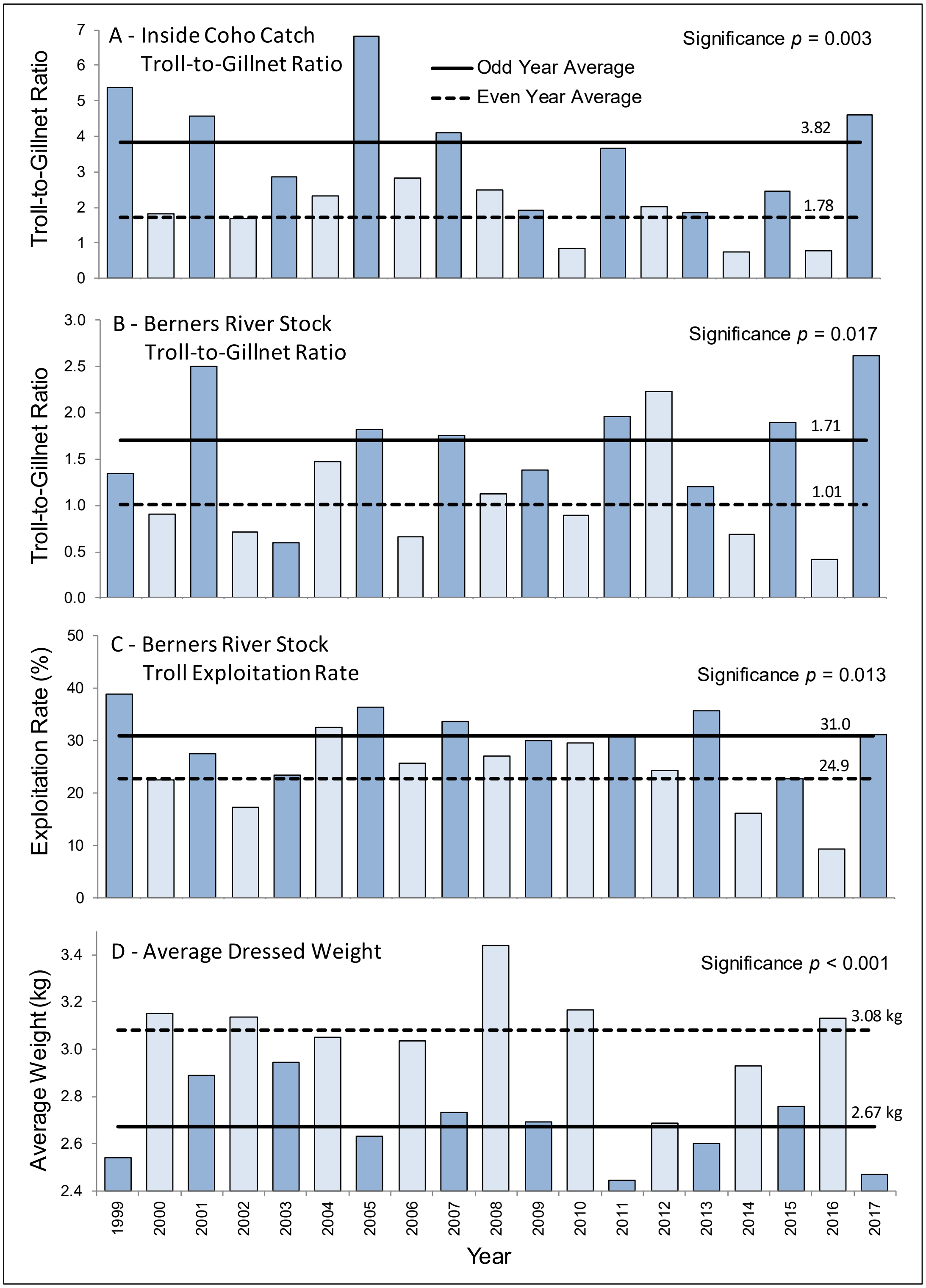

Figure 40.–Annual estimates and even- versus odd-year averages for the troll-to-gillnet ratio of (A) the total coho salmon catch in inside waters of northern Southeast Alaska, (B) the troll-to-gillnet ratio of the total harvest of the Berners River stock, and (C) the troll exploitation rate for the Berners River stock. Significance values are for two-tailed *t*-tests if even- versus odd-year values. Annual odd- and even-year values are shaded dark and light, respectively. Significance (*p*) is based on a 2-tailed *t*-test.

We suspect that, as in coho salmon, declining size of older Chinook salmon has been linked to abundance of offshore squid prey populations and to the same climatic and top-down controls on those populations. The stronger biennial pattern in coho salmon likely reflects that species' dependence on a single even- or odd-year squid line, whereas older Chinook salmon likely feed to some extent on both squid lines. The increasing size trend in younger Chinook salmon (Ohlberger et al. 2018) may reflect trends in coastal forage fish populations that, in some cases, increased from the early 1980s to the 2000s (e.g., herring in Southeast Alaska; Hebert 2017) while the trend in coho salmon adult size indicates that a key prey species in offshore waters has decreased, a trend that may have more effect on older Chinook salmon that appear to range beyond the inshore forage fish community utilized year-round by smaller "feeder kings".

Olhberger et al. (2018) discounted interspecific competition with other salmon species as a likely reason for the decline in average age and size-at-age in older Chinook salmon based on results of stable isotope research (Johnson and Schindler 2009) indicating that Chinook salmon (as well as coho salmon) feed at a substantially higher trophic level (involving presumably different prey species) compared with pink, sockeye and chum salmon. In contrast, direct observation based on maturing salmon sampled on the high seas during summer indicates that diets can be remarkably similar across species (including a substantial squid component) except in chum salmon which rarely consume maturing squid (Pearcy et al. 1988; Kaeriyama et al. 2004; Davis 2003; Aydin 2000; and others).

The probable reason for the discrepancy between direct observation and stable isotope analysis lies in the brief period of about 2 months (beginning in mid- to late June) after the majority of maturing pink salmon have achieved sufficient size (≥1 kg) to be effective predators on maturing *B. anonychus* (Aydin 2000; Davis 2003), a period so late and brief that direct competition with pink salmon feeding on the current-year squid cohort does not contribute to the substantial estimated influence by pink salmon on size of maturing Southeast Alaska coho salmon (Shaul and Geiger 2016). Instead, pink salmon appear to exert their influence on current-year coho salmon growth through predation by prior generations of salmon on prior generations of squid prey (along common biennial lines).

This late ontogenetic dietary shift by pink salmon from zooplankton to squid would likely not be reflected in adult pink salmon muscle tissue because δ^{15}N uptake estimates for fish muscle tissue indicate that a diet switch becomes detectable after about 6 months, whereas muscle tissue represents an annual mean of diet δ^{15}N and may not reflect equilibrium with the new diet prior to nearly 2 years of continuous feeding (MacNeil et al. 2006). Whereas older Chinook salmon consume a diet comprised primarily of higher trophic level prey (squid and fish) that has been integrated into their tissue over a period of years, it appears unlikely that even an intensive diet of squid over a period of 2 months (following a primarily planktivorous existence) becomes fully integrated into the tissue of mature pink salmon. Never-the-less, several studies from across the subarctic North Pacific and Bering Sea indicate that, during their final weeks at sea, maturing pink salmon have an important influence on squid populations that comprise the most important component of the offshore diets of coho salmon, steelhead, and Chinook salmon (Ito 1964; Davis 2003; Jorgensen 2011; Atcheson 2012a; Shaul and Geiger 2016).

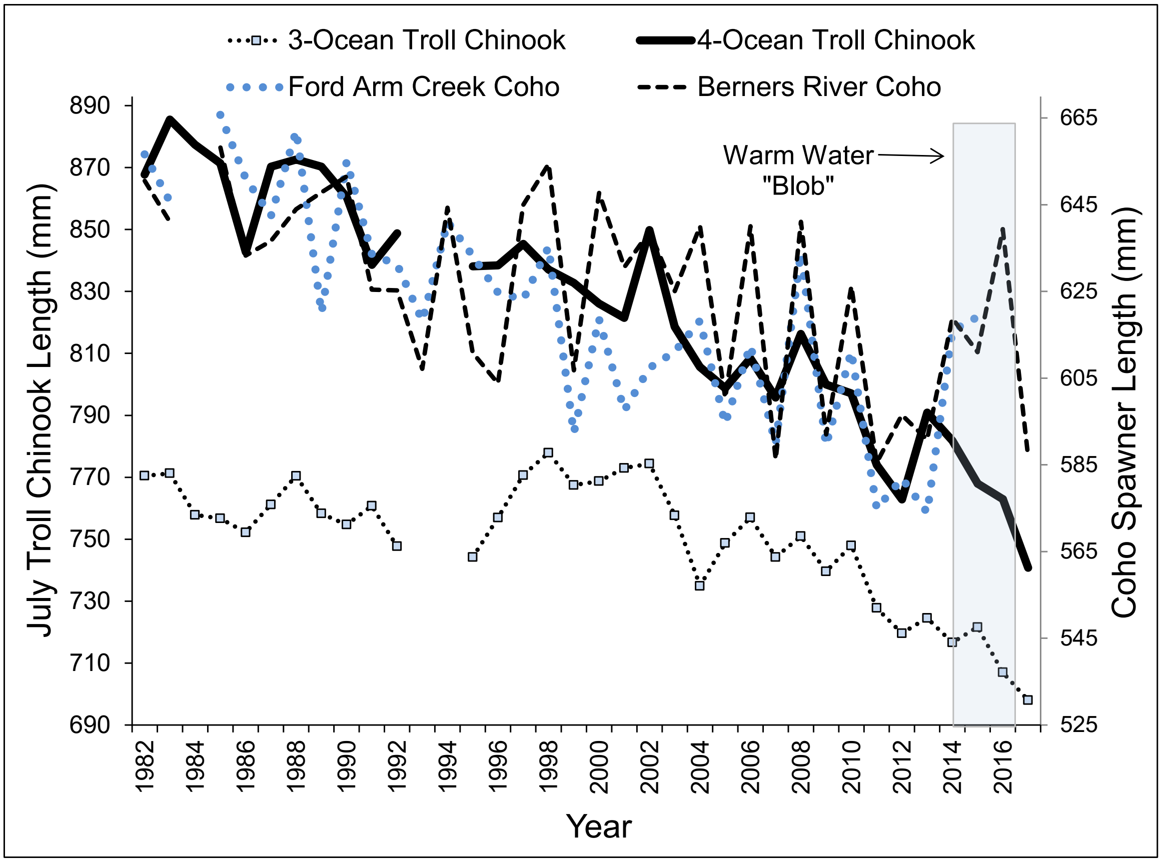

Figure 41.–Mean-average length of male and female age-.1 coho salmon spawners in the Berners River and Ford Arm Creek compared with the average length of 3-ocean and 4-ocean Chinook salmon harvested by the Alaska troll fishery in early to mid-July. Chinook salmon lengths are the mean-average for freshwater ages 0 and 1.

DISCUSSION

Southeast Alaska coho salmon stocks appear to be in good condition as a whole. We found no stocks of concern from a fishery management perspective. Escapements of stocks that have formal escapement goals have been within or above target ranges in the vast majority of cases.

SURVIVAL AND ABUNDANCE TRENDS

Although estimated abundance of wild coho salmon available to the troll fishery has maintained a slight increasing trend since 1982, there have been substantial geographical changes in the source of the abundance, as indicated by returns to specific wild indicator systems. During 1982–2004, returns to inside indicator systems throughout the region were relatively closely synchronized with each other and with abundance in the troll fishery (Figure 42). Returns to Lynn Canal systems dropped sharply beginning in 2005 from a combination of lower smolt production and lower marine survival. Berners River smolt production fully recovered during the 2014–2017 returns, under warmer climatic conditions, and the 2014 adult return was the largest since 2004 (although still 16% below 1989–2004 median return; Figure 25). However, marine survival, which had decreased from a 15-year average of 19% for 1990–2004 adult returns to 12% during 2005–2015, subsequently dropped to only 5–6% in 2016–2017. The Auke Creek jack indicator and juvenile trawl survey results suggest marine survival rates will be similar or lower for the Berners stock in 2018 and 2019 (Figures 16 and 19; King et al. 2019).

In southern Southeast Alaska, favorable marine survival beginning in the mid-2000s, and consistently high smolt production after 2010, resulted in a series of strong adult returns to Hugh Smith Lake beginning in 2007 that closely tracked wild abundance in the troll fishery through 2014. Returns decreased sharply under a series of poorer (6–7%) marine survival rates during 2015–2017 (Figure 42).

Despite declines in inside indicator systems, however, overall wild abundance in the troll fishery remained high during 2015–2017, apparently from strong contributions by wild coho salmon stocks located along the outer coast of Southeast Alaska and along the British Columbia coast. The consistent trend in overall wild coho salmon abundance available in outer coastal fishing areas, despite the declines in major inside production areas, demonstrates a strong portfolio effect in the Alaska troll coho salmon fishery. While coho salmon in Southeast Alaska and northern British Columbia lack the ocean age diversity found in sockeye salmon (Schindler et al. 2010), they benefit from diverse geography, habitat, and life history strategies (Shaul et al. 2013).

Although thus far limited to systems inside the Alexander Archipelago, the recent sharp decline in marine survival is of concern for a number of reasons. Foremost, the observed decline in survival of age 1-ocean coho salmon likely foreshadows similar declines in species such as sockeye, Chinook, and chum salmon that commonly remain at sea for 3 or 4 years. This will likely present a hardship for resource users who are more dependent upon fishing in inside waters. Results of NOAA trawl surveys conducted on inside waters of northern Southeast Alaska indicate that 2018 smolts are likely to continue the recent trend toward historically poor marine survival: trawl survey CPUE was the lowest on record for coho salmon in 2018, and was also universally low for all other salmon species (King et al. 2019).

Inland waters where salmon rear for a period of months before migrating to the open sea can serve as important nursery areas that contribute to substantially higher marine survival compared with streams that drain more directly into the oceanic waters. For example, coho salmon smolts entering inside waters from Auke Creek, Berners River, and Taku River in 2004 and 2005 survived to adulthood at a mean-average rate of 13% (range 6–21%) compared with a survival rate estimated at 5% in those years for smolt that entered the Situk-Ahrnklin Lagoon before passing directly over the bar into oceanic waters (Shaul et al. 2010). A similar survival advantage has been experienced in most years by coho salmon stocks rearing in Puget Sound, where marine survival averaged 12% compared with 4–6% for stocks located on the Washington Coast, and inside and outer coastal marine survival rates have been only weakly correlated (Shaul et al 2007; Zimmerman et al. 2015).

The benefit of rearing for an extended period in inside waters before entering the main ocean may turn into a disadvantage, however, when conditions for survival deteriorate in those same waters. In addition to the recent decrease in coho salmon survival (Figure 15), other signs of change include a marked increase in odd-year dominance in northern inside pink salmon runs and a substantial decrease in even-year pink salmon runs since 2011 (Gray et al. 2016), a decline in inside herring populations (Hebert 2017), and very low catches of juvenile pink and chum salmon during trawl surveys conducted in 2017 and 2018 in Icy and upper Chatham straits by the NOAA Southeast Coastal Ecosystem Monitoring project (King et al. 2019). Several recent patterns suggest that outer coastal marine waters have been less affected, including high recent coho salmon catches in the Situk-Ahrnklin set gillnet fishery during 2013–2017 (Figure 18), a record escapement count in Sitka area streams in 2016 (Figure 5), a large contribution to the troll coho salmon harvest by the Klawock Hatchery (Figure 22), and continued high biomass in Sitka and Klawock herring populations (Hebert 2017).

