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Berners River Coho Salmon Studies, 1972–2014

by

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and

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

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

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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BERNERS RIVER COHO SALMON STUDIES, 1972–2014

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ABSTRACT

The coho salmon population in the Berners River was studied as an indicator for fishery management during 1972–2014. Smolt estimates from 1989 to 2013 averaged 193,800 fish (range: 89,200–326,300) and survival to adulthood the following year averaged 16.3% (range: 8.4–30.2%). Smolt production accounted for 48% of variation in adult abundance while marine survival accounted for 52%. Approximately equal decreases in smolt production and marine survival during the mid-2000s resulted in a 60% decline in adult returns from 38,200 fish in 1990–2004 to 15,200 fish in 2005–2013. A strong correlation with summer-fall precipitation in the year prior to smolthood existed for 17 years, but smolt production declined independent of precipitation and brood-year escapement during 2006–2013. We hypothesize that the decline in smolt production was caused by a decrease in overwinter survival and movement of juveniles during colder winter–spring conditions that prevailed during the latter period. Marine survival was positively correlated with adult size and was likely influenced by both nearshore conditions and growth-related, sex-specific mortality linked to effects of climate and pink salmon biomass on offshore squid prey. On average, the drift gillnet fishery reduced average length of adult males and females by 12.3 mm and 3.7 mm, respectively, and the female-to-male ratio from 0.80 prior to the fishery to 0.75 in the spawning escapement. Based on a hockey stick model fit to brood year escapements (adjusted to constant average per capita reproductive potential) and returns (adjusted to constant marine survival), we recommend a biological escapement goal of 3,600–8,100 spawners based on survey counts or 4,500–10,000 spawners based on expanded survey counts. We present and discuss information on the ecology of the Berners River population and the larger Chilkat River stock, and their management in common drift gillnet and troll fisheries.

Key words: Coho salmon, *Oncorhynchus kisutch*, escapement, spawner-recruit, exploitation rate, smolts, marine survival, gillnet selectivity, growth, reproductive potential, Berners River, Southeast Alaska

INTRODUCTION

The coho salmon (*Oncorhynchus kisutch*) population in the Berners River was one of four intensively monitored wild indicator populations established in Southeast Alaska in the early 1980s (Shaul et al. 2011). It is an important contributor to the commercial troll fishery in northern Southeast Alaska and Yakutat and the commercial drift gillnet fishery in Lynn Canal, and it contributes to a lesser extent to marine sport fisheries and commercial purse seine fisheries from Cross Sound to upper Chatham Strait.

The Berners River, a relatively compact drainage (Figure 1; Appendix G1), is one of three rivers entering upper Berners Bay (Figure 2; Appendix G2) and contains the majority of high quality coho rearing habitat in the bay. A large proportion of the system is composed of ponds, sloughs and wetlands that provide excellent rearing habitat for coho salmon (Figure 3). It was recognized as an important coho salmon producer in the early 1970s, and an Alaska Department of Fish and Game (ADF&G) research project was initiated in which juvenile coho salmon were marked with fluorescent pigment and an adipose clip in 1972 and recovered in fisheries and the spawning escapement in 1974 (Gray et al. 1978). Similar experiments were repeated from 1976 to 1979 using coded wire tags (CWTs) (Shaul 1994; Shaul et al. 2004, 2005, 2008, and 2011). In 1989, the tagging portion of the project transitioned from marking rearing juveniles during early summer to marking migrating smolts during May and early June. In 1982, the Berners River was recommended as a long-term indicator stock by an interagency committee that reviewed the Southeast Alaska coho salmon research and stock assessment program (ADF&G 1983).

A distinctive characteristic of the Berners River among Southeast Alaska coho salmon systems is its conduciveness to an effective survey count of the spawning population. The spawning run is temporally compressed and accumulates in predictable areas over a light sand/gravel bottom where water clarity is usually suitable and there are few visual obstructions (Figure 4). The upper system has steep surrounding topography with little water storage capacity, so that flow responds rapidly to rainfall in spawner survey areas in the upper drainage. However, the lower drainage, obstructed by bed load from the neighboring Lace River, is low in gradient and water from freshets accumulates in extensive off-channel wetland habitat and is released slowly over a period of days and weeks. Together, these characteristics contribute to the system's suitability for rearing coho salmon, while also making it possible to conduct representative surveys of spawning escapement in the upper reaches of the drainage within hours after rainfall abates.

Although the annual peak survey count of spawners is clearly a conservative measure, it has historically been used as a representation of total escapement. An escapement goal of 6,300 (range 4,000–9,200) spawners was established by Clark et al. (1994) based on a spawner-recruit analysis of escapement and return information for the 1979, 1982, 1983, and 1985–1989 brood years. They based the goal on a Ricker model fit of adult return estimates that were adjusted to a constant average presmolt-to-adult survival rate to reduce variability in the response variable related to (assumed non-compensatory) survival in the marine environment.

In this report, we will update the spawner-recruit analysis of Clark et al. (1994), fitting the Ricker model as well as the Hockey Stick model (Barrowman and Meyers 2000) that has been applied to coho salmon populations from Oregon to southern British Columbia (Bradford et al. 2000). We will also calibrate the survey count to total escapement using a method of estimating total escapement and survey efficiency based on the assumption of an equal troll fishery exploitation rate between the Berners River stock and the population in Auke Creek, located 56 km to the south near Juneau. Resultant total escapement estimates will be used in the spawner-recruit analysis.

In addition, we will examine patterns of survival and production, fishery exploitation, and selectivity by the drift gillnet fishery. Shaul et al. (2011) found that simultaneous decreases occurred in smolt production and marine survival after the 2003 sea-entry year that resulted in a dramatic decrease in adult returns to the system after 2004 compared with the average return in the prior 15 years. They observed that a strong positive correlation existed between smolt production and total precipitation at the Juneau airport in the summer and fall (July–November) in the year prior to sea-entry, but that this relationship had deteriorated as smolt production declined in the mid-2000s. A similar decline in production from the Chilkat River drainage suggested that the primary agent in the decline operated over a broad geographic area. Here, we will update the relationship between precipitation and smolt production and examine the hypothesis that decreases in smolt production and marine survival were climate-related and caused by recent cooling in the northeast Pacific Ocean. We will summarize information presented in other publications about inter-system movement and marine rearing by juveniles prior to smolting (Shaul et al. 2013) and relationships between adult size, survival, and reproductive capacity of Berners River coho salmon and variables representing bottom-up and top-down influences on the primary offshore prey of coho salmon in the Gulf of Alaska, the minimal armhook squid (*Berryteuthis anonychus*; Shaul and Geiger 2016). Finally, we will investigate and summarize information and considerations relevant to management of the troll and drift gillnet fisheries to meet biological escapement goals (*BEG*s) for the Berners River and the nearby Chilkat River (Figure 2).

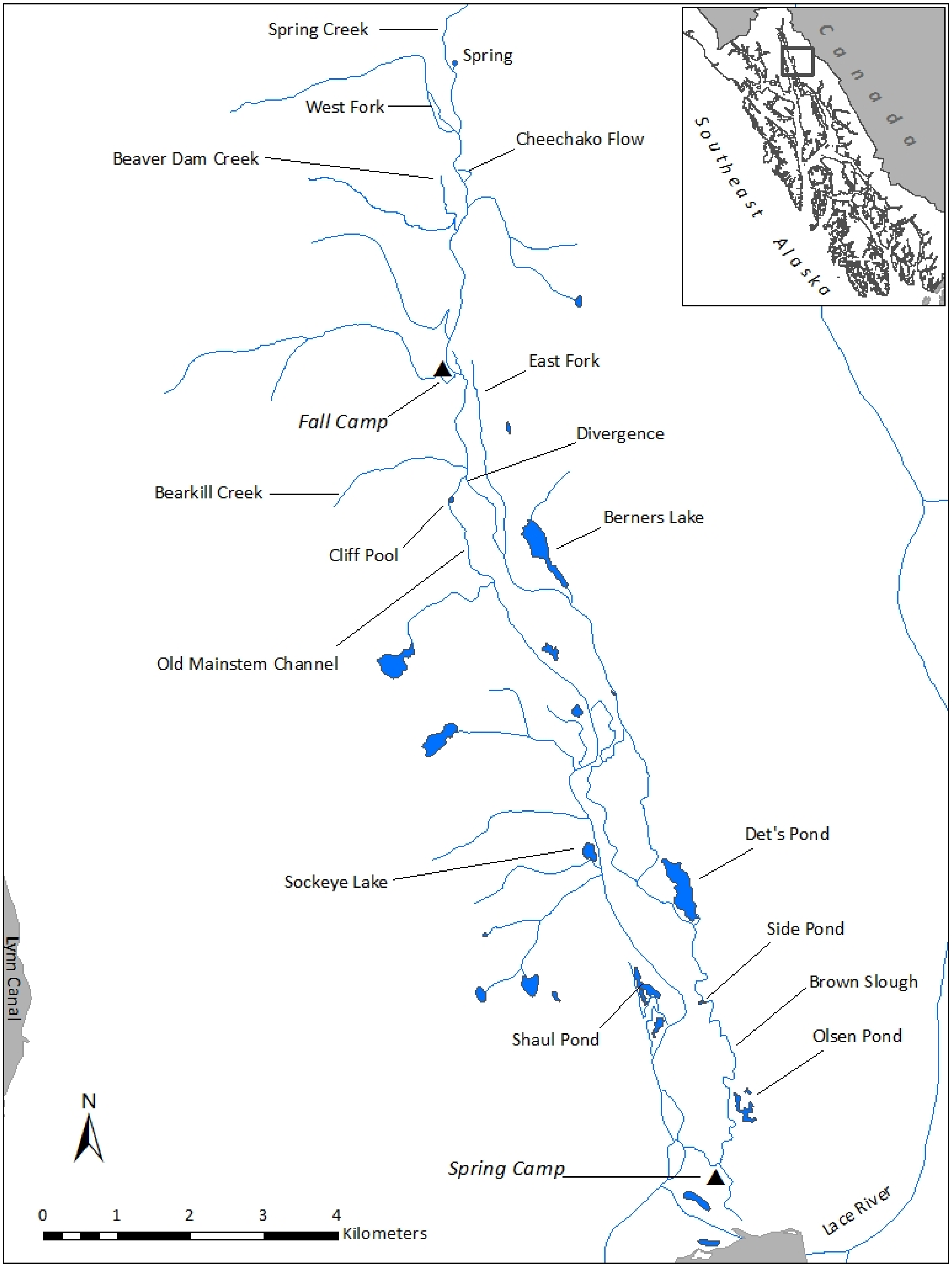

Figure 1.–Map of the Berners River drainage.

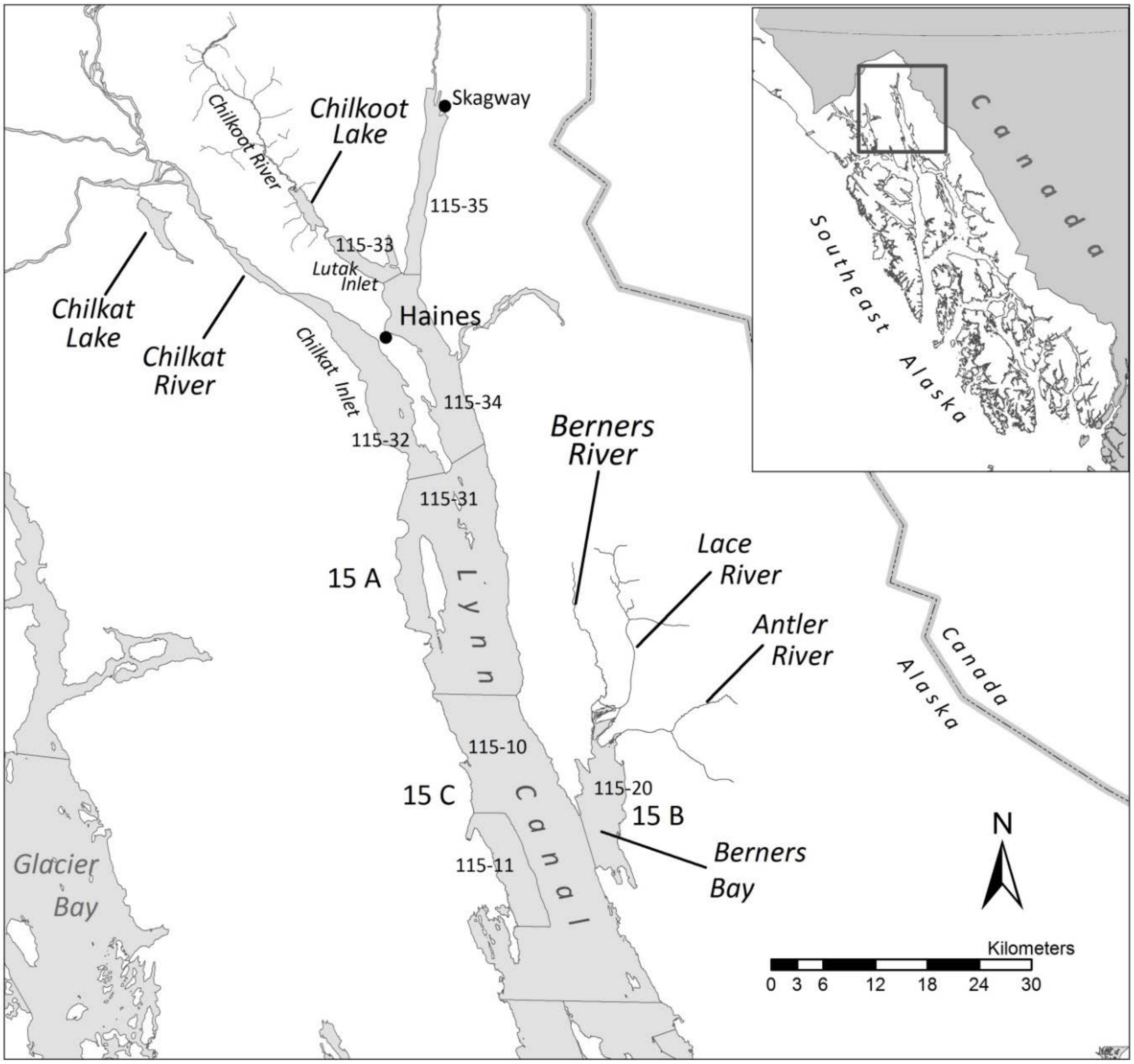

Figure 2.–Map of Lynn Canal (District 115) with the location of the Berners River and fishery sub-districts.

METHODS

SMOLT PRODUCTION

Smolt and Presmolt Tagging and Sampling

Tagging of rearing presmolts with CWTs was conducted annually in late June and early July in 1972, 1976, 1977, 1980–1981 and 1983–1988. Presmolts (fish ≥ 62 mm snout-fork length) were captured for marking using minnow traps fished in lower Brown Slough and adjacent ponds (Figure 1). Tagging was conducted soon after the spring smolt migration by a crew of four over the course of a 12-day trip, which made the method relatively cost-effective. However, disadvantages were that it provided a low marked proportion in the adult population, and it did not allow for clear delineation between freshwater production and marine survival because presmolts (which averaged 70–75 mm in length) faced 11 additional months in freshwater, on average, before migrating to sea. Therefore, tagging effort was shifted to smolts after 1988.

Figure 3.–A view to the north from the lower Berners River Valley with the complex of off-channel basins known as Shaul Pond in the foreground (©2014 ADF&G/photo by Scott Forbes).

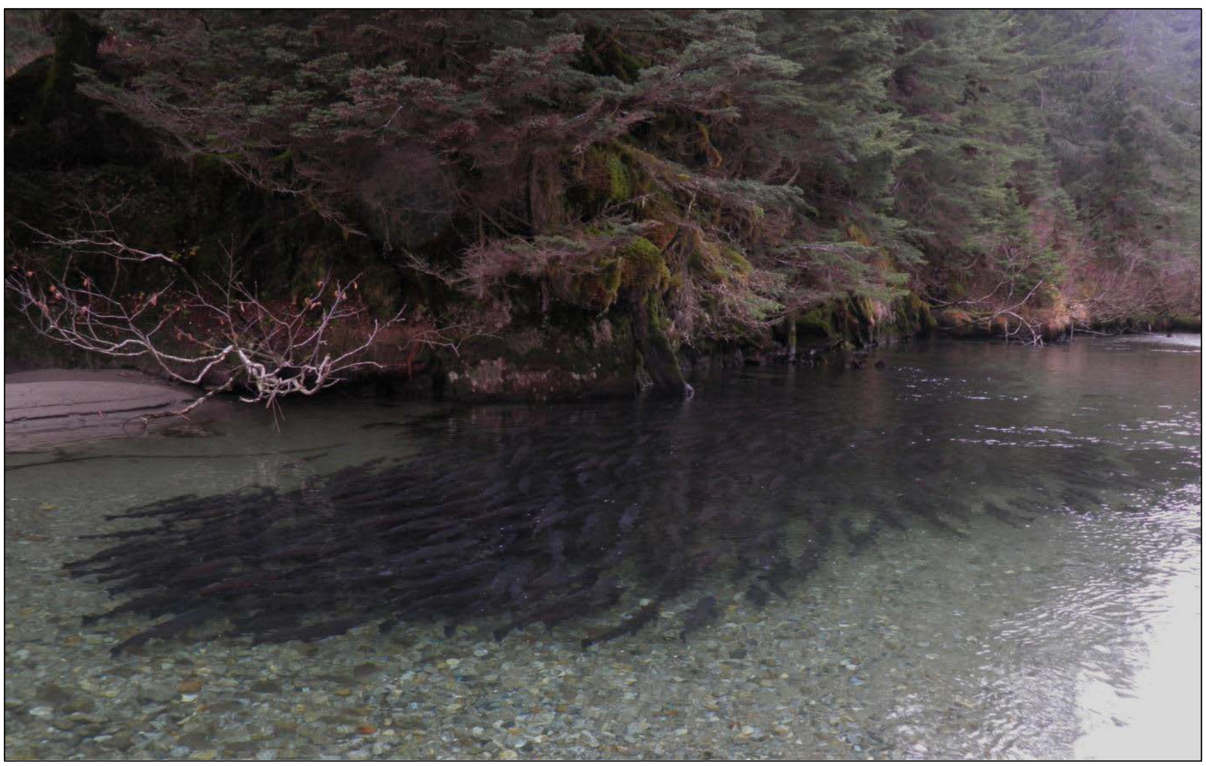

Figure 4.–Coho salmon spawners in a pool in the upper Berners River (©2014 ADF&G/photo by Leon Shaul).

Figure 5.–Trough traps used to capture coho salmon smolts migrating over beaver dams at Shaul Pond and Det’s Pond (©1997 ADF&G/photo by Leon Shaul).

Beginning in 1989, smolts were captured using trough traps of a type described by Elliott (1992) and Magnus et al. (2006) that were deployed on the major spillways of beaver dams (Figure 5) on two major lower river rearing ponds, Det’s Pond and Shaul Pond, and in some years on a third smaller pond (Olsen Pond). Other spillways over the same dams were blocked with plastic screen (0.64 cm mesh) in order to funnel fish toward the traps. The trough traps directed the fish through a 10.2 cm diameter pipe or flexible hose into a floating holding box. The traps on larger producing ponds were tended twice daily, in the morning and evening, while traps installed at less productive locations were checked only in the morning. Coho smolts were sorted from other species and transported in aerated holding boxes to holding pens located at the tagging site on lower Brown Slough. Fish from different ponds were kept in separate pens so discrete age-length and tag recovery samples could be taken.

After the mid-1990s, access to Det’s Pond on the east side of the valley became difficult because of channel shifts and beaver dam development in Brown Slough. In addition, the level of the pond dropped substantially due to deterioration of its beaver dam. Therefore, Det’s Pond was abandoned as a trapping site, and smolts were instead captured in Brown Slough using a smolt weir with an incline plane trap and baited magnum minnow traps (Magnus et al. 2006). Combined, these methods of capturing smolts for tagging greatly increased the marked rate of the population and the precision of resultant estimates compared with pre-smolt marking.

Coho salmon smolts were sorted into three groups based on snout to fork length for tagging: 80–100 mm, 101–130 mm, and >130 mm. Separate tag machine settings were used for each size group. Fish under 80 mm comprised a small proportion of the total catch; they were assumed not to be smolts and were released untagged. Tagged smolts were held in a holding pen in quiet water until dark the following evening and then released.

Smolts were sampled daily from each pond for age and length according to a daily target based on average migration timing and an annual objective of 600 samples from each pond. Approximately 10 scales were taken with a surgical scalpel from the left side of the fish approximately two rows above the lateral line along a diagonal downward from the posterior insertion of the dorsal fin to the anterior insertion of the anal fin (INPFC 1963). The scales were distributed separately across one of four quadrants on a glass microscope slide. Samples from four fish were placed on each slide, which was labeled with numbers and corresponding lengths on the frosted end. When a slide was full, a clean slide was fastened over it with clear tape to protect the scales.

Estimation of Smolt Abundance

Abundance of coho salmon smolts was estimated using Chapman's modification of Petersen's estimator for closed populations (Seber 1982, p. 60). A sample of smolts was marked and tagged and a sample of adult spawners was inspected for marks in the following year, under assumption that the population was open to mortality but closed to recruitment during the year at sea. The abundance of smolts (N_S) was estimated as follows:

$$\hat{N}_S = \frac{(M+1)(C+1)}{(R+1)} - 1, \tag{1}$$

where M is the number of smolts marked and released in a year and R is the number of adipose clip marks in a sample of C adults inspected in the escapement for marks a year later.

In this equation, R is the random variable, and C and M are assumed to be constants. In mark–recapture sampling, R follows a hyper geometric distribution by definition, which can be approximated with the Poisson distribution (Thompson 1992). By simplifying the Petersen mark–recapture equation, we have

$$\frac{1}{\hat{N}_S} \approx \frac{R}{C\,M}. \tag{2}$$

In the Poisson approximation for R, the mean and variance are the same, so that the variance (var), standard error (SE), and coefficient of variation (CV) of $\frac{1}{\hat{N}}$ are calculated as follows:

$$\text{var}\left(\frac{1}{\hat{N}_S}\right) \approx \frac{R}{(C\,M)^2}; \tag{3}$$

$$\text{SE}\left(\frac{1}{\hat{N}_S}\right) = \frac{\sqrt{R}}{C\,M}\text{; and,} \tag{4}$$

$$\text{CV}\left(\frac{1}{\hat{N}_S}\right) = \frac{1}{\sqrt{R}} \cdot 100. \tag{5}$$

If the numbers of mark-recoveries are moderate or large, the pooled Petersen estimate should meet the criteria outlined above. The distribution for R can then be approximated with the normal distribution. Under these circumstances, we will assume $\frac{1}{\hat{N}_S}$ is approximately normally distributed, and we will generate 95% confidence intervals for $\frac{1}{N_S}$ as,

$$\frac{1}{\hat{N}_S} \pm 1.96 \cdot \mathrm{SE}(\frac{1}{\hat{N}_S}) \,. \tag{6}$$

Finally, 95% confidence intervals for N_S will be generated by inverting the confidence intervals for $\frac{1}{N_S}$.

In cases with returning adipose clipped adults from releases that were not representative of the smolt migration (such as half-length tagged fry), it was necessary to substitute an estimate of R by multiplying the number of adipose clips in the escapement sample by the proportion of random and select fishery recoveries that were from representative smolts (F_S) compared with recoveries from other release groups (F_O) including emergent fry, presmolts, and mixtures of smolts and presmolts:

$$\hat{R} = R\left(\frac{F_S}{F_S + F_O}\right). \tag{7}$$

M represents the number of adipose clipped fish released without an adjustment for estimated tag loss at the time of release. Tag loss was estimated based on the proportion of fish in the escapement that registered no signal with the field detector and were found not to contain a tag upon further examination at the tag lab under an inherent assumption of no natural incidence of adipose clips (i.e., missing adipose fins). Tag loss was assumed to be equal among all tagged groups unless a substantial difference in tag retention was evident at the time of release (e.g., if estimated tag loss was zero for representative smolts and 8% for emergent fry). In those few cases, an exception was made to the equal loss assumption and all tag loss was attributed to the group with evident high loss, usually the emergent fry group. Potential error introduced by the assumption about the distribution of tag loss was minimal because fish tagged as representative smolts typically had a very high retention rate approaching 100% and greatly dominated recoveries among tagged adults.

Presmolt–adult and smolt–adult survival rates were estimated for the 1990 adult return based on presmolts tagged in 1988 and smolts tagged in 1989. Smolt Abundance in 1973, 1977, 1978, 1981, 1982, and 1984–1988 was estimated by assuming that the ratio of presmolt–adult survival rate and smolt–adult survival rate remained constant at the same level as for the 1990 return. Smolt production ($\hat{N}_{S(i)}$) for other smolt migration years prior to 1989 was estimated by dividing the estimated total adult return ($\hat{N}_{A(i+1)}$) by the associated presmolt–adult survival rate ($\hat{S}_{p(i-1)}$) and multiplying the result by the survival rate of 1988 presmolts ($\hat{S}_{p(1988)}$) over the survival rate of 1989 smolts ($\hat{S}_{s(1989)}$):

$$\hat{N}_{S(i)} = \left(\frac{\hat{N}_{A(i+1)}}{\hat{S}_{p(i-1)}}\right)\left(\frac{\hat{S}_{p(1988)}}{\hat{S}_{s(1989)}}\right). \tag{8}$$

Relationships Between Climate and Smolt Production

Results of a number of studies of coho salmon populations have indicated a positive relationship between precipitation or streamflow during the rearing period and smolt production (Smoker 1955; Mathews and Olson 1973; Scarnecchia 1981; Lawson et al. 2004). Greater summer and fall precipitation increases stream flow and the area of wetted habitat available to juvenile coho salmon during a period of rapid growth. In contrast, extended periods with low precipitation may result in elevated temperatures that may reduce growth and increase mortality of fry and juveniles confined within more restricted rearing habitat. These conditions may result in reduced growth associated with increased competition for food and a higher metabolic rate, combined with potential for increased predation when fish are more concentrated. The data time series for the Berners River presents an opportunity to examine the relationship between local indicators of precipitation and subsequent smolt production from mainland river habitat in northern Southeast Alaska.

Shaul et al. (2011) found that, during years prior to the mid-2000s, a strong correlation existed between smolt production and total precipitation at the Juneau Airport during summer and fall (July–November). We updated this data series using monthly total precipitation data for the Juneau International Airport obtained from the U.S. National Weather Service (https://www.ncdc.noaa.gov/cdo-web). We then examined relationships with smolt production in the following year, computing values for R^2 and p for the linear relationships between the independent variable (precipitation in cm) and the dependent variable (number of smolts). In addition, we examined winter and spring temperature records from Juneau International Airport for patterns and correlations with smolt production under the hypothesis that a post-2004 decline in smolt abundance (and deteriorated relationship with summer–fall precipitation) may be explained by emergence of winter–spring freshwater mortality as a primary bottleneck affecting smolt production during the recent cool period.

ADULT ESCAPEMENT

Adult escapement assessment in the Berners River is based on an extensive foot survey of the upper drainage, supplemented with the use of helicopter surveys to observe coho salmon in the middle and lower sections of the drainage.

Escapement Surveys

An escapement survey and sampling trip was conducted on the upper Berners River annually between mid-October and early November from 1982 to 2014. With the exception of a 4-day trip in 1984, when no biological sampling was conducted, the survey and sampling trips were planned for a period of 10 days in duration. In the early to mid-1980s, the surveys were conducted over a period of several days during which the camp location and sampling operations were moved progressively downstream. Beginning in 1987, the camp was centrally located within the survey area (Figure 1) and surveys were thenceforth conducted upstream and downstream from camp on sequential days whenever weather conditions permitted.