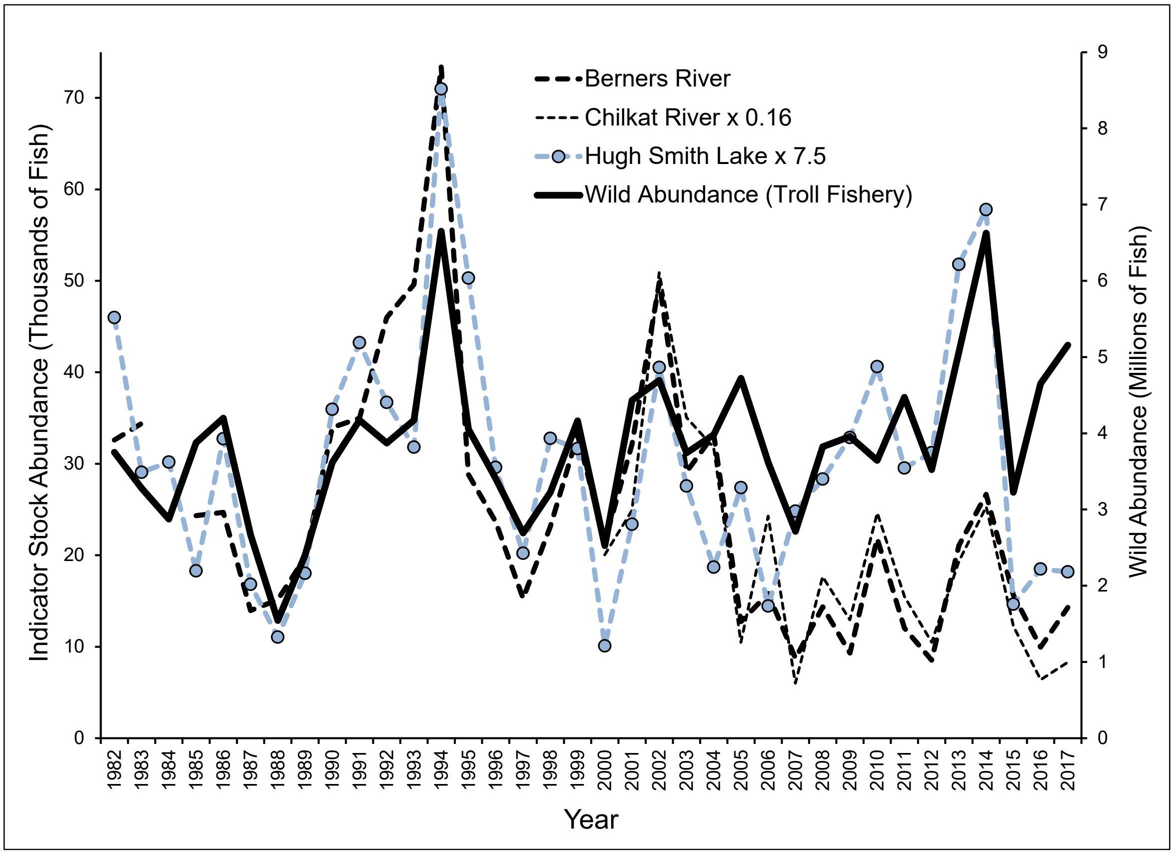

Figure 42.–Estimated total adult coho salmon returns to the Berners River (unexpanded escapement), and scaled returns to the Chilkat River and Hugh Smith Lake, compared with an estimate of the abundance of wild coho salmon available to the Alaska troll fishery by adult return year.

Also of concern is uncertainty about the cause of the decline in marine survival, its probable duration, and the reason why its impact, while broadly distributed over the length of the region, has thus far been specific to inside waters. Similar declines in marine survival of coho salmon in the Salish Sea have been highly protracted, particularly in the case of the Georgia Strait basin (Beamish et al. 2010; DFO 2017), suggesting persistent, low-frequency causal factors. An additional concern is the lack of a clear, convincing explanation for the declines in marine survival in the Salish Sea (Zimmerman et al. 2015), where the research focus has for decades been on bottom-up processes involving food and growth (e.g., Beamish et al. 2004). New research there has pointed to high levels of predation, although the relative importance of various predators remains unclear. Acoustic tagging studies showed high early-marine mortality (estimated at 2.4% per km during a 40 km migration) in coho salmon smolts migrating from an inlet in Georgia Strait (Melnychuk et al. 2013). Genetic studies of prey utilization indicate that harbor seals (*Phoca vitulina*) are an important predator of coho and Chinook salmon smolts in both Georgia Strait and Puget Sound (Thomas et al. 2017; Chasco et al. 2017; Allegue 2017; Nelson et al. 2018).

Circumstances surrounding the sharp drop in marine survival of coho salmon originating in inside waters of Southeast Alaska beginning in the 2015 sea-entry year are thus far suggestive of increased early-marine mortality from predation rather than a decrease in forage in early marine waters. However, if this is the case, the predator species involved and reasons for the increase in predation remain unknown, which means that it is difficult to predict when survival might improve again. The most optimistic scenario may involve a single, strong recruitment event in a particular predator that preys heavily on juvenile salmon, but undergoes an ontogenetic change, as it grows, to other locations and prey resources. One example of this type of predator is sablefish (*Anoplopoma fimbria*), a species which experienced a strong recruitment event in the Gulf of Alaska in 2014, including in Southeast Alaska (Sturdevant et al. 2012; Hanselman et al. 2017; Sullivan et al. 2019). Little is known about the diet or abundance trends of some potentially serious predators, such as armhook squid (*Berryteuthis magister*), which have reportedly been highly abundant in inside waters from Lynn Canal and Stephens Passage southward through lower Clarence Strait in recent years, based on anecdotal reports of widespread high sport fishing success (Richard Yamada, Juneau, personal communication). Fish were the most commonly identified prey consumed by *B. magister* individuals in the Bering Sea (Hunsicker et al. 2010). If *B. magister* preys on juvenile salmon and prefers the same warm conditions as its smaller offshore epipelagic cousin, *B. anonychus* (as indicated by the positive relationship with the PDO index in the coho weight model), the decrease in inside salmon survival and herring biomass estimates since 2015 could potentially be explained in part by a rapid population increase in *B. magister* in response to the North Pacific Blob that formed in 2014.

A potentially more problematic scenario than cyclical abundance of a predator species responding to recent climatic variation would be a low-frequency predator response to large annual releases of hatchery smolts, potentially involving intelligent, longer lived species like humpback whales or harbor seals. Hatchery operators have become aware of intensifying predator fields and declining marine survival near some hatchery facilities (Chenoweth et al. 2017; Chenoweth and Criddle 2019), an awareness that has prompted a number of Permit Alteration Requests to out-plant smolts at marine release locations distant from central incubation facilities (Flip Pryor, ADF&G, Douglas, personal communication). The potential effect that predator response to increasing smolt production may have on wild stock marine survival is unknown, but should be considered in light of coincident declining marine survival in the most inside districts of Southeast Alaska (districts 101, 102, 106–108, 110–112, and 115) where hatchery releases of all species increased to an average of 508 million smolts and fry during 2013–2017, with a 10-year (2008–2017) average annual rate of increase of 2%/year following a period of little change in total numbers released between 1995–2008 (ADF&G Mark, Tag and Age Laboratory data; Figure 43). Chum salmon accounted for the majority (78%) of hatchery fish released in these inside waters during 2013–2017, but coho salmon have shown the greatest proportionate increase (35%) in average release between 2003–2007 and 2013–2017 (chum salmon releases increased by 22%).

Aside from recent success at Klawock Hatchery, steady increases in the number of coho salmon smolts released from Southeast Alaska hatcheries has scarcely moved the needle in terms of the absolute contribution to the Alaska troll catch of hatchery coho salmon, or even to the proportionate contribution relative to wild stocks. Hatchery production of coho salmon has been boosted proportionately the most of any species in the region in an attempt to bring the troll fishery's share of the total landed value from hatchery-produced salmon up to its target range, as coho salmon is an important species to the troll fishery, the gear group that is farthest below its allocation (Pryor 2017). Although a decreasing exploitation rate since the 1990s is a contributing reason for the poor response by the troll catch to increasing releases, it should be of some concern that increasing hatchery smolt releases have also been offset by lower marine survival rates at most facilities (Shaul et al. 2011). This pattern suggests that the marine predator community may be receiving substantially greater proportionate benefits compared with the common property fishery from increasing smolt releases.

An important concern is the potential effect on wild stocks related to poor hatchery marine survival. A minimal response to steadily increasing smolt releases in the proportionate contribution by hatchery fish to the total troll catch suggests that survival of wild smolts has declined substantially less than hatchery smolt survival. However, since 2004, there has been an increasing trend in releases of juvenile salmon (now exceeding 0.5 billion per year) into the inner-most waters of the region (Figure 43). This pattern should be of concern, because marine survival has dropped sharply in these same waters and has thus far remained low for three consecutive years with evidence from NOAA juvenile salmon trawl survey results pointing to at least two more years of low early-marine survival (King et al. 2019). Increasing hatchery releases may negatively affect wild-stock marine survival through competition (King and Beamish 2000) and/or a predator response (Nickelson 2003; Allegue 2017). Large numbers of hatchery fish have the potential to improve survival of intermixed wild juveniles to the extent that they may temporarily swamp predators (Furey et al. 2016); however, the benefits of this effect likely depend on a high level of temporal and spatial overlap between hatchery and wild smolts, while such behavior may potentially increase vulnerability by wild juveniles to humpback whales, an important predator on schooling hatchery salmon (Chenoweth et al. 2017; Chenoweth and Criddle 2019).

In Oregon coastal streams, the number of hatchery smolts released in a watershed was negatively correlated with productivity of wild coho salmon, while the proportion of hatchery spawners in the population was not, suggesting that ecological effects of hatchery smolt releases were more important than genetic effects of spawners of hatchery origin (Nickelson 2003). The author presented evidence that higher predation on wild fish by predators attracted to hatchery smolts was the primary factor responsible for the decrease in stock productivity. Recent decreases in marine survival of wild coho salmon stocks in inside areas of both northern Southeast Alaska (Auke Creek and Berners River) and southern Southeast Alaska (Hugh Smith Lake; Figure 15) highlight the importance of understanding interactions in marine waters between wild juvenile salmon and coho and chum salmon juveniles that have been released in steadily increasing numbers from hatcheries in the region. Results of recent investigations in Puget Sound and Georgia Strait highlight the importance of predation by one class of predator (marine mammals) on estuarine and early marine mortality of juvenile salmon, particularly species like coho and Chinook salmon that enter the sea at a larger size (Chasco et al. 2017; Thomas et al. 2017). These studies also highlight the importance of looking beyond competitive interactions between wild and hatchery-produced salmon to potential negative interactions mediated through predation such as intermixing of wild salmon with aggregations of hatchery salmon targeted by predators (Nickelson 2003; Chenoweth et al. 2017; Allegue 2017) and general habituation of predators to salmon as prey, particularly when other potential prey are in decline as is the case for Pacific herring in inside waters of Southeast Alaska (Hebert 2017).

The role of marine competition for food likely also plays a role in marine survival, although the extent is highly uncertain. Data on salmon diets and forage collected during NOAA trawl surveys in northern Southeast Alaska suggest that the amount of food available to juvenile salmon several weeks after sea-entry was ample (Orsi et al. 2004; Weitkamp and Sturdevant 2008), although potential food limitation has been less studied earlier and in nearshore habitats. Intra-specific competition may not be the only concern regarding competition for food, as King and Beamish (2000) found that juvenile chum salmon (as well as hatchery coho salmon) are competitors of wild coho salmon during early summer in Georgia Strait.

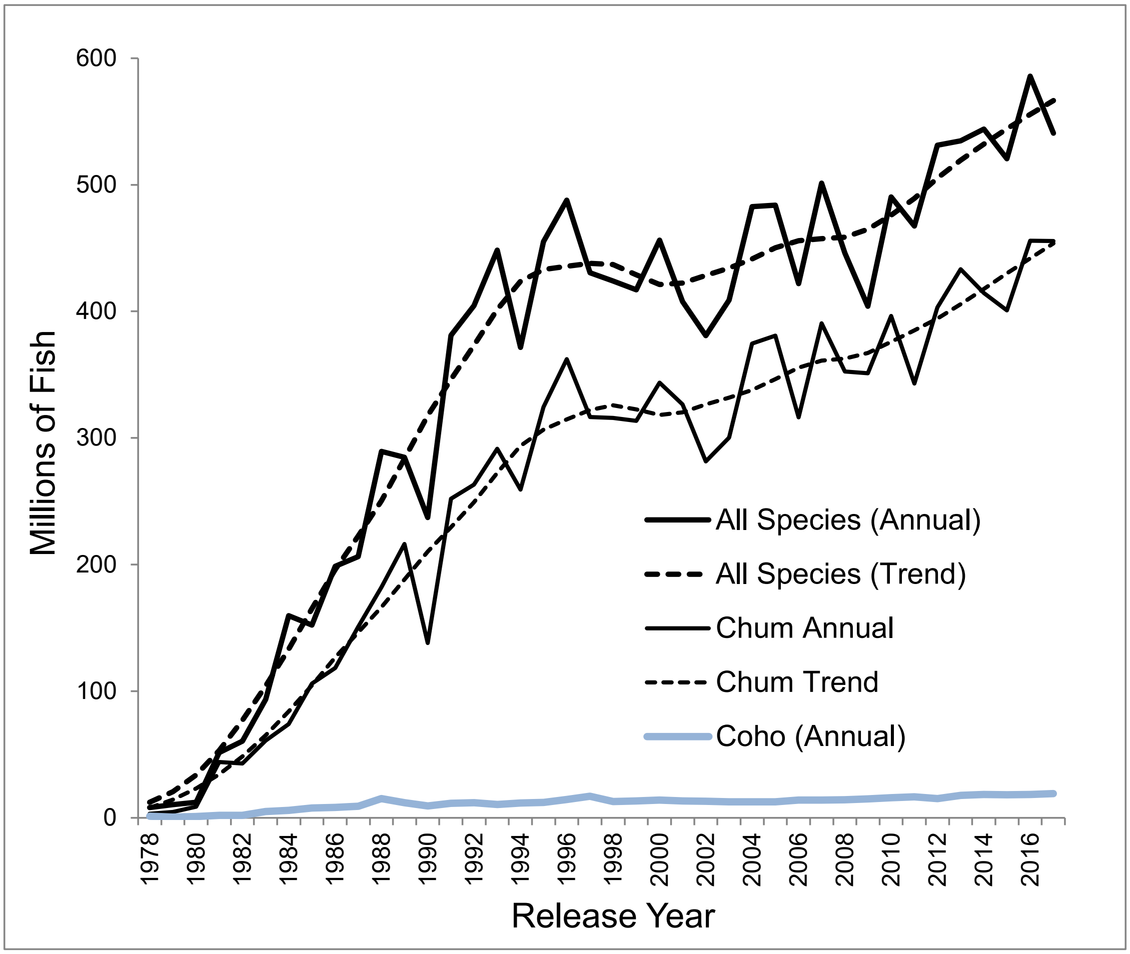

Figure 43.–Number of coho and chum salmon, and all species combined, released into marine waters in inside districts of Southeast Alaska (Districts 101–102, 106–108, 110–112 and 115) where marine survival of coho salmon has recently declined.

INTERACTIONS WITH PINK SALMON AND INFLUENCE OF CLIMATE

A wet coastal climate and the resulting abundant small streams are essential to Southeast Alaska's status as the leading North American region in harvest of wild pink salmon and the leading region in the world in harvest of wild coho salmon. Recent research has shown how these species interact with each other in various important ways in both fresh- and saltwater, and how their interaction is affected by climatic variation.

Pink salmon import into streams important marine derived nutrients (MDN) that support freshwater growth and survival of rearing coho salmon through various pathways, including increased biofilm growth and higher densities of aquatic invertebrates (Wipfli et al. 1998; 1999), colonization of carcasses by aquatic invertebrates (Chaloner and Wipfli 2002; Chaloner et al.

2002b), and direct consumption of eggs and tissue (Bilby et al. 1996) and pink salmon fry in fresh and marine waters (Hargreaves and LeBrasseur 1985; Hofmeister 1987). Wipfli et al. (2003) showed that coho salmon fry grew much faster and larger in Southeast Alaska streams enriched with salmon carcasses and eggs. At Ford Arm Creek, coho salmon production approximately doubled when the abundance of spawning pink salmon increased from a very low index count of 10,000 spawners to a nominal saturation level of 116,000 spawners (Shaul et al. 2014). The apparent nutrient subsidy from pink salmon explained substantially more of the variation in coho salmon freshwater production (57%) than did the number of coho salmon spawners (5%). However, positive effects on coho salmon growth and production from increasing biomass of pink salmon spawners are greatest at low-to-intermediate levels (Wipfli et al. 2003), while oxygen demand generated by breathing and decomposing pink salmon spawners can reduce saturated oxygen to levels that are lethal for both adult and juvenile coho salmon, especially during periods of low precipitation and streamflow (Shaul et al. 2014; Figure 14).

More recently, we have come to understand that a very important interaction between these species occurs in offshore waters that exerts a substantial influence on growth, survival, and reproductive potential of adult coho salmon through a common prey species. In this report, we have updated the predictive model for dressed weight of troll-caught coho salmon developed by Shaul and Geiger (2016) to include four additional years (Figure 37). The updated model explains a remarkable 67% of variation in coho salmon weight over a period of 49 years (1970–2018) based on only two variables, the most important of which is a negative relationship with the average catch biomass of pink salmon from populations that mature primarily in the Gulf of Alaska (GOA) at lags of 2 and 4 years (55% weighting). The other significant variable (average PDO index at lags 0, 2 and 4 years) has a 45% weighting.

The long declining trend in the size of odd-year coho salmon from a peak in 1977 suggests that top-down control on some squid populations (likely those in the northernmost GOA) has been unsustainable. The negative effect of an increasing trend in odd-year pink salmon biomass was reinforced by the apparent negative effect of post-1998 cooling with a declining trend in PDO index values (Figure 44), a factor that appears to be detrimental to survival and recruitment of the coho salmon's primary offshore prey species (*B. anonychus*), a calorie-rich squid that is also a key component of the diet of steelhead and Chinook salmon in offshore waters and is utilized when available by maturing pink and sockeye salmon (Davis 2003; Kaeriyama et al. 2004; Atcheson et al. 2012a). This species of squid appears to prefer warmer conditions associated with a positive PDO index and its range extends south of the salmon range throughout the transition zone of the North Pacific to the Subarctic Boundary, where its primary predators include (instead of salmon) neon flying squid (*Ommastrephes bartramii*) and Pacific pomfrets (*Brama japonica*) (Watanabe et al. 2003, 2004).

As a consequence, recent warming associated with the warm-water Blob (2014–2016) appears to have been a positive factor in coho salmon growth, as troll dressed weight increased during 2014–2016 from odd- and even-year lows during 2011–2012 (Figure 37), while model residuals were positive (i.e., average coho salmon weight was higher than predicted). However, average length of age 3- and 4-ocean troll-caught Chinook salmon continued a long-term declining trend during this period (Figure 41), perhaps because Chinook salmon have lower thermal tolerance compared with coho salmon (Abdul-Aziz et al. 2011). A decreasing trend in the sex ratio of adult Berners River coho salmon suggests that female coho salmon may also have succumbed under physiological stress from elevated temperature.

Although the commercial harvest of pink salmon that mature in the Gulf of Alaska has followed an increasing long-term trend, pink salmon biomass has declined very recently on both cycles from all-time peak harvests of 341.5 thousand metric tons in 2013 (odd-year record) and 181.7 thousand tons in 2010 (even-year record; Figure 44). Recent warming (and associated higher PDO index values) combined with moderation of pink salmon abundance should produce larger adult coho salmon on both even- and odd-year squid lines, and may even lead to a meaningful reversal in the long-term decline in size of older age 3- and 4-ocean Chinook salmon (Figure 41) and an associated increase in late-ocean survival. However, much may depend on whether the recent reversal from the post-1998 cooling pattern proves lasting without returning to the harmfully high temperatures prevalent during the Blob that resulted in apparent lower late-ocean growth and survival of the less thermally tolerant Chinook salmon (Abdul-Aziz et al. 2011).

Over the longer-term, these higher trophic level species will need ample forage to help offset increased metabolic demand placed on them by a warming ocean (Beauchamp 2009; Atcheson et al. 2012b) if they are to continue to produce a meaningful biological surplus for fisheries. Beyond variation in thermal tolerance among species (Abdul-Aziz et al. 2011), larger salmon have lower temperature thresholds beyond which weight loss occurs. However, diets with higher energy density (including more squid and fish; Davis et al. 1998) can increase both optimal growth temperature and thermal tolerance, especially at larger body sizes (Beauchamp 2009).

A choice may need to be made between ocean ranching of flexible planktivores, especially pink salmon, and maintenance of larger, higher trophic level species at population levels and reproductive capacity that will support substantial exploitation. Chum salmon, which have the most distinctive diet among species of Pacific salmon (Welch and Parsons 1993) and consume few maturing squid (Kaeriyama et al. 2004), offer an alternative to pink salmon for aquaculture with substantially fewer negative effects on higher trophic level species. Unique digestive structure that includes a relatively wide esophagus and large stomach with strong gastric acid (Welch 1997) allows chum salmon to rapidly digest gelatinous zooplankton including Ctenophora and Cnidaria (Arai et al. 2003).

Although average marine survival of hatchery chum salmon fry has averaged about half that of hatchery pink salmon, their per capita landed value to fisheries is about 5 to 6 times as high compared with pink salmon, suggesting that equivalent fishery value might potentially be achieved by raising chum salmon even at lower numbers of fed fry released. However, it is also important to weigh other considerations, including potential competitive interactions with wild chum salmon and other species (including coho salmon; King and Beamish 2000) in nearshore waters near release sites (see Trends in Wild Stock Abundance in the Taku Inlet Fall Drift Gillnet Fishery). After increasing in the 1990s (concurrent with increasing hatchery returns and improving overall salmon returns), the commercial harvest of wild chum salmon in Southeast Alaska declined in the mid-2000s. During 2007–2016, hatchery fish comprised 85% of the total commercial harvest of chum salmon, and the harvest of wild chum salmon during that period averaged only about 1/5th of the average harvest in the 50 years leading up to statehood in 1959 (Piston and Heinl 2017). The historically low contribution of wild chum salmon to the harvest in recent years may potentially reflect a negative interaction with hatchery stocks involving some degree of replacement (rather than enhancement) of wild stock returns (Amoroso et al. 2017). While their distinctive diet after the first summer at sea appears to recommend chum salmon over pink salmon as a target species for ocean ranching, particularly concerning interspecific competition in offshore waters, an optimal enhancement management strategy must also account for inshore effects and a broader range of potential intra-species interactions.

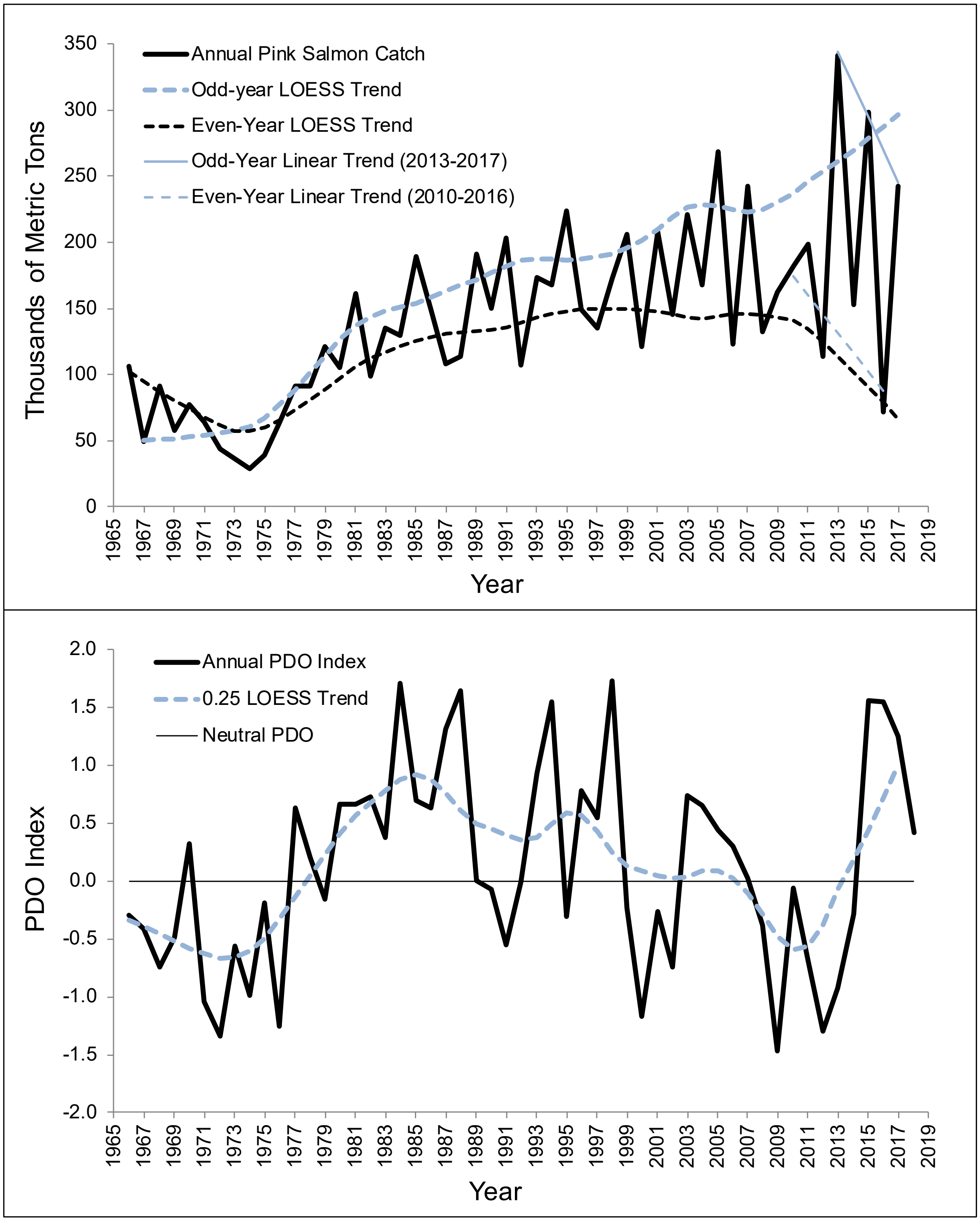

Figure 44.–Commercial harvest of pink salmon from populations maturing in the Gulf of Alaska (includes the total harvest in North America, excluding the Bering Sea and Aleutian Islands; top graph) and the April–March PDO index (bottom graph), 1966–2017.

In addition to a strong effect on growth, pink salmon biomass also has a negative relationship with marine survival of Berners River coho salmon that is heavily sex-specific (greatest influence on females). Per capita reproductive potential of adult spawners (as indicated by egg biomass) is doubly affected in years of poor growth (predominantly odd years) when (1) average female size is small, resulting in lower egg biomass, and (2) marine survival of females relative to males is comparatively lower than in years of poor growth, resulting in a relatively less abundant female component in the spawning escapement.

Because maturing pink salmon begin feeding heavily on squid only in the last weeks of their ocean life, the interaction involves an intergenerational lagged effect in which the primary effect of pink salmon on coho salmon growth is through their consumption of squid from prior generations (parents and grandparents) rather than through direct interspecies competition for the current-year cohort. In an irony of nature, a cohort of returning adult pink salmon that directly benefits growth of juvenile coho salmon through various nutrient pathways in freshwater and estuarine environments has already consumed the prospective parents of squid that would have fed those same coho salmon to maturity in the ocean.

The Berners River coho salmon population, comprised nearly 100% of a single ocean age (age .1) at maturity, provides potential insight into controlling factors responsible for declining size-at-age, average age, and marine survival in northern-feeding populations of another higher trophic level species (Chinook salmon; Ohlberger et al. 2018; Riddell et al. 2018). Findings presented here, and by Shaul and Geiger (2016) and Shaul et al. (2017), indicate that marine mortality in the Berners River coho salmon population is related to poor growth and that growth-related mortality has fallen most heavily on the female component. Shaul and Geiger (2016) proposed that female coho salmon respond to poor feeding conditions tied to lower epipelagic squid abundance (usually during odd years) by taking greater risk (physiological or with predators). A similar response involving a disproportionate increase in female mortality also offers a potential explanation for widespread declines in both size-at-age and age-at-maturity in Chinook salmon, a species with multiple ocean ages that present an obstacle to differentiation between two time-related factors (maturity and mortality). Closer examination of total returns by sex may help determine whether female Chinook salmon have been responding to declining late-ocean growth through a sex-specific increase in mortality (as in Berners River coho salmon), or to some influence tied to early maturation (Siegel et al. 2018). Unfortunately, unbiased age-sex-length data sets for Chinook salmon returns are rare, particularly for stocks that are substantially exploited at older ages.

Some authors have suggested that declines in age-at-maturity, size-at-age and overall marine survival in Chinook salmon may be explained by an increase in abundance of a specific predator species (Ohlberger et al. 2018; Riddell et al. 2018). Two known predators of large Chinook salmon in northern waters that are thought to have increased include resident killer whales (*Orcinus orca*) and salmon sharks (*Lamna ditropis*) (Ohlberger et al. 2018; Seitz et al. 2019). Our findings from the Berners River coho salmon population are not inconsistent with predation as the cause of mortality. However, significant (even-year dominant) biennial patterns in the size and sex ratio in the Berners River coho salmon population suggest that the decline in larger fish and females has been influenced by a late-marine growth-related mortality factor, rather than by an increase in on one or more predator populations. Whereas predation may be the proximate cause of late-ocean mortality of Berners River coho salmon, food-related physiological stress and/or risk-taking with predators appears the more likely ultimate cause.

EXPLOITATION RATES

The recent decrease in coho salmon returns to important inside production areas justifies lower exploitation rates compared with years of higher average abundance during the 1990s. Total exploitation rates for most inside stocks have, in fact, moderated commensurately thus far without implementation of major management restrictions in targeting fisheries. For mainland rivers in northern Southeast Alaska that are substantially exploited by both the troll and drift gillnet fisheries, recent 10-year (2008–2017) average all-fishery exploitation rates have been moderate, ranging from 39% for the Chilkat River to 44% for the Berners and Taku rivers. For the latter two rivers, this rate of exploitation represents a substantial reduction from higher 1992–1996 average rates of 70% for Berners River and 61% for the Taku River. At Hugh Smith Lake, a southern inside stock exposed to an extensive gauntlet of troll, purse seine, gillnet, and sport fisheries, the average total exploitation rate fell from 76% to 51% between those periods, resulting in an even larger proportionate effect (an approximate doubling at constant run size) on escapement compared with the northern mainland rivers. In both cases, the reduction in total exploitation has resulted in roughly a doubling of spawning escapement at a constant adult return.

The situation was somewhat different at Ford Arm Creek where the 2008–2015 average total exploitation rate of 67% was actually above the 1992–1996 average of 64%. Although the average troll fishery exploitation rate dropped from 57% to 45% between those periods, the increase in total exploitation resulted primarily from removal of a large proportion of terminal runs during 2010–2014 by the intensive purse seine fishery in Khaz Bay. This increase appeared to have been the result of a combination of intensive fishing and behavioral changes in some years that appeared to result in more coho salmon entering seining areas in Khaz Bay earlier than in prior decades.

In previous decades, the purse seine fishery, which targets primarily pink salmon, had only a small influence on coho salmon escapement in Ford Arm Creek, with an average exploitation rate in all districts of only 4% during 1982–2009. The reason for such a strong, exceptionally early migration from the ocean into the seine fishery and stream during 2011–2014 is unknown. These events occurred during (and just after) a period of cooling in the northeast Pacific associated with low PDO index values. Returning spawners averaged very small during 2011–2013 (but somewhat larger in 2014); however, it is unclear why fish would return from the ocean earlier when growth is poor although, as speculated above, it is possible that they tend to progress more directly toward their streams of origin in the absence of profitable prey concentrations in offshore and outer coastal waters. Kovach et al. (2015) observed a broad trend toward earlier migration in coho salmon returning to streams in Southeast Alaska. In any case, these events indicate that, while exploitation rates on fall coho salmon stocks by terminal purse seine fisheries directed at pink salmon are usually low, they can be substantial under certain conditions.

Growth-related physical and behavioral features of maturing coho salmon also have a substantial influence on their exploitation by various fisheries. High growth and large size-at-maturity favors harvest by drift gillnet gear and low growth and small adult size favors the troll fishery (and likely the marine sport fishery). Significant size-related even- versus odd-year differences in the troll exploitation rate and troll-to-gillnet harvest ratio for the Berners River stock and in the troll-to-gillnet ratio in the overall coho salmon harvest in northern inside waters since 1999 (Figure 40) indicate that the status of offshore prey populations has a substantial influence on the gear-type allocation of the coho salmon harvest, as well as conservation status of the stocks.

MANAGEMENT OUTLOOK

A slight increasing trend in wild coho salmon abundance available to the Alaska troll fishery since 1982, combined with a decrease in the troll exploitation rate (from average index of 40% in the 1990s to 28% in 2008–2017), has permitted historically liberal fishing seasons of up to 122 consecutive days (4 months) in some recent years without compromising spawning escapement goals or changing the historical gear-type allocation among users for important inside stocks harvested by a gauntlet of fisheries, including the Chilkat and Berners rivers in Lynn Canal (Shaul et al. 2017).