The 1982 trip was conducted in early November. However, earlier-timed surveys appeared to provide a more complete count, on average, and greater flexibility to respond to changing weather and water conditions. The objective was to survey when fish were most visible while concentrated in upper pools close to spawning areas but before a large proportion had begun spawning. A target date of 19 October emerged as the optimal date for initiation of the survey based on the observation that the majority of the run typically holds in water within the foot survey area, and only a limited number of fish hold below the foot survey area or are actively spawning by that date. During 1989–2014, the surveys were all conducted between 17 and 27 October, and occurred on average during 20–21 October (Appendix A1).

Access to the camp in the upper drainage was by helicopter. The main river and Brown Slough were surveyed during the flight to camp and sometimes during the flight out at the end of the trip. The fall crew drove to Echo Cove where they met a helicopter pilot who transported them and their gear to camp in two trips, including one while slinging a cargo net. During the trip with only an internal load, the river was surveyed upstream beginning where the clearest water from the Berners River proper enters Berners Bay on the west side and proceeding upstream. Fish were rarely observed below the confluence with the Lace River, but were present in some years in four pools between the confluence and the entrance to Brown Slough. The survey was continued from the confluence with Brown Slough up the west side of the valley to near Side Pond (Figure 1), where it diverted to Brown Slough and occasional holding areas for spawners from just below Side Pond to above Det's Pond, before returning and continuing along the original route up the main channel. The survey then proceeded along the main flow past Sockeye Lake, following the main channel to the east side of the valley past Berners Lake and ended at the Divergence. The flight then proceeded southeast to observe the Cliff Pool and waters leading downstream toward the main channel, where the helicopter turned and flew directly upstream to the fall camp. Pools below the foot survey area that have commonly been occupied by adult coho salmon were re-examined on the flight out at the end of the trip.

Beginning in 1987, a thorough escapement survey of the upper river was conducted by foot immediately after arrival, water conditions permitting. An additional later survey was conducted if there was evidence that additional fish had moved into the upper river. The survey area was usually covered in two sequential days, from camp to the headwaters on the first day and downstream on the second day. The upper survey area included the east branch (Spring Creek) all the way to its origin in a spring, and the west branch to a distance of approximately 2 km above the fork (Appendix G3). In some years, the crew was dropped off by the helicopter at the headwaters forks, time and water conditions permitting. They surveyed Spring Creek first and then crossed the valley and intercepted the west fork and followed it downstream, continuing down from the confluence to camp. If conditions and time did not permit initiation of the survey on the first day, the crew started early in the morning from camp and surveyed the entire upstream circuit in one day. In addition to the mainstem and headwaters forks, the upstream survey included two side tributaries that enter from the west, which were surveyed upstream to the uppermost reaches used by fish. The more extensive upper tributary passes through an area that is intermittently flooded by beaver ponds (Beaver Dam Creek), while the smaller lower tributary intersects the mainstem a couple of bends above camp. Smaller, shorter streams and side channels were also examined.

The lower section was surveyed by foot downstream past the old mainstem channel (known as the divergence) to the pool where the new primary channel meets the mountainside on the east side of the valley just below the outlet of Berners Lake. The observer then crossed overland to the old mainstem channel on the west side and continued counting upstream to the divergence, including the Cliff Pool where a small number of spawners often become entrained below the dry wash. The channels on both sides of the valley below the divergence were also counted by helicopter; if no fish were seen in lower sections under good visibility conditions, those areas were sometimes excluded from the foot survey. The East Fork, on the eastern side of the valley (Figure 1) was also surveyed from a point upstream of a major avalanche area due east of camp to the vicinity of the divergence pool. This stream was typically surveyed on the return trip upstream toward camp, but occasionally while traveling downstream.

Although survey efficiency likely increased during the 1980s as a result of the change in the timing and duration of surveys, observer efficiency in counting the fish present at any time in specific locations under given conditions has likely remained relatively constant since 1982. The 1974, 1978, and 1979 counts were made by Phillip Gray (ADF&G Commercial Fisheries Biologist, retired) who conducted the 1982 survey jointly with Leon Shaul. Shaul was the primary observer during 1983–2014.

Foot surveys were conducted only during conditions of low to moderate flow when visibility was suitable. Observers wore polarized sunglasses of either dark or light shading, depending on light conditions. In headwaters sections and tributaries, the observer walked upstream along the bank or in the stream channel, if necessary, to avoid dense vegetation. The observer looked ahead and counted fish individually as they darted downstream past the observer or under banks or logs. Rocks were thrown into suspected hiding areas to drive fish out to be counted. In some small tributaries with overhanging root systems, the observer probed under banks to drive hiding fish out to be counted. Pools with larger schools of over 100 fish were counted repeatedly from different angles and directions until the observer was satisfied with the count, which was often the average of several counts. The observer moved quietly and slowly along the bank above the fish and attempted to count without disturbing them. Counting larger schools was often done by tens or alternately by tens and hundreds for the largest aggregations of over 1,000 spawners. Coho salmon carcasses were rare in most years; however, any dead fish or fresh parts (jaws or pyloric caeca) that could be identified as individual fish were included in the count. A second observer was usually designated to count carcasses and other remains located above water. Species identification was not a serious problem as the coho was the only salmon species (with rare exceptions) present in the area during late October, although schools of smaller, lighter colored Dolly Varden char (*Salvelinus malma*) were present in some areas.

Helicopter surveys of lower river pools were conducted from an altitude of 30–50 m with the sun at the observer's back. The observer wore wear polarized glasses to reduce reflective glare. Helicopter airspeed varied from zero to approximately 50 km per hour depending on terrain, visibility, and the presence or absence of fish. The helicopter was maneuvered so the stream could be continuously viewed from the observer’s side, usually with the window open. When approaching pools frequented by adult coho salmon, the helicopter was first held stationary off to the side of the pool, so that prop wash on the water did not obscure visibility and so that the fish remained somewhat stationary and did not stir up bottom sediment. The helicopter was then moved past the fish or in a circle around them if the observer needed to see their movement to confirm that all fish had been counted.

Escapement Survey Expansion

The escapement survey is extensive, but it is not a total count because of temporal and spatial limitations and potential observer counting bias. Unsuccessful efforts to directly estimate a survey expansion factor with which to estimate total escapement were undertaken in 1988 and 2004. The objective of the first attempt (1988) was to obtain a mark–recapture estimate of total escapement. During 19–28 September, a crew of two technicians captured 228 adult spawners from pools in the lower river (218 by beach seine and 10 by sport rod) and marked 222 of them with an opercle punch prior to release. Different marks were applied to 114 fish released during 19–23 September and 108 fish released during 24–29 September. The total number of fish marked in the lower river was low, largely because of extended periods of high, murky water when fish were difficult to observe and capture. Mark recovery was conducted during the normal late October survey trip near the spawning grounds. The mark recovery rate was very low: only 6 marks from the first release group and 8 marks from the second release group recovered from a total sample of 958 adult spawners. It was impossible to develop a reliable total escapement estimate based on these marking and recovery statistics. Seining pools in the lower river capture area had a substrate of fine sand and silt, which may have resulted in abrasion and loss of protective mucous from fish captured and brought near shore in the beach seine. Fungus was observed in opercle marks of some adults in the recovery sample. Therefore, while the number of adults marked was low, we suspect that delayed mortality during the month between marking and recovery may also have contributed to the low marked rate among spawners in the upper river.

Figure 6.–Preparing to sample adult coho salmon captured with a beach seine (left; ©2014 ADF&G/photo by Scott Forbes) and spawners observed holding in a pool during the survey count (right; ©2014 ADF&G/photo by Leon Shaul).

The objective of the second attempt (2004) was to radio-tag fish in the lower river and track them to their final destination in order to estimate the fraction of the total spawning population that was present in surveyed areas. Sixty-one fish were captured and radio tagged in the lower river primarily with the use of a drift gillnet and, to a lesser extent, rod and reel. This attempt was also relatively unsuccessful, due largely to an atypical distribution of fish during the 2004 survey. A substantially larger than normal proportion of the escapement was counted from a helicopter in locations just downstream of the normal foot survey area. The large concentration of radio signals coming from this limited area made it very difficult to pinpoint the location of individual fish to specific channels or ponds from the helicopter. A positive outcome of the project was that there was no indication that radio-tagged fish held within or returned to areas that were not normally examined during the annual escapement survey, either by foot or helicopter.

Calibration Based on Exploitation Data

The presence of a coho salmon indicator stock at Auke Creek, 56 km south of the Berners River (Shaul et al. 2011), provides another potential method to calibrate the Berners River survey count to total escapement. We estimated the average proportion of fish counted during the survey based on the assumption of an equal troll fishery exploitation rate between the Berners River and Auke Creek populations. Accounting for the Auke Creek stock was complete, with a 100% tagging rate on smolts and complete adult enumeration through a solid permanent weir structure (Lum 2003). The close geographic proximity of the Berners River and Auke Creek stocks offers the possibility that they are exposed to nearly identical exploitation rates in the mixed stock troll fishery located a substantial distance seaward of both systems. To evaluate this assumption, we compared the average temporal and spatial distributions of the stocks in the troll fishery during 1990–2014 (excluding 1992, when a direct estimate of troll exploitation rate was unavailable for Auke Creek). The proportionate distribution of CWT recoveries (expanded by quadrant and statistical week[1]) across statistical weeks was used to compare temporal similarity between the populations. Spatial similarity was examined by comparing the average distribution of observed (unexpanded) CWT recoveries across 6 groups of fishing districts during the 24-year period. Temporally and spatially consistent patterns of harvest would suggest that the exploitation rate by the troll fishery was likely approximately equal between the two stocks.

Contingent on results of this comparison, we went on to develop an expansion factor for annual survey counts. Annual escapement survey efficiency (Eff_i) is described by the following relationship:

$$Eff_i = \frac{Ns_i}{Nt_i}, \qquad (9)$$

where

Ns_i = unweighted survey count of Berners River coho escapement in year i;

Nt_i = total spawning escapement in year i;

Nt_i can be estimated as follows, contingent upon an assumed equal troll exploitation rate between the Berners River and Auke Creek populations:

$$\hat{N}t_i = \left(\hat{C}TROLL_i \big/ \hat{A}ukeTrRate_i \right) - \hat{C}SUM_i, \qquad (10)$$

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[1] ADF&G statistical weeks are numbered sequentially starting from the beginning of the calendar year, and start on Sunday at 12:01 a.m. and end the following Saturday at midnight.

where

$AukeTrRate_i$ = troll fishery exploitation rate on the Auke Creek stock in year *i*, based on CWT recoveries;

$CTROLL_i$ = catch of Berners River coho salmon by the commercial troll fishery in year *i*; and

$CSUM_i$ = total catch of Berners River coho salmon by all fisheries in year *i*.

Annual escapement survey efficiency (Eff_i) is therefore estimated as follows:

$$\hat{E}ff_i = \frac{Ns_i}{\left[\left(\hat{C}TROLL_i \middle/ \hat{A}ukeTrRate_i\right) - \hat{C}SUM_i\right]}, \tag{11}$$

In theory, estimates used to represent total escapement to the Berners River for population analysis could be based on the annual estimates of survey efficiency generated in this fashion. In practice, however, annual estimates of Eff_i using equation 11 can be variable due to sampling error in the CWT-based estimates, particularly in years of more intensive non-troll exploitation when error in fishery contribution estimates is magnified in resultant estimates of survey efficiency (Eff_i) and spawning escapement (Nt_i). Also, although 100% of Auke Creek smolts were marked with CWTs, statistical precision in the estimated exploitation rate was limited by the relatively small size of the population, which averaged fewer than 6,000 smolts. Testing indicated that variation in input variables was magnified in estimates of Eff_i computed using equation 11. We concluded that this leveraging effect was likely to introduce substantially more error in annual estimates of Eff_i compared with actual variation in the proportion of spawners counted. We addressed the influence of statistical variation on estimates of Eff_i by computing a single universal survey expansion factor ($\hat{E}XP$) for all counts made during a period when survey methods were consistent and the trend in survey efficiency appeared stable.

Changes in methods and timing of surveys since the early 1980s suggest that pooling survey efficiency estimates over the entire data series might introduce bias to estimates in different periods. Earlier (pre-1987) surveys that were conducted while traveling downstream over a period of several days likely accounted for a lower fraction of the total escapement because some fish moved upstream at night and were not counted during the survey. In addition, the timing of the survey was shifted progressively earlier for a period of years after 1982, in an effort to target a peak count when most fish were holding in pre-spawning aggregations where they could be counted and before a substantial number of fish had been removed from spawning areas by predators. Although the strategy of surveying earlier may have resulted in an under-count of late migrants in some years, it likely increased overall survey efficiency.

A substantial increase in precision of Berners River fishery contribution estimates (following the transition from juvenile to smolt marking) was another factor in favor of restricting expansion of survey counts to more recent years. After considering these factors and evaluating the trend in $\hat{E}ff_i$ (Figure 11), we elected to average $\hat{E}ff_i$ values during 1989–2014, and to compute a single universal expansion factor ($\hat{E}XP$) for all survey counts during the period.

The universal expansion factor (*EXP*) was calculated as the inverse of the average of estimates of survey efficiency ($\hat{E}ff_i$) for the period from 1989–2014, excluding 1992:

$$\hat{E}XP = \frac{\sum i}{\sum Eff_i}. \qquad (12)$$

Annual estimates of total escapement (Nt_i) used in the population analysis were then generated by multiplying the annual survey count (Ns_i) by the expansion factor:

$$\hat{N}t_i = \hat{E}XP(Ns_i). \qquad (13)$$

Biological Sampling of Escapement

Fish were captured with a 13-m long beach seine (4.6 m deep) and sampled for coded wire tags and age, length, and sex (Figures 6 and 7). In the earlier years of the study, the coded wire tag sampling objective was to examine 1,500 adults. The proportion of tagged fish in the escapement increased substantially after 1990 and, as a result, the sampling objective was reduced to a minimum of 1,000 adults. Additional fish above the minimum were sampled if time allowed. The ability to capture fish for sampling depended on spawner abundance, water level, and access (with the beach seine) to concentrations of fish in pools with minimal woody debris. A three-person crew deployed the beach seine in holding pools. Adults that were captured in the seine were marked with a partial dorsal fin clip using wire cutters and examined for a missing adipose fin that indicated it was tagged. If the fish was not adipose-clipped, it was marked with a dorsal fin clip and released. Prior to 1990, all adipose-clipped fish were sacrificed and the heads (along with length and sex data) were sent to the ADF&G Mark, Tag and Age Laboratory (MTA Lab) for tag recovery and decoding. Later, a field detector (initially trough-type and later wand-type) was used to examine each adipose-clipped fish for a tag, and only those that did not produce a positive signal were sacrificed and examined at the MTA Lab. After 1997, adult spawners that produced a weaker than normal signal on the detector were sacrificed for tag recovery and matching age-sex-length sample, as were those that produced a signal from the area of the back posterior to the dorsal fin (indicating a back tag injected in a marked smolt). A weak signal and/or a back tag indicated that the fish likely contained a half-length CWT implanted as a newly emerged fry for aging validation.

Age-length-sex samples were taken from a sample of approximately 600 fish caught in the beach seine. Each fish was placed in a padded measuring trough and measured from mid eye to fork of tail (MEF) to the nearest millimeter. Sex was determined from examination of external dimorphic sexual maturation characteristics, such as kype development, belly shape, and trunk depth, and presence or absence of an ovipositor. The length and sex were recorded. Four scales were taken from the left side of the fish approximately two rows above the lateral line along a diagonal downward from the posterior insertion of the dorsal fin to the anterior insertion of the anal fin (INPFC 1963). Scales were mounted on gum cards and impressions later made in cellulose acetate (Clutter and Whitesel 1956).

Estimation of Age Composition

All smolt and adult scale samples were analyzed and aged by the same technician, Molly Kemp. Total adult returns by brood year were estimated by multiplying the estimated total return by the proportion of readable adult scales collected from the escapement that were assigned to each of three freshwater age categories. Aging of Southeast Alaska coho salmon has long been accompanied by substantial uncertainty. In order to help address this problem, an aging validation study was initiated at the Berners River beginning in 1996. The scale reader, Molly

Kemp, studied scales from resultant known-age smolts and adults to calibrate her aging technique. She then re-aged the historical adult scale collection, including samples used in the spawner-recruit analysis by Clark et al. (1994).

Aging Validation Study

During 1996–2013, up to 6,200 newly emerged fry (fish ≥38 mm snout to fork length) were marked annually with half-length CWTs and released into rearing habitat, primarily in Shaul Pond. The objective was to generate known-age smolts and adults in order to validate aging methods as part of a broader study that included other systems that will be reported upon separately. Fry were captured using a fine-mesh dipnet as they congregated at the margin of the river at the outflows from ponds. Capture and marking of fry was conducted during smolt season, but as a secondary priority to smolt tagging, depending on both the work schedule and availability of fry for capture. Fry were adipose clipped and tagged using a similar procedure to smolt marking, but with the use of a specialized head mold developed specifically for small fish.

In most years, all of the tagged fry were released into Shaul Pond, but during 2000–2005 approximately half of the captured fry were marked with a separate tag code and released into Det's Pond or nearby locations in Brown Slough. A sample of resulting adipose-clipped smolts migrating from Shaul Pond was sacrificed for both CWT and scales in order to generate known-age scale samples. During 1997–2007, an average of 217 (range 130–321) adipose clipped smolts (with healed clips) were sampled annually. During 2008–2013, this number was reduced to an average of 64 (range 37–81) marked smolts in order to allow more marked smolts to survive and be recovered as known-aged adult spawners the following year. Beginning in 2008, tagged smolts that were released were tagged with a full-length CWT in the back (anterior to the dorsal fin) so that they could later be easily identified on the spawning area using a magnetic detection wand waved over the fish's back.

Fry Survival

It was possible to estimate survival of marked fry to smolthood and adulthood as a byproduct of the aging validation study. The total contribution to the adult population by marked fry released into Shaul Pond was estimated by return year by dividing the sum of expanded adult recoveries (in both harvest and escapement) in that return year by the overnight tag retention rate reported for the appropriate tag code. The result was divided by the marine survival rate for Berners River smolts (same return year) to estimate the number of those fish that survived to smolthood and were not sacrificed as smolts for the aging validation study. The number of fish associated with each release group that were sacrificed as smolts was estimated by dividing the number of tags recovered by the overnight retention rate for that code.

Survival to smolthood and adulthood for each group of fry released into Shaul Pond was estimated by adding the estimated number of adipose-clipped smolts from the release group that migrated from the system to the number sacrificed as smolts during migration (across all sea-entry years), and dividing the result by the total number released of adipose-clipped fry associated with the same tag code.

Estimation of Per Capital Egg Biomass

Methods used in spawner-recruit analysis commonly presume per capital reproductive potential to be constant. We determined that variation in average reproductive capacity should be included in the analysis because the proportion of females in the spawning population and their fecundity has varied substantially with marine growth and survival (Shaul and Geiger 2016).

Per capita reproductive potential was assumed to be proportionate to per capita egg biomass (PCEB). We used an average relationship between egg biomass (EB) and female length from two British Columbia coastal streams, Mamquam River and Tenderfoot Creek (Fleming and Gross 1990), and converted the postorbital-hypural body length used in that study to MEF length based on the conversion equation for coho salmon reported by Pahlke (1989).

Letting MEF denote the mid eye to fork length (mm), the following is the conversion relationship applied to the Berners River: $EB = 2.33 \times 10^{-7}\ [MEF]^{3.39}$. Predicted egg biomass based on average female length was multiplied by the proportion of females in the adult population to estimate PCEB, which was then converted to a PCEB index by dividing the annual value by the average for all 26 brood years from 1989 through 2014. A separate PCEB index was computed for 1990–2014 for the analysis by Shaul and Geiger (2016).

Figure 7.–Preparing to measure and sample an adult male coho salmon (©2014 ADF&G/photo by Scott Forbes).

ESTIMATION OF HARVEST

Methods described in Bernard and Clark (1996) were used to estimate the harvest of coho salmon from the Berners River using information from stratified harvest sampling of marine commercial and recreational fisheries throughout Southeast Alaska. The sample goal was to inspect at least 20% of the total harvest of coho salmon within time/area strata for missing adipose fins, indicating the likely presence of a CWT. Heads were removed from fish missing their adipose fin and sent on a weekly basis to the MTA Lab in Juneau to test for the presence of a valid wire tag. Data from tags were decoded and entered into a coast-wide database. Commercial harvest data for the analysis were summarized by ADF&G statistical week and district (for drift gillnet fisheries), by seine area for purse seine fisheries, or by troll period and quadrant for commercial troll fisheries. Troll periods were periods of time bounded by regulatory changes and varied from year to year. Data on recovery of tags from recreational fisheries were obtained from reports provided by the MTA Lab and summarized by biweek and fishery. Resulting estimates of the harvest of tagged fish from the Berners River were divided by the proportion tagged (Θ) among fish sampled in the escapement to estimate the total contribution of Berners River fish to the harvest. We did not estimate freshwater sport harvests, which are indicated by statewide sport harvest survey results to occur at trace levels that are impossible to accurately estimate.

ADULT ABUNDANCE, EXPLOITATION RATE, AND MARINE SURVIVAL

Estimates of run size (N_A) of 1-ocean adult coho salmon returning to the Berners River and the associated exploitation rates (U) in commercial and sport fisheries are based on the sum of estimates of harvest (H) and escapement (E):

$$\hat{N}_A = \hat{H} + \hat{E}, \tag{14}$$

$$\text{var}(\hat{N}_A) = \text{var}(\hat{H}) + \text{var}(\hat{E}), \text{ and} \tag{15}$$

$$\hat{U} = \frac{\hat{H}}{\hat{H} + \hat{E}}. \tag{16}$$

Variance for equation 16 was approximated with the delta method (Seber 1982, p. 8) to be:

$$\text{var}(\hat{U}) \cong \frac{\text{var}(\hat{H})\hat{E}^2}{\hat{N}_A^4} + \frac{\text{var}(\hat{E})\hat{H}^2}{\hat{N}_A^4}. \tag{17}$$

Survival rate of smolts to adults (S) was estimated as:

$$\hat{S} = \frac{\hat{N}_A}{\hat{N}_S}, \tag{18}$$

Variance for equation 18 as approximated with the delta method to be:

$$\text{var}(\hat{S}) \cong \hat{S}^2\left[\frac{\text{var}(\hat{N}_A)}{\hat{N}_A^2} + \frac{\text{var}(\hat{N}_S)}{\hat{N}_S^2}\right]. \tag{19}$$

The proportion of variation in the number of returning adults attributed to freshwater factors (including spawning escapement) reflected in smolt production versus marine survival were estimated based on the proportionate contribution by each stage to the sum of the coefficients of variation squared (CV^2) for both stages.

REMOVAL RATE

The removal rate is defined as the total harvest within a specific fishery divided by the total number of fish available to that fishery. The number of available fish is the total return (N_A) minus fish harvested in preceding fisheries.

The removal rate provides a more accurate measure than the exploitation rate of a fishery's relative impact on escapement in isolation from other fisheries. The advantage of comparing removal rates is that they provide an objective comparison of how relative management changes in specific fisheries will likely affect escapement. For example, in a series of three fisheries that each exert a 25% exploitation rate totaling 75%, a 5% reduction (from 25% to 20%) in the exploitation rate by the first fishery in the sequence will increase escapement by 5% while the same exploitation rate reduction in the third fishery will increase escapement by 10% because the third fishery removes its harvest from the remaining 50% of the original run. Any fish that escape the third fishery will likely enter the system to spawn, whereas half of the savings from the same reduction in the first fishery likely will be reallocated to harvest in the remaining two fisheries, and only half would be expected to pass through to spawn. A comparable 5% reduction in the intermediate fishery would increase escapement by 6.7%. These calculations assume no effort response by downstream fisheries to changes in abundance.

It is necessary to assume a direction of migration in order to estimate removal rates. For this analysis, the direction of migration of Berners River coho salmon was assumed to be the most direct route from the open ocean toward the system of origin through two sequential fishing areas. The removal rate in the first fishing area (R_1) is the same as the exploitation rate in that area (U_1). For subsequent fisheries where $i > 1$, R_i was estimated as follows:

$$\hat{R}_i = \frac{\hat{U}_i}{1 - \Sigma U_{i-1}}. \qquad (20)$$

We estimated the removal rate for only the two primary harvesting fisheries, the commercial troll fishery and the Lynn Canal (District 115) commercial drift gillnet fishery, because the harvest in other marine fisheries (commercial purse seine and drift gillnet, and marine sport) was relatively minor (collectively accounting for an average of <3% of the return) and overlapped geographically with the troll fishery. The removal rate by the troll fishery was assumed to be equal to its exploitation rate because it was the first fishery encountered by returning fish and therefore had access to the entire returning adult population. The removal rate by the Lynn Canal drift gillnet fishery was calculated by dividing the estimated harvest of Berners River coho salmon in that fishery by the sum of the same harvest and the escapement estimate.

SPAWNER-RECRUIT ANALYSIS

We conducted spawner-recruit analysis using total escapement estimates based on expanded survey counts for the 1989–2010 brood years and total adult return estimates during 1992–2014, apportioned to individual brood years. The age composition estimate from a target sample of age-.1 adults in the spawning escapement was used to estimate production by brood year. Adult ages rather than smolt ages were used because adults sampled in the main spawning area were presumed to better reflect the age composition of the population than smolts captured from a mix of capture locations in the lower system, including some smolts leaving specific off-channel rearing ponds.

In order to remove variation in marine survival, which was assumed to be density independent (therefore adding non-useful noise to the predictive relationship between spawners and adult recruits), we adjusted adult returns to reflect a constant average marine survival rate. This was accomplished by dividing estimated total adult production in a particular return year by the corresponding estimated smolt–adult survival rate for that return year, and multiplying the result by the long-term (1990–2014) average survival rate. It is possible that low escapements tend to produce larger smolts that survive better in the ocean and that marine survival is related to some extent to the density of smolts entering the ocean. However, the territorial nature of coho salmon and the fact that most density dependent population adjustment appears to occur in the first summer in freshwater (Crone and Bond 1976) suggests that density effects on smolt size are not great, and also the density of smolts emerging from small, dispersed systems typical of coho salmon may not be high enough or vary enough to have any substantial effect on marine survival. In addition, there appears to be no consistent relationship between smolt size and survival (Holtby et al. 1990).

We evaluated the spawner-recruit relationship by fitting three models to paired estimates of spawning escapement and production, including the Ricker model (Ricker 1975) and two variations of the hockey stick model, the simple (generalized) hockey stick (HS) and the logistic hockey stick (LHS) models (Barrowman and Myers 2000), which transition from a proportionate response by production to escapement (at low population sizes) to a constant return (independent of escapement) above a fixed reference point. The Beverton-Holt model (Beverton and Holt 1957) and bent hockey stock (BHS) model (Shaul et al. 2013) were initially also tested.