However, we have entered a period (beginning with the 2016 adult return) of substantially lower marine survival in systems draining into inside waters of the archipelago that has presented an additional management challenge to historical patterns of exploitation. Indications that this change has happened primarily in the nearshore, early marine environment (as opposed to growth-related offshore mortality; Shaul and Geiger 2016) include its apparent specificity to inside waters in the region and the fact that it has been evident not only in returning adults, but also in age 0-ocean Auke Creek jacks that only spend about 4 months in the ocean, during which time they likely do not venture much beyond inside waters. If the decline in survival continues, it will be important to investigate the causes with research similar to that underway in the Salish Sea system. This is particularly important because large-scale releases of juvenile salmon into these waters since the 1980s means that some hypotheses for declining survival are directly related to an activity under direct human control (ocean ranching).

While continued abundance available to the troll fishery (despite this decline) is evidence of a strong “portfolio effect” (Schindler et al. 2010) among coho salmon stocks in the broader region, potential continuation of these patterns will present managers with the challenge of finding ways to provide mixed stock fisheries with access to more abundant elements of the portfolio while meeting escapement and commercial harvest allocation objectives for weaker stocks.

The rebound in Berners River smolt production during 2013–2016 after a series of colder years with low smolt production (2004–2012) offers some reason for optimism in the outlook for returns to major inside mainland rivers. In general, moderately warm conditions in the northeast Pacific appear to favor smolt production from mainland rivers (through improved winter–spring freshwater survival) as well as late-ocean growth and survival (through improved survival and recruitment of late-ocean prey). While warm conditions during the 1980s and 1990s historically also favored overall marine survival of smolts from northern inside systems, like the Berners, Chilkat, and Taku rivers, the pattern has not extended to recent warming after 2013–2014, when returns have depended upon improved smolt production to help offset a sharp decline in marine survival. During 1990–2014, variation in smolt production accounted for nearly half (48%) of variation in adult returns to the Berners River, while marine survival accounted for slightly more than half (52%: Shaul et al. 2017). The addition of three more years of adult returns (2015–2017) shifted these proportions to 43% smolt production versus 57% marine survival, as marine survival dropped to new lows. Clearly, both of these factors are important. Part of the resilience in mainland river coho salmon populations stems from a lack of correlation between smolt production and marine survival (e.g., Berners River $r = 0.08$; $n = 28$).

Although we identified no stocks of concern from a fishery management perspective, the Joint Northern Boundary Technical Committee (2002) described land-use practices in the region that have likely reduced habitat capability for coho salmon. Most habitat loss is a long-term ongoing process resulting from historical forestry practices that have resulted in loss and reduced recruitment of woody debris in stream channels. Problems have also been identified with improperly installed culverts that block fish passage under logging roads. These effects apply primarily to smaller streams in areas where timber has been harvested. Most wetland habitat that is essential to coho salmon production in larger mainland river systems is in nearly pristine condition. However, the process of isostatic rebound from a period of extensive glaciations is likely affecting some wetland habitat, particularly in the Yakutat area (Shaul et al. 2010).

While forecast warmer climatic conditions may have some benefits for smolt production in mainland river valleys, associated reduced summer flow and increased temperature will likely result in reduced growth and lower smolt production in smaller watersheds, particularly those on islands (Bryant 2009).

Unfortunately, the recent decline in early-marine survival in inside waters is not well understood from a causal perspective and remains an ongoing concern. On the other hand, there is reason for optimism that, with a recent combination of favorable climate for recruitment of squid prey combined with moderating top-down control by pink salmon (Figures 38 and 44), adult coho salmon size and reproductive potential will continue to recover on the even-year squid cycle and increase from recent lows on the odd-year cycle (Appendix D3). This may (in the near term) improve late-ocean coho salmon growth and survival, particularly survival of females which would increase both landed value and the per capita reproductive effectiveness of spawners. In the longer term, much will depend upon variables that are difficult to forecast: North Pacific climate and the abundance of various species (particularly pink salmon) foraging in offshore waters.

Preseason and inseason methods have been developed to assess overall wild coho salmon abundance from power troll CPUE, as well as smolt production and marine survival for some indicator stocks (Shaul et al. 2009, 2014, 2017). While these forecasting models proved relatively accurate through the 1990s, apparent changes in fish migration, fishery exploitation patterns, and the geographic distribution of smolt production and marine survival have presented increasing challenges to forecasting in more recent years. Apparent changes in the distribution of adult abundance in favor of more southern production areas likely explains the consistent early peak in wild troll CPUE during 2013–2017 (Figure 30) that resulted in over-estimates by CPUE-based forecasts of region-wide wild coho salmon abundance. At the same time, declining troll exploitation, resulting in part from a more southward distribution of troll harvest of CWTs in some cold-regime years, resulted in overly pessimistic forecasts of marine survival, abundance, and escapement for the Hugh Smith Lake stock. Managers have remained relatively successful in achieving escapement goals despite forecast limitations related to resource, climate, and fishery complexity. Success of management will depend upon continuing to integrate a wide variety of clues about overall abundance and distribution of returning fish.

Substantial inter-system variability in abundance of specific coho salmon stocks (Shaul et al. 2009), combined with the broad distribution of production across many streams, present challenges to management for *MSY*. However, the disadvantage to fishery management resulting from mixed stock fishing on populations with limited synchrony is offset, to some extent, by characteristics of the species that provide resilience and flexibility under mixed stock management in which fishing effort and patterns tend to be stable (Shaul et al. 2013). Most coho salmon stocks appear to perform well under a broad range of escapements and have high intrinsic productivity that provides resilience and rapid recovery from low escapement events. To the extent that higher brood year escapements above *MSY* may produce larger average returns under a bent hockey stick or

Beverton-Holt relationship, fisheries may be slightly more economically efficient (i.e., achieve a similar harvest from a larger return) and gain a slight buffer against poor marine survival in the following cycle. The flexible population response characteristic of the species is relatively forgiving of management error in either direction and is compatible with the pattern of primarily mixed stock fishing conducted in Southeast Alaska.

While accurate inseason assessments have become more challenging, economic pressures on the fisheries have at the same time reduced the need for active management. For example, 23 days of region-wide troll fishery closures (40 days in southern Southeast Alaska) were implemented in response to very poor catch rates in 1988, a year when the value of troll-caught coho salmon was very high compared with recent years in inflation-adjusted terms. While these measures reduced the Alaska troll exploitation rate to 28% from an average of 40% in the other 12 years in the 1982–1994 period, the Alaska troll exploitation rate on the stock during 2008–2017 averaged only 24% under liberal seasons that (in three of those years) included 4 months of uninterrupted coho salmon retention. Much of the savings from the 1988 troll restrictions was reallocated to other fisheries, including the northern B.C. troll fishery and the Alaska purse seine fishery, resulting in only a limited reduction in the all-fishery exploitation rate to 65% in 1988 compared with 69% in other years during 1982–1994. During 2008–2017, the all-fishery exploitation rate averaged only 51%, a difference compared with 1988 that would have increased spawning escapement by 40% at the same adult run size. With an escapement of 513 spawners, the current *BEG* for Hugh Smith Lake (500–1,600 fish) was achieved under extensive fishery restrictions implemented in 1988, but would now likely be achieved under a 30% smaller run (smaller than any in the past 36 years) under liberal inseason troll fishery management comparable to the past decade.

Although current resource conditions are challenging in terms of marine survival and abundance of some important coho salmon stocks, economic pressures on the troll fishery, through both operational costs and product pricing, have at the same time forced participants to increasingly self-regulate by allocating effort only when and where it generates an adequate net return. In some cases, economic viability can be obtained by improvement in locating and catching available fish, but ultimately recent economic conditions are dictating that the number of boat-days invested (and ultimately the number of participants actively engaged) in directed fisheries for this species will likely continue to be sensitive to the abundance of coho salmon, which have demonstrated substantial population resilience under exploitation. It will serve the resource well, and the long-term health of the fishery and participants best, if fishery managers can continue to accept and adapt to these and future changes while resisting temptation to over-regulate fisheries for this species.

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APPENDIX A:
ESCAPEMENT COUNTS AND ESTIMATES

Appendix A1.–Northern Inside area coho salmon escapements, 1980–2017.

	Juneau Roadside			Berners River		Chilkat River		
Year	Auke Creek (Weir)	Montana Creek	Peterson Creek	Index Count	Expanded Estimate	Index Count	Expanded Estimate	Taku River
1980	698	–	–	–	-	–	–	–
1981	646	227	219	-	-	–	–	–
1982	447	545	320	7,505	-	–	–	–
1983	694	636	219	9,840	-	–	–	–
1984	651	581	189	2,825	-	–	–	–
1985	942	810	276	6,169	-	–	–	–
1986	454	60	363	1,752	-	–	–	–
1987	668	314	204	3,260	-	1,113	37,432	55,457
1988	756	164	542	2,724	-	877	29,495	39,450
1989	502	566	242	7,509	9,320	1,452	48,833	56,808
1990	697	1,711	324	11,050	13,715	3,383	79,807[a]	72,196
1991	808	1,415	410	11,530	14,311	2,513	84,517	127,484
1992	1,020	2,512	403	15,300	18,991	2,307	77,588	83,729
1993	859	1,352	112	15,670	19,450	1,731	58,217	119,330
1994	1,437	1,829	318	15,920	19,760	5,781	194,425	96,343
1995	460	600	277	4,945	6,138	1,687	56,737	55,710
1996	515	798	263	6,050	7,509	1,110	37,331	44,635
1997	609	1,018	186	10,050	12,474	1,294	43,519	32,345
1998	862	1,160	102	6,802	8,443	1,460	50,758[a]	61,382
1999	845	1,000	272	9,920	12,313	1,699	57,140	60,768
2000	683	961	202	10,650	13,219	2,635	84,843	64,700
2001	865	1,119	106	19,290	23,943	3,232	107,697	104,394
2002	1,176	2,448	195	27,700	34,382	5,660	204,805[a]	219,360
2003	585	808	203	10,110	12,549	3,950	133,045[a]	183,112
2004	416	364	284	14,450	17,936	2,006	67,053	129,327
2005	450	351	139	5,220	6,479	977	34,575[a]	135,558
2006	581	1,110	439	5,470	6,789	2,399	79,050	122,384
2007	352	324	226	3,915	4,859	758	24,770	74,246
2008	600	405	660	6,870	8,527	1,706	56,369	95,226
2009	360	698	123	4,230	5,250	1,453	47,911	103,950
2010	417	630	467	7,520	9,334	2,650	84,909	126,830
2011	517	709	138	6,050	7,509	1,979	61,099	70,871
2012	837	394	190	5,480	6,802	1.150	36,961	70,775
2013	736	367	126	6,280	7,795	1,546	51,324	68,117
2014	1,533	911	284	15,480	19,214	3,926	130,200	124,171
2015	517	1,204	202	9,940	12,338	1,461	47,372	60,178
2016	204	717	52	6,733	8,357	823	26,280	87,704
2017	283	634	20	7,040	8,738	1,021	34,482	57,868
Average	676	850	251	8,924	12,291	2,121	69,959	90,465
Goals:								
Point	340	–	–	–		1,550	50,000	70,000
Lower	200	400	100	3,600		950	30,000	50,000
Upper	500	1,200	250	8,100		2,200	70,000	90,000

[a] Mark–recapture estimates of Chilkat River escapement. Other estimates are expanded index counts.

Appendix A2.–Peak coho salmon survey counts for 5 streams in the Sitka area escapement survey index and coho salmon escapement estimates (combination of weir counts and mark–recapture [M–R] estimates) at Ford Arm Creek, 1982–2017.

	Index Streams:					Combined	
Year	Starrigavan Creek	Sinitsin Creek	St. John's Creek	Nakwasina River	Eagle River	Sitka Index	Ford Arm Creek[a] (Weir and M–R)
1982	317	46	***116***	***580***	***486***	1,545	2,655
1983	45	31	20	217	***144***	457	1,931
1984	385	160	154	715	***649***	2,063	-
1985	193	144	109	408	***392***	1,246	2,324
1986	57	***72***	***53***	275	245	702	1,552
1987	36	21	***22***	47	167	293	1,694
1988	45	56	71	104	***127***	403	3,119
1989	101	76	89	129	***181***	576	2,176
1990	39	80	38	195	214	566	2,192
1991	142	186	107	621	454	1,510	2,761
1992	241	265	110	654	629	1,899	3,866
1993	256	213	90	***644***	513	1,716	4,202
1994	304	313	227	404	717	1,965	3,227
1995	274	152	99	626	336	1,487	2,446
1996	59	150	201	553	488	1,451	2,500
1997	55	90	68	300	296	809	4,718
1998	123	109	57	653	300	1,242	7,049
1999	167	48	25	291	***245***	776	3,800
2000	144	62	30	459	108	803	2,304
2001	133	132	80	753	417	1,515	2,209
2002	227	169	100	713	659	1,868	7,109
2003	95	102	91	440	373	1,101	6,789
2004	143	112	79	399	391	1,124	3,539
2005	76	67	173	892	460	1,668	4,257
2006	386	152	121	996	992	2,647	4,737
2007	130	39	86	385	426	1,066	2,567
2008	96	73	43	839	66	1,117	5,173
2009	128	160	140	335	393	1,156	2,181
2010	70	171	85	307	640	1,273	1,610
2011	230	392	163	636	801	2,222	1,908
2012	59	133	144	296	525	1,157	2,282
2013	113	125	179	412	585	1,414	1,573
2014	274	255	156	600	876	2,161	3,025
2015	286	252	152	1,133	421	2,244	3,281
2016	328	199	398	1,098	920	2,943	No data
2017	122	62	73	545	478	1,280	No data
Average	163	135	110	518	448	1,374	3,235

Note: Total index is the sum of counts and interpolated values. Interpolated values are shown in shaded bold italic print.

[a] The Ford Arm Creek project was discontinued after 2015.

Appendix A3.–Peak coho salmon survey counts for 14 streams in the Ketchikan area escapement survey index and total adult coho salmon escapement to Hugh Smith Lake, 1987–2017.

	Index Streams:														Combined Survey Index	Hugh Smith L. (Weir)
Year	Herman Creek	Grant Creek	Eulachon River	Klahini River	Indian River	Barrier Creek	King Creek	Choca Creek	Carroll River	Blossom River	Keta River	Marten River	Humpback Creek	Tombstone River		
1987	92	***78***	154	***65***	***336***	***70***	***282***	***113***	180	700	800	740	650	532	4,792	1,117
1988	72	150	205	20	300	50	175	150	193	790	850	600	52	1,400	5,007	513
1989	75	101	290	15	925	450	510	200	70	1,000	650	1,175	350	950	6,761	433
1990	150	30	235	150	***242***	***50***	***35***	***81***	***136***	800	550	575	135	275	3,444	870
1991	245	50	285	50	550	100	300	220	375	725	800	575	671	775	5,721	1,836
1992	115	270	860	90	675	100	250	150	360	650	627	1,285	550	1,035	7,017	1,426
1993	90	175	460	50	475	325	110	300	310	850	725	1,525	600	1,275	7,270	832
1994	265	220	755	200	560	175	325	225	475	775	1,100	2,205	560	850	8,690	1,753
1995	250	94	435	165	600	220	415	180	400	800	1,155	1,385	82	2,446	8,627	1,781
1996	94	92	383	40	570	230	457	220	240	829	1,506	1,924	440	1,806	8,831	950
1997	75	***82***	420	60	***353***	***73***	***295***	175	140	1,143	571	759	32	847	5,025	732
1998	94	130	460	120	304	50	411	190	***280***	1,004	1,169	1,961	256	666	7,095	983
1999	75	127	657	150	356	25	627	225	425	598	1,895	1,518	520	840	8,038	1,246
2000	135	94	600	110	380	72	620	180	275	1,354	1,619	1,421	102	1,672	8,634	600
2001	80	110	929	151	1,140	***164***	891	450	173	1,561	***1,714***	1,956	506	***1,442***	11,267	1,580
2002	88	138	1,105	20	940	70	700	220	270	1,359	1,368	2,302	2,004	1,639	12,223	3,291
2003	242	***194***	875	39	690	57	1,140	380	***469***	1,940	1,934	1,980	214	1,745	11,899	1,510
2004	150	230	801	170	935	250	640	180	455	1,005	1,200	1,835	1,230	823	9,904	840
2005	510	300	1,240	360	890	190	810	270	500	3,680	3,290	1,130	500	1,170	14,840	1,732
2006	165	***113***	190	176	280	30	405	130	***272***	2,300	645	335	260	1,600	6,901	891
2007	134	75	***276***	35	245	15	290	210	***170***	990	970	351	3	***552***	4,316	1,244
2008	115	55	570	25	1,250	23	420	100	***660***	7,100	***2,549***	925	2,600	360	16,752	1,741
2009	***149***	330	330	340	750	110	1,050	100	1,100	***1,536***	315	1,675	700	225	8,710	2,281
2010	85	102	370	***62***	880	90	570	190	***180***	350	550	350	200	***584***	4,563	2,878
2011	***87***	***83***	350	***69***	175	***74***	110	85	***201***	1,235	***776***	350	850	***652***	5,098	2,137
2012	25	60	400	***162***	170	40	***703***	110	330	2,400	3,300	2,650	360	1,250	11,960	1,908
2013	***194***	***184***	***722***	***153***	***792***	***164***	***664***	***266***	215	2,140	1,560	2,370	530	1,340	11,295	3,048
2014	425	80	660	***226***	1,500	***242***	850	400	220	2,000	1,300	***2,661***	***1,110***	5,000	16,675	4,110
2015	20	200	550	***136***	1,200	***242***	550	200	450	2,310	1,470	1,555	210	1,035	10,128	956
2016	160	25	810	450	370	90	540	***315***	750	3,070	2,470	2,120	280	1,970	13,420	948
2017	40	***167***	540	280	850	20	100	240	285	3,100	2,450	1,675	830	980	11,557	1,266
Average	149	132	546	129	628	128	505	207	342	1,566	1,314	1,406	552	1,225	8,830	1,539
Goal:																
Point															5,100	850
Lower															4,250	500
Upper															8,500	1,600

Note: Combined survey count is the sum of counts and interpolated values. Interpolated values are shown in shaded bold italic print.

Appendix A4.–Yakutat area coho salmon peak escapement survey counts and available total escapement estimates, 1972–2016.

	Tawah Creek		Situk River		Tsiu River
Year	Count	Mark–Recapture	Count	Mark–Recapture	Count
1972	3,000	-	5,100	-	-
1973	1,978	-	1,719	-	30,000
1974	2,500	-	4,260	-	15,000
1975	800	-	4,500	-	8,150
1976	1,200	-	3,280	-	30,000
1977	3,000	-	3,750	-	25,000
1978	2,200	-	3,850	-	40,000
1979	3,250	-	7,000	-	25,000
1980	3,200	-	8,100	-	18,000
1981	5,793	-	8,430	-	20,000
1982	7,100	-	9,180	-	40,000
1983	5,950	-	5,300	-	16,500
1984	4,200	-	14,000	-	30,000
1985	3,300	-	6,490	-	52,350
1986	3,300	-	3,162	-	14,100
1987	5,000	-	2,000	-	8,500
1988	1,600	-	11,000	-	16,000
1989	1,490	-	3,900	-	38,000
1990	9,460	-	1,630	-	16,800
1991	975	-	-	-	16,600
1992	4,235	-	13,820	-	30,800
1993	5,436	-	10,703	-	18,500
1994	6,000	-	21,960	-	55,000
1995	2,642	-	-	-	30,000
1996	4,030	-	-	-	19,000
1997	2,550	-	9,780	-	22,000
1998	-	-	-	-	12,000
1999	-	-	-	-	-
2000	1,572	-	-	-	12,000
2001	3,190	-	5,030	-	17,000
2002	8,093	-	40,000	-	31,000
2003	5,907	23,685	6,009	-	35,850
2004	2,214	47,566	10,284	49,582	-
2005	1,241	-	2,514	33,644	16,600
2006	1,156	-	7,950	23,169	14,500
2007	1,751	-	5,763	-	14,000
2008	-	-	-	-	25,200
2009	3,581	-	5,814	-	28,000
2010	2,393	-	11,195	-	11,000
2011	1,221	-	3,652	-	21,000
2012	-	-	3,007	-	10,500
2013	2,593	-	14,853	-	47,000
2014	3,555	-	8,226	-	27,000
2015	2,015	-	7,062	-	19,500
2016	746	-	6,177	-	31,000
2017	1,455		4,122		38,000
Average	3,259	35,626	7,810	35,465	24,336
Goals:					
Lower Bound	1,600		3,300		10,000
Upper Bound	4,800		9,800		29,000

APPENDIX B:
INDICATOR STOCK HARVEST AND ESCAPEMENT

Appendix B1.–Estimated fishery sample size (expanded CWT recoveries), harvest by gear type, escapement, and total run of coho salmon returning to Auke Creek, 1980–2017.

Year	Fishery Sample Size	Number of Fish						
		Troll	Seine	Drift gillnet	Sport	Total Harvest	Escapement	Total Return
1980	15	117	0	29	24	170	698	868
1981	70	280	0	31	19	330	646	976
1982	45	149	117	24	2	292	447	739
1983	129	385	10	28	122	545	694	1,239
1984	124	372	8	13	51	444	651	1,095
1985	177	594	3	71	73	741	942	1,683
1986	110	421	2	60	37	520	454	974
1987	145	438	2	48	23	511	668	1,179
1988	145	306	12	72	55	445	756	1,201
1989	182	533	7	15	49	604	502	1,106
1990	168	635	15	57	78	785	697	1,482
1991	47	200	8	152	11	371	808	1,179
1992	53	603	10	196	46	855	1,020	1,875
1993	169	611	8	92	19	730	859	1,589
1994	330	1,064	224	218	112	1,618	1,437	3,055
1995	82	264	5	65	26	360	460	820
1996	160	446	11	133	36	626	515	1,141
1997	43	94	4	0	50	148	609	757
1998	157	437	17	43	54	551	862	1,413
1999	160	485	5	58	42	590	845	1,435
2000	103	228	6	23	29	286	683	969
2001	149	435	10	41	55	541	865	1,406
2002	125	288	8	77	51	424	1,176	1,600
2003	97	211	4	59	45	319	585	904
2004	62	199	47	71	15	332	416	748
2005	66	240	0	6	31	277	450	727
2006	80	196	0	77	26	299	581	880
2007	47	134	6	30	14	184	352	536
2008	105	292	0	76	9	377	600	977
2009	75	179	0	46	8	233	360	593
2010	86	194	0	134	22	350	417	767
2011	79	137	31	93	16	277	517	794
2012	65	212	4	7	17	240	837	1,077
2013	128	406	28	69	27	530	736	1,266
2014	86	265	0	107	21	393	1,533	1,926
2015	44	140	2	14	17	173	517	690
2016	22	20	0	49	0	69	204	273
2017	39	163	0	19	14	196	283	479
Average		326	16	63	35	440	676	1,116

Appendix B2.–Estimated fishery sample size (expanded CWT recoveries), harvest by gear type, escapement, and total run of coho salmon returning to the Berners River, 1982–2017.

Year	Fishery Sample Size	Number of Fish								
		Troll	Seine	Drift Gillnet	Sport	B.C. Net	Cost Recovery	Total Harvest	Escapement	Total Return
1974	157	9,161	406	4,581	0	0	0	14,148	4,124	18,272
1978	124	7,208	0	4,144	0	0	0	11,352	3,119	14,471
1979	84	4,892	411	1,774	95	0	0	7,172	3,460	10,632
1982	52	14,140	0	10,965	0	0	0	25,104	7,505	32,609
1983	125	17,176	0	6,977	421	0	0	24,574	9,840	34,414
1984	-	-	-	-	-	-	-	-	2,825	-
1985	93	10,861	290	7,016	0	0	0	18,167	6,169	24,336
1986	159	13,565	0	8,804	566	0	0	22,935	1,752	24,687
1987	52	7,211	0	3,317	166	0	0	10,694	3,260	13,954
1988	102	6,060	167	6,196	0	0	0	12,424	2,724	15,148
1989	58	10,583	0	1,665	0	0	0	12,247	7,509	19,756
1990	471	15,007	184	7,351	369	0	0	22,911	11,050	33,961
1991	1,025	6,449	285	16,640	84	0	0	23,457	11,530	34,987
1992	701	15,318	508	14,679	189	0	0	30,695	15,300	45,995
1993	1,498	19,308	166	14,282	180	0	0	33,936	15,670	49,606
1994	2,644	27,339	1,381	27,909	810	10	0	57,449	15,920	73,369
1995	1,383	8,766	25	14,869	210	0	0	23,870	4,945	28,815
1996	601	10,529	234	6,434	406	0	0	17,604	6,050	23,654
1997	312	2,453	231	2,254	278	0	18	5,234	10,050	15,284
1998	613	10,424	395	5,223	293	0	0	16,335	6,802	23,137
1999	948	12,876	200	9,572	578	0	0	23,225	9,920	33,145
2000	692	4,811	171	5,330	497	0	6	10,815	10,650	21,465
2001	747	8,814	178	3,523	347	0	0	12,863	19,290	32,153
2002	787	8,650	312	12,077	1,080	0	0	22,118	27,700	49,818
2003	1,328	6,823	251	11,377	550	0	0	19,001	10,110	29,111
2004	756	10,792	83	7,352	497	0	0	18,724	14,450	33,174
2005	392	4,639	121	2,546	232	0	0	7,538	5,220	12,758
2006	701	4,082	0	6,161	110	0	0	10,352	5,470	15,822
2007	293	2,937	40	1,668	161	0	0	4,807	3,915	8,722
2008	423	3,878	0	3,469	149	0	0	7,497	6,870	14,367
2009	201	2,807	63	2,037	180	0	0	5,087	4,230	9,317
2010	324	6,451	110	7,258	477	0	0	14,297	7,520	21,817
2011	174	3,722	251	1,900	106	0	0	5,979	6,050	12,029
2012	159	2,071	0	929	51	0	0	3,051	5,480	8,531
2013	374	7,521	369	6,289	609	0	0	14,788	6,280	21,068
2014	287	4,301	0	6,241	626	0	0	11,168	15,480	26,648
2015	306	3,543	120	1,869	177	0	0	5,709	9,940	15,649
2016	173	919	11	2,198	87	0	0	3,215	6,733	9,948
2017	153	4,455	863	1,706	234	0	0	7,258	7,040	14,298
Average		8,435	206	6,805	285	0	1	15,732	8,512	24,393

Appendix B3.–Estimated fishery sample size (expanded CWT recoveries), harvest by gear type, escapement, and total run of coho salmon returning to the Berners River based on the expanded escapement survey count, 1989–2017.

		Number of Fish								
Year	Fishery Sample Size	Troll	Seine	Drift Gillnet	Sport	B.C.Net	Cost Recovery	Total Harvest	Escapement	Total Run
1989	58	10,583	0	1,665	0	0	0	12,247	9,320	21,567
1990	471	15,007	184	7,351	369	0	0	22,911	13,715	36,626
1991	1,025	6,449	285	16,640	84	0	0	23,457	14,311	37,768
1992	701	15,318	508	14,679	189	0	0	30,695	18,991	49,686
1993	1,498	19,308	166	14,282	180	0	0	33,936	19,450	53,386
1994	2,644	27,339	1,381	27,909	810	10	0	57,449	19,760	77,209
1995	1,383	8,766	25	14,869	210	0	0	23,870	6,138	30,008
1996	601	10,529	234	6,434	406	0	0	17,604	7,509	25,113
1997	312	2,453	231	2,254	278	0	18	5,234	12,474	17,708
1998	613	10,424	395	5,223	293	0	0	16,335	8,443	24,778
1999	948	12,876	200	9,572	578	0	0	23,225	12,313	35,538
2000	692	4,811	171	5,330	497	0	6	10,815	13,219	24,034
2001	747	8,814	178	3,523	347	0	0	12,863	23,943	36,806
2002	787	8,650	312	12,077	1,080	0	0	22,118	34,382	56,500
2003	1,328	6,823	251	11,377	550	0	0	19,001	12,549	31,550
2004	756	10,792	83	7,352	497	0	0	18,724	17,936	36,660
2005	392	4,639	121	2,546	232	0	0	7,538	6,479	14,017
2006	701	4,082	0	6,161	110	0	0	10,352	6,789	17,141
2007	293	2,937	40	1,668	161	0	0	4,807	4,859	9,666
2008	423	3,878	0	3,469	149	0	0	7,497	8,527	16,024
2009	201	2,807	63	2,037	180	0	0	5,087	5,250	10,337
2010	324	6,451	110	7,258	477	0	0	14,297	9,334	23,631
2011	174	3,722	251	1,900	106	0	0	5,979	7,509	13,488
2012	159	2,071	0	929	51	0	0	3,051	6,802	9,853
2013	374	7,521	369	6,289	609	0	0	14,788	7,795	22,583
2014	287	4,301	0	6,241	626	0	0	11,168	19,214	30,382
2015	306	3,543	120	1,869	177	0	0	5,709	12,338	18,047
2016	173	919	11	2,198	87	0	0	3,215	8,357	11,572
2017	153	4,455	863	1,706	234	0	0	7,258	7,040	14,298
Average		7,940	226	7,062	330	0	1	15,560	12,291	27,851

Appendix B4.–Estimated fishery sample size (expanded CWT recoveries), harvest by gear type, escapement, and total run of coho salmon returning to Ford Arm Creek, 1982–2015.

Year	Fishery Sample Size	Number of Fish							
		Alaska Troll	Seine	Drift Gillnet	Sport	B.C. Troll	Total Harvest	Escapement	Total return
1982	38	1,927	106	0	0	0	2,033	2,655	4,688
1983	93	3,344	912	0	0	0	4,256	1,931	6,187
1984	–	–	–	–	–	–	–	–	–
1985	49	2,482	0	0	0	0	2,482	2,324	4,806
1986	87	2,483	63	0	0	0	2,546	1,552	4,098
1987	71	1,458	81	0	0	0	1,539	1,694	3,233
1988	151	2,816	46	0	0	31	2,893	3,119	6,012
1989	218	3,799	185	0	0	0	3,984	2,176	6,160
1990	174	2,982	100	0	0	0	3,082	2,192	5,274
1991	193	3,203	44	10	0	0	3,257	2,761	6,018
1992	199	5,252	233	0	0	0	5,485	3,866	9,351
1993	349	7,749	434	0	176	0	8,359	4,202	12,561
1994	236	6,856	1,020	0	384	0	8,260	3,227	11,487
1995	82	3,582	759	0	0	0	4,341	2,446	6,787
1996	64	3,083	0	0	281	0	3,364	2,500	5,864
1997	242	4,702	0	0	351	0	5,053	4,718	9,771
1998	320	7,835	435	20	785	0	9,075	7,049	16,124
1999	146	5,893	66	0	436	0	6,395	3,800	10,195
2000	193	4,604	916	14	211	0	5,745	2,304	8,049
2001	131	5,821	115	0	480	0	6,416	2,209	8,625
2002	246	5,751	1,260	0	998	0	8,009	7,109	15,118
2003	225	4,154	504	0	1,770	0	6,428	6,789	13,217
2004	153	7,722	524	0	319	0	8,565	3,539	12,104
2005	81	5,134	60	0	672	0	5,866	4,257	10,123
2006	137	3,866	367	0	844	0	5,077	4,737	9,814
2007	188	5,673	217	7	202	0	6,099	2,567	8,666
2008	231	4,563	1,047	0	277	0	5,887	5,173	11,060
2009	156	4,604	248	0	93	0	4,945	2,181	7,126
2010	96	2,149	582	0	132	0	2,863	1,610	4,473
2011	52	2,610	6,238	0	79	0	8,927	1,908	10,835
2012	117	2,884	903	0	151	0	3,938	2,282	6,220
2013	122	3,426	2,069	0	241	0	5,736	1,573	7,309
2014	103	4,927	2,397	0	407	0	7,731	3,025	10,756
2015	71	3,078	380	0	118	0	3,576	3,281	6,857
Average		4,130	655	2	270	1	5,057	3,140	8,446

Appendix B5.–Estimated fishery sample size (expanded CWT recoveries), harvest by gear type, escapement, and total run of coho salmon returning to Hugh Smith Lake, 1982–2017.