The Beverton-Holt and BHS models are appropriate for data series that show an overall positive relationship between escapement and production above escapement that produces maximum sustainable yield (*MSY*) or S_{msy}. These models have proven most suitable for Southeast Alaska coho salmon populations at Ford Arm Creek and Hugh Smith Lake (Shaul et al. 2009, 2013, and 2014). However, this was not the case for the Berners River for which these models provided poorer fits to the data series compared with the HS and LHS models. The HS is a simple piecewise linear spawner-recruit model that is intuitively consistent with the freshwater life history of the coho salmon, including the territorial nature of juveniles. It assumes that freshwater survival is constant (independent of density) up to a critical spawner level, above which the habitat becomes fully seeded and production remains constant irrespective of spawner density. Predicted return (R) when escapement (S) is between zero and carrying capacity (K) is proportionate to escapement and the return/spawner is equal to intrinsic productivity (α) throughout that range:

$$R = \alpha S\,. \tag{21}$$

At escapements above the optimum level (S_{msy}), returns remain constant:

$$R = \alpha S_{msy}\,. \tag{22}$$

The abrupt transition in the simple hockey stick model may not be biologically realistic, so we also fitted a variation called the “logistic” hockey stick (LHS) that allows for a more gradual transition to density dependence. This model and methods for fitting it are also presented by Barrowman and Myers (2000). As escapement increases, the LHS model allows for a smooth transition rather than an abrupt shift from a stable return/spawner to a constant total return.

We first fitted the simple hockey stick model by plotting the matched spawner and recruit estimates using the Excel spreadsheet chart function with the ascending slope forced through the origin. A regression model was thus fitted to the data points beginning at the lowest observed *S* and adding each higher data point in sequence. Carrying capacity (*K*) of each succeeding model was computed as a constant average return associated with all levels of spawning escapement above the highest escapement included in the regression model. At each step, the next lowest *S* observation was dropped from the calculation of *K* and transferred to the regression model. The least sum of squares was measured at each step until the best fit was identified. The procedure was conducted with the entire data series to ensure that the overall best fit was achieved rather than one based on a localized minimum sum of squares.

The optimal α and S_{msy} parameters derived from fitting the simple (HS) model were then used as a starting point for the logistic model:

$$R = \alpha\theta\mu(1+e^{-1/\theta})\left[\frac{S}{\theta\mu} - \log\left(\frac{1+e^{(S-\mu)/(\theta\mu)}}{1+e^{-1/\theta}}\right)\right], \qquad (23)$$

where μ is the inflection point of spawner abundance (S_{msy} from the generalized model) and Θ is the smoothness parameter used to tune the model for optimal fit. In some cases, the logistic model offers no improvement in fit and reverts to the shape of the generalized model.

The Ricker model has an over-compensation feature that predicts declining production from higher levels of escapement above a peak population size. However, over-compensation appears inconsistent with most spawner-recruit data series for coho salmon (Barrowman et al. 2003; Shaul et al. 2013). While the HS model is biologically more appropriate than the Ricker model for coho salmon (Bradford et al. 2000), we included the Ricker model for comparison because of its much wider general use for salmon populations.

FISHERY SELECTION

Returning Berners River coho salmon are exploited intensively by two primary harvesting fisheries, including a troll fishery in outer coastal waters and passages, and the Lynn Canal drift gillnet fishery which is conducted in close proximity to the Berners River (Figure 2). Much smaller harvests by marine sport and commercial purse seine fisheries and other drift gillnet fisheries have each removed fewer than 1% of the returning fish, on average. Of these fisheries, the gillnet fisheries have been found to affect size and reproductive potential of spawners and, over time, to induce microevolutionary change in salmon populations (Kendall et al. 2014). In order to estimate size selection in drift gillnet fishery, we reconstructed the pre-fishery length distribution and computed average length (following Kendall and Quinn 2012). Extension of the analysis to the troll fishery was precluded by continued growth of fish after exposure to the troll fishery but prior to entering the river.

Recovery (from the region-wide drift gillnet harvest) of coded-wire-tagged Berners River adults with associated length measurements provided a means for estimating the length composition of the harvest and to reconstruct the length composition of the run prior to exposure to the drift gillnet fishery. For the period 1990–2014, a total of 8,475 tagged adult Berners River coho salmon (average 339 fish per year) were recovered (with associated length measurements) from a target weekly sample of 20% of the drift gillnet harvest. Length measurements associated with spawners (average 602 samples per year) and with tagged fish recovered from the drift gillnet harvest across all districts were assigned to 10 mm length categories to estimate separate proportional size distributions for harvest and escapement, respectively. In 2006, MEF replaced snout to fork (SNF) as the standard length measurement taken from adipose clipped fish sampled from fishery harvests. For the years prior to 2006, an appropriate conversion equation (Pahlke 1989) was applied to estimate MEF length based on SNF length.

Sex was not determined for fish sampled from the catch, so estimation of the effect of the harvest on the sex ratio of the escapement required an assumption that fish of the same length were subject to equal fishery selection regardless of sex. Since girth is an important factor in vulnerability of fish to a gillnet fishery, we examined the relationship between girth and sex of pre-spawning adults in the Berners River to evaluate potential bias in estimates of the sex ratio of the catch based on assumption that fishery selectivity is determined by length, independent of sex. In 2014, we collected matching girth measurements at the anterior insertion of the dorsal fin from 68 males and 38 females seined from pools in the upper river. The samples indicated slightly smaller girth in females, and the difference increased with increase in fish size, but differences between the sexes were small relative to differences in girth associated with length, particularly in fish in smaller size ranges where size selectivity was most evident (see results).

To evaluate the influence of size-selective fishing patterns in the drift gillnet fishery on the size distribution and sex ratio of fish on the spawning grounds, we first calculated the proportion of available fish of each length that were harvested annually (1990–2014) in the drift gillnet fishery following methods adapted from Kendall and Quinn (2012). We estimated the annual removal rate (*R*, the proportion of available fish caught) by year (*y*) and length (*l*) as:

$$R_{y,l} = \frac{C_{y,l}}{C_{y,l}+E_{y,l}}, \tag{24}$$

where $C_{y,l}$ was the number of fish caught in the drift gillnet fishery of length *l* in year *y* and $E_{y,l}$ was the number of fish of that length that escaped in that year. Average fish length was the average length of all fish in the total run available to the drift gillnet fishery (catch and escapement).

In a given year we multiplied the proportion of females within each 10 mm length category in the escapement by the estimated catch of fish in the same length category under the assumption that the occurrence of each sex (*s*) was equal at a given length (*l*) in both the catch and escapement:

$$C_{s,l} = \frac{E_{s,l}R_l}{1-R_l}. \tag{25}$$

An annual linear selection differential by sex ($LSD_{s,y}$) was calculated as the difference in the average length of fish of the same sex in the pre-fishery total run ($\bar{L}_{T_{s,y}}$) and in the escapement ($\bar{L}_{E_{s,y}}$):

$$LSD_{s,y} = \bar{L}_{E_{s,y}} - \bar{L}_{T_{s,y}}. \tag{26}$$

Linear regression analysis was used to examine the sex-specific linear selection differential ($LSD_{s,y}$) as a function of the annual removal rate (R_y) by the drift gillnet fishery.

RESULTS AND DISCUSSION

NUMBER OF FISH TAGGED

During 1972–1988, the number of fish coded-wire-tagged in years when tagging was conducted averaged 10,373 presmolts and ranged from 7,826 presmolts in 1981 to 15,326 presmolts in 1984 (Appendix B3). These fish were all captured in standard minnow traps deployed in Brown Slough and adjacent off-channel habitats and in Det's Pond, a large pond on the east side of the valley (Figure 1).

In 1989, the first year of smolt tagging, 6,438 smolts were tagged primarily from Det's Pond (Appendix B2). In 1990, the number tagged increased to 23,598 smolts following the discovery of a major rearing pond complex (Shaul Pond) on the west side of the valley (Figure 3). During 1989–1991, minnow traps were employed to catch a mixture of smolts and rearing presmolts, in addition to the smolt catch in trough traps. These fish were excluded from the marked sample used to generate Chapman estimates of total smolt production, because they included a mix of fish, including smaller size classes (<80 mm SNF length) tagged with a separate code, that did not migrate to sea in the year when they were marked.

After the initial exploratory year (1989), the number of smolts marked averaged 29,525 smolts during 1990–2013 and ranged from 10,945 smolts in 2008 to 58,262 smolts in 2000. Capture effort remained more constant during this time, but more fish escaped in some years due to flood events or collapses in Beaver Dams. The catch in Brown slough was more variable, depending on changing flow patterns and beaver activity. The incline plane trap was first deployed in the slough in 1992 and was only moderately effective in most years. During 2000–2002, construction of a beaver dam across the upper portion of Side Pond (Figure 1) created an opportunity to employ a trough trap in the area of the main flow down Brown Slough. A long 0.64 cm plastic mesh fence was used to direct fish away from the area of a highest flow across the dam into a trough trap installed on a minor spillway. This installation was most effective in 2000, resulting in a record catch of 31,281 smolts from Brown Slough (Appendix B1). The number of smolts captured from Shaul Pond, and in total from all sites, decreased markedly after 2005.

Tagging of emergent fry (<39 mm SNF length) for the aging validation study resulted in 1,340 to 6,178 (average 4,345) fry tagged annually (Appendix B3). These fry were released in Shaul Pond during 1996–1999 and 2006–2013, but were apportioned (and tagged with separate codes) between Shaul Pond and Det's Pond during 2000–2005.

TAGGING RATE

After tagging effort stabilized beginning in the 1990 smolt year, the proportion of adipose-clipped adults in the escapement averaged 17.5% (range 8.9–30.6%) for 1991–2014 adult returns (Appendix A2). The high proportion marked during these years resulted in solid smolt estimates with moderate relative precision (95% confidence) and averaged about 14% (Appendices B2 and B3).

FISHERY CONTRIBUTION

During 1974–2014, the estimated contribution of Berners River coho salmon to all fisheries averaged 16,618 fish but varied over 10-fold from 3,051 fish in 2012 to 57,449 fish in 1994

(Appendix A4). On average, commercial trollers took the largest average harvest of 8,904 fish (range 2,071 fish in 2012 to 27,339 fish in 1994). Drift gillnetters operating primarily in Lynn Canal accounted for the second largest average harvest of 7,223 fish (range 929 fish in 2012 to 27,909 fish in 1994). Far smaller harvests of Berners River coho salmon were estimated in purse seine fisheries directed at other salmon species (average 195 fish; range 0–1,381 fish) and marine sport fisheries (average 295 fish; range 0–1,080 fish).

These estimates were based on 52 to 2,644 observed fishery recoveries of Berners River tags annually in random samples taken from commercial and sport fisheries (Appendix D1). The number of random fishery recoveries within defined harvest strata increased greatly after the switch to smolt marking, from an average of 101 tags (range 52–159) during 1974–1989 to 723 tags (range 159–2,644) during 1991–2014.

During 1990–2014 the Berners River contributed an average of 13.0% of the total drift gillnet harvest of coho salmon in Lynn Canal (District 115). The Berners River is representative of later returning stocks in the district—the numerical contribution typically peaked in mid-September, and the average proportionate contribution by the stock increased from 5% in late August to 18–19% during late September and early October (Figure 8).

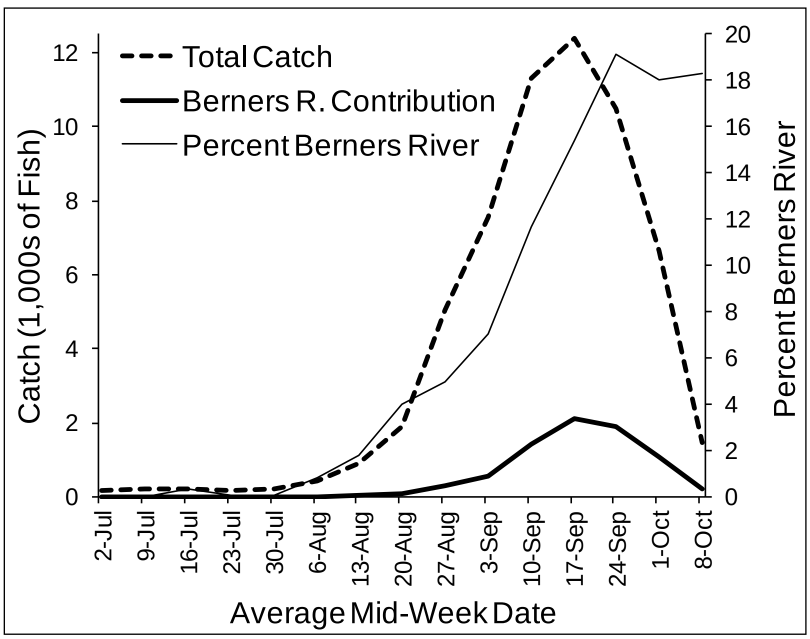

Figure 8.–Average coho salmon catch in the traditional Lynn Canal commercial drift gillnet fishery and the average Berners River catch and percent contribution to the total harvest, 1990–2014.

ESCAPEMENT SURVEY COUNTS

Survey counts of the number of spawners in the Berners River during 1982–2014 varied widely from 1,752 fish in 1986 to 27,700 fish in 2002 (Appendix A1). Conditions for surveys varied from year-to-year, but the poorest conditions were encountered in the year of the lowest count (1986) when floods occurring in close sequence necessitated numerous recounts over a 9-day period in order to cover the entire survey area.

In 2002, visibility in the lower portion of the survey area was occluded by glacial silt introduced from a tributary entering from the west by camp. The 18 October survey count of 9,496 spawners in the upper portion of the area above camp was divided by the average fraction of the total count observed in that area during 1990–2001 (0.3428; SE = 0.0493) to arrive at an expanded survey count of 27,700 spawners. The river did not become clear enough to conduct a survey of the lower area before we departed on 24 October and downstream visibility was still inadequate to obtain a complete, comparable count when we returned for another attempt on 1 November. The 1 November count was conducted under poor visibility conditions in lower sections and it was evident that 100s to 1,000s of fish had been removed from the stream, consumed and scattered through the woods along upper reaches. The resultant count of 18,416 fish (of which 9,648 were seen above camp) on 1 November should be considered a very minimal estimate. However, considering timing and visibility limitations, the record direct count during the second survey was consistent with the record (expanded) count of 27,700 fish from the 18 October survey. In 2003, the water remained slightly occluded in the same section but was adequate to obtain a comparable survey count. In 2004, visibility returned to pre-2002 conditions.

The evolution in survey methods during the early to mid-1980s clearly improved counting efficiency by concentrating the survey within a shorter period under uniformly suitable conditions. Also, the shift in survey timing from early November in 1982 to mid- to late October after 1986 likely resulted in counts that were more complete and uniform.

Helicopter counts below the foot survey area seldom totaled more than 10% of the total count. Fish observed in the lower river were typically concentrated in five pools between the confluence with the Lace River and the lower entrance to Brown Slough (Figure 1). Extensive surveys conducted in several years over the remainder of the system (including side tributaries, both major channels and the small inlet stream to Berners Lake) failed to document fish spawning outside of the normal foot survey area, with the exception of Bearkill Creek where a handful of spawners was counted from 1994 to 1997 (this stream was dropped after 1997 because of the low number of fish and risk of close bear encounters, and also because its glacial silt load precludes observation of fish outside of spawning riffles). It is probable, however, that some additional spawning occurs in small tributaries.

EXPANDED SURVEY COUNTS

The most feasible method for estimating average survey efficiency (needed to generate an expansion factor) depends upon CWT-generated harvest estimates and an assumed equal average exploitation rate between the populations in the Berners River and Auke Creek. This assumption is dependent upon closely similar migratory behavior in returning adults.

From a spatial perspective, the average distribution of unexpanded CWTs recovered from the troll fishery shows that the Berners River and Auke Creek stocks were similarly distributed across fishing areas and both were concentrated primarily in the same districts in northern Southeast Alaska (Figure 9). The two stocks also displayed a similar temporal distribution of troll harvest, with a peak from the last week of August to mid-September, after which the troll harvest of the Auke Creek stock decreased slightly earlier, on average, compared with the Berners River stock (Figure 10). Both stocks were relatively late in harvest timing in the troll fishery compared with the overall mixture of harvested coho salmon stocks.

The largest difference in the average geographic distribution of tag recoveries occurred in Yakutat area waters north of Cape Fairweather, where an average of 10.8% of Berners River tags were recovered, compared with 7.4% for Auke Creek. The proportion of recoveries between Cape Fairweather and Cape Spencer (Districts 116, 156, 157) was nearly equal between the stocks, whereas proportionately fewer (3.7% in total) Berners River recoveries (compared with Auke Creek) were recovered from districts south of Cape Spencer (101–115, 150, 152, and 154). Although the Berners River stock exhibited a slightly later, more northward distribution in the troll fishery, the stocks were judged to be temporally and geographically similar enough in their distributions within the broadly distributed troll fishery to assume a negligible difference in their exploitation rate for the purpose of estimating average survey efficiency.

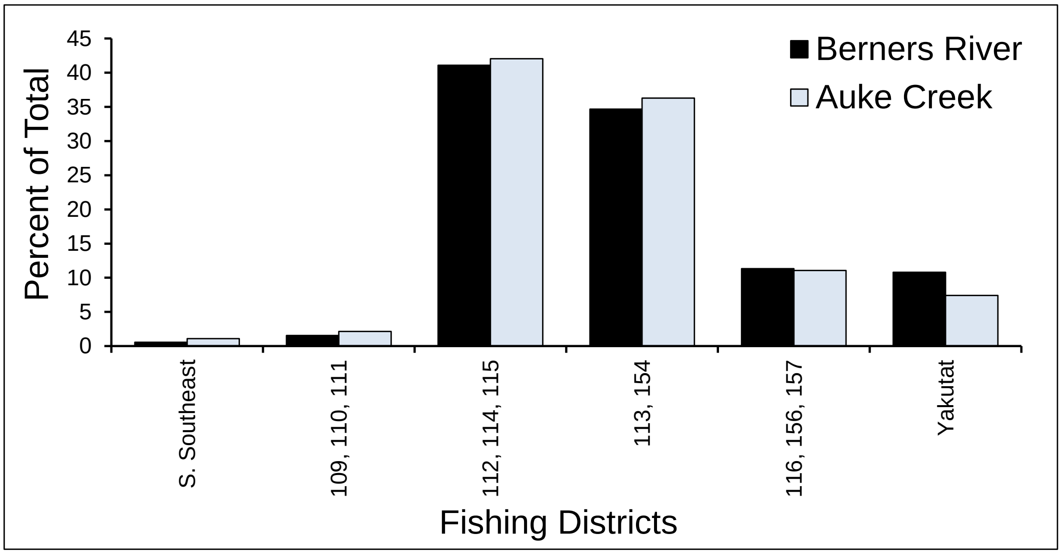

Figure 9.–Average (1990–2014) distribution of unexpanded troll fishery CWT recoveries from the Berners River and Auke Creek coho salmon across groups of fishing districts in Southeast Alaska. The S. Southeast area includes southern Districts 101–108, 150, and 152, and Yakutat includes Districts 181–191.

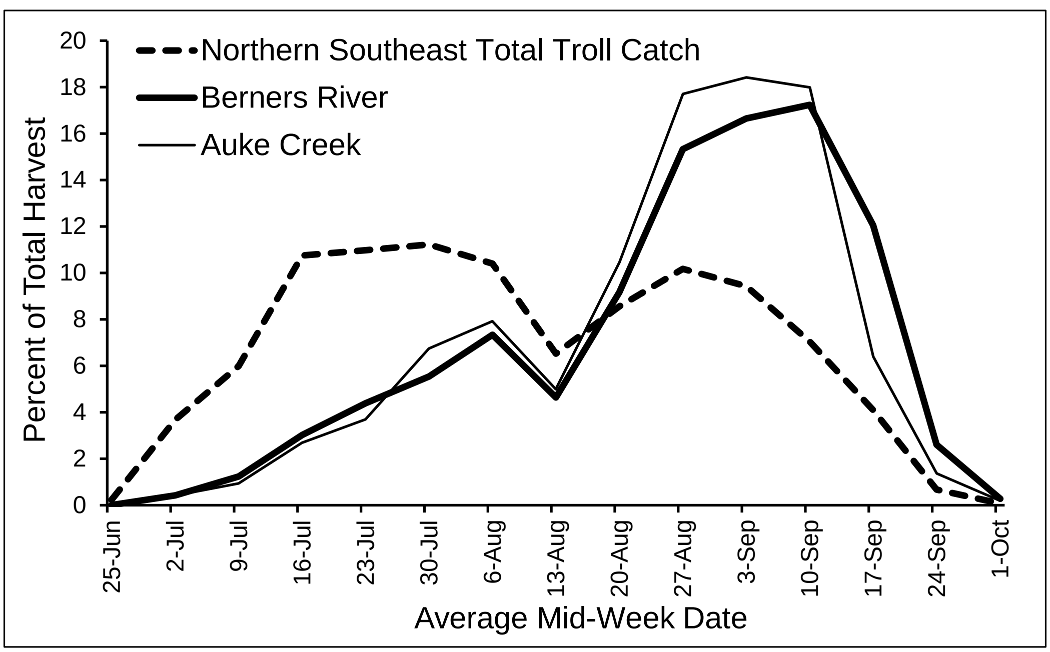

Figure 10.–Average weekly proportion of the total annual commercial troll harvest of Berners River and Auke Creek coho salmon, and the aggregate of all coho salmon stocks, in northern Southeast Alaska, 1990–2014.

Implied survey efficiency ($\hat{Eff}_i$) increased sharply from an average of 30.1% during 1982–1988 before leveling off at an average of 80.6% during 1989–2014 (Figure 11; Appendix A1). The latter period beginning in 1989 coincided with stabilization of survey methods in time, duration and sequence. Based on these considerations, as well as a dramatic post-1989 increase in the annual number of tag recoveries available to generate estimates for Berners River coho salmon, we elected to expand survey counts to total escapement only for the period after 1988.

Annual estimates of implied survey efficiency during 1989–2014 varied substantially (CV = 0.286) from 0.3840 to 1.2458. The Auke Creek troll exploitation rate was based on an average of only 83 observed CWT recoveries from the troll harvest, whereas the harvest estimates for the Berners River were based on larger average samples of 338 tags for the troll fishery and 689 tags for the combined harvest by all fisheries (Appendix D1).

Exploration of the potential effects of statistical error indicated that error in CWT-based harvest and exploitation rate estimates is magnified in the annual estimates of escapement and survey efficiency. In particular, an increase in the exploitation rate by non-troll fisheries (drift gillnet, purse seine, marine sport) increases the extent to which errors in CWT-based estimates of the troll harvest (for Berners River) or troll exploitation rate (for Auke Creek) become magnified in estimates of escapement and survey efficiency. On average, 10% error in the estimated troll harvest of Berners River fish would result in 17.1% error in the escapement estimate, and the resulting error varied substantially from 11.4% in 2012 to 47.3% in 1995.

However, although leveraging of error in the estimator produced annual survey efficiency estimates of questionable utility for producing annual estimates of escapement, the method produced a reasonable universal expansion factor for post-1988 survey counts when implied efficiency is averaged over 25 years. Average implied efficiency ($\hat{Eff}_i$) during 1989–2014 (excluding 1992) was 0.8057, while the resultant survey expansion factor (based on the inverse of average implied efficiency) was 1.2412. Therefore, escapement estimates based on the peak survey count were multiplied by this factor to reconstruct total adult returns, estimate marine survival rates, and develop spawner-recruit models for the 1989–2010 brood years.

UNADJUSTED ADULT RETURNS

Total return estimates based on the unexpanded peak survey count are available for 1974, 1978–1979, 1982–1983, and 1985–2014 (Figure 12; Appendix A4). Unadjusted run estimates increased from an average of 14,458 fish (range 10,632–18,272 fish) for estimates in the 1970s to 23,238 fish (range 13,954–34,414 fish) in the 1980s, and 36,195 fish (range 15,284–73,369 fish) in the 1990s, then decreased to 22,671 fish (range 8,722–49,818 fish) during 2000–2009 and 18,018 fish (range 8,531–26,648 fish) during 2010–2014.

Management of the Berners River stock and other coho populations in the fall Lynn Canal drift gillnet fishery has varied substantially, depending upon the relative abundance of the two primary target species, chum (*O. keta*) and coho salmon, and the number of boats participating in the fishery. The cumulative fall drift gillnet catch-per-boat-day (CPUE) in Lynn Canal during statistical weeks 36–39 (Figure 13) indicates that fall chum salmon returns (predominantly to the Chilkat River) were relatively abundant during the 20-year period from 1969 to 1988, but chum salmon CPUE declined by 56% (despite lower fishing effort) during the 15-year period (1990–2004) when Berners River coho salmon returns were most abundant.

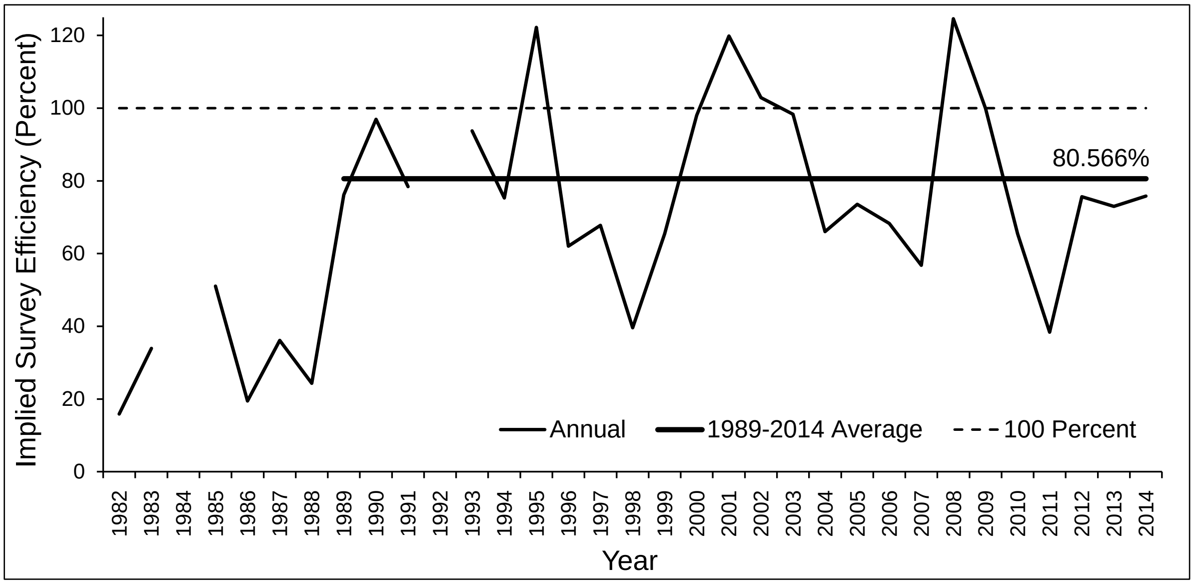

Figure 11.–Implied efficiency of survey counts in accounting for the total coho salmon escapement to the Berners River based on the assumption of an equal troll fishery exploitation rate for the Berners River and Auke Creek stocks. Average implied efficiency $(\hat{Eff}_i)$ is shown for 1989–2014.