		Number of fish										
		Alaska					B.C.					
Year	Fishery Sampling Size	Troll	Seine	Drift Gillnet	Trap	Sport	Troll	Net	Sport	Total Harvest	Escapement	Total Return
1982	91	2,758	628	203	0	0	316	84	0	3,989	2,144	6,133
1983	185	1,374	424	277	49	0	214	50	0	2,388	1,487	3,875
1984	151	1,266	504	471	18	0	331	27	0	2,617	1,407	4,024
1985	213	868	287	137	5	0	201	39	0	1,537	903	2,440
1986	256	1,598	493	213	0	16	236	28	0	2,584	1,782	4,366
1987	99	657	82	148	4	28	155	53	0	1,127	1,117	2,244
1988	41	406	207	78	0	0	242	27	0	960	513	1,473
1989	91	1,217	320	247	0	62	106	20	0	1,972	433	2,405
1990	263	1,803	566	637	23	0	840	54	0	3,923	870	4,793
1991	399	2,103	190	941	0	38	614	44	0	3,930	1,836	5,766
1992	497	1,854	676	600	0	40	289	10	0	3,469	1,426	4,895
1993	155	2,227	269	666	0	0	207	41	0	3,410	832	4,242
1994	838	4,333	1,123	1,450	0	45	694	53	13	7,711	1,753	9,464
1995	432	2,018	947	1,588	0	98	236	28	11	4,926	1,781	6,707
1996	502	1,585	623	487	0	125	125	38	14	2,997	950	3,947
1997	480	1,321	108	397	0	45	91	0	0	1,962	732	2,694
1998	668	1,771	471	980	0	150	0	0	15	3,387	983	4,370
1999	623	1,757	283	726	0	180	0	0	30	2,976	1,246	4,222
2000	161	489	45	116	0	97	0	0	0	747	600	1,347
2001	314	696	454	324	0	58	7	0	0	1,539	1,580	3,119
2002	434	892	451	555	0	91	65	0	61	2,115	3,291	5,406
2003	335	894	354	690	0	106	91	31	0	2,166	1,510	3,676
2004	244	1,017	196	243	0	60	48	20	69	1,653	840	2,493
2005	256	1,163	122	532	0	59	36	8	0	1,920	1,732	3,652
2006	169	703	64	170	0	7	34	0	58	1,036	891	1,927
2007	294	1,262	175	300	0	74	57	11	186	2,065	1,244	3,309
2008	302	716	244	779	0	33	59	12	192	2,035	1,741	3,776
2009	253	1,049	268	483	0	18	265	0	19	2,102	2,281	4,383
2010	632	1,205	287	692	0	36	218	0	101	2,539	2,878	5,417
2011	376	778	148	417	0	25	189	4	239	1,800	2,137	3,937
2012	542	821	348	703	0	41	169	0	173	2,255	1,908	4,163
2013	552	1,754	767	793	0	108	283	32	121	3,858	3,048	6,906
2014	566	1,873	399	798	0	121	218	0	188	3,597	4,110	7,707
2015	203	470	112	272	0	24	102	6	12	998	956	1,954
2016	123	767	150	429	0	90	39	0	43	1,518	948	2,466
2017	93	674	50	273	0	56	106	0	0	1,159	1,266	2,425
Average		1,337	357	523	3	54	191	20	43	2,527	1,532	4,059

Appendix B6.–Estimated harvest and escapement of coho salmon bound for the Taku River above Canyon Island, 1987–2017.

	Number of Fish							
Year	Troll	Seine	Drift Gillnet	Marine Sport	Inriver	Total Harvest	Escapement	Total Return
1987	-	-	-	-	6,519	-	55,457	-
1988	-	-	-	-	3,643	-	39,450	-
1989	-	-	-	-	4,033	-	56,808	-
1990	-	-	-	-	3,685	-	72,196	-
1991	-	-	-	-	5,439	-	127,484	-
1992	41,713	2,283	79,013	431	5,629	129,069	83,729	212,798
1993	78,371	3,430	40,308	3,222	4,659	129,990	119,330	249,320
1994	97,039	26,352	86,198	19,018	14,786	243,393	96,343	339,736
1995	45,041	1,853	56,820	7,857	13,835	125,406	55,710	181,116
1996	24,779	220	17,069	2,461	5,119	49,648	44,635	94,283
1997	8,822	550	1,489	4,963	2,717	18,541	32,345	50,886
1998	28,827	742	19,371	4,427	5,176	58,543	61,382	119,925
1999	36,231	2,881	7,507	4,170	5,619	56,408	60,768	117,176
2000	21,236	2,132	11,466	4,137	5,478	44,449	64,700	109,149
2001	38,326	2,065	11,777	3,094	3,121	58,383	104,394	162,777
2002	39,053	3,456	30,894	6,642	3,870	83,915	219,360	303,275
2003	36,433	3,646	27,694	10,503	3,702	81,978	183,112	265,090
2004	62,002	5,335	30,961	14,108	9,804	122,210	129,327	251,537
2005	46,521	4,325	23,546	4,654	8,393	87,439	135,558	222,997
2006	49,394	613	37,879	4,621	11,803	104,310	122,384	226,694
2007	23,519	6,484	18,795	2,124	8,133	59,055	74,246	133,301
2008	47,997	0	25,254	1,530	4,064	78,845	95,226	174,071
2009	51,748	4,749	46,838	6,720	10,006	120,061	103,950	224,011
2010	34,554	3,988	52,497	14,287	14,666	119,992	126,830	246,822
2011	23,825	6,383	11,353	4,804	12,702	59,067	70,871	129,938
2012	14,648	0	12,108	1,212	14,204	42,171	70,775	112,946
2013	34,849	2,372	24,986	2,472	10,613	75,293	68,117	143,410
2014	12,118	773	32,145	3,656	16,792	65,484	124,171	189,655
2015	16,355	5,634	8,737	3,063	10,434	44,223	60,178	104,401
2016	9,801	326	14,757	1,210	11,720	37,814	87,704	125,518
2017	19,552	5,984	10,230	4,723	7,960	48,449	57,868	106,317
Average 1992–2017	36,260	3,714	28,450	5,389	8,654	82,467	94,347	176,813

Appendix B7.–Estimated fishery sample size (expanded CWT recoveries), harvest by gear type, escapement, and total run of coho salmon returning to the Chilkat River, 1982–2017.

	Fishery	Number of Fish								
	Sample			Drift	Marine	Inriver		Total		Total
Year	Size	Troll	Seine	Gillnet	Sport	Sport[a]	Subsistence	Harvest	Escapement[b]	return
1987	–	–	–	–	–	–		–	37,432	
1988	–	–	–	–	–	–		–	29,495	
1989	–	–	–	–	–	–		–	48,833	
1990	–	–	–	–	–	–		–	**79,807**	
1991	–	–	–	–	–	–		–	84,517	
1992	–	–	–	–	–	–		–	77,588	
1993	–	–	–	–	–	–		–	58,217	
1994	–	–	–	–	–	–		–	194,425	
1995	–	–	–	–	–	–		–	56,737	
1996	–	–	–	–	–	–		–	37,331	
1997	–	–	–	–	–	–		–	43,519	
1998	–	–	–	–	–	–		–	**50,758**	
1999	–	–	–	–	–	–		–	57,140	
2000	265	19,988	876	17,055	1,529	688	199	40,335	84,843	125,178
2001	250	30,465	601	13,436	1,544	1,996	126	48,168	107,697	155,865
2002	325	61,724	719	66,541	2,159	3,342	574	135,059	**204,925**	339,984
2003	426	51,629	1,045	26,520	3,880	2,433	498	86,005	**133,109**	219,114
2004	254	82,827	1,030	35,895	5,167	2,822	455	128,196	67,053	195,249
2005	141	17,409	312	10,597	769	1,203	335	30,625	**34,575**	65,200
2006	200	37,077	83	24,416	2,523	1,782	353	66,234	79,050	145,284
2007	73	9,307	0	3,546	0	540	107	13,500	24,770	38,270
2008	358	20,999	0	28,908	737	738	390	51,772	56,369	108,141
2009	326	11,931	346	15,352	37	2,059	460	30,185	47,911	78,096
2010	427	29,028	379	37,732	1,501	449	344	69,433	84,909	154,342
2011	219	19,329	1,201	13,861	747	1,184	299	36,621	61,099	97,720
2012	164	11,421	0	15,426	682	397	210	28,136	36,961	65,097
2013	355	25,419	873	41,766	696	1,014	445	70,213	51,324	121,537
2014	88	10,792	0	13,737	245	958	513	26,245	130,200	156,445
2015	90	10,558	576	11,552	409	988	361	24,444	47,372	71,816
2016	56	2,412	0	10,771	237	512	310	14,242	26,280	40,522
2017	49	5,868	0	9,122	1,579	***692***	239	17,500	34,482	51,982
Average 2000–2017		26,607	447	22,013	1,358	1,321	345	50,939	72,871	123,880

[a] The freshwater sport harvest is based on a mail-out survey; the 2017 harvest was interpolated based on the relationship between escapement and freshwater sport harvest in 2000–2016.

[b] Mark–recapture estimates of escapement are shown in bold.

Appendix B8.–Mean-average catch-per-boat-day (CPUE) in the Taku Inlet drift gillnet fishery for wild and total fall coho salmon and fall chum salmon in statistical weeks 35–38 compared with the number of summer chum salmon fry released in Gastineau Channel and Limestone Inlet lagged by fall chum ocean ages of 3 years (67%) and 4 years (33%).

	Coho Salmon CPUE				Fall Chum	Lagged Hatchery Chum
Year	Wild	Hatchery	Total	% Hatchery	Salmon CPUE	Release (Millions)
1969	35.4	0.0	35.4	0.0%	50.2	0.0
1970	37.7	0.0	37.7	0.0%	109.1	0.0
1971	28.0	0.0	28.0	0.0%	41.9	0.0
1972	28.4	0.0	28.4	0.0%	58.6	0.0
1973	25.7	0.0	25.7	0.0%	95.5	0.0
1974	28.3	0.0	28.3	0.0%	68.2	0.0
1975	-	-	-	-	-	-
1976	53.9	0.0	53.9	0.0%	78.4	0.0
1977	48.4	0.0	48.4	0.0%	49.2	0.0
1978	32.1	0.0	32.1	0.0%	37.0	0.0
1979	16.3	0.1	16.3	0.4%	77.8	0.0
1980	24.0	0.0	24.0	0.0%	119.6	0.1
1981	39.8	0.0	39.8	0.0%	57.2	0.1
1982	39.2	0.0	39.2	0.0%	39.0	0.0
1983	54.0	0.0	54.1	0.0%	34.3	0.1
1984	30.5	2.1	32.6	6.6%	45.3	0.2
1985	63.3	1.1	64.4	1.8%	80.7	0.7
1986	48.9	0.7	49.6	1.5%	70.8	0.7
1987	46.2	0.1	46.4	0.3%	80.6	0.9
1988	62.8	0.7	63.4	1.0%	49.6	1.2
1989	77.4	3.2	80.6	3.9%	41.0	3.3
1990	91.5	1.9	93.4	2.0%	49.6	6.1
1991	96.3	19.0	115.4	16.5%	25.4	15.5
1992	81.8	28.0	109.8	25.5%	13.4	18.8
1993	61.8	3.7	65.5	5.7%	10.2	30.1
1994	74.8	13.0	87.8	14.8%	7.4	21.8
1995	44.1	15.6	59.6	26.1%	8.2	38.4
1996	39.7	10.6	50.3	21.1%	10.0	48.4
1997	18.3	8.8	27.2	32.5%	15.6	48.4
1998	36.6	12.8	49.4	25.9%	6.2	33.9
1999	33.4	3.0	36.4	8.1%	10.8	54.1
2000	28.7	5.0	33.6	14.8%	6.9	70.0
2001	49.3	6.7	56.0	12.0%	5.3	66.6
2002	72.6	2.5	75.1	3.3%	2.2	47.0
2003	48.9	4.7	53.5	8.7%	2.5	37.1
2004	55.7	3.5	59.2	5.9%	7.0	40.8
2005	36.6	1.2	37.9	3.3%	6.4	43.0
2006	62.7	2.6	65.3	4.0%	6.5	42.8
2007	20.1	0.6	20.7	2.8%	6.4	46.8
2008	43.2	2.8	46.0	6.1%	6.8	48.9
2009	39.0	0.1	39.0	0.1%	3.2	49.9
2010	49.6	4.8	54.4	8.9%	3.4	49.4
2011	21.3	2.1	23.3	8.8%	2.8	50.9
2012	33.0	2.3	35.3	6.5%	4.0	50.8
2013	50.6	13.8	64.3	21.4%	6.1	50.6
2014	41.0	4.1	45.1	9.0%	2.3	41.7
2015	28.5	8.2	36.7	22.3%	1.4	43.2
2016	28.8	12.6	41.4	30.4%	1.6	49.0
2017	35.9	4.4	40.3	10.8%	6.3	49.6
Average						
1969–1981	33.2	0.0	33.2	0.0%	70.2	0.0
1982–1990	57.1	1.1	58.2	1.9%	54.6	1.5
1991–1999	54.1	12.7	66.8	19.6%	11.9	34.4
2000–2017	41.7	4.6	46.3	9.9%	4.4	48.7

APPENDIX C:
INDICATOR STOCK EXPLOITATION RATES

Appendix C1.–Estimated harvest (by gear type) and escapement as a percent of the total Auke Creek coho salmon run, 1980–2017.

Year	Fishery Sample Size	Percent of Total Return Troll	Seine	Drift Gillnet	Sport	Total Harvest	Escapement	Total Return
1980	15	13.5	0.0	3.3	2.8	19.6	80.4	100.0
1981	70	28.7	0.0	3.2	1.9	33.8	66.2	100.0
1982	45	20.2	15.8	3.2	0.3	39.5	60.5	100.0
1983	129	31.1	0.8	2.3	9.8	44.0	56.0	100.0
1984	124	34.0	0.7	1.2	4.7	40.5	59.5	100.0
1985	177	35.3	0.2	4.2	4.3	44.0	56.0	100.0
1986	110	43.2	0.2	6.2	3.8	53.4	46.6	100.0
1987	145	37.2	0.2	4.1	2.0	43.3	56.7	100.0
1988	145	25.5	1.0	6.0	4.6	37.1	62.9	100.0
1989	182	48.2	0.6	1.4	4.4	54.6	45.4	100.0
1990	168	42.8	1.0	3.8	5.3	53.0	47.0	100.0
1991	47	17.0	0.7	12.9	0.9	31.5	68.5	100.0
1992	53	32.2	0.5	10.5	2.5	45.6	54.4	100.0
1993	169	38.5	0.5	5.8	1.2	45.9	54.1	100.0
1994	330	34.8	7.3	7.1	3.7	53.0	47.0	100.0
1995	82	32.2	0.6	7.9	3.2	43.9	56.1	100.0
1996	160	39.1	1.0	11.7	3.2	54.9	45.1	100.0
1997	43	12.4	0.5	0.0	6.6	19.6	80.4	100.0
1998	157	30.9	1.2	3.0	3.8	39.0	61.0	100.0
1999	160	33.8	0.3	4.0	2.9	41.1	58.9	100.0
2000	103	23.5	0.6	2.4	3.0	29.5	70.5	100.0
2001	149	30.9	0.7	2.9	3.9	38.5	61.5	100.0
2002	125	18.0	0.5	4.8	3.2	26.5	73.5	100.0
2003	97	23.3	0.4	6.5	5.0	35.3	64.7	100.0
2004	62	26.6	6.3	9.5	2.0	44.4	55.6	100.0
2005	66	33.0	0.0	0.8	4.3	38.1	61.9	100.0
2006	80	22.3	0.0	8.8	3.0	34.0	66.0	100.0
2007	47	25.0	1.1	5.6	2.6	34.3	65.7	100.0
2008	105	29.9	0.0	7.8	0.9	38.6	61.4	100.0
2009	75	30.2	0.0	7.8	1.3	39.3	60.7	100.0
2010	86	25.3	0.0	17.5	2.9	45.6	54.4	100.0
2011	79	17.3	3.9	11.7	2.0	34.9	65.1	100.0
2012	65	19.7	0.4	0.6	1.6	22.3	77.7	100.0
2013	128	32.1	2.2	5.5	2.1	41.9	58.1	100.0
2014	86	13.8	0.0	5.6	1.1	20.4	79.6	100.0
2015	44	20.3	0.3	2.0	2.5	25.1	74.9	100.0
2016	22	7.3	0.0	17.9	0.0	25.3	74.7	100.0
2017	39	34.0	0.0	4.0	2.9	40.9	59.1	100.0
Average		28.0	0.0	5.9	3.1	38.2	61.8	100.0

Appendix C2.–Estimated harvest (by gear type) and escapement as a percent of the total Berners River coho salmon run based on the unadjusted escapement survey count, 1982–2017.

	Fishery	Percent of Total Return								
Year	Sample Size	Troll	Seine	Drift Gillnet	Sport	B.C. Net	Cost Recovery	Total Harvest	Escapement	Total Return
1974	157	50.1	2.2	25.1	0.0	0.0	0.0	77.4	22.6	100.0
–	–	–	–	–	–	–	–	–	–	–
1978	124	49.8	0.0	28.6	0.0	0.0	0.0	78.4	21.6	100.0
1979	84	46.0	3.9	16.7	0.9	0.0	0.0	67.5	32.5	100.0
–	–	–	–	–	–	–	–	–	–	–
1982	52	43.4	0.0	33.6	0.0	0.0	0.0	77.0	23.0	100.0
1983	125	49.9	0.0	20.3	1.2	0.0	0.0	71.4	28.6	100.0
1984	–	–	–	–	–	–	–	–	–	–
1985	93	44.6	1.2	28.8	0.0	0.0	0.0	74.7	25.3	100.0
1986	159	54.9	0.0	35.7	2.3	0.0	0.0	92.9	7.1	100.0
1987	52	51.7	0.0	23.8	1.2	0.0	0.0	76.6	23.4	100.0
1988	102	40.0	1.1	40.9	0.0	0.0	0.0	82.0	18.0	100.0
1989	58	53.6	0.0	8.4	0.0	0.0	0.0	62.0	38.0	100.0
1990	471	44.2	0.5	21.6	1.1	0.0	0.0	67.5	32.5	100.0
1991	1,025	18.4	0.8	47.6	0.2	0.0	0.0	67.0	33.0	100.0
1992	701	33.3	1.1	31.9	0.4	0.0	0.0	66.7	33.3	100.0
1993	1,498	38.9	0.3	28.8	0.4	0.0	0.0	68.4	31.6	100.0
1994	2,644	37.3	1.9	38.0	1.1	0.0	0.0	78.3	21.7	100.0
1995	1,383	30.4	0.1	51.6	0.7	0.0	0.0	82.8	17.2	100.0
1996	601	44.5	1.0	27.2	1.7	0.0	0.0	74.4	25.6	100.0
1997	312	16.0	1.5	14.7	1.8	0.0	0.1	34.2	65.8	100.0
1998	613	45.1	1.7	22.6	1.3	0.0	0.0	70.6	29.4	100.0
1999	948	38.8	0.6	28.9	1.7	0.0	0.0	70.1	29.9	100.0
2000	692	22.4	0.8	24.8	2.3	0.0	0.0	50.4	49.6	100.0
2001	747	27.4	0.6	11.0	1.1	0.0	0.0	40.0	60.0	100.0
2002	787	17.4	0.6	24.2	2.2	0.0	0.0	44.4	55.6	100.0
2003	1,328	23.4	0.9	39.1	1.9	0.0	0.0	65.3	34.7	100.0
2004	756	32.5	0.3	22.2	1.5	0.0	0.0	56.4	43.6	100.0
2005	392	36.4	1.0	20.0	1.8	0.0	0.0	59.1	40.9	100.0
2006	701	25.8	0.0	38.9	0.7	0.0	0.0	65.4	34.6	100.0
2007	293	33.7	0.5	19.1	1.8	0.0	0.0	55.1	44.9	100.0
2008	423	27.0	0.0	24.1	1.0	0.0	0.0	52.2	47.8	100.0
2009	201	30.1	0.7	21.9	1.9	0.0	0.0	54.6	45.4	100.0
2010	324	29.6	0.5	33.3	2.2	0.0	0.0	65.5	34.5	100.0
2011	174	30.9	2.1	15.8	0.9	0.0	0.0	49.7	50.3	100.0
2012	159	24.3	0.0	10.9	0.6	0.0	0.0	35.8	64.2	100.0
2013	374	35.7	1.8	29.9	2.9	0.0	0.0	70.2	29.8	100.0
2014	287	16.1	0.0	23.4	2.3	0.0	0.0	41.9	58.1	100.0
2015	306	22.6	0.8	11.9	1.1	0.0	0.0	36.5	63.5	100.0
2016	173	9.2	0.1	22.1	0.9	0.0	0.0	32.3	67.7	100.0
2017	153	31.2	6.0	11.9	1.6	0.0	0.0	50.8	49.2	100.0
Average		34.4	0.9	25.8	1.2	0.0	0.0	62.3	37.7	100.0

Appendix C3.–Estimated harvest (by gear type) and escapement as a percent of the total Berners River coho salmon run based on the unadjusted escapement survey count, 1982–2017.

	Fishery	Percent of Total Run								
Year	Sample Size	Troll	Seine	Drift Gillnet	Sport	B.C. Net	Cost Recovery	Total Harvest	Escapement	Total Run
1989	58	49.1	0.0	7.7	0.0	0.0	0.0	56.8	43.2	100.0
1990	471	41.0	0.5	20.1	1.0	0.0	0.0	62.6	37.4	100.0
1991	1,025	17.1	0.8	44.1	0.2	0.0	0.0	62.1	37.9	100.0
1992	701	30.8	1.0	29.5	0.4	0.0	0.0	61.8	38.2	100.0
1993	1,498	36.2	0.3	26.8	0.3	0.0	0.0	63.6	36.4	100.0
1994	2,644	35.4	1.8	36.1	1.0	0.0	0.0	74.4	25.6	100.0
1995	1,383	29.2	0.1	49.6	0.7	0.0	0.0	79.5	20.5	100.0
1996	601	41.9	0.9	25.6	1.6	0.0	0.0	70.1	29.9	100.0
1997	312	13.9	1.3	12.7	1.6	0.0	0.1	29.6	70.4	100.0
1998	613	42.1	1.6	21.1	1.2	0.0	0.0	65.9	34.1	100.0
1999	948	36.2	0.6	26.9	1.6	0.0	0.0	65.4	34.6	100.0
2000	692	20.0	0.7	22.2	2.1	0.0	0.0	45.0	55.0	100.0
2001	747	23.9	0.5	9.6	0.9	0.0	0.0	34.9	65.1	100.0
2002	787	15.3	0.6	21.4	1.9	0.0	0.0	39.1	60.9	100.0
2003	1,328	21.6	0.8	36.1	1.7	0.0	0.0	60.2	39.8	100.0
2004	756	29.4	0.2	20.1	1.4	0.0	0.0	51.1	48.9	100.0
2005	392	33.1	0.9	18.2	1.7	0.0	0.0	53.8	46.2	100.0
2006	701	23.8	0.0	35.9	0.6	0.0	0.0	60.4	39.6	100.0
2007	293	30.4	0.4	17.3	1.7	0.0	0.0	49.7	50.3	100.0
2008	423	24.2	0.0	21.7	0.9	0.0	0.0	46.8	53.2	100.0
2009	201	27.2	0.6	19.7	1.7	0.0	0.0	49.2	50.8	100.0
2010	324	27.3	0.5	30.7	2.0	0.0	0.0	60.5	39.5	100.0
2011	174	27.6	1.9	14.1	0.8	0.0	0.0	44.3	55.7	100.0
2012	159	21.0	0.0	9.4	0.5	0.0	0.0	31.0	69.0	100.0
2013	374	33.3	1.6	27.8	2.7	0.0	0.0	65.5	34.5	100.0
2014	287	14.2	0.0	20.5	2.1	0.0	0.0	36.8	63.2	100.0
2015	306	19.6	0.7	10.4	1.0	0.0	0.0	31.6	68.4	100.0
2016	173	7.9	0.1	19.0	0.8	0.0	0.0	27.8	72.2	100.0
2017	153	27.9	5.4	10.7	1.5	0.0	0.0	45.4	54.6	100.0
Average		27.6	0.8	22.9	1.2	0.0	0.0	52.6	47.4	100.0

Appendix C4.–Estimated harvest (by gear type) and escapement as a percent of the total Ford Arm Creek coho salmon run, 1982–2015.

	Fishery	Percent of Total Return							
Year	Sample Size	Alaska Troll	Seine	Drift Gillnet	Sport	Canadian Troll	Total Harvest	Escapement	Total Return
1982	38	41.1	2.3	0.0	0.0	0.0	43.4	56.6	100.0
1983	93	54.0	14.7	0.0	0.0	0.0	68.8	31.2	100.0
1984	–	–	–	–	–	–	–	–	–
1985	49	51.6	0.0	0.0	0.0	0.0	51.6	48.4	100.0
1986	87	60.6	1.5	0.0	0.0	0.0	62.1	37.9	100.0
1987	71	45.1	2.5	0.0	0.0	0.0	47.6	52.4	100.0
1988	151	46.8	0.8	0.0	0.0	0.5	48.1	51.9	100.0
1989	221	61.7	3.0	0.0	0.0	0.0	64.7	35.3	100.0
1990	174	56.5	1.9	0.0	0.0	0.0	58.4	41.6	100.0
1991	193	53.2	0.7	0.2	0.0	0.0	54.1	45.9	100.0
1992	199	56.2	2.5	0.0	0.0	0.0	58.7	41.3	100.0
1993	349	61.7	3.5	0.0	1.4	0.0	66.5	33.5	100.0
1994	236	59.7	8.9	0.0	3.3	0.0	71.9	28.1	100.0
1995	91	52.8	11.2	0.0	0.0	0.0	64.0	36.0	100.0
1996	64	52.6	0.0	0.0	4.8	0.0	57.4	42.6	100.0
1997	241	48.1	0.0	0.0	3.6	0.0	51.7	48.3	100.0
1998	315	48.6	2.7	0.1	4.9	0.0	56.3	43.7	100.0
1999	145	57.8	0.6	0.0	4.3	0.0	62.7	37.3	100.0
2000	193	57.2	11.4	0.2	2.6	0.0	71.4	28.6	100.0
2001	131	67.5	1.3	0.0	5.6	0.0	74.4	25.6	100.0
2002	246	38.0	8.3	0.0	6.6	0.0	53.0	47.0	100.0
2003	225	31.4	3.8	0.0	13.4	0.0	48.6	51.4	100.0
2004	153	63.8	4.3	0.0	2.6	0.0	70.8	29.2	100.0
2005	81	50.7	0.6	0.0	6.6	0.0	57.9	42.1	100.0
2006	137	39.4	3.7	0.0	8.6	0.0	51.7	48.3	100.0
2007	188	65.5	2.5	0.1	2.3	0.0	70.4	29.6	100.0
2008	231	41.3	9.5	0.0	2.5	0.0	53.2	46.8	100.0
2009	156	64.6	3.5	0.0	1.3	0.0	69.4	30.6	100.0
2010	96	48.0	13.0	0.0	3.0	0.0	64.0	36.0	100.0
2011	52	24.1	57.6	0.0	0.7	0.0	82.4	17.6	100.0
2012	117	46.4	14.5	0.0	2.4	0.0	63.3	36.7	100.0
2013	122	46.9	28.3	0.0	3.3	0.0	78.5	21.5	100.0
2014	103	45.8	22.3	0.0	3.8	0.0	71.9	28.1	100.0
2015	71	44.9	5.5	0.0	1.7	0.0	52.2	47.8	100.0
Average		51.0	7.5	0.0	2.7	0.0	61.2	38.8	100.0

Appendix C5.–Estimated harvest (by gear type) and escapement as a percent of the total Hugh Smith Lake coho salmon run, 1982–2017.

	Fishery	Percent of Total Return										
Year	Sample Size	Alaska Troll	Alaska Seine	Alaska Gillnet	Alaska Trap	Alaska Sport	B.C. Troll	B.C. Net	B.C. Sport	Total Harvest	Escapement	Total Return
1982	91	45.0	10.2	3.3	0.0	0.0	5.2	1.4	0.0	65.0	35.0	100.0
1983	185	35.5	10.9	7.1	1.3	0.0	5.5	1.3	0.0	61.6	38.4	100.0
1984	151	31.5	12.5	11.7	0.5	0.0	8.2	0.7	0.0	65.0	35.0	100.0
1985	213	35.6	11.8	5.6	0.2	0.0	8.2	1.6	0.0	63.0	37.0	100.0
1986	256	36.6	11.3	4.9	0.0	0.4	5.4	0.7	0.0	59.2	40.8	100.0
1987	99	29.3	3.6	6.6	0.2	1.3	6.9	2.4	0.0	50.2	49.8	100.0
1988	41	27.6	14.0	5.3	0.0	0.0	16.4	1.8	0.0	65.2	34.8	100.0
1989	91	50.6	13.3	10.3	0.0	2.6	4.4	0.8	0.0	82.0	18.0	100.0
1990	263	37.6	11.8	13.3	0.5	0.0	17.5	1.1	0.0	81.9	18.1	100.0
1991	399	36.5	3.3	16.3	0.0	0.7	10.6	0.8	0.0	68.2	31.8	100.0
1992	497	37.9	13.8	12.3	0.0	0.8	5.9	0.2	0.0	70.9	29.1	100.0
1993	155	52.5	6.3	15.7	0.0	0.0	4.9	1.0	0.0	80.4	19.6	100.0
1994	838	45.8	11.9	15.3	0.0	0.5	7.3	0.6	0.1	81.5	18.5	100.0
1995	432	30.1	14.1	23.7	0.0	1.5	3.5	0.4	0.2	73.5	26.5	100.0
1996	502	40.2	15.8	12.3	0.0	3.2	3.2	1.0	0.4	75.9	24.1	100.0
1997	480	49.0	4.0	14.7	0.0	1.7	3.4	0.0	0.0	72.8	27.2	100.0
1998	668	40.5	10.8	22.4	0.0	3.4	0.0	0.0	0.3	77.5	22.5	100.0
1999	623	41.6	6.7	17.2	0.0	4.3	0.0	0.0	0.7	70.5	29.5	100.0
2000	161	36.3	3.4	8.6	0.0	7.2	0.0	0.0	0.0	55.4	44.6	100.0
2001	314	22.3	14.6	10.4	0.0	1.9	0.2	0.0	0.0	49.3	50.7	100.0
2002	434	16.5	8.3	10.3	0.0	1.7	1.2	0.0	1.1	39.1	60.9	100.0
2003	335	24.3	9.6	18.8	0.0	2.9	2.5	0.8	0.0	58.9	41.1	100.0
2004	244	40.8	7.9	9.7	0.0	2.4	1.9	0.8	2.8	66.3	33.7	100.0
2005	256	31.8	3.4	14.6	0.0	1.6	1.0	0.2	0.0	52.6	47.4	100.0
2006	169	36.5	3.3	8.8	0.0	0.4	1.8	0.0	3.0	53.7	46.3	100.0
2007	294	38.1	5.3	9.1	0.0	2.2	1.7	0.3	5.6	62.4	37.6	100.0
2008	302	19.0	6.5	20.6	0.0	0.9	1.6	0.3	5.1	53.9	46.1	100.0
2009	253	23.9	6.1	11.0	0.0	0.4	6.0	0.0	0.4	48.0	52.0	100.0
2010	632	22.2	5.3	12.8	0.0	0.7	4.0	0.0	1.9	46.9	53.1	100.0
2011	376	19.8	3.8	10.6	0.0	0.6	4.8	0.1	6.1	45.7	54.3	100.0
2012	542	19.7	8.4	16.9	0.0	1.0	4.1	0.0	4.2	54.2	45.8	100.0
2013	552	25.4	11.1	11.5	0.0	1.6	4.1	0.5	1.8	55.9	44.1	100.0
2014	566	24.3	5.2	10.4	0.0	1.6	2.8	0.0	2.4	46.7	53.3	100.0
2015	203	24.1	5.7	13.9	0.0	1.2	5.2	0.3	0.6	51.1	48.9	100.0
2016	123	31.1	6.1	17.4	0.0	3.6	1.6	0.0	1.7	61.6	38.4	100.0
2017	93	27.8	2.1	11.3	0.0	2.3	4.4	0.0	0.0	47.8	52.2	100.0
Average		33.0	8.4	12.3	0.1	1.5	4.6	0.5	1.1	61.5	38.5	100.0

Appendix C6.–Estimated harvest (by gear type) and escapement as a percent of the total Taku River coho salmon run above Canyon Island, 1992–2017.