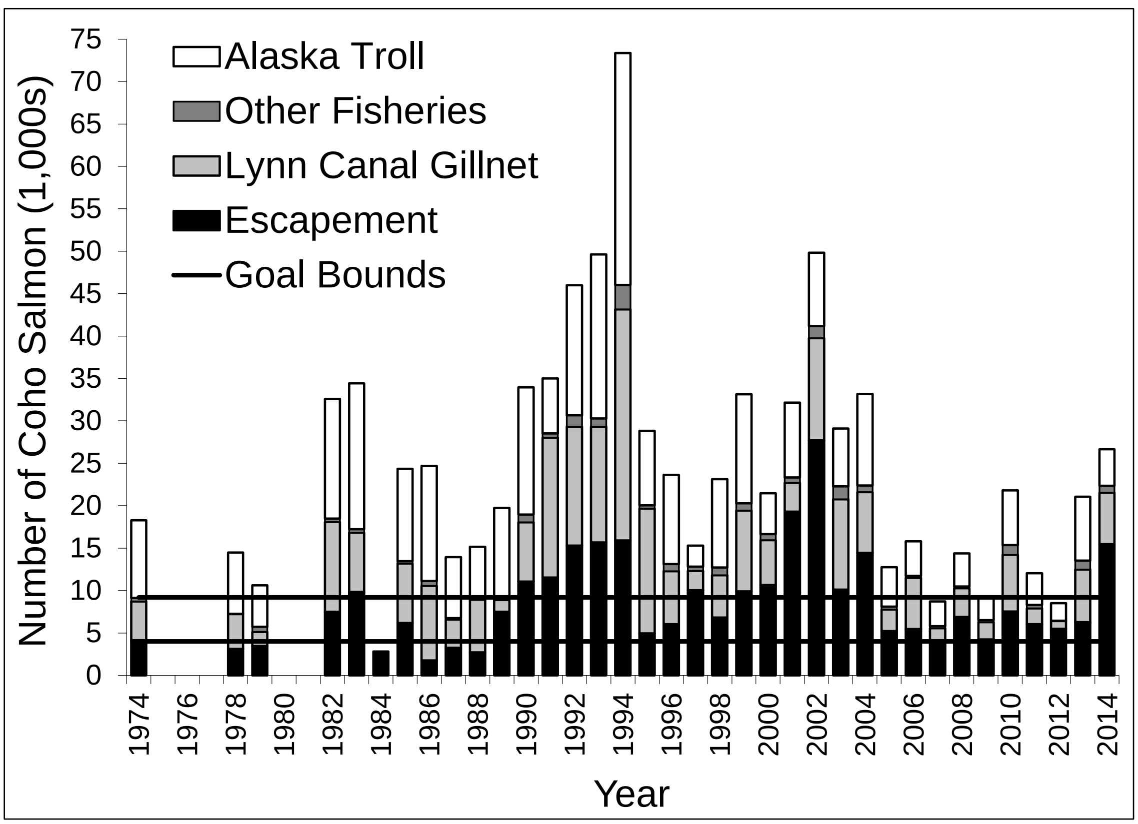

Figure 12.–Estimated harvest by fishery and escapement for the adult coho salmon return to the Berners River, 1974–2014, based on the unexpanded peak escapement survey count and biological escapement goal bounds from Clark et al. (1994). Other fisheries include commercial purse seine and marine sport fisheries and commercial drift gillnet fisheries conducted outside of Lynn Canal (District 115). In 1984, an escapement survey was conducted but harvest was not estimated.

Average fall chum salmon CPUE recovered by 30% during the most recent 10-year period (2005–2014) but remained far below the average of the 1970s and 1980s. The abrupt decrease in chum salmon abundance and increase in coho salmon occurred near a climatic transition in the North Pacific Ocean that some have referred to as a 1989 "regime shift" (Hare and Mantua 2000), and also coincided with initiation of an enhancement program involving the release of millions of fed summer-run chum salmon fry along the western and eastern shores of lower Lynn Canal at Boat Harbor and Amalga Harbor beginning in 1988. Management of the fall drift gillnet fishery shifted abruptly from an emphasis on harvesting chum salmon (while affording some protection for coho salmon) prior to 1989 to exploiting abundant coho salmon returns (while protecting Chilkat River fall chum salmon) from 1990 through 2004. Coho salmon returns decreased beginning in 2005 while chum salmon CPUE showed limited recovery during 2005–2013, before it decreased abruptly in 2014 (Figure 13).

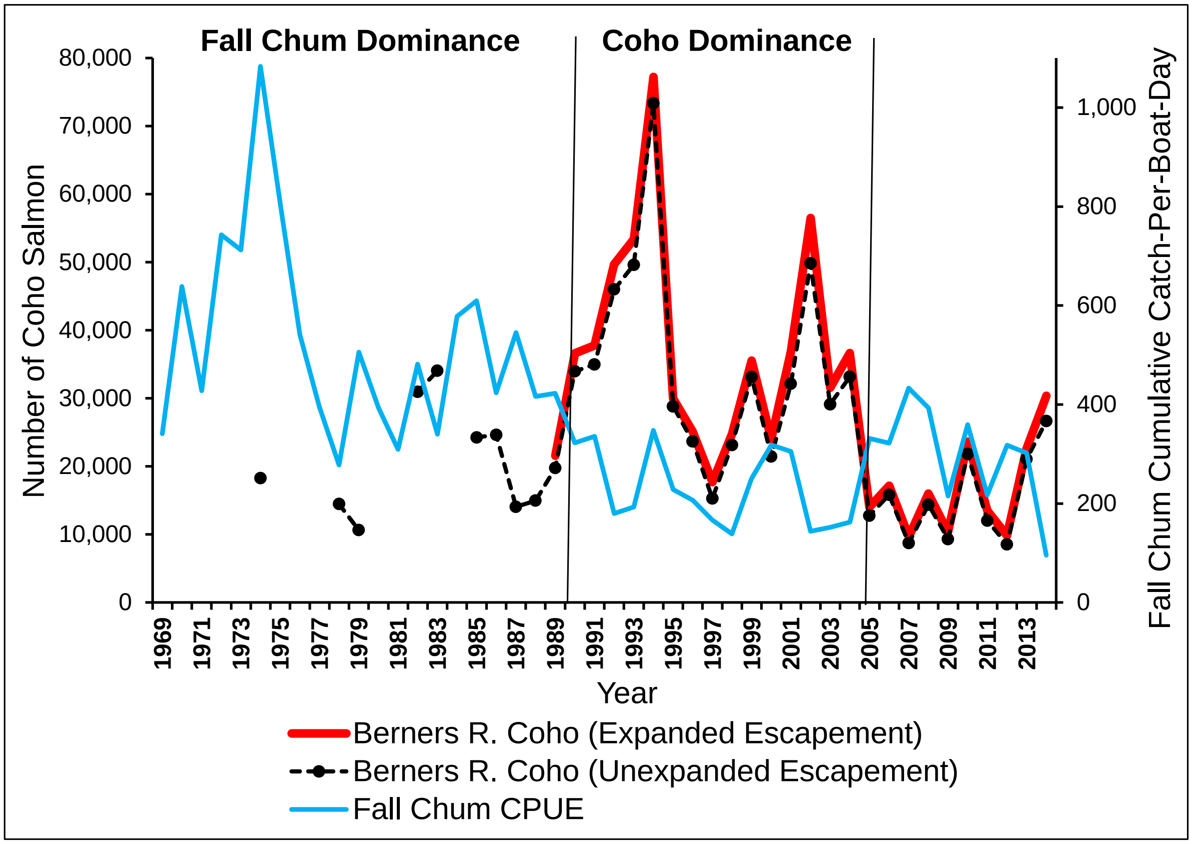

Figure 13.–Estimated number of coho salmon returning to the Berners River based on the unexpanded survey count (1974–2014) and the expanded survey count (1989–2014), and the cumulative catch-per-boat-day of chum salmon in the Lynn Canal commercial drift gillnet fishery (1969–2014).

TOTAL RETURN ESTIMATES BASED ON EXPANDED ESCAPEMENT COUNTS

Total return estimates based on the expanded survey count are available beginning in 1989 (Figure 14). During 1989–2014, the estimated total adult coho salmon return to the Berners River (including harvest and expanded survey count) averaged 29,310 fish and ranged from 9,666 fish in 2007 to 77,209 fish in 1994 (Appendices A6 and D3). Run estimates peaked at an average of 38,225 fish during 1990–2004, before decreasing by 60% during a period of lower returns that averaged 15,193 fish from 2005 through 2013. The 2014 return, estimated at 30,382 fish, represented a marked improvement from the recent period of poor returns.

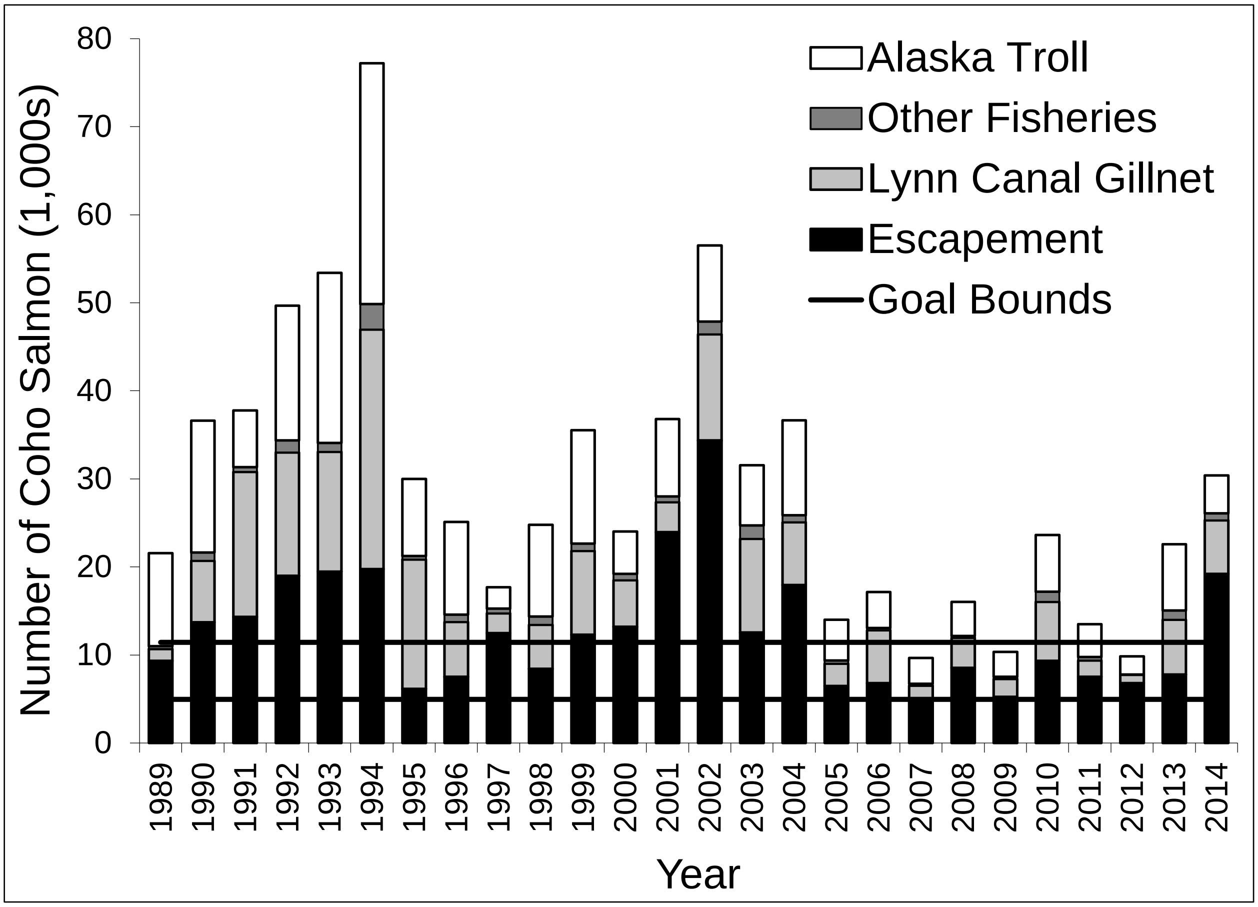

Figure 14.–Estimated harvest by fishery and escapement for the adult coho salmon return to the Berners River, 1990–2014. Other fisheries include commercial purse seine, marine sport, and commercial drift gillnet fisheries conducted outside of Lynn Canal (District 115). Depicted escapement and biological escapement goal bounds are based on the survey count goal (Clark et al. 1994) multiplied by 1.2412.

EXPLOITATION RATES

The total all-fishery exploitation rate averaged 54.6% (range 29.6–79.5%) for coho salmon returning to the Berners River during 1989–2014 (Figure 15; Appendices A7 and D4). The average total exploitation rate on the population decreased markedly between 1989–1999 (62.9%) and 2000–2014 (48.6%), though the average distribution of harvest between troll and drift gillnet fisheries remained relatively stable at 53–55% troll to 45–47% drift gillnet. Although the all-fishery exploitation rate was generally high in the 1990s, the decade average of 63% was influenced by extensive troll and drift gillnet fishery restrictions in 1997 aimed primarily at conserving a weak Taku River coho salmon return. The combined restrictions resulted in a 1997 exploitation rate of only 30%. Under recent lower exploitation rates, the current escapement goal was achieved throughout the 2005–2013 period of decreased returns, with the exception of 2007.

Over the entire 26-year period, the troll fishery accounted for the highest average exploitation rate (28.7%; range 13.9–49.1%), followed closely by the Lynn Canal drift gillnet fishery (23.4%; range 6.3–49.0%), and the combined exploitation rate by other fisheries averaged only 2.6%

(range 0.5–4.9%) of which marine sport, commercial purse seine, and commercial drift gillnet fisheries outside of Lynn Canal accounted for an average of 1.2%, 0.7% and 0.7%, respectively (Appendices A7 and D4).

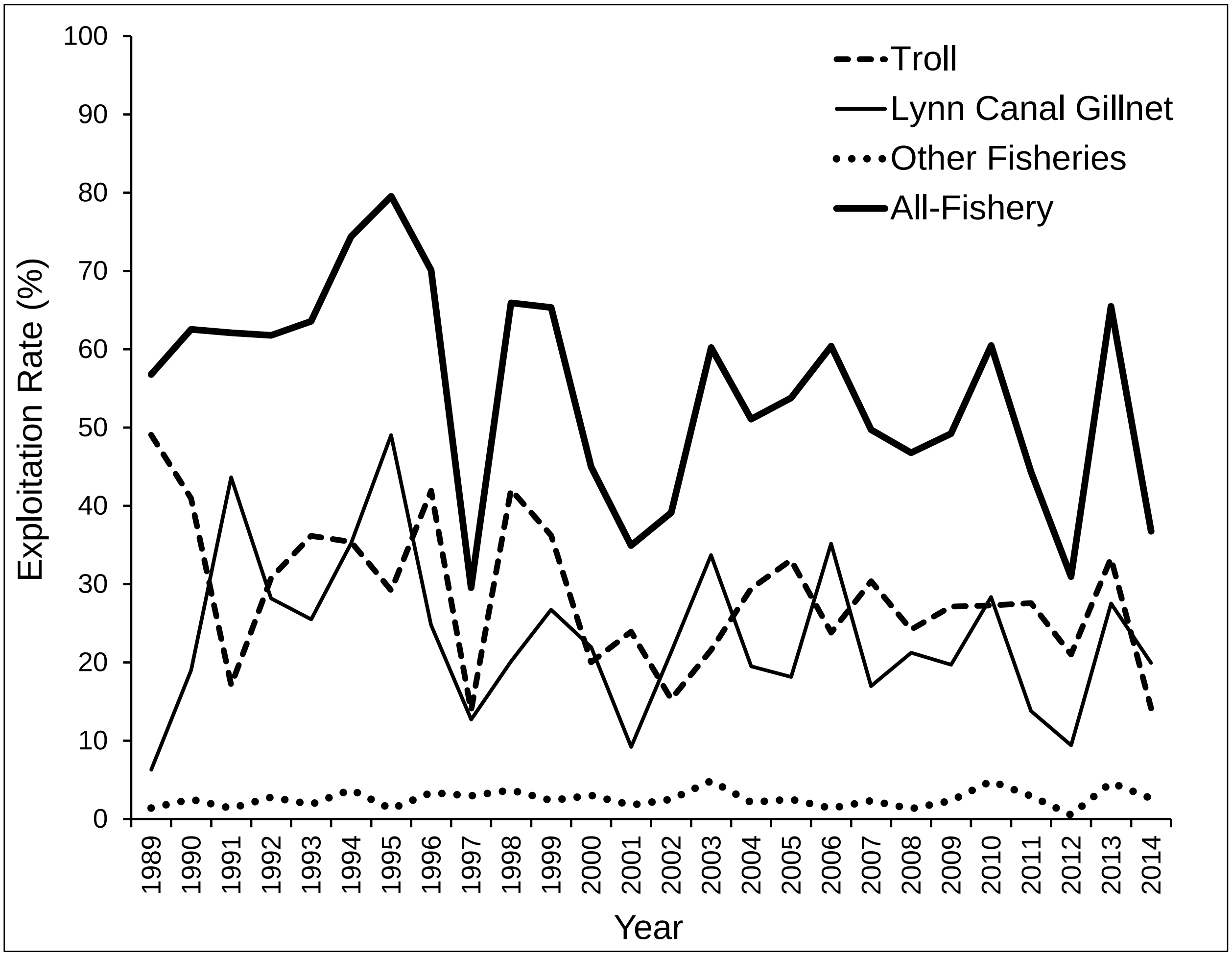

Figure 15.–Estimated average exploitation rate on coho salmon bound for the Berners River by the two primary harvesting fisheries, other fisheries, and by all fisheries combined.

Average weekly exploitation rates peaked at 4.3–4.7% during the last week of August to mid-September in the troll fishery and at 4.8–6.6% in the Lynn Canal drift gillnet fishery during the second to fourth weeks of September, and the average lag between the fisheries was about 2 weeks (Figure 16; Appendix A9). The average troll fishery exploitation rate decreased in mid-August, an artifact of mid-season troll fishery closures of up to 10 days in many years.

REMOVAL RATES

Although the Lynn Canal drift gillnet fishery has harvested a smaller average proportion of the total adult population returning to the Berners River (compared with other fisheries combined), its relative effect on the spawning escapement is similar, because it is the final fishery faced by returning fish, and operates on a population that has already been reduced (by an average of 31%) by previous fisheries.

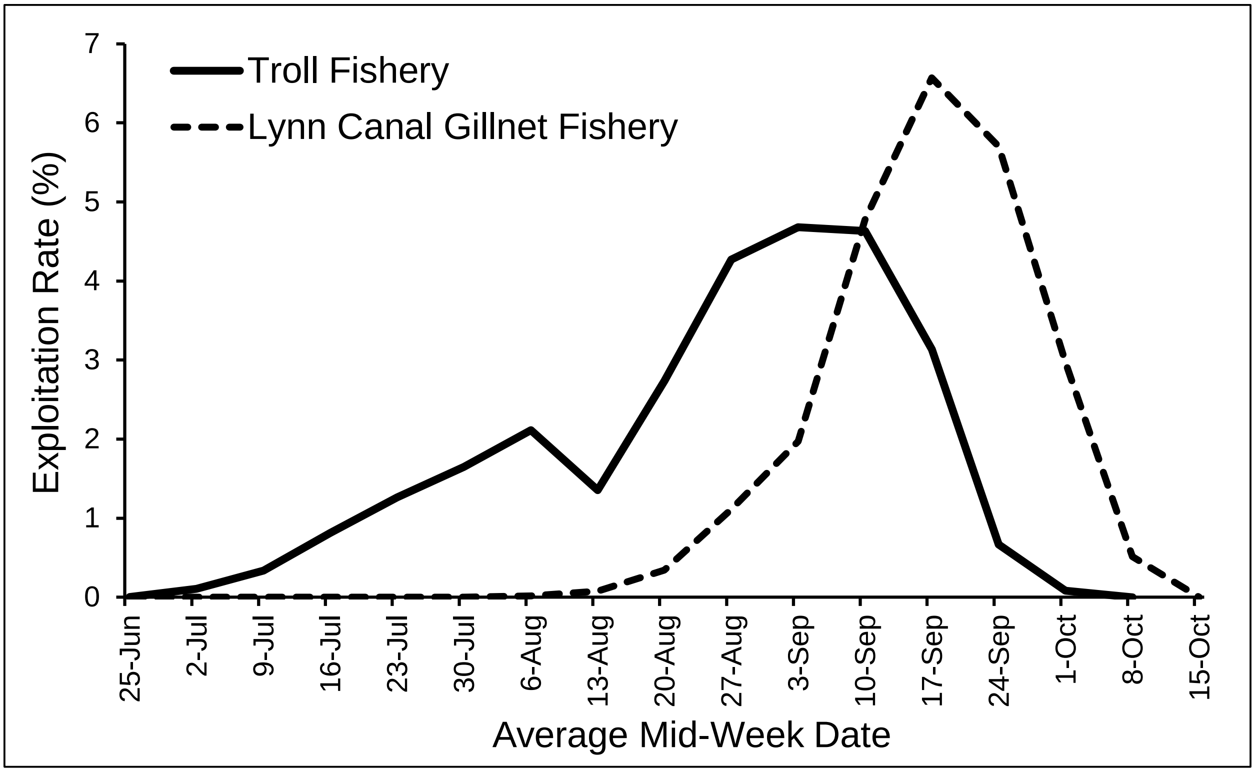

Figure 16.–Estimated average weekly exploitation rate on the Berners River coho salmon return by the commercial troll fishery and Lynn Canal commercial drift gillnet fishery, 1990–2014.

While the troll fishery harvested an estimated average of 28.7% of available Berners River coho salmon, the Lynn Canal drift gillnet fishery accounted for an average of 34.4% of available adults after removal by other fisheries (Figure 17; Appendix A8). In comparing the most recent 15-year period (2000–2014) with the earlier (1989–1999) period of higher all-fishery exploitation rates, the average estimated removal rate showed proportionately similar decreases in the primary harvesting fisheries, from 34% to 25% for the troll fishery and from 41% to 29% for the Lynn Canal drift gillnet fishery, while the overall exploitation rate by all fisheries decreased from 63% to 49%. The peak exploitation/removal rate by the troll fishery (49%) occurred in 1989, whereas the peak removal rate by the Lynn Canal drift gillnet fishery (71%) and by all fisheries combined occurred in 1995, when a substantial number of drift gillnet vessels entered Berners Bay and harvested nearly half of the surviving run in a single opening in statistical week 38, most of which were reportedly harvested during a single night.

During 1997, when fisheries were restricted for a weak coho salmon return to the Taku River, the troll and Lynn Canal drift gillnet fisheries removed only 13.9% and 15.3% of the Berners River stock available to each fishery, respectively. Excluding 1997, the average all-fishery exploitation rate in the 1990s was 67%, and the Lynn Canal drift gillnet fishery had a greater average influence on escapement (average removal rate 47%) compared with the troll fishery (average exploitation/removal rate 34%). During the subsequent period of generally lower exploitation (2000–2014), the average removal rate by the Lynn Canal drift gillnet fishery decreased proportionately more but still remained higher at 1.2 times the removal rate by the troll fishery compared with a ratio of 1.4 to 1 in the 1990s.

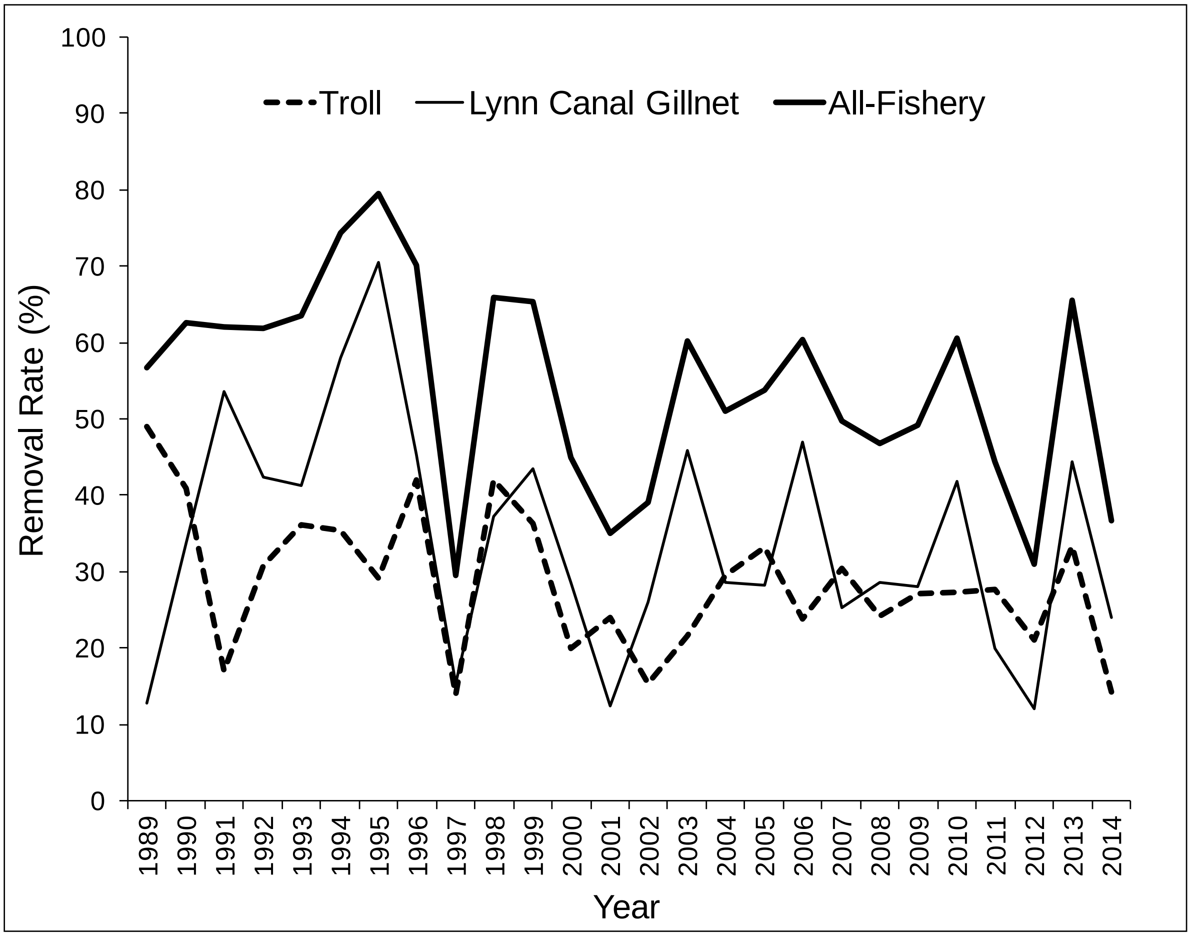

Figure 17.–Estimated average removal rate of surviving coho salmon bound for the Berners River by the two principal harvesting fisheries and by all fisheries combined.

Timing of fishery removal rates has varied substantially over the 25-year period from 1990 to 2014. The peak removal rate in the troll fishery ranged from as early as August 20 in 1996 to at least mid-September in 1991, when the run appeared to be just approaching the peak in trolling areas at the season end on 20 September (Figure 18). Removal rates in the Lynn Canal drift gillnet fishery ranged from as early as late August to mid-September in 1996 to as late as the beginning of October in 1991.

PER CAPITA REPRODUCTIVE POTENTIAL

Estimated per capita egg biomass (PCEB) is a function of female size and the sex ratio (females/male) in the spawning escapement (Figure 19). PCEB estimates for age-.1 spawners ranged from 244 to 460 g/fish (average 334 g/fish) during 1989–2014 (Table 1), and the lowest value was approximately half (53%) of the highest value. When converted to an index, comparing annual estimates to the average, values for the same period ranged from 0.730 in 2011 to 1.380 in 2008 (Figure 19C). The PCEB index averaged lower in odd years (0.89) compared with even years (1.11; $p = 0.001$).

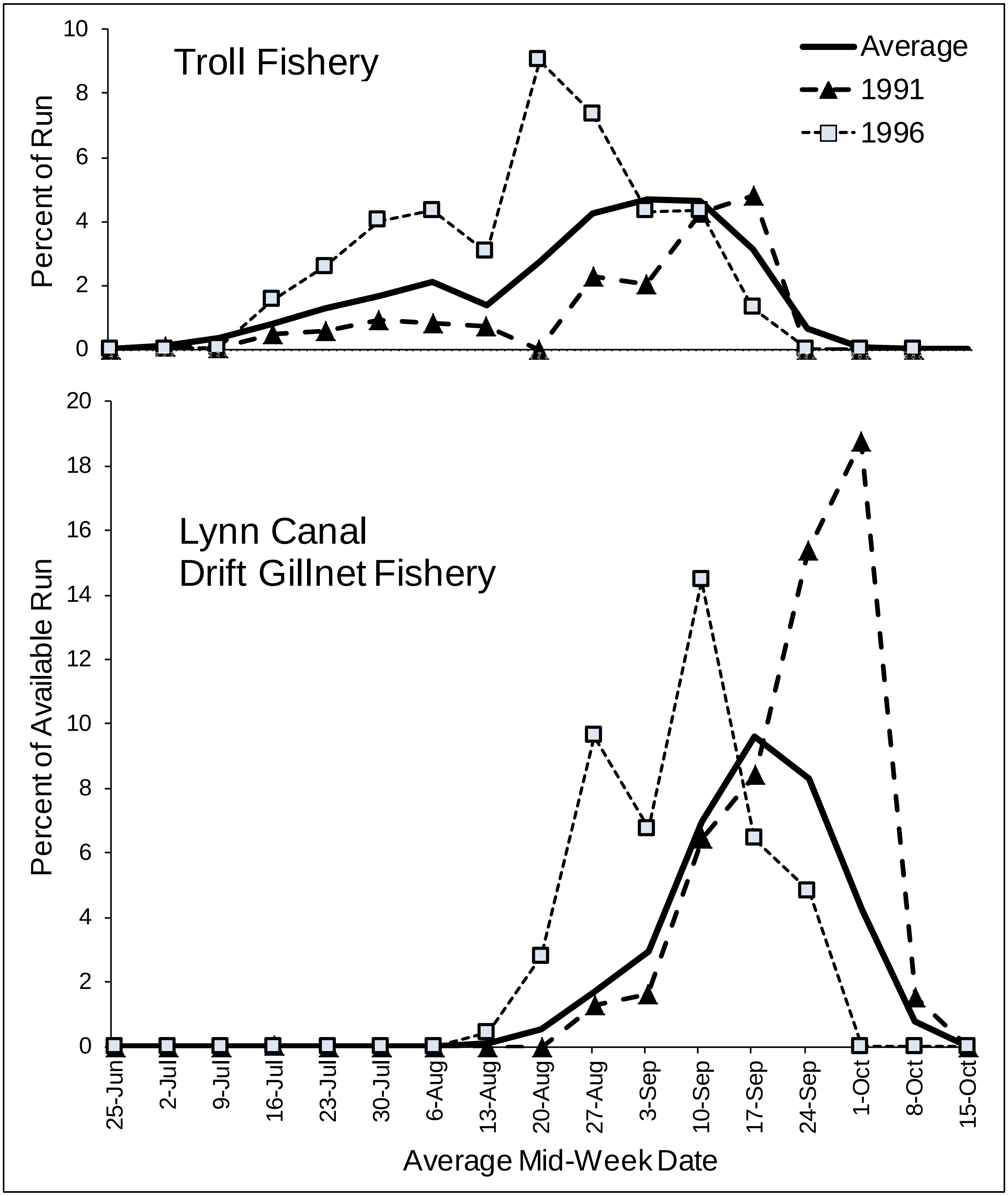

Figure 18.–Estimated average weekly percent harvested of the run of Berners River coho salmon available to the Alaska commercial troll fishery and the Lynn Canal commercial drift gillnet fishery, 1990–2014. Also shown are estimates for selected years when the run was early (1996) and late (1991). The available run includes the total adult return (troll fishery), and escapement plus District 115 drift gillnet catch (Lynn Canal drift gillnet fishery).

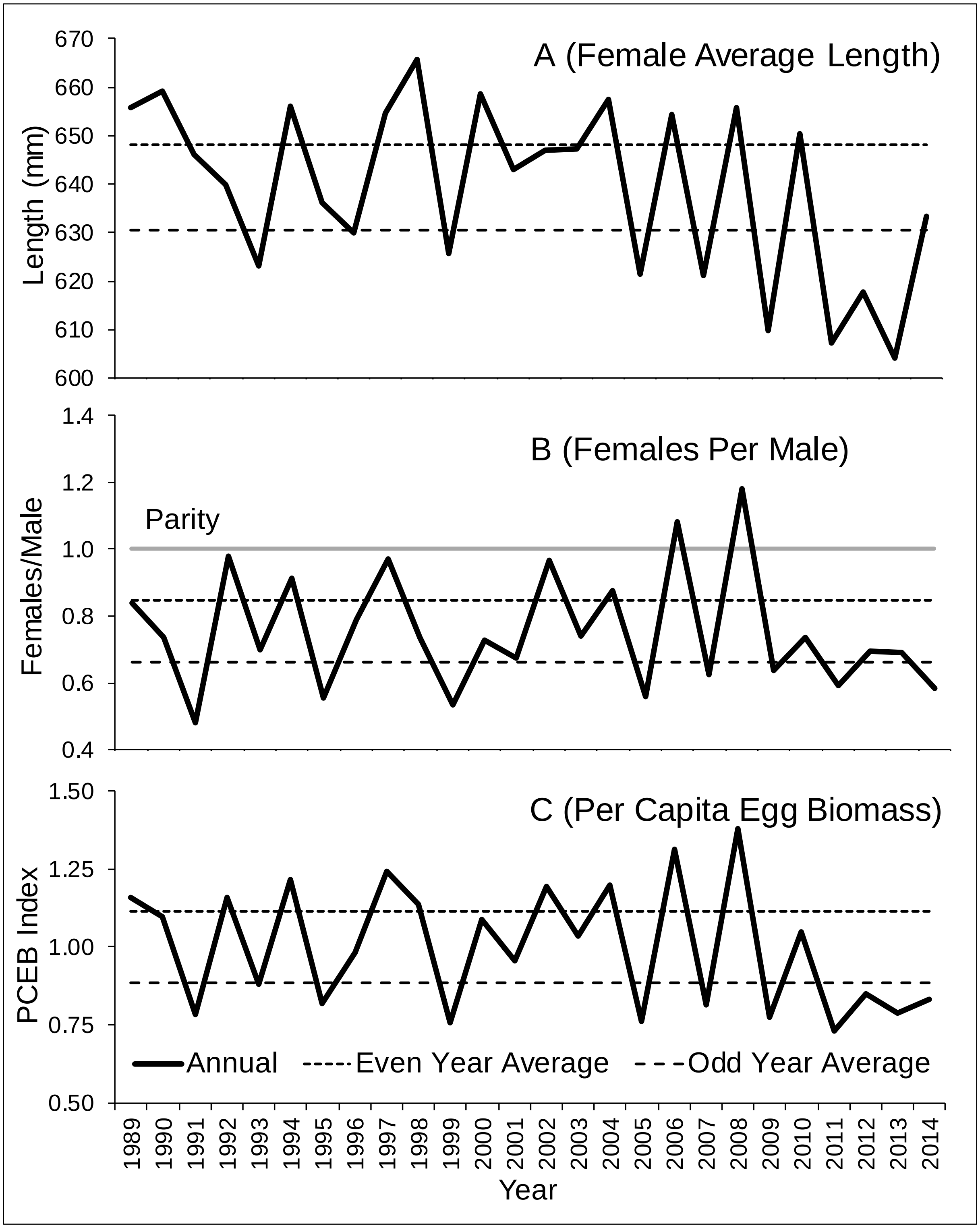

Figure 19.–Average length of females (A), sex ratio (B), and per capital egg biomass (PCEB) index (C) of age-.1 coho salmon spawners in the Berners River, showing even- and odd-year averages.

More than half (58%) of inter-annual variation in PCEB was attributed to variation in the proportion of females in the escapement, while variation in average female size accounted for the remaining 42%. Average female spawner length declined significantly during 1989–2014 ($p = 0.014$), whereas the female proportion of the total escapement did not ($p = 0.655$).

Females were both smaller and comprised a smaller fraction of the escapement in odd years, based on two-tailed *t*-tests. The ratio of females to males averaged 0.661 in odd years compared with 0.846 in even years ($p = 0.005$), and females comprised more than half of spawners sampled in only 2 years (2006 and 2008; Figure 19B). Female spawners averaged shorter (630 mm) in odd years compared with even years (648 mm; $p = 0.010$).

This biennial pattern of significantly lower odd-year values for both the growth-related parameter (female size) and the survival-related parameter (sex ratio), as well as the combined parameter (PCEB index) appears to reflect a cyclical influence on both growth and (sex-specific) survival of coho salmon by differences in the number and biomass of pink salmon (*O. gorbuscha*) in the Gulf of Alaska in odd versus even years. Shaul and Geiger (2016) inferred that the specific mechanism likely responsible for this biennial cycle is the variable influence of top-down control of offshore squid prey populations by pink salmon over sequential 2-year life cycles (of both pink salmon and squid). Female coho salmon appear to suffer differentially greater mortality compared with males when prey is scarce, perhaps as a consequence of a willingness to take greater risk in trading survival for growth, likely involving physiological stress and/or predation (Holtby and Healy 1990; Shaul and Geiger 2016).

The relationship between growth and survival, including differential survival of females relative to males, results in increased variation in effective escapement (adjusted for per capita reproductive potential) compared with nominal escapement (Shaul and Geiger 2016). Adjusting for variation in per capita egg biomass increased the coefficient of variation (CV) of spawning escapement estimates from 0.553 for nominal escapement (prior to adjustment) to 0.644 for effective escapement estimates adjusted for variation in PCEB.

AGE COMPOSITION AND BROOD YEAR RETURN

During 1985–2014, age determinations could be made for an average 481 (range 280–578) scale samples collected annually (Appendix A10). In addition to these fish, an average of 17.3% percent of the total sample could not be accurately aged, primarily because of scale regeneration in the freshwater zone.

On average, 51.8% of adults were determined to be age 1.1, 48.0% were age 2.1, and 0.2% were age 3.1. The total age composition of 1985–1992 samples used by Clark et al. (1994) to establish the existing escapement goal differed substantially in some years from the distribution of ages that were revised based on experience with known-age smolt scale samples from the Berners River. The revised ages increased the average proportion of younger adults that had spent only one year in freshwater before smolting. On average, 3 year-old fish comprised 5.6% more of the revised age composition, 2.7% fewer fish were classified as age 4, and 2.8% fewer fish were classified as age 5. A single fish that was classified as age 6 in the early aging effort was reclassified to age 5 in the revised sample.

Age-.0 jacks were not a significant component of either the total return or the spawning population. During 1990–2014, 0-ocean jacks accounted for an average of only 1 (0.17%) of 603 spawners sampled, and only 0.29% of the combined sample of 0-ocean and 1-ocean males (Appendix A3). Jacks are typically not retained by the troll fishery and are too small to be captured by drift gillnet fisheries, but are occasionally captured by purse seine fisheries, which have had only a minor effect on Berners River returns (the average exploitation rate on adult returns was<1%; Appendix A8). Assuming that fishery exploitation of Berners River jacks has been nil, their contribution to the estimated combined return to both fisheries and escapement has averaged only 0.06%, and their contribution to the male component of the total return has averaged only 0.11% (based on the estimated pre-gillnet sex ratio).

Table 1.–Berners River coho salmon estimated sex ratio, proportion female, average female MEF length (mm), per capita egg biomass (PCEB), PCEB index, and effective spawning escapement (based on a constant average PCEB).

	Sample of Age .1 Spawners				Average			PCEB Index[b]		Estimated Escapement	
Year	Males	Females	Females Per Male	Proportion Female	Female Length	Ovary Mass (g)	PCEB[a]	1989–2014	1990–2014	Total Spawners	Effective Spawners
1989	259	217	0.838	0.456	656	850	387	1.161	-	9,320	10,819
1990	288	212	0.736	0.424	659	865	367	1.099	1.106	13,715	15,073
1991	424	204	0.481	0.325	646	807	262	0.786	0.791	14,311	11,243
1992	318	312	0.981	0.495	640	781	387	1.159	1.167	18,991	22,011
1993	390	273	0.700	0.412	623	714	294	0.881	0.887	19,450	17,145
1994	339	309	0.912	0.477	656	851	406	1.215	1.223	19,760	24,014
1995	394	219	0.556	0.357	636	767	274	0.821	0.826	6,138	5,038
1996	339	268	0.791	0.442	630	741	327	0.980	0.987	7,509	7,360
1997	297	288	0.970	0.492	655	844	415	1.245	1.253	12,474	15,527
1998	344	253	0.735	0.424	666	894	379	1.135	1.142	8,443	9,580
1999	414	221	0.534	0.348	626	724	252	0.755	0.760	12,313	9,302
2000	347	253	0.729	0.422	659	862	363	1.088	1.096	13,219	14,389
2001	358	241	0.673	0.402	643	794	320	0.958	0.964	23,943	22,928
2002	266	257	0.966	0.491	647	812	399	1.195	1.203	34,382	41,089
2003	340	252	0.741	0.426	647	812	346	1.036	1.043	12,549	13,004
2004	320	280	0.875	0.467	657	856	400	1.197	1.205	17,936	21,478
2005	374	209	0.559	0.358	621	708	254	0.760	0.765	6,479	4,926
2006	288	312	1.083	0.520	654	843	438	1.314	1.322	6,789	8,918
2007	370	231	0.624	0.384	621	706	271	0.813	0.818	4,859	3,951
2008	275	325	1.182	0.542	656	850	460	1.380	1.388	8,527	11,763
2009	366	233	0.637	0.389	610	663	258	0.773	0.778	5,250	4,058
2010	346	254	0.734	0.423	650	826	350	1.048	1.055	9,334	9,781
2011	376	223	0.593	0.372	607	654	244	0.730	0.735	7,509	5,480
2012	354	246	0.695	0.410	618	693	284	0.851	0.857	6,802	5,790
2013	355	245	0.690	0.408	604	643	262	0.786	0.791	7,795	6,129
2014	406	237	0.584	0.369	633	754	278	0.833	0.838	19,214	16,006
Average	344	253	0.754	0.424	639	781	334	1.000	1.000	12,577	12,954

[a] Per Capita Egg Biomass, including both female and male spawners.

[b] The PCEB index was calculated for two periods; the first (1989–2014) was used for spawner-recruit analysis in this report while the second (1990–2014) was used in the analysis by Shaul and Geiger (2016).

During 1990–2014, 1-ocean adults averaged 54.6% age-3, 45.2% age-4, and 0.2% age-5. However, there was a marked shift toward younger freshwater age in the mid-2000s (Figure 20A; Appendix A10): spawners that returned during 2005–2014 averaged 72% age-3 and 28% age-4, compared with an average of 43% age-3 and 57% age-4 during 1990–2004. When adjusted to constant average marine survival (Figure 20B), the average age-3 return increased from 14.1 thousand adults in 1990–2004 to 15.8 thousand adults in 2005–2014, while the average age-4 return decreased by 66% from 18.7 thousand adults to 6.3 thousand adults.

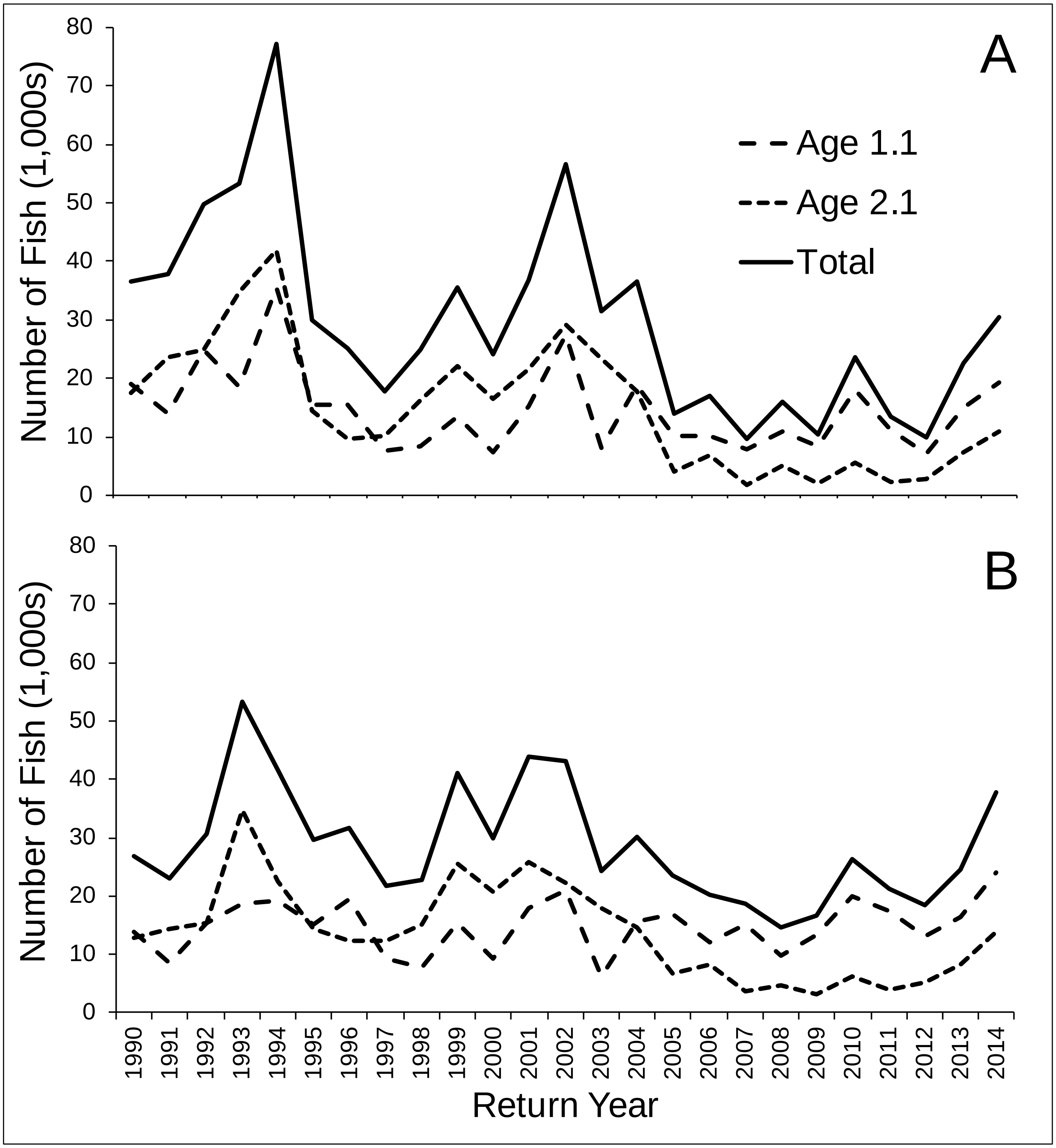

Figure 20.–Estimated coho salmon return to the Berners River (total and by primary age class: A) and the adjusted return standardized to a constant average marine survival rate (B).

SPAWNER-RECRUIT ANALYSIS

Spawner-recruit analysis was based on the estimated total number of spawners adjusted to a constant average per capita egg biomass (PCEB) and resulting 1-ocean brood year adult returns adjusted to a constant average marine survival rate (Figure 21; Appendix A11). Brood-year returns (adjusted to constant average marine survival) decreased markedly from an average of 33.1 thousand adults in the first half of the 22-year data series (1987–1999) to 21.3 thousand adults during 2000–2010. While freshwater brood year production of age-3 adults remained relatively stable between the periods at averages of 14.1 thousand and 15.0 thousand fish, respectively, age-4 returns decreased by two-thirds from 19.1 thousand to 6.3 thousand adults (Figure 21).

The marked decrease in brood-year returns was not substantially influenced by variation in spawning escapement. Return-per-spawner decreased markedly during 2000–2010 compared with 1989–1999 (Figure 22). Discounting the 2002 outlier, predicted production from an average effective escapement of about 12,500 spawners was 38.5% lower (24,149 adults) based on the 2000–2010 relationship compared with 39,242 adults based on the 1989–1999 relationship.

Linear relationships between escapement and production show a shift in intercept rather than slope (Figure 22), suggesting that the decrease in production may reflect a decrease in density-independent survival rather than a density-dependent effect related to a decrease in habitat capacity. We hypothesize that this decrease in freshwater survival was caused by a post-1998 cooling period in the North Pacific climate cycle (see Smolt Production and Climatic Indicators).

Return data were fitted with two spawner-recruit models, the Ricker model and the hockey stick (HS) model (Figure 23; Table 2). Logistic (Barrowman and Myers 2000) and bent (Shaul et al. 2013) versions of the HS model were tested, but offered no improvement over the simple HS model with this data series. The Berners River data series has a great deal of variation and, unlike data series for Ford Arm Creek (Shaul et al. 2014) and Hugh Smith Lake (Shaul et al. 2009), does not show a significant positive relationship between escapement and return above estimated S_{msy}, for which a Beverton-Holt model (Beverton and Holt 1957) or Bent HS model (Shaul et al. 2013) would be more suitable.

For the full series (1989–2010), the Ricker model points to a substantially higher spawning escapement at *MSY* (S_{msy} = 9,870 spawners) for the entire series, or 2.5 times S_{msy} indicated by the HS model (3,952 spawners). Lower and upper 90% of *MSY* bounds indicated by Ricker were 1.77 and 2.19 times comparable escapement bounds indicated by the HS model (Table 2). The Ricker model produced a nearly identical statistical fit compared with the HS model for the entire 22-year data series. Weighting the two models by the inverse of the sum of errors squared results in virtually identical weighting of 50.0% each and point to a goal of 6,912 (range 4,932–10,214) spawners.

However, the HS model deserves greater consideration because it is more consistent with the life history and dynamics of coho salmon populations (Bradford et al. 2000). Although the HS model is biologically more attractive for application to coho salmon populations, it points to a relatively low *BEG* that may be impractically narrow for management purposes. The indicated point goal and lower bound (based on ≥ 90% of *MSY*) do not vary with the average marine survival regime (Figure 24; Table 3). However the indicated upper goal bound is substantially (44–54%) higher in a favorable ocean regime with high average survival in the upper quintile (25.4%) compared with a low survival regime in the bottom quintile (9.5%). The indicated goal also varies with the freshwater production regime, decreasing from 5,038 (range 4,534–8,099) spawners in a period of high freshwater production per spawner (1989–1999) to 3,952 (range 3,557–5,688) spawners in the recent cooler period (2000–2010).

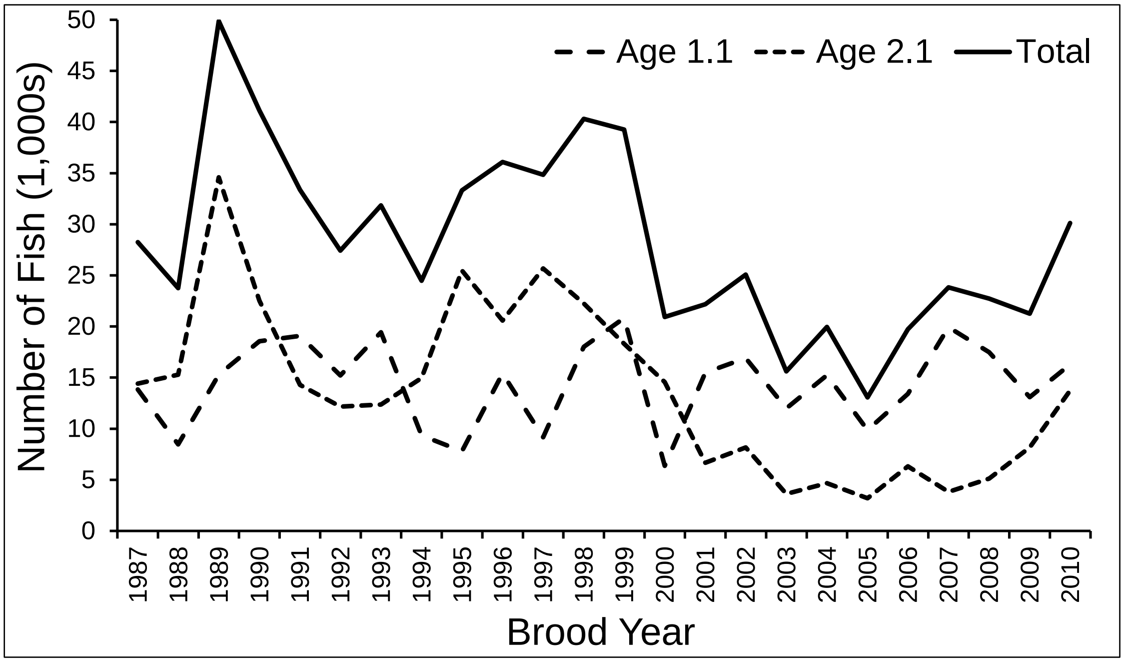

Figure 21.–Estimated age-1.1, age-2.1, and total coho salmon returns to the Berners River by brood year, standardized to a constant average marine survival rate.

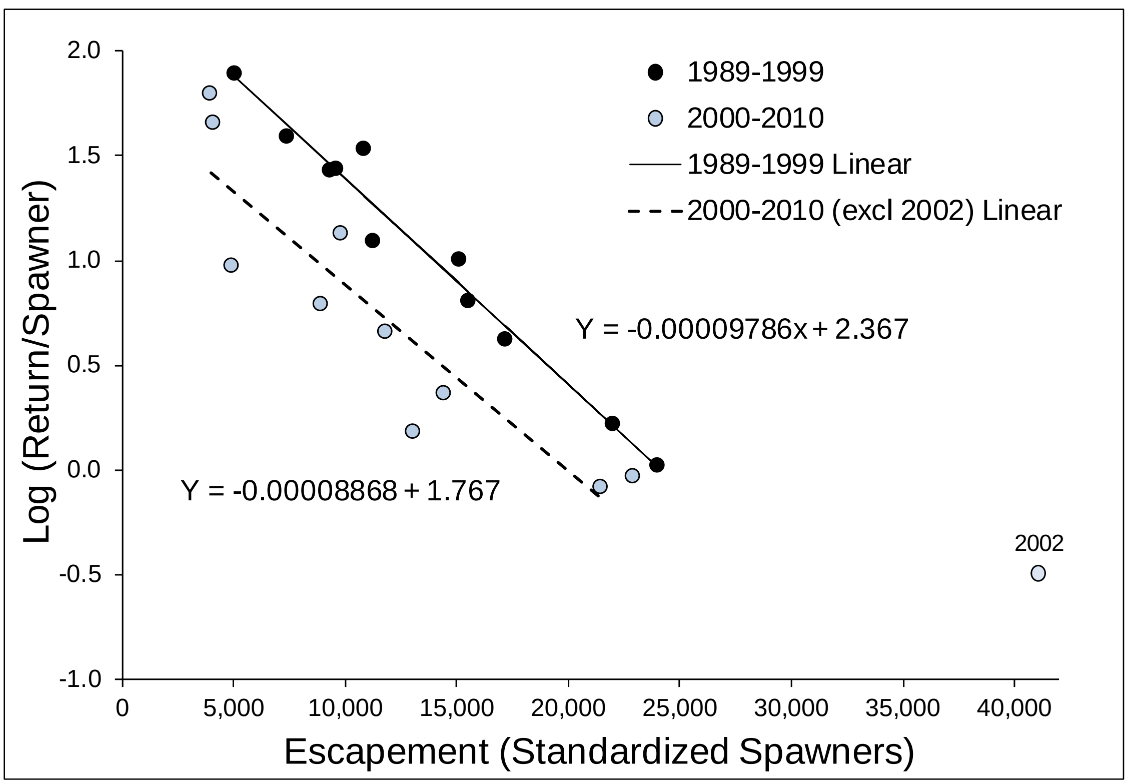

Figure 22.–Relationship between escapement (spawners standardized to a constant average per capita egg biomass) and log (return/spawner) for the Berners River coho salmon population by brood year, showing linear relationships for 1989–1999 and 2000–2010, excluding 2002.