	Percent of Total Return							
Year	Troll	Seine	Gillnet	Marine Sport	Inriver	Total Harvest	Escapement	Total Return
1992	19.6	1.1	37.1	0.2	2.6	60.7	39.3	100.0
1993	31.4	1.4	16.2	1.3	1.9	52.1	47.9	100.0
1994	28.6	7.8	25.4	5.6	4.4	71.6	28.4	100.0
1995	24.9	1.0	31.4	4.3	7.6	69.2	30.8	100.0
1996	26.3	0.2	18.1	2.6	5.4	52.7	47.3	100.0
1997	17.3	1.1	2.9	9.8	5.3	36.4	63.6	100.0
1998	24.0	0.6	16.2	3.7	4.3	48.8	51.2	100.0
1999	30.9	2.5	6.4	3.6	4.8	48.1	51.9	100.0
2000	19.5	2.0	10.5	3.8	5.0	40.7	59.3	100.0
2001	23.5	1.3	7.2	1.9	1.9	35.9	64.1	100.0
2002	12.9	1.1	10.2	2.2	1.3	27.7	72.3	100.0
2003	13.7	1.4	10.4	4.0	1.4	30.9	69.1	100.0
2004	24.6	2.1	12.3	5.6	3.9	48.6	51.4	100.0
2005	20.9	1.9	10.6	2.1	3.8	39.2	60.8	100.0
2006	21.8	0.3	16.7	2.0	5.2	46.0	54.0	100.0
2007	17.6	4.9	14.1	1.6	6.1	44.3	55.7	100.0
2008	27.6	0.0	14.5	0.9	2.3	45.3	54.7	100.0
2009	23.1	2.1	20.9	3.0	4.5	53.6	46.4	100.0
2010	14.0	1.6	21.3	5.8	5.9	48.6	51.4	100.0
2011	18.3	4.9	8.7	3.7	9.8	45.5	54.5	100.0
2012	13.0	0.0	10.7	1.1	12.6	37.3	62.7	100.0
2013	24.3	1.7	17.4	1.7	7.4	52.5	47.5	100.0
2014	6.4	0.4	16.9	1.9	8.9	34.5	65.5	100.0
2015	15.7	5.4	8.4	2.9	10.0	42.4	57.6	100.0
2016	7.8	0.3	11.8	1.0	9.3	30.1	69.9	100.0
2017	18.4	5.6	9.6	4.4	7.5	45.6	54.4	100.0
Average	20.2	2.0	14.8	3.1	5.5	45.7	54.3	100.0

Appendix C7.–Estimated harvest (by gear type) and escapement as a percent of the total Chilkat River coho salmon run, 2000–2017.

Year	Fishery Sample Size	Percent of Total Return								
		Troll	Seine	Drift Gillnet	Marine Sport	FW Sport	Subsistence	Total Harvest	Escapement	Total Return
2000	265	16.0	0.7	13.6	1.2	0.5	0.2	32.2	67.8	100.0
2001	250	19.5	0.4	8.6	1.0	1.3	0.1	30.9	69.1	100.0
2002	325	18.2	0.2	19.6	0.6	1.0	0.2	39.7	60.3	100.0
2003	426	23.6	0.5	12.1	1.8	1.1	0.2	39.3	60.7	100.0
2004	254	42.4	0.5	18.4	2.6	1.4	0.2	65.7	34.3	100.0
2005	141	26.7	0.5	16.3	1.2	1.8	0.5	47.0	53.0	100.0
2006	200	25.5	0.1	16.8	1.7	1.2	0.2	45.6	54.4	100.0
2007	73	24.3	0.0	9.3	0.0	1.4	0.3	35.3	64.7	100.0
2008	358	19.4	0.0	26.7	0.7	0.7	0.4	47.9	52.1	100.0
2009	326	15.3	0.4	19.7	0.0	2.6	0.6	38.7	61.3	100.0
2010	427	18.8	0.2	24.4	1.0	0.3	0.2	45.0	55.0	100.0
2011	219	19.8	1.2	14.2	0.8	1.2	0.3	37.5	62.5	100.0
2012	164	17.5	0.0	23.7	1.0	0.6	0.3	43.2	56.8	100.0
2013	355	20.9	0.7	34.4	0.6	0.8	0.4	57.8	42.2	100.0
2014	88	6.9	0.0	8.8	0.2	0.6	0.3	16.8	83.2	100.0
2015	90	14.7	0.8	16.1	0.6	1.4	0.5	34.0	66.0	100.0
2016	56	6.0	0.0	26.6	0.6	1.3	0.8	35.1	64.9	100.0
2017	49	11.3	0.0	17.5	3.0	1.3	0.5	33.7	66.3	100.0
Average		19.3	0.3	18.2	1.0	1.2	0.3	40.3	59.7	100.0

APPENDIX D:
ADULT WEIGHT AND LENGTH

Appendix D 1.–Average and coefficient of variation of mid-eye to fork length of male and female adult age-.1 coho salmon returning to Auke Creek and the Berners River, 1980–2017.

Year	Auke Creek (Males)		Auke Creek (Females)		Berners River (Males)		Berners River (Females)	
	Average Length (mm)	CV	Average Length (mm)	CV	Average Length (mm)	CV	Average Length (mm)	CV
1980	607	0.0888	613	0.0627	-	-	-	-
1981	633	0.0746	643	0.0560	-	-	-	-
1982	622	0.0720	624	0.0604	642	0.0901	660	0.0459
1983	617	0.0838	631	0.0610	628	0.1058	654	0.0533
1984	644	0.0712	649	0.0548	-	-	-	-
1985	644	0.0631	656	0.0499	647	0.0979	670	0.0539
1986	635	0.0932	629	0.0768	611	0.1298	656	0.0539
1987	628	0.0619	630	0.0436	633	0.0896	640	0.0641
1988	636	0.0757	630	0.0656	628	0.1016	660	0.0563
1989	609	0.0866	621	0.0604	640	0.0912	656	0.0503
1990	603	0.0848	615	0.0565	644	0.1060	659	0.0592
1991	595	0.0772	605	0.0551	605	0.1090	646	0.0526
1992	600	0.0889	617	0.0634	611	0.1142	640	0.0590
1993	602	0.0852	610	0.0612	591	0.1134	623	0.0603
1994	633	0.0811	645	0.0484	633	0.1044	656	0.0593
1995	608	0.0688	620	0.0671	585	0.1176	636	0.0678
1996	615	0.0682	628	0.0631	578	0.1421	630	0.0690
1997	616	0.0819	626	0.0654	635	0.0903	655	0.0548
1998	617	0.0839	639	0.0496	643	0.0978	666	0.0465
1999	581	0.0946	593	0.0618	588	0.1017	626	0.0515
2000	606	0.0880	614	0.0692	637	0.1008	659	0.0547
2001	603	0.0973	615	0.0726	618	0.1118	643	0.0725
2002	603	0.0922	620	0.0776	631	0.1084	647	0.0649
2003	613	0.0729	626	0.0580	603	0.1093	647	0.0568
2004	612	0.0732	625	0.0579	623	0.1105	657	0.0594
2005	591	0.0978	604	0.0723	579	0.1073	621	0.0603
2006	616	0.0740	615	0.0566	626	0.0949	654	0.0545
2007	595	0.0943	601	0.0781	551	0.1260	621	0.0742
2008	645	0.0711	653	0.0502	626	0.1189	656	0.0573
2009	595	0.0966	606	0.0825	574	0.1203	610	0.0769
2010	596	0.0964	617	0.0592	602	0.1069	650	0.0509
2011	589	0.0725	602	0.0625	564	0.1180	607	0.0630
2012	594	0.0710	600	0.0597	575	0.1149	618	0.0618
2013	606	0.0887	606	0.0567	578	0.1192	604	0.0669
2014	617	0.0769	616	0.0660	604	0.1066	633	0.0618
2015	593	0.0620	607	0.0567	600	0.0861	622	0.0553
2016	604	0.0795	609	0.0490	622	0.0900	656	0.0435
2017	590	0.1002	605	0.0611	561	0.1205	613	0.0610
Average								
1982-1989	629	0.0759	634	0.0591	633	0.1009	656	0.0539
1990-1999	607	0.0815	620	0.0592	611	0.1097	644	0.0580
2000-2009	608	0.0857	618	0.0675	607	0.1108	642	0.0632
2010-2017	599	0.0809	608	0.0589	588	0.1078	626	0.0576
All Years	611	0.0813	621	0.0613	610	0.1078	642	0.0587

Appendix D 2.–Average and coefficient of variation of mid-eye to fork length of male and female adult age-.1 coho salmon returning to Ford Arm Creek and Hugh Smith Lake, 1980–2017.

	Ford Arm Cr. (Males)		Ford Arm Cr. (Females)		Hugh Smith L. (Males)		Hugh Smith L. (Females)	
Year	Average Length (mm)	CV	Average Length (mm)	CV	Average Length (mm)	CV	Average Length (mm)	CV
1982	653	0.0814	660	0.0608	648	0.0862	654	0.0533
1983	642	0.0901	649	0.0689	595	0.1069	627	0.0759
1984	-	-	-	-	655	0.0920	670	0.0609
1985	665	0.0680	667	0.0678	660	0.0910	662	0.0814
1986	649	0.0968	653	0.0771	678	0.0973	675	0.0582
1987	630	0.0903	655	0.0547	645	0.0820	658	0.0716
1988	656	0.0862	668	0.0624	636	0.1030	653	0.0752
1989	597	0.1193	643	0.0707	613	0.0964	623	0.0641
1990	641	0.1116	669	0.0674	650	0.1072	661	0.0620
1991	617	0.0950	650	0.0516	612	0.1026	632	0.0707
1992	620	0.0944	643	0.0586	642	0.0927	651	0.0648
1993	605	0.1021	631	0.0565	612	0.1173	641	0.0603
1994	623	0.1007	659	0.0576	624	0.1202	645	0.0952
1995	616	0.0869	650	0.0454	628	0.1022	651	0.0630
1996	607	0.1127	642	0.0580	613	0.1131	630	0.0720
1997	606	0.1000	641	0.0503	616	0.1061	644	0.0674
1998	622	0.0977	649	0.0492	652	0.1075	663	0.0682
1999	575	0.1160	610	0.0800	573	0.1231	611	0.0761
2000	597	0.0974	641	0.0518	598	0.1215	634	0.0726
2001	573	0.1242	622	0.0739	611	0.1235	631	0.0827
2002	584	0.1199	631	0.0719	594	0.1412	635	0.0765
2003	596	0.1007	626	0.0552	592	0.1296	631	0.0691
2004	596	0.1122	641	0.0521	625	0.0963	638	0.0734
2005	571	0.1160	618	0.0597	604	0.1119	630	0.0685
2006	597	0.0942	628	0.0593	606	0.1251	631	0.0831
2007	563	0.1167	617	0.0657	581	0.1144	616	0.0764
2008	615	0.1034	652	0.0538	613	0.1131	641	0.0796
2009	560	0.1110	619	0.0720	577	0.1214	609	0.0946
2010	588	0.1061	635	0.0599	641	0.1090	657	0.0731
2011	563	0.0905	587	0.0770	601	0.0973	617	0.0754
2012	553	0.1150	611	0.0619	595	0.1124	616	0.0710
2013	554	0.1254	594	0.0923	587	0.1220	604	0.0860
2014	600	0.1093	632	0.0779	619	0.1197	639	0.0851
2015	610	0.0741	629	0.0527	606	0.0967	630	0.0606
2016	-	-	-	-	617	0.1043	646	0.0652
2017	-	-	-	-	593	0.1121	610	0.0704
Average								
1982-1989	642	0.0903	656	0.0661	641	0.0943	653	0.0676
1990-1999	613	0.1017	644	0.0575	622	0.1092	643	0.0700
2000-2009	585	0.1096	630	0.0615	600	0.1198	630	0.0776
2010-2017	578	0.1034	615	0.0703	607	0.1092	627	0.0734
All Years	604	0.1020	637	0.0629	617	0.1088	638	0.0723

Appendix D 3.–Southeast Alaska troll-caught coho salmon average dressed weight compared with modeled weight based on based on a multiple regression model with two standardized variables fitted to 1970–2018 weight data: the standardized April–March PDO Index (average for lag 0, 2, and 4 years; 0.451 weighting) and the average commercial catch of pink salmon in North America (excluding the Bering Sea and Aleutian Islands) lagged by 2 and 4 years (0.549 weighting). Model forecasts are shown for 2019–2020 (based on a 1970–2018 fit). Also shown is the mean-average length of male and female spawners from four wild indicator stocks in Southeast Alaska.

	Predictive Variables					Mean-Average Spawner Length (mm)[c]	
Year	PDO Index	Pink Salmon Catch Biomass (1,000s of m-tons)	Modeled Weight (kg)	Observed Weight (kg)	Residual	Males	Females
1970	-0.24	98.92	3.12	3.23	0.11	-	-
1971	-0.65	53.32	3.16	3.16	0.00	-	-
1972	-0.59	84.40	3.07	2.85	-0.21	-	-
1973	-0.70	61.04	3.12	3.28	0.16	-	-
1974	-0.67	60.55	3.13	3.16	0.03	-	-
1975	-0.60	50.51	3.19	2.95	-0.24	-	-
1976	-1.20	36.16	3.05	3.14	0.09	-	-
1977	-0.04	37.80	3.41	3.64	0.24	-	-
1978	-0.68	46.01	3.18	2.96	-0.21	-	-
1979	0.09	65.22	3.35	3.15	-0.20	-	-
1980	-0.13	77.26	3.24	3.19	-0.04	-	-
1981	0.38	106.30	3.29	3.38	0.09	-	-
1982	0.53	98.33	3.37	3.28	-0.08	641	649
1983	0.29	140.93	3.14	3.18	0.04	621	640
1984	1.03	102.13	3.51	3.75	0.25	652	667
1985	0.58	147.83	3.20	3.46	0.27	654	664
1986	1.02	114.13	3.46	3.46	0.00	643	653
1987	0.79	161.92	3.22	3.08	-0.13	634	646
1988	1.32	139.13	3.47	3.44	-0.02	639	653
1989	0.67	148.67	3.23	3.02	-0.20	615	636
1990	0.73	131.25	3.31	3.10	-0.21	634	651
1991	0.25	149.62	3.09	2.95	-0.14	607	633
1992	0.52	132.01	3.24	3.16	-0.08	618	637
1993	0.12	196.79	2.88	2.57	-0.31	603	627
1994	0.49	128.57	3.24	3.34	0.10	628	651
1995	0.02	187.91	2.88	3.33	0.45	610	639
1996	0.77	137.28	3.30	3.17	-0.13	603	632
1997	0.39	198.34	2.96	3.10	0.14	618	641
1998	1.35	158.23	3.41	3.46	0.06	633	654
1999	0.00	179.48	2.91	2.54	-0.37	579	610

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	Predictive Variables						
		Pink Salmon Catch Biomass	Modeled Weight	Observed Weight		Mean-Average Spawner Length (mm)[c]	
Year	PDO Index	(1,000s of m-tons)	(kg)	(kg)	Residual	Males	Females
2000	0.45	160.73	3.11	3.15	0.04	609	637
2001	0.02	170.51	2.94	2.89	-0.05	601	628
2002	-0.06	147.01	3.01	3.14	0.13	603	633
2003	0.08	206.88	2.83	2.94	0.11	601	633
2004	-0.42	133.09	2.94	3.05	0.11	614	640
2005	0.30	214.55	2.87	2.63	-0.24	586	618
2006	0.07	156.50	3.01	3.04	0.03	611	632
2007	0.40	244.54	2.79	2.73	-0.06	573	614
2008	0.19	145.77	3.09	3.44	0.35	625	651
2009	-0.34	255.13	2.53	2.69	0.16	577	611
2010	-0.04	128.10	3.08	3.17	0.09	607	640
2011	-0.71	202.03	2.60	2.45	-0.16	579	603
2012	-0.58	157.23	2.81	2.69	-0.12	579	611
2013	-1.03	180.20	2.58	2.60	0.02	581	602
2014	-0.55	147.69	2.85	2.93	0.08	610	630
2015	-0.02	270.00	2.57	2.76	0.18	602	622
2016	-0.01	133.47	3.07	3.13	0.07	611	638
2017	0.63	319.67	2.59	2.47	-0.13	578	610
2018	0.56	112.60	3.32	3.23	-0.09	-	-
2019	0.97[a]	270.25	2.88[a]	-	-	-	-
2020	0.98[b]	70.73	3.51[b]	-	-	-	-

[a] The forecast average weight in 2019 includes the average of the first 6 months of the 12 months of the PDO index at lag-0.

[a] The PDO index value for the 2020 weight forecast is based a separate model fit using the average PDO values at lags of 2 years and 4 years only, and excludes lag-0.

[c] Average lengths were interpolated for the Berners River and Ford Arm Creek in 1984 and for Ford Arm Creek in 2016–2018 based on the method presented by Brown (1974).