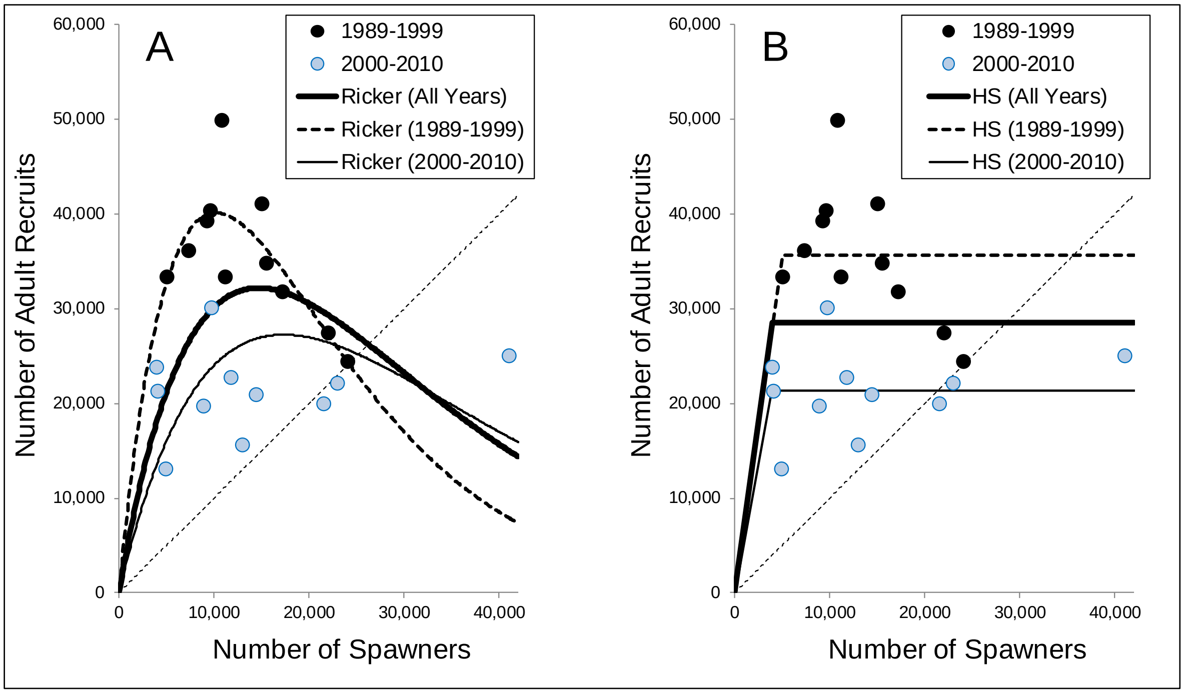

Figure 23.–Spawner-recruit relationships for the Berners River coho salmon population based on the Ricker (A) and Hockey Stick (B) models, showing separate model fits for early (1989–1999) and late (2000–2010) brood years and all brood years combined. The number of spawners is standardized to a per capita egg biomass (PCEB) index of 1 while adult returns are adjusted to a constant marine survival rate of 16.3%.

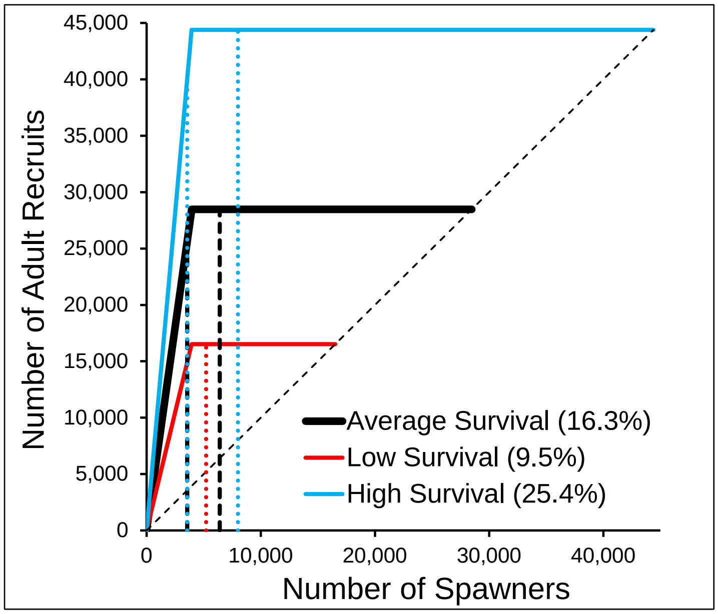

Figure 24.–Indicated biological escapement goal ranges for Berners River coho salmon based on the 1989–2010 brood years and marine survival-adjusted returns calibrated to a constant marine survival rate based on the 1990–2014 average (16.3%), the average of the lowest 20% (9.5%), and the average of the highest 20% (25.4%) of observations.

Table 2.–Berners River coho salmon indicated biological escapement goal (*BEG*) based on Ricker and Hockey Stick (HS) model fits and lower and upper escapement bounds predicted to produce 90% or more of *MSY*. Returns are adjusted to an average marine survival rate (16.3%).

		Number of Fish			Model Parameters			
Model (Brood Years)		S_{msy}	Lower	Upper	α	β	*K*	*MSY*
<u>Ricker Models</u>								
1989–1999	Escapement	8,110	5,097	11,782	10.656	-0.00009774	17,140	31,005
	Smolts/Spawner	29.6	39.7	20.7				
2000–2010	Escapement	10,076	6,508	14,109	4.276	-0.00005775	13,159	14,003
	Smolts/Spawner	14.7	18.0	11.6				
1989–2010	Escapement	9,870	6,307	14,022	5.951	-0.00006801	16,035	20,150
	Smolts/Spawner	18.7	23.8	14.1				
<u>Hockey Stick Models</u>								
1989–1999	Escapement	5,038	4,534	8,099	7.075	-	35,646	30,608
	Smolts/Spawner	43.4	43.4	27.0				
2000–2010	Escapement	3,952	3,557	5,688	5.393	-	21,312	17,361
	Smolts/Spawner	33.1	33.1	23.0				
1989–2010	Escapement	3,952	3,557	6,405	7.207	-	28,479	24,527
	Smolts/Spawner	44.2	44.2	27.3				
1989–2010 Adjusted PCEB Index[a]	Escapement	4,990	4,491	8,099	-	-	-	-
Current Goal[b]	Escapement	7,820	4,965	11,419	-	-	-	-
Recommended Goal	Escapement	5,000	4,500	10,000	-	-	-	-

[a] HS estimate divided by the average of PCEB index values for nominal brood year escapements under 6,500 spawners (0.792).

[b] Current biological escapement goal (4,000–9,200 spawners) recommended by Clark et al. (1994) multiplied by a survey expansion factor of 1.2412.

Selection of a specific biological escapement objective may benefit from consideration of several factors including (A) the utility of a broad *BEG* that can produce high sustained yield in a variety of production regimes (including favorable conditions in both freshwater and saltwater habitat (like during 1989–1999), (B) variable per capita reproductive potential and its relationship with survival and abundance, (C) consistency of alternative spawner-recruit models with coho salmon life history, (D) the relative statistical fit by models with the data, and (E) consideration of how the goal will likely be used to inform and evaluate management of the particular fisheries of concern.

The PCEB index for spawners was positively correlated with marine survival (r = 0.449; $p = 0.024$) and has declined substantially over the 25-year period 1990–2014. Although the PCEB index was not positively correlated with nominal escapement (r = 0.305; p = 0.138) during 1989–2014, the 4 lowest escapements of fewer than 6,500 spawners had a significantly lower PCEB index (average 0.792) compared with escapements over that level (average 1.038; $p < 0.001$).

Based on these results, it may be prudent to assume that lower escapements will have below-average per capita reproductive capacity and to adjust the goal accordingly. We divided the HS-based estimates for both the lower bound and S_{msy} (based on the 1989–2010 brood years) by the average PCEB index value (0.792) for years with fewer than 6,500 spawners to obtain what may be a more realistic prediction of effective escapement when nominal escapement is near these reference points (which remain unchanged across all marine survival regimes).

This adjustment increases respective point goals and ranges indicated by the HS model fit for the full series (1989–2010) from 3,952 (3,557–6,405) to 4,990 (4,491–6,405) spawners (with the upper bound based on average marine survival; Table 3). Unfortunately, this adjustment further narrows the indicated escapement objective.

However, we also recommend that the upper goal bound be adjusted upward to insure that maximum potential yield can be realized during a combination of high freshwater capacity and high marine survival. The HS model fitted to a combination of favorable (1989–1999) freshwater conditions and high average marine survival (25.4%) points to an upper bound for ≥ 90% of *MSY* of 10,091 spawners (Table 3). A comparable point estimate and range based on the unexpanded survey count would be 4,020 (range 3,618–8,130) spawners after dividing by the expansion factor. Our recommended *BEG* for both the expanded and unexpanded counts, respectively is based on rounding of these values.

Table 3.–Indicated optimum escapements and ranges predicted to produce 90% or more of *MSY* under (A) three constant marine survival scenarios representing observed average survival rates for the bottom 20% of years, top 20% of years, and all return years during 1990–2014, and hockey stick model fits for (B) three periods representing high and low freshwater survival (1989–1999 and 2000–2010 brood years, respectively) and average for all brood years. Adjusted lower point and lower bound estimates for the 1989–2010 period are also shown adjusted to the average estimated per capita egg biomass (PCEB) index at escapements lower than 6,500 spawners (0.792). The values shown in bold were rounded to arrive at the recommended *BEG*.

Marine	S_{msy} and >90%	Escapement (Time Period)			Predicted Return (Time Period)		
Survival Rate	of *MSY* Bounds	1989–1999	2000–2010	1989–2010	1989–1999	2000–2010	1989–2010
9.5%	Point	5,038	3,952	3,952	20,680	12,364	16,522
(Bottom 20%)	Lower	4,534	3,557	3,557	18,612	11,128	14,870
	Upper	6,602	4,793	5,209	20,680	12,364	16,522
	Alpha	4.105	3.129	4.181	---	---	---
25.4%	Point	5,038	3,952	3,952	55,563	33,221	44,392
(Top 20%)	Lower	4,534	3,557	3,557	50,007	29,899	39,953
	Upper	**10,091**	6,879	7,996	55,563	33,221	44,392
	Alpha	11.029	8.406	11.233	---	---	---
16.3%	Point	5,038	3,952	3,952	35,646	21,312	28,479
(All Years)	Lower	4,534	3,557	3,557	32,081	19,181	25,631
	Upper	8,099	5,688	6,405	35,646	21,312	28,479
	Alpha	7.075	5.393	7.207	---	---	---
PCEB Index	Point	---	---	**4,990**	---	---	---
= 0.792	Lower	---	---	**4,491**	---	---	---

DRIFT GILLNET FISHERY SELECTION

The change in average length of returning age .1 adults after exposure to the drift gillnet fishery was relatively small in most years, particularly in females (Appendix E1; Figure 25). Estimated drift gillnet fishery linear selection differentials (LSDs) averaged -12.3 mm for male coho salmon (Figure 26A). This value falls within the range of 0.7 mm to -21.8 mm (average -8.3 mm) estimated for male sockeye salmon (*O. nerka*) for eight gillnet fisheries in central western Alaska by Kendall and Quinn (2012). However, our average estimate for female coho salmon (-3.7 mm; Figure 26B) was below the range of their estimates for female sockeye salmon (-5.5mm to -13.6 mm; average -9.1 mm). Unsurprisingly, LSDs were significantly correlated with the removal rate on the run passing through the drift gillnet fishery, and the exceptionally high removal rate of 71% in 1995 had the greatest influence on average size of spawners (Figure 26).

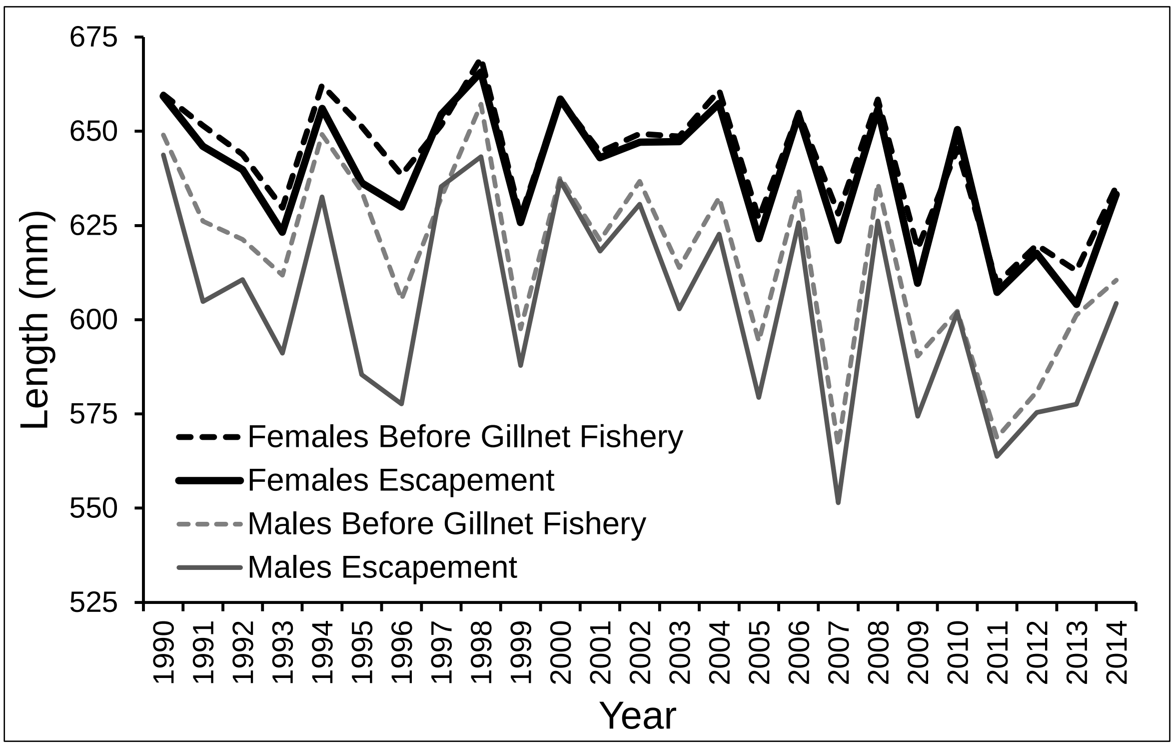

Figure 25.–Estimated average mid eye to fork length of age-.1 male and female coho salmon returning to the Berners River when entering the drift gillnet fishery and entering the river to spawn.

Average drift gillnet fishery selectivity over the 25-year period was neutral for fish between 580 and 589 mm (MEF length), and declined sharply at lower sizes, and no tagged fish in the 450–459 mm range were recovered from the harvest during the 25-year period (Figure 27). The fishery consistently selected for larger fish in all length classes from 590 to 739 mm (range 1.03–1.23). Therefore, estimated selection for females in the harvest was limited by the small percentage of females falling under 580 mm, which averaged 2.3% in even years and 4.3% in odd years (3.3% overall).

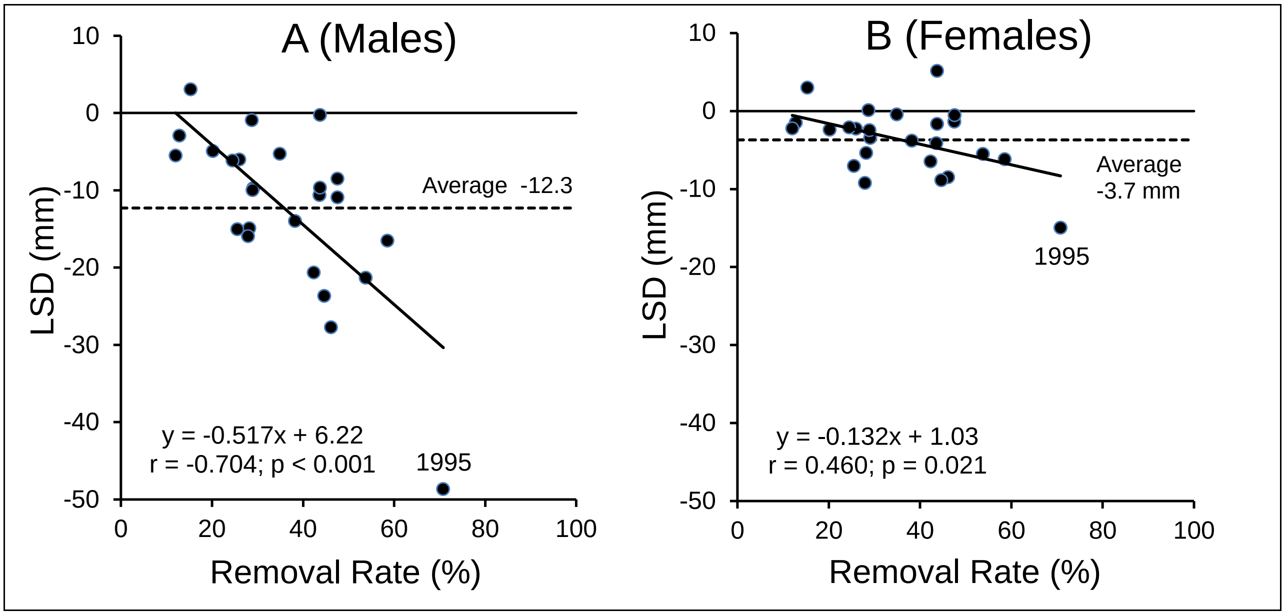

Figure 26.–Linear selection differential (LSD) estimates for male and female age-.1 Berners River coho salmon exploited by drift gillnet fisheries, 1990–2014. The estimated run size used to calculate the removal rate includes only spawning escapement and the drift gillnet catch.

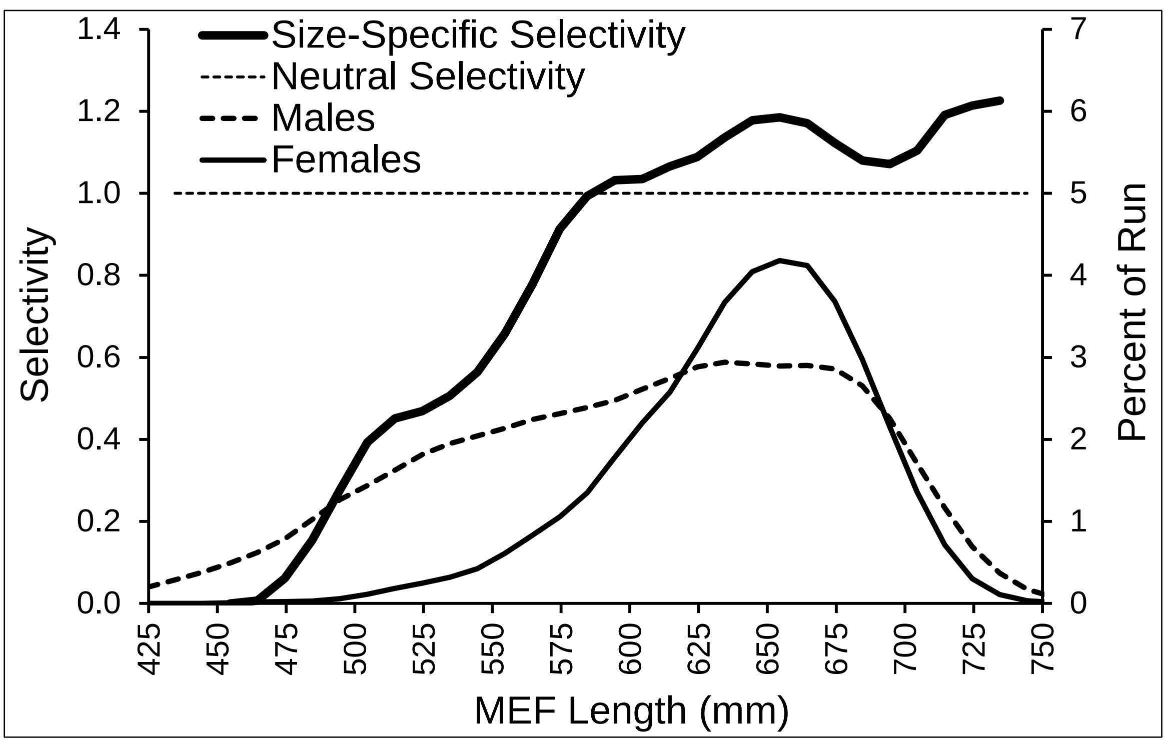

Figure 27.–Estimated average drift gillnet fishery selectivity curve for coho salmon returning to the Berners River calibrated to a neutral selectivity value = 1, for the period 1990–2014. Selectivity on a length class is considered neutral when the size-specific exploitation rate is equal to the drift gillnet exploitation rate on the total population. Also shown is the estimated average percent of the pre-gillnet run comprised of males and females by 10 mm length category.

Linear relationships between girth and length indicate little difference in girth between the sexes at smaller lengths (<600 mm), but show increasing divergence between the sexes with increasing length (Figure 28A). Larger females were found to have a smaller girth compared with males of the same length. Regression relationships indicated a narrowing of the difference from 16 mm (3.7% of girth) at a length of 700 mm to zero at a length of 508 mm, the respective lengths of the largest and smallest females in the sample. Although the sexes have a similar girth at shorter lengths, the softer mid-section area of females may give them an advantage in working their way through gillnet mesh after being wedged.

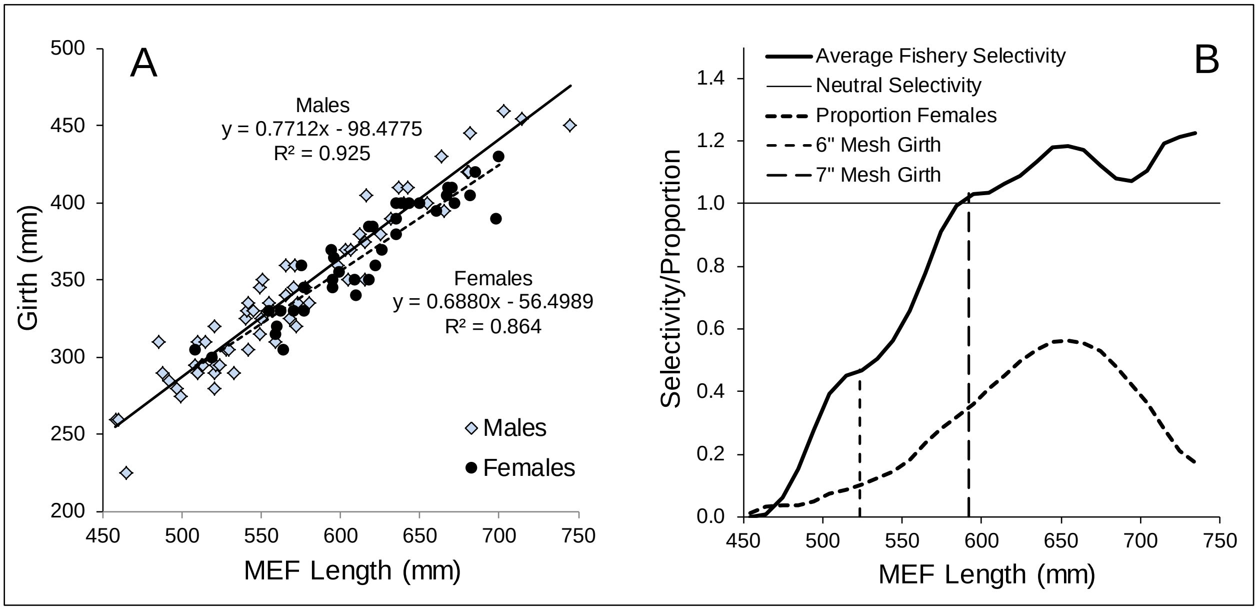

Figure 28.–Linear relationships between length and girth for 1-ocean male and female coho salmon spawners sampled in the Berners River in 2014 (A) and average drift gillnet fishery selectivity by length and proportion of females in the pre-gillnet population, 1990–2014, showing lengths corresponding to a predicted circumference matching 6″ and 7″ gillnet mesh (B).

The divergence in girth between the sexes with increasing size appears to arise from greater sexual dimorphism in larger males that develop a pronounced hump for the dominant breeding role. Smaller males that are typically stealth (satellite) spawners are often more drab in coloration, and their bodies are not as deep compared with larger, more territorial dominant (alpha) males that develop a pronounced hump. This relationship suggests that there should be little difference in selectivity by sex among smaller spawners below the inflection point in fishery selectivity around 585 mm. The difference in girth between males and females at a length of 585 mm was predicted at only 6.7 mm (1.9%), a smaller difference than the predicted change in circumference (6.9–7.7 mm) from a shift in length of only 10 mm in either direction. Therefore, we assumed that the effect of sex-selection based on girth is negligible in estimation of the pre-gillnet sex ratio of the run and sex-specific fishery selection, which is calculated across a broad range of lengths.

It is likely that some fishermen change nets to optimize their catch in individual years. Use of 6″ (152mm) mesh is common because it is fairly effective for fall (coho and chum) salmon and allows maximum flexibility under various regulatory mesh restrictions (Dave Harris, ADF&G Management Biologist, Douglas, personal communication). However, some fishermen employ nets as large as 7″ (178 mm; normally used to target chinook salmon, *O. tshawytscha*) in order to optimize their catch of coho salmon in years when average size is large. A localized inflection point at 515 mm (Figure 28B) coincides with a projected girth of 295–298 mm that is just under the mesh circumference (305 mm) of the smallest (6″) nets typically employed. A second higher inflection point at about 585 mm coincides with a projected girth of 346–352 mm, close to the mesh circumference (356 mm) of the largest (7″) nets typically used.

At larger sizes, mid-section girth is likely less important in determining selectivity. The mid-section at the anterior edge of the dorsal fin is the most common area where we have observed marking indicating temporary gillnet capture. A second area is around the head in front of the gills, usually on the largest fish with large heads.

We did not measure the circumference of fish at their head forward of the gills to determine the average length (by sex) at which head circumference exceeds commonly employed mesh sizes. However, we have commonly observed gillnet marks forward of the gills on larger fish, indicating escape after failure to penetrate the mesh past the operculum. There was a decrease in selectivity between 670 and 710 mm, followed by an increase in selectivity in the largest size range between 710 and 739 mm, where the average percentage of the run comprised of females declined to under one-third of adults from a peak of 56% between 640 and 669 mm (Figure 28B). The increase in selectivity between 690 mm and a second peak at the largest size class (≥730 mm) that includes only a small female component (21%) suggests that low vulnerability by the largest males to wedging in the mesh is more than offset by their increased vulnerability to entanglement.

This pattern contrasts with selectivity curves for sockeye salmon in the Nushagak River in Bristol Bay that typically show a single peak (Kendall 2011), but is consistent with some other studies indicating bimodal selectivity curves representing fish caught by wedging and tangling, respectively (Hamley and Regier 1973; Hamley 1975). The largest Berners River coho salmon were most vulnerable to the drift gillnet fishery, likely because they were predominantly larger males with well-developed kypes that are easily entangled in gillnet material.

On average during the 25-year period, the estimated effect of the drift gillnet fishery on the ratio of females to males was not significant (p = 0.336), and the estimated average ratio before and after the fishery decreased from 0.80 to 0.75. On balance, although there appear to be mechanisms that may favor one sex over another at various points over the size distribution, there is no indication of a morphological difference between the sexes (other than size) that would likely have a material effect on the overall sex ratio of fish removed by the drift gillnet fishery.

The primary driver of the linear selection differential (LSD) is the removal rate. We did not find a significant correlation between LSD and average pre-gillnet length (including both sexes combined) or the coefficient of variation (CV) of length in tests using simple regression models. However, a multiple regression model using standardized predictive variables assigned a weighting of 36% to CV in length (p = 0.010) compared with 64% for removal rate (p < 0.001) and explained over half of variation in the LSD (R^2 = 0.564; adjusted R^2 = 0.525) compared with 41% explained by removal rate alone (R^2 = 0.409; adjusted R^2 = 0.383).

Variation in pre-gillnet length for the combined sexes was negatively correlated with average length (r = -0.608; p = 0.001), as a result of both a higher proportion of males and greater variation in length of males in the population in years of poor growth. During 1999–2014, a recent period of strong even-year dominance in adult length, variation in the pre-gillnet length of the combined sexes was significantly higher in odd years (p = 0.019; two-tailed t-test). Among spawners, there was a positive correlation between the female-to-male ratio and average length of males (r = 0.423; p = 0.035) and females (r = 0.469; p = 0.018) as well as strong negative correlations ($p < 0.001$) between average length and variation in length for males (r = -0.688) and females (r = -0.608).

During 1990–2014, the estimated sex ratio more strongly favored males in odd years (p = 0.012; two-tailed t-test), prior to exposure to the drift gillnet fishery, suggesting that females experienced proportionately higher marine mortality when growth conditions were poor (Shaul and Geiger 2016). Returning males show a more pronounced bimodal pattern (reinforced by exposure to the drift gillnet fishery) under poor growth conditions (Figure 29). Females comprised an average of 41.4% of pre-gillnet adults in odd years compared with 46.3% in even years. During the 25-year period 1990–2014, the estimated ratio of females-to-males among age-.1 adults prior to the drift gillnet fishery averaged 0.80 (range 0.57–1.24), and was significantly lower in odd years (0.71) compared with even years (0.88; 2-tailed t-test, p = 0.006).

Although small age-.1 males <500 mm in length are relatively common in even years, there was a pronounced size shift toward more small males in odd years (Figure 29), suggesting differentially higher survival of small males or a shift in strategy by some males to sacrifice size for survival (Holtby and Healy 1990), thereby adopting a stealth (satellite) mating role instead of dominance in a more competitive breeding environment with a relatively less abundant female component in the spawning population (Shaul and Geiger 2016). This apparent strategy also increases survival to spawning by reducing vulnerability of smaller males to the drift gillnet fishery.

During the 26-year period 1989–2014, the ratio of females-to-males among age-.1 spawners averaged 0.75 (range 0.48–1.18), and was significantly lower in odd years (0.66) compared with even years (0.85; 2-tailed t-test, p = 0.005). However, the sex ratio was relatively low in the two most recent even years (2012 and 2014), at 0.73 and 0.58, respectively (Figure 19B), possibly because growth was poorer as indicated by average adult length that was well-below average for even years (Figure 19A).

We attempted to estimate fishery selection only for the drift gillnet fishery, as growth during the fishing season complicates estimation of selection by other fisheries (troll, marine sport and purse seine) in which peak catches occur weeks before the run peaks in the drift gillnet fishery (Shaul 1994). A comparison of the pre-gillnet length distribution with the length distribution of troll-caught fish restricted to later weeks (late August through September) suggested that fish increased by about 1 cm in their last 2 weeks at sea before entering the drift gillnet fishing area and that the troll fishery was relatively non-selective for size, with the exception that the smallest size classes below 520 mm (comprised almost entirely of males) were under-represented. There is not a strong market for such small fish, and some trollers have indicated that they frequently catch small fish but often either release the smallest males or retain them for personal use. However, sex-selective harvest (independent of size selection) by the troll fishery cannot be ruled out because females may feed more actively compared with males to attain necessary growth for successful reproduction (Holtby and Healy 1990).

Interaction between Growth, Sex-specific Survival and Fishery Selection

A remarkably consistent difference in adult size between even and odd years developed in the 1990s and intensified in the late 1990s prior to a sharp decrease in even-year size in 2012. A 14-

year period with a consistent biennial cycle in size during 1998–2011 offers the potential to examine differences between “good” and “poor” growth years for adult size, survival, and reproductive variables, with minimal influence by potential background trends. The consistent alternating pattern in adult size during this period also facilitates exploration of the interaction between fishery selection and natural factors affecting growth and survival.

The average survival rate of smolts to the drift gillnet fishery by adult length and sex varied markedly between good and poor growth years (Table 4; Figure 29). Before entering the drift gillnet fishery, both sexes averaged significantly shorter (6.4% for males and 4.2% for females) in the odd years, a difference that increased slightly to 7.1% and 4.7%, respectively, in the spawning population. However, average variation (CV) in length of spawners was greater in odd years, but only significantly more so (17.3%) in females ($p = 0.049$).

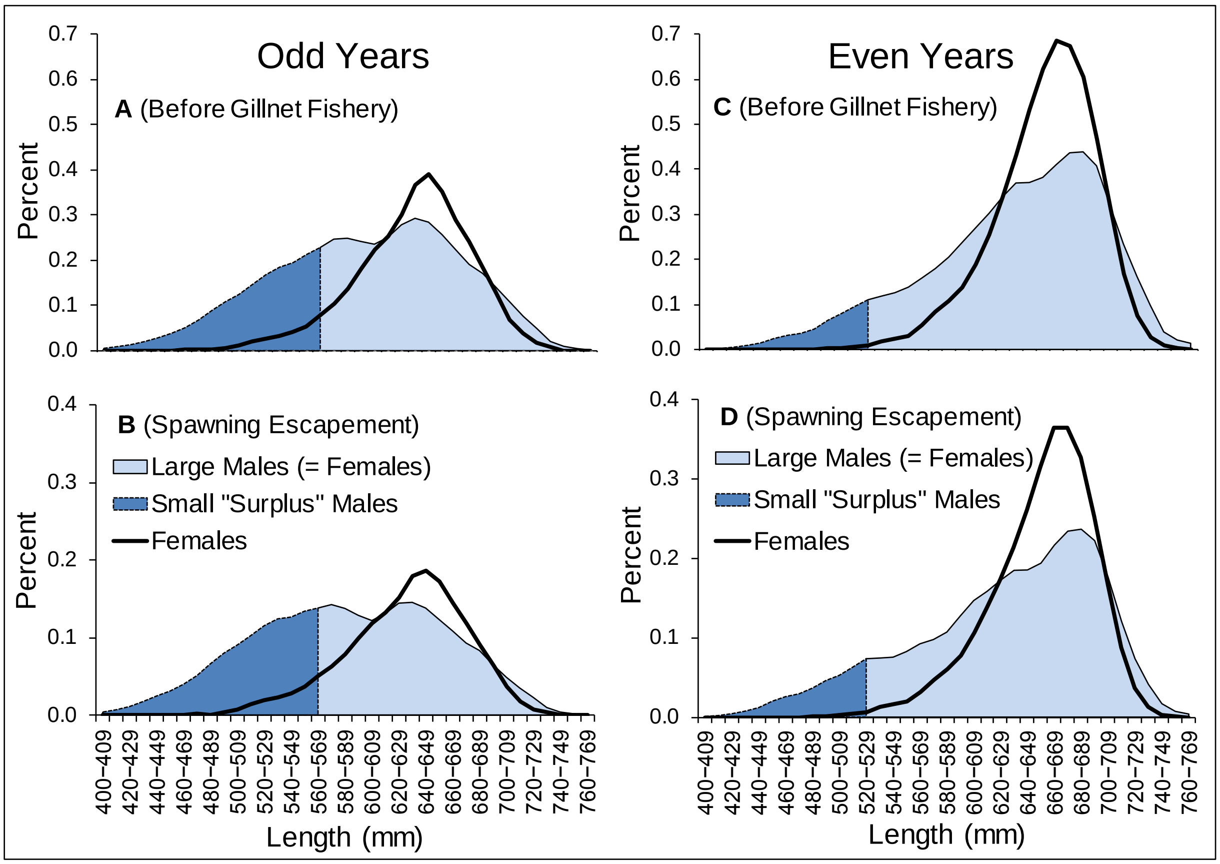

Figure 29.–Estimated average percent of Berners River coho salmon smolts returning as adults by MEF length and sex in even years compared with odd years during 1998–2011, both before and after exposure to drift gillnet fisheries. The proportion of males above a 50:50 sex ratio is shaded.

Estimates of marine survival to the drift gillnet fishery averaged lower in odd years, but only significantly so for females (39%; $p = 0.028$), while the difference between odd and even years in total survival from smolt to returning adult (combined sexes) narrowly missed significance ($p = 0.053$). The estimated ratio of females to males prior to the drift gillnet fishery averaged 25% lower in odd years (0.695) compared with even years (0.930), a difference that was accentuated by exposure to the drift gillnet fishery, which reduced the average female-to-male ratio by 10.3% in odd years compared with only 3.1% in even years. Likewise, per capita reproductive potential was 26% lower prior to the drift gillnet fishery and 30% lower in the spawning escapement in odd-years (Table 4), as the drift gillnet fishery reduced average PCEB by 8.3% in odd years compared with only 2.1% in even years.

Table 4.–Comparison of even-year and odd-year averages for variables related to growth, survival, and sex ratio, and reproductive potential (per capita egg biomass in grams) of coho salmon returning to the Berners River during a 14-year period (1998–2011) when adult MEF length (mm) was strongly even-year dominant. P-values are based on a 2-tailed *t*-test, with those values significant at $p = 0.05$ shown in bold.

	Average		
Variable	Even Years	Odd Years	*p*
Male Length (Pre-Gillnet)	634	593	**0.001**
Female Length (Pre-Gillnet)	657	629	**0.001**
Male Length (Spawners)	627	583	**0.001**
Female Length (Spawners)	656	625	**0.001**
CV of Male Length (Spawners)	0.105	0.113	0.097
CV of Female Length (Spawners)	0.055	0.065	**0.049**
Male Survival (Pre-Gillnet)	6.31%	5.03%	0.150
Female Survival (Pre-Gillnet)	5.88%	3.56%	**0.028**
Male Survival (River)	3.43%	2.93%	0.347
Female Survival (River)	3.11%	1.86%	**0.042**
Marine Survival (Total)	16.9%	12.5%	0.053
Females Per Male (Pre-Gillnet)	0.930	0.695	**0.024**
Females Per Male (Spawners)	0.901	0.623	**0.006**
Per Capital Egg Biomass (Pre-Gillnet)	407	303	**<0.001**
Per Capital Egg Biomass (Spawners)	398	278	**<0.001**

Even-year adult size decreased markedly in 2012. Pre-gillnet length averaged 1% shorter than the odd-year mean-average during 1998–2011 for both sexes. Overall marine survival (8.8%) and the female-to-male ratio (0.738) in 2012 were closer to recent odd-year averages (12.5% and 0.695, respectively) than even-year averages (16.9% and 0.827, respectively), adding support for the hypothesis that differences in growth and (sex-specific) survival in odd years versus even years during 1998–2011 reflect the influence of lower prey abundance on growth and late-ocean survival, rather than some other coincidental biennial factor (Appendices B2 and E1).

Figure 29 incorporates elements of sex-specific growth, survival, and fishery selection, showing how males maintained a higher survival rate in poor growth (odd) years while becoming more bimodal in their size distribution, a factor that is also accentuated by the fishery to a greater extent in odd years, when a larger proportion of males returned at a size small enough to avoid capture in the drift gillnet fishery. The dominant mode in the average length-frequency distribution of males prior to the drift gillnet fishery decreased by about 50 mm to 630–639 mm in odd years, compared with 680–689 mm in even years, and the secondary mode underwent an equal shift between 630–639 mm and 580–589 mm (Figure 29A). In contrast, the mode in average length-frequency distribution for females (Figure 29C) underwent a shift of about half that magnitude, from 660–669 mm (even years) to 640–649 mm (odd-years).

Overall, the drift gillnet fishery appears to have had a relatively small influence on the sex ratio compared with a far greater influence by growth-related, sex-specific mortality that occurred prior to the drift gillnet fishery. However, gillnet selection tends to magnify growth- and survival-related influences, exerting a proportionately greater effect on the sex ratio and average size and reproductive potential of spawners during poor growth conditions when returning adults average smaller and tend to be more variable in size.

SMOLT ESTIMATES

Only 6,438 smolts were captured in the first year of smolt marking (1989), primarily from trough traps installed on beaver dam spillways on Det's Pond. Suitable capture sites at larger-producing Shaul Pond were discovered late in the 1989 season and only 908 smolts were captured from that location. After 1989, the total catch from all locations averaged 29,558 smolts, and ranged from a low of 10,985 smolts in 2008 to 58,345 smolts in 2000 (Appendix B1). Because of habitat changes, Shaul Pond was the only consistently trapped location during 1990–2013, with catches ranging from 7,322–35,861 smolts (average 21,011 smolts; Figure 28). After 1989, Shaul Pond produced an average of 72% of the total smolt catch. The catch from the pond declined markedly after 2005 from an average of 25.5 thousand smolts during 1990–2005 to only 12.0 thousand during 2006–2013, and reached a low of 7.3 thousand smolts in 2009. Smolt production from Shaul Pond declined later and more abruptly than production from the overall Berners River system (Figure 30).

After 1996, the main beaver dam containing Det's Pond deteriorated and the pond level dropped, so trapping there was discontinued until a 3-year period (2006–2008) when a trough trap was installed at a new, smaller dam below the old one (Figure 5, right photo). During 1992–1993, 1997–2005, and 2009–2013, smolts were trapped from Brown Slough (and adjacent small ponds and sloughs) at varying locations using various means including incline plane traps, trough traps, and baited magnum minnow traps. Minnow traps were used exclusively to capture smolts from the main slough during 2009–2013. The exceptionally large catch of 31,281 smolts from Brown Slough in 2000 (Appendix B1) was taken primarily from a trough trap on a beaver dam across the upper part of Side Pond (Figure 1), which received most of the flow from the slough during that period. In that year, a plastic mesh fence was constructed across part of the pond to direct most fish away from the main flow and into the trap on a smaller spillway.

The transition from presmolt to smolt tagging beginning in 1989 increased the proportion tagged (Θ) in the adult population from an average of 1.9% (range 0.9–2.8%) in the 1982–1989 returns to 9.2% in 1990, the first year with returns from smolt tagging, and 17.3% (range 8.5–30.6%) since 1991 (Appendix A2).

A focus on smolts and improved tagging rates since 1989 has produced relatively precise estimates of total smolt production (Figure 30; Appendix B3). Chapman estimates of the total smolt production from the Berners River system during 1989–2013 averaged 193,822 smolts and ranged from 89,169 smolts in 2007 to 326,312 smolts in 1992. Smolt production showed an overall cyclical pattern, with periods of high production during the 1992–1996 and 1999–2002 return years preceding a period of low production during the 2005–2013 return years (Figure 30).

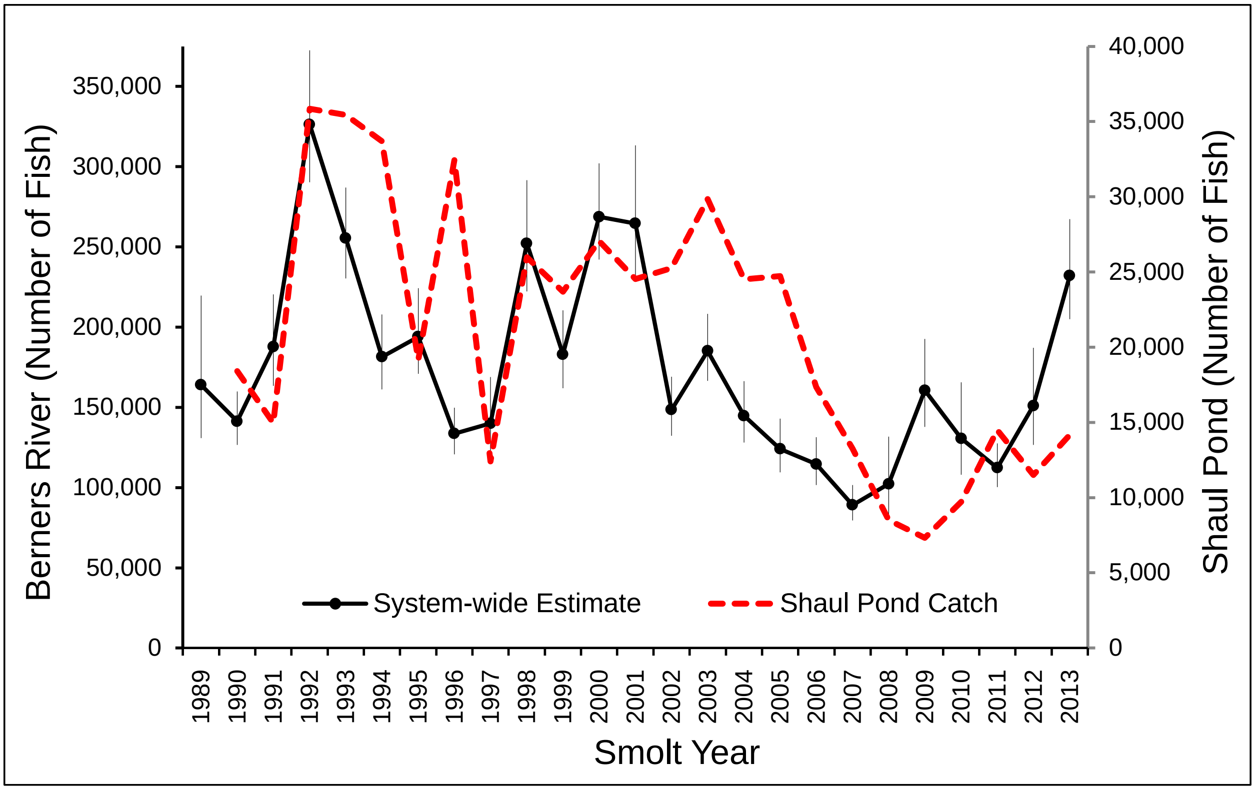

Figure 30.–Annual catch of coho salmon smolts from Shaul Pond (1990–2013) compared with estimated total smolt production (with a 95% confidence interval) from the overall Berners River (1989–2013).

A mark–recapture estimate of the presmolt population in 1988 (368,626 fish) was 2.248 times the estimate of 163,998 smolts that migrated from the system the following spring. Based on an assumed constant presmolt-to-smolt survival rate, projected smolt populations during 9 years prior to the smolt project ranged from 107,577 to 216,369 fish (average 161,611 fish). Estimates during the 1970s (1973, 1977, and 1978) averaged 117,129 smolts, similar to the average for the more recent period of lowest average smolt production (119,124 smolts) during 2005–2011 (Figure 31; Appendix B3). No projection was made for 1981 smolts because the inverse of the proportion marked ($1/\Theta$) was highly uncertain (relative precision = 121%).

During 1990–2013, the number of smolts caught showed a moderate positive correlation (r = 0.672) with the system-wide smolt estimate (based on the marked rate of returning spawners). Beginning in 2009, 2 to 4 magnum minnow traps were fished in the main river below the confluence with Brown Slough (and nearly all of the rearing habitat in the system) in order to estimate the marked fraction of the return in an effort to obtain a real-time smolt estimate that would be useful for fishery management. To date, these efforts have produced only limited success, with catches ranging from 1,247 smolts in 2009 to as low as 115 smolts in 2013 (Appendix B5). Although the marked rate was positively correlated between recapture methods during the 5-year period (r = 0.878), the average marked rate based on the minnow trap catch (9.3%) was lower than the 11.0% average marked rate in the adult return.

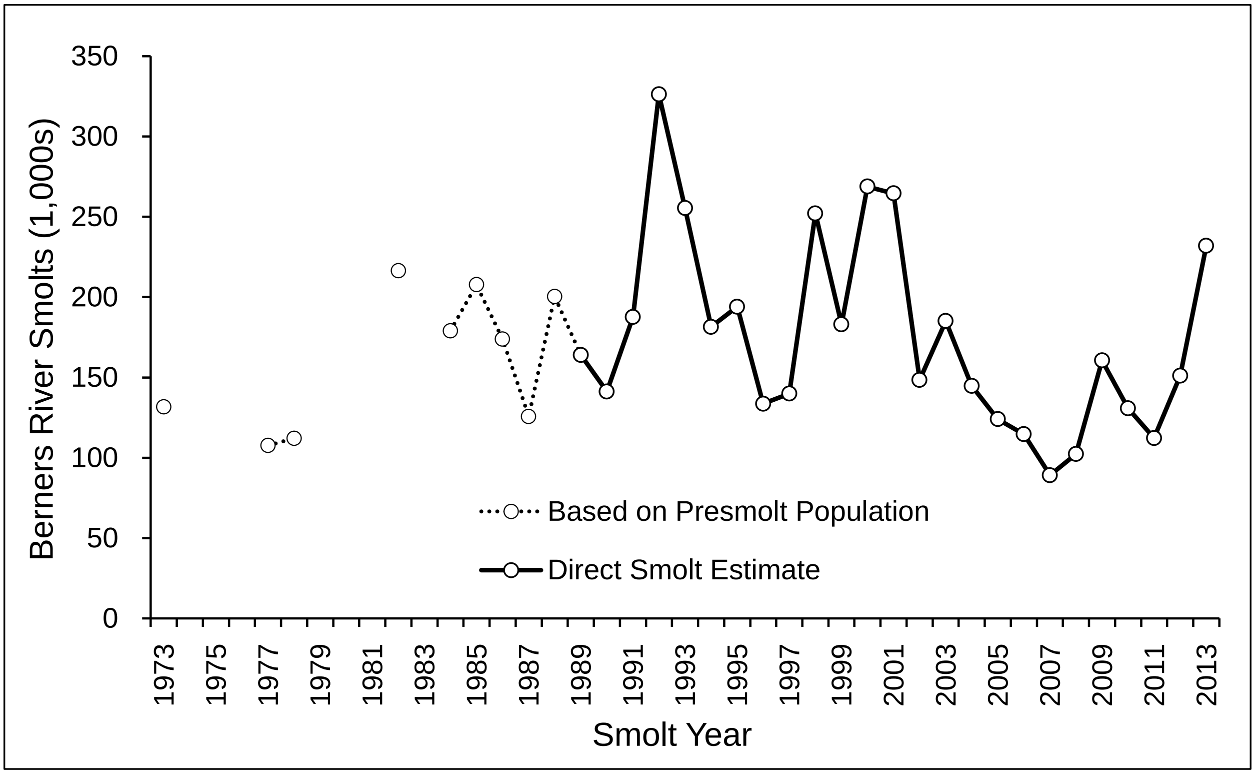

Figure 31.–Berners River coho salmon smolt production estimates based on direct mark–recapture estimates for smolts (1989–2013) and predicted smolt abundance based on the presmolt estimate from the prior summer multiplied by 0.4449 (1973, 1977–1978, 1982, and 1984–1989).

MARINE SURVIVAL

Marine survival estimates during the 1990–2014 return years averaged 16.3% and ranged from 8.4% in 2007 to 30.2% in 1994 (Figure 32; Appendix B2). The trend in survival peaked during 1990–1994 at an average of 24.4% (range 16.4–30.2%). A second lower peak (average 20.8%; range 19.8–21.4%) occurred during 2002–2004, after which survival declined to an average of 12.2% (range 8.4–18.0%) during 2005–2014. During 1990–2014, marine survival accounted for 51.7% of the variation in adult returns and freshwater factors, including parent escapement, accounted for 48.3%.

The decrease in marine survival in the mid-2000s may have been influenced by the effect of climatic cooling on early marine conditions, an influence that appears to have varied geographically within the region. During the 1989–2007 sea-entry years, marine survival of smolts from the Berners River averaged 17.7%, which was substantially higher than survival of smolts that migrated from Hugh Smith Lake (13.3%), also a mainland system located 490 km to the south (Figure 33; Appendix B2). During this period, marine survival was strongly positively correlated between the two systems (r = 0.750; p < 0.001). However, the prevailing pattern changed during 2008–2013 when average survival of Berners River smolts decreased to 12.0%, whereas survival of Hugh Smith Lake smolts was consistently higher, increasing to an average of 15.9%.

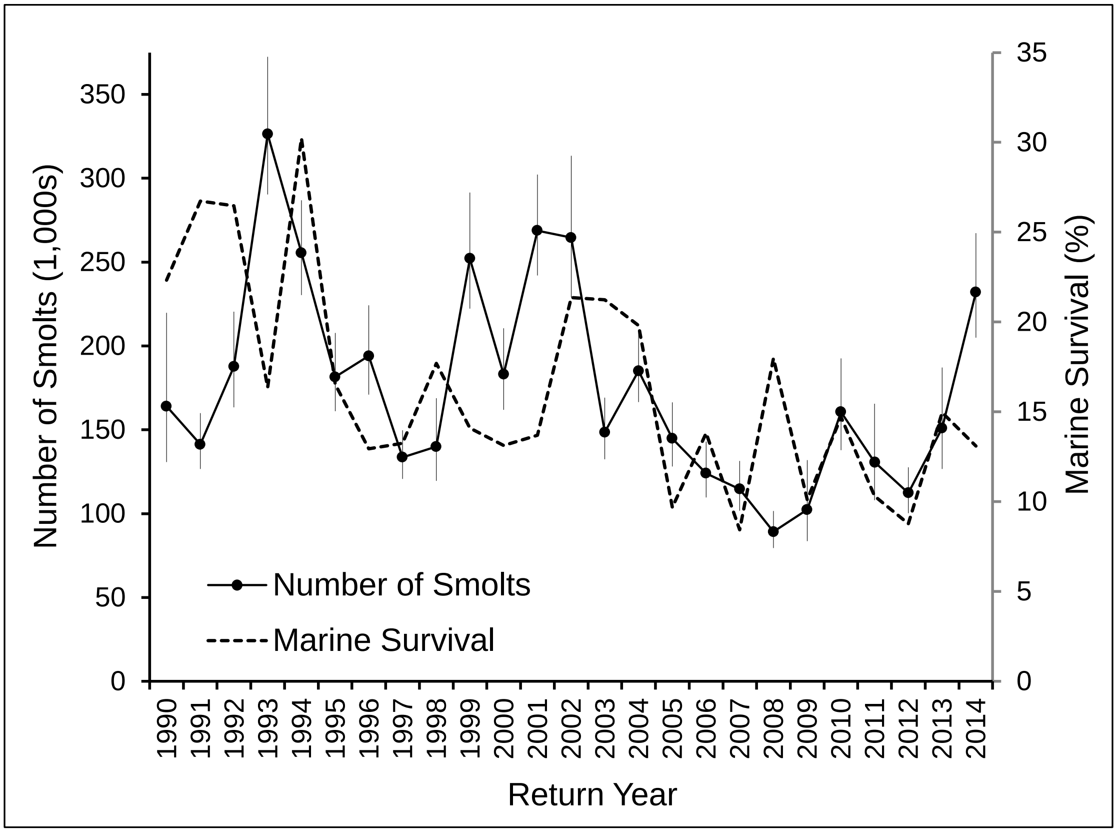

Figure 32.–Estimated smolt production (with 95% confidence bounds) and marine survival of coho salmon returning to the Berners River by return year, 1990–2014.

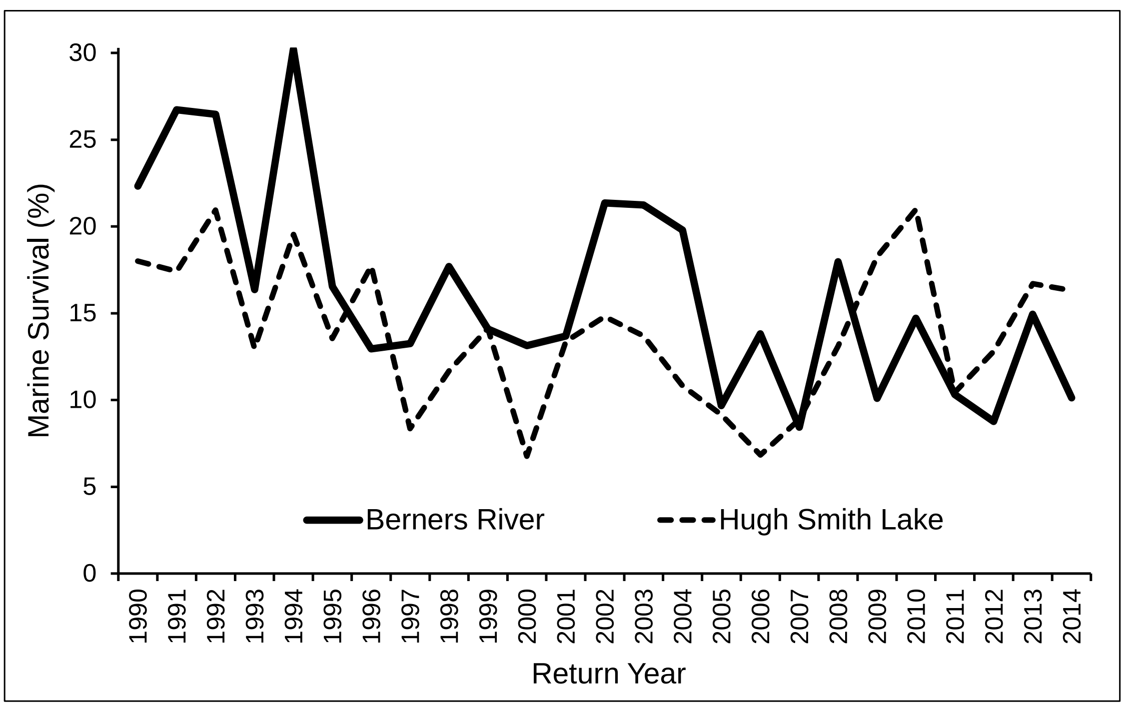

Figure 33.–Estimated marine survival rates from smolt to adult for 1990–2014 coho salmon returns to the Berners River and Hugh Smith Lake.

There has been a significant positive relationship between the Pacific Decadal Oscillation (PDO) Index and the ratio of the marine survival rate for the Berners River to marine survival for Hugh Smith Lake ($r = 0.484$; $p = 0.014$; Figure 34). A shift in favor of the southern indicator stock, Hugh Smith Lake, over the Berners River stock occurred coincident with a period of primarily negative PDO Index values (September–August average ending in the sea-entry year), suggesting that it may have been caused by a recent period of cooling in the northeast Pacific. There was a significant linear decline in marine survival for Berners River adults returning during 1990–2014 ($r = -0.627$; $p < 0.001$), but not for Hugh Smith Lake adults returning during the same period ($p = 0.368$; Figure 33).

While this pattern suggests that atmospheric forcing related to the PDO influences marine survival during the early period in the ocean, there is also evidence in support of an important late marine period in which survival is related to growth, which is in turn related to climatic effects and salmon predation on the primary offshore prey of coho salmon (Shaul and Geiger 2016).

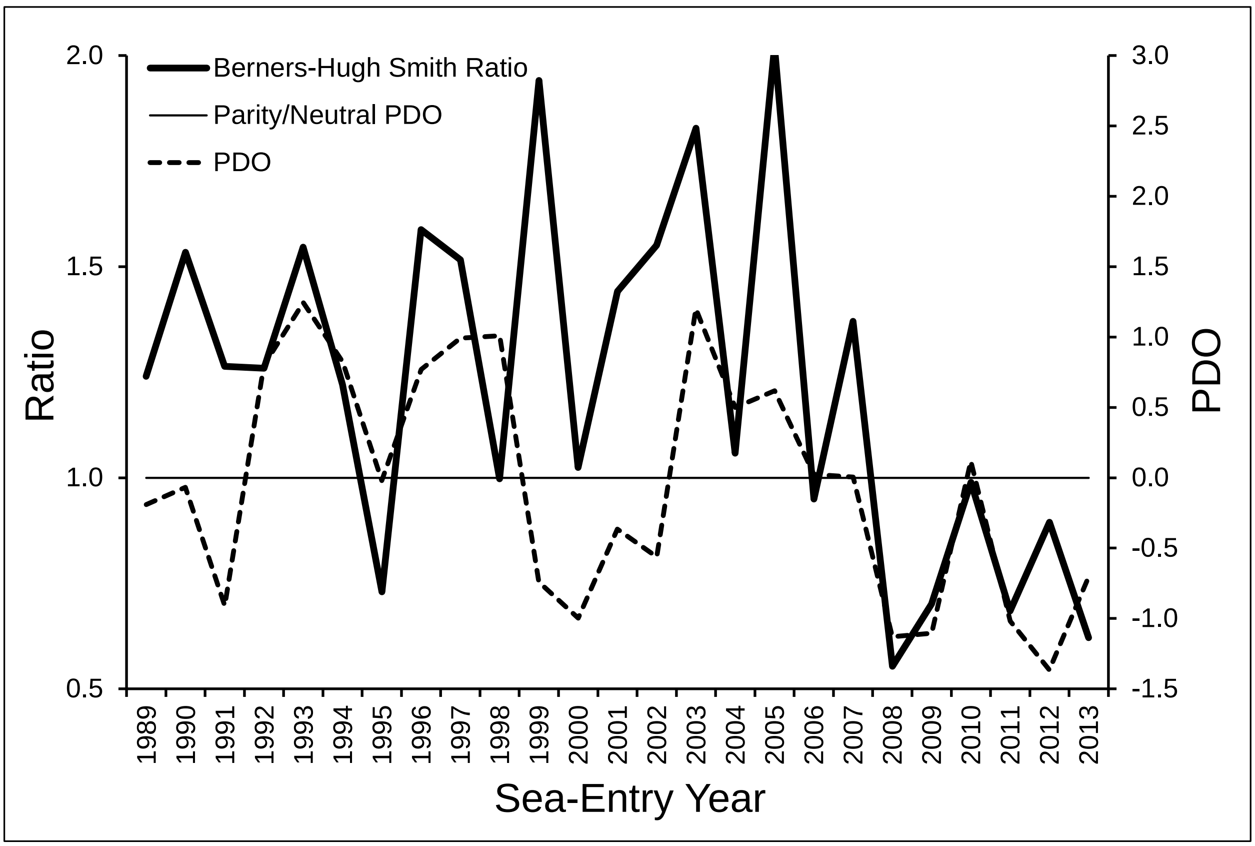

Figure 34.–Ratio of coho salmon marine survival rates for the Berners River to Hugh Smith Lake compared with the September–August Pacific Decadal Oscillation (PDO) Index ending in the sea-entry year, 1989–2013.

Variables targeted at both bottom-up (climatic) effects and top-down (predation) effects on the primary offshore prey (*Berryteuthis anonychus*) of coho salmon also explain some of the variation in marine survival of Berners River coho salmon. Lagged variables representing the Gulf of Alaska pink salmon biomass when squid are maturing and the April–March PDO Index, during the period of squid paralarva emergence and development, explain about 38% of the variation in marine survival of 1990–2014 adult returns (Figure 35) but the regression coefficient for the PDO variable failed to reach significance (Shaul and Geiger 2016). The pink salmon biomass variable alone explained about 33% of variation in marine survival. However, while diagnostics for this model were poor, the same variable explained 38% of the year-to-year change in survival with much better diagnostics. This suggests that while other factors may have influenced the trend in survival, pink salmon have an important influence on year-to-year variation in survival (Shaul and Geiger 2016).

A positive relationship between adult size and marine survival supports the hypothesis that overall survival in the ocean is related to late-marine growth. There was a moderate correlation (Spearman's rho = 0.669, $p < 0.001$) between marine survival and adult length prior to exposure to the drift gillnet fishery (Shaul and Geiger 2016; Figure 36). An evident decrease in variation in survival at smaller adult sizes suggests that slower late-marine growth may reduce both average survival and the potential range of survival rates. This suggests that 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. As shown earlier, this effect may be more important in influencing survival of females.

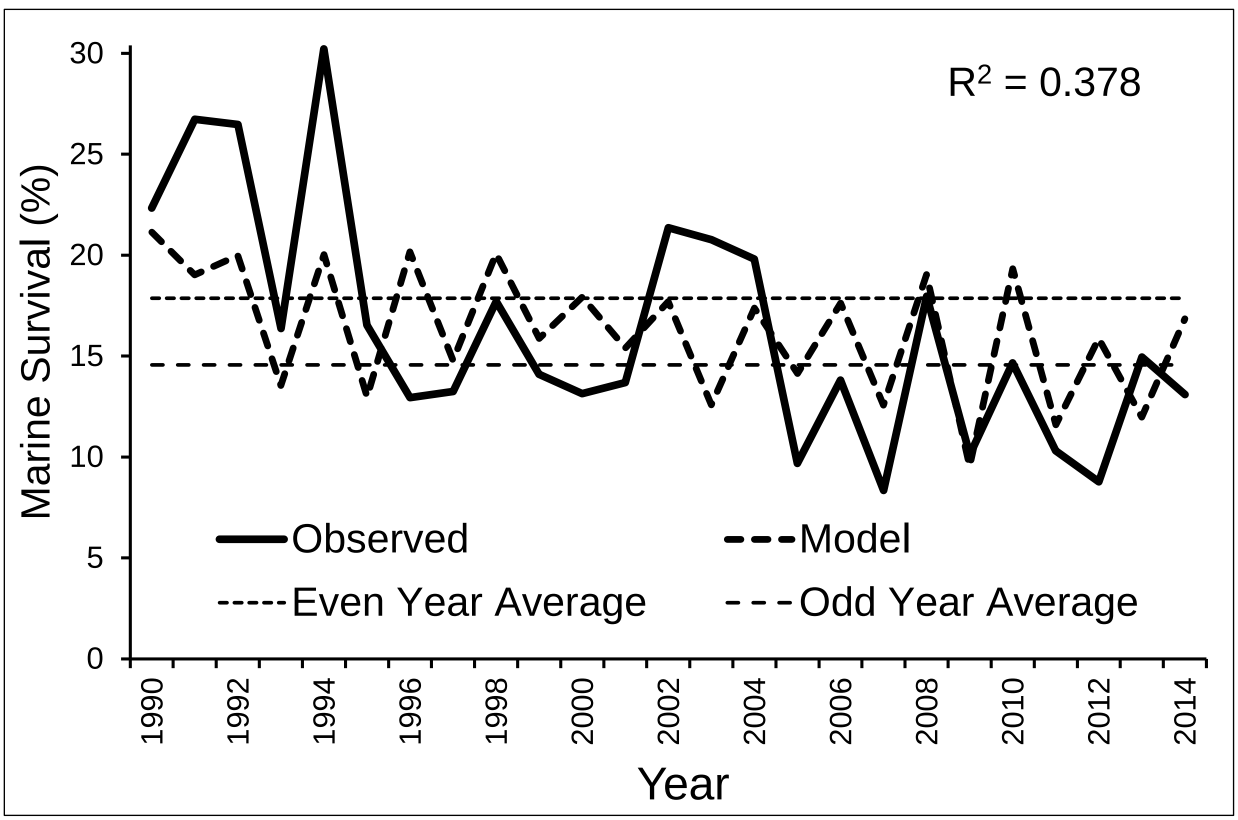

Figure 35.–Marine survival rate of returning age-.1 Berners River coho salmon and modeled survival rate based on the Pink-PDO predictors (Shaul and Geiger 2016) by return year.

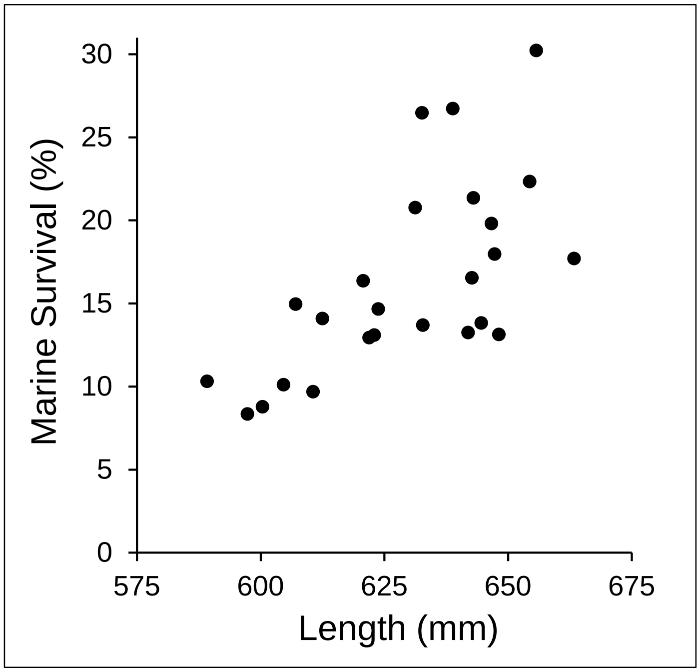

Figure 36.–Relationship between the mean-average mid eye to fork length of returning male and female age-.1 coho salmon prior to exposure to the drift gillnet fishery and their marine survival rate (Spearman's rho = 0.669, $p < 0.001$).

SMOLT PRODUCTION AND CLIMATIC INDICATORS

During the initial 17-year period of high average smolt production (1989–2005), the relationship between precipitation at the Juneau International Airport and Berners River smolt production was significant when precipitation was cumulated over longer periods of the summer and fall. During the period June–November, Shaul et al. (2011) found that the strongest correlation was for cumulative total precipitation from July through November ($R^2 = 0.725$, $p<0.0001$; Figures 37 and 38).

However, subsequent smolt production began falling well below expected abundance based on the earlier relationship with precipitation. Although no on-site physical monitoring has been conducted in the Berners River drainage throughout the year, we suspect that the recent decrease in smolt production may be related to a recent trend toward colder spring temperatures beginning in the mid-2000s (Figure 39), and probable longer annual periods of snow-on-ice coverage on off-channel habitats.

March–May air temperature at the Juneau International Airport averaged 1.1°C lower in 2006–2013 compared with the 1989–2005 average, coincident with a trend toward lower index values for the PDO, an indicator of the distribution of heat in the North Pacific Ocean (Mantua et al. 1997; Newman et al. 2016). Smolt production reached a record low in 2007 (Figure 37) following a 2006–2007 winter of record snowfall that resulted in major winter-spring mortality and a reduction in populations of moose (*Alces alces*) and mountain goats (*Oreamnos americanus*) in Berners Bay (White et al. 2012a and 2012b).

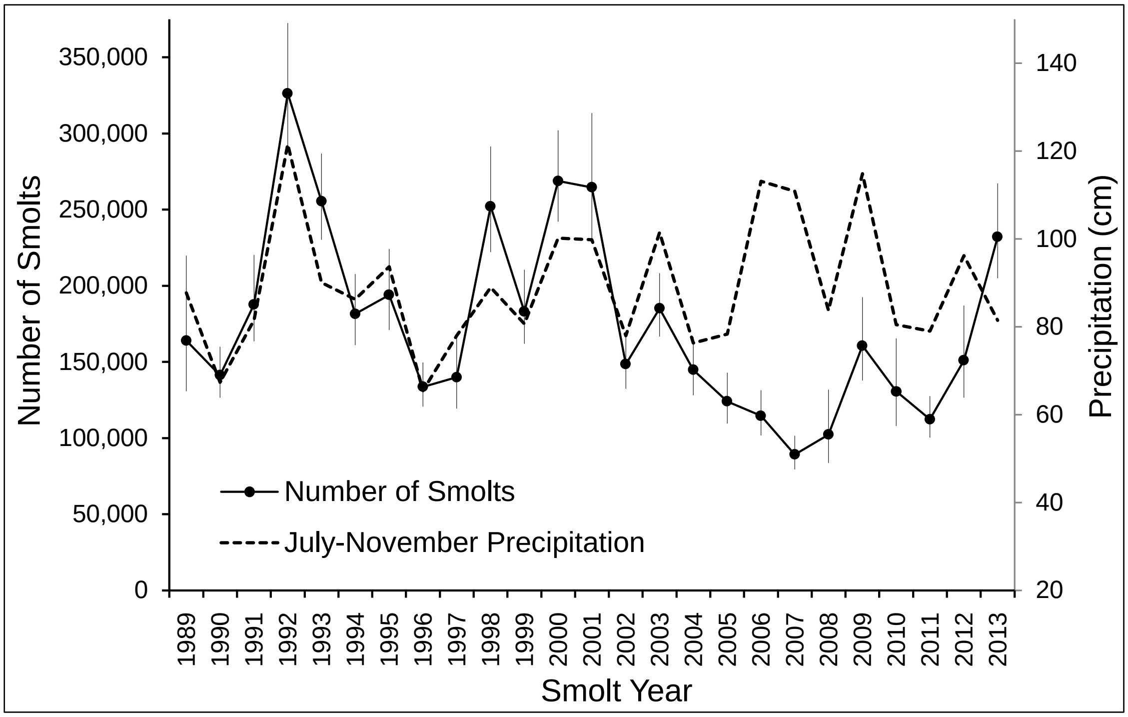

Figure 37.–Estimated coho salmon smolt production from the Berners River, with 95% confidence intervals, compared with total recorded rainfall at the Juneau International Airport during July–November of the year prior to migration to sea.

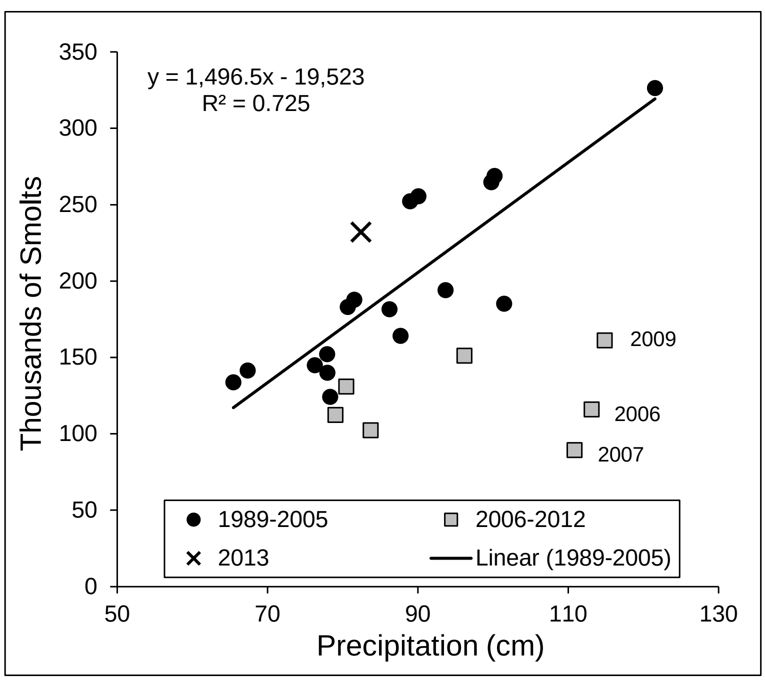

Figure 38.–Linear relationship between total July–November precipitation at the Juneau Airport and coho salmon smolt production from the Berners River the following spring (1989–2005 smolt years), showing recent (2006–2012) lower-than-predicted production based on the relationship.

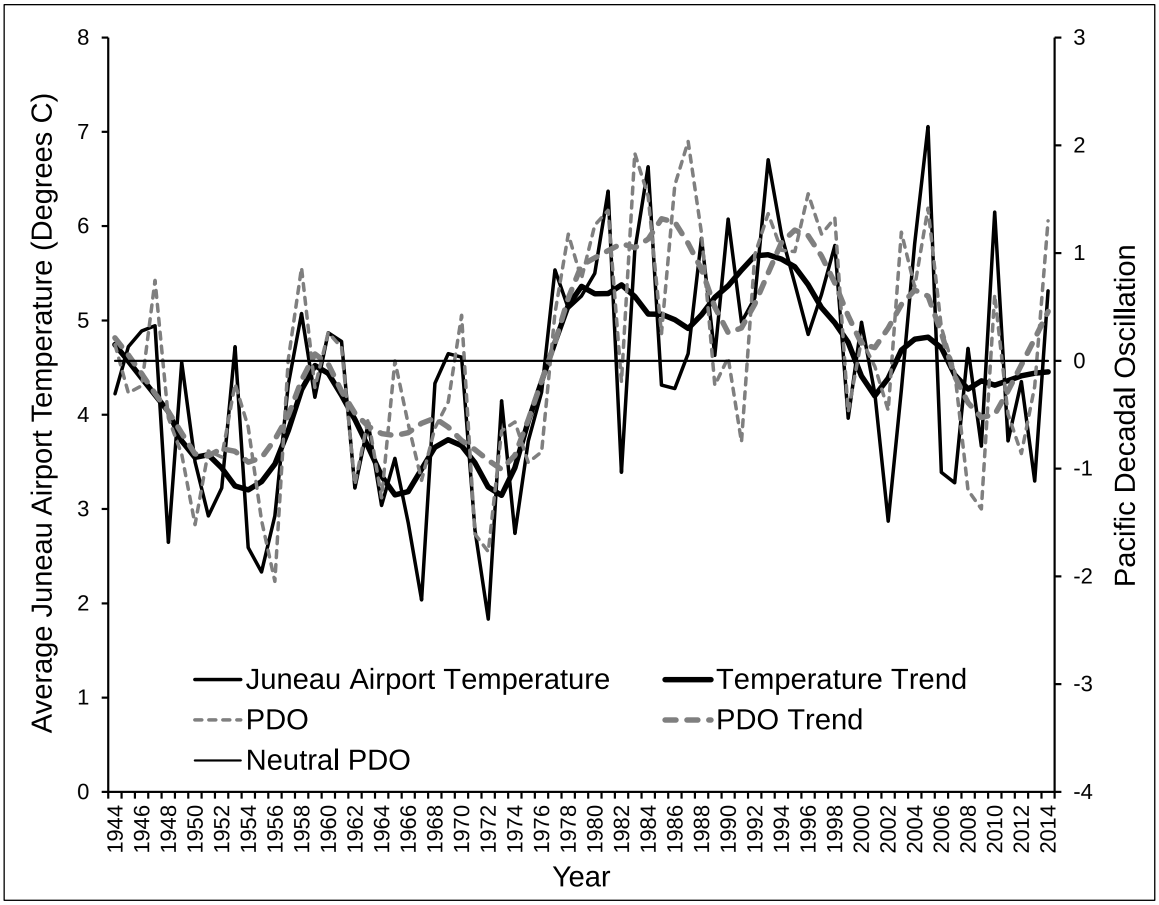

Figure 39.–March–May average daily temperature (°C) at the Juneau International Airport and the March–May average monthly Pacific Decadal Oscillation (PDO) Index, 1944–2014.

The Juneau Airport temperature was strongly positively correlated with the spring (March–May) PDO index during a period of 71 years ($R^2 = 0.565$; $p < 0.001$), but the correlation was not as strong during summer and fall months. We did not find a significant correlation ($p = 0.05$) between the Juneau Airport temperature and smolt production, and our hypothesis about a connection with cooler spring temperatures associated with the PDO is based primarily upon coincident lower trends in smolt production and temperature.

However, the depth and duration of snow and ice cover in the Berners River drainage may be affected by a complex combination of temperature and precipitation patterns throughout the winter–spring period. In warmer years, more precipitation may fall as rain. Precipitation events involving heavy rain on snow may result in infiltration of oxygenated water under ice and reduced snow depth, increasing potential light penetration and photosynthesis. Reduced light penetration resulting from snow cover has been found to be a key factor in reducing photosynthesis and promoting oxygen depletion (Greenbank 1945; Prowse and Stephenson 1986). Slightly cooler temperatures may substantially increase the depth and duration of snow coverage, resulting in a longer period during which oxygen demand from bacterial decomposition is not offset by the effect of photosynthesis and other sources of oxygen, including water run-in and surface agitation.

Smolts of both ages 1 and 2 sampled at Shaul Pond reached a period of peak average size (106 mm for age 1 and 115–117 mm for age 2) during the period of three consecutive years (2006–

2008) when total smolt production from the Berners River reached record lows ranging from 89.2 to 115.8 thousand smolts (Figure 40; Appendix B2). Overall, there was a significant negative correlation between system-wide smolt production and average length of Shaul Pond smolts of age 1 (r = -0.563; p = 0.004) and age 2 (r = -0.465; p = 0.022), suggesting that the factors responsible for the decline in the number of smolts did not impede their growth. To the contrary, it indicates that growth may have benefited from lower density. This suggests either that an increase in mortality occurred early enough prior to smoltification for growth of juveniles to benefit from the decrease in density, or that the decline in smolt production resulted from a decrease in the ability by fry and juveniles to enter prime rearing habitat in Shaul Pond and other similar off-channel habitats in the Berners River system. Large average size in less accessible off-channel habitats may point to a limitation in the ability of fish to distribute themselves optimally within the system.

Oddly, survival-adjusted adult returns indicate that a reduction in abundance of freshwater age-2 smolts accounted for nearly all of the decrease in freshwater production, while age-1 smolts showed little change (Figure 21). A strong negative correlation exists between total brood-year freshwater production (approximated by the survival-adjusted adult return) and the proportion of adults returning at age 3 (p = 0.002; r = -0.594), pointing to density dependent growth as one likely cause of the shift toward younger smolts. It is also possible that there were age-specific mortality effects due to climate, potentially based on differences in preferred habitat and/or a difference in tolerance to low oxygen levels.

During the 2004–2013 smolt years, the age composition of Shaul Pond smolts changed relatively little. The age-2 component accounted for an average of 49% of the migration compared with 53% during the prior 14 years (1990–2003), and the average freshwater age-2 component of the spawning escapement in the Berners River decreased markedly from 57% to 28% (Figure 41). The fact that there was a comparatively smaller shift in age composition of Shaul Pond smolts compared with system-wide smolts (reflected in the age composition of returning adults) suggests that reduced production specifically from that location may reflect reduced access by fry and juveniles, rather than differentially higher mortality in older juveniles within the pond complex.

Therefore, it appears likely that production of older juveniles fell much more sharply in other rearing habitats in the system. While the access limitation hypothesis appears to more closely fit the data from Shaul Pond, the winter-kill hypothesis cannot be ruled out as a cause of the decline in smolt production from some habitats that may see a proportionately greater reduction in oxygen when covered with ice and snow, or have more limited winter refuge habitat.

Indirect smolt production estimates for 1974, 1978, and 1979 returns (inferred from rearing juvenile estimates; Figure 31; Appendix B3) suggest that freshwater production during this earlier period (which transcends the 1977 North Pacific regime shift) was also low, averaging about 117 thousand smolts, similar the average of 126 thousand smolts associated with the recent (2005–2013) period of low adult production. For adults returning during 1983–1989, inferred freshwater production averaged higher (184 thousand smolts), although slightly below the average for direct population estimates (202 thousand smolts) for the 15-year period of peak adult returns (1990–2004). The most recent (2014) adult return was produced by an estimated migration of 232 thousand smolts in spring 2013, the largest smolt migration since spring 2002.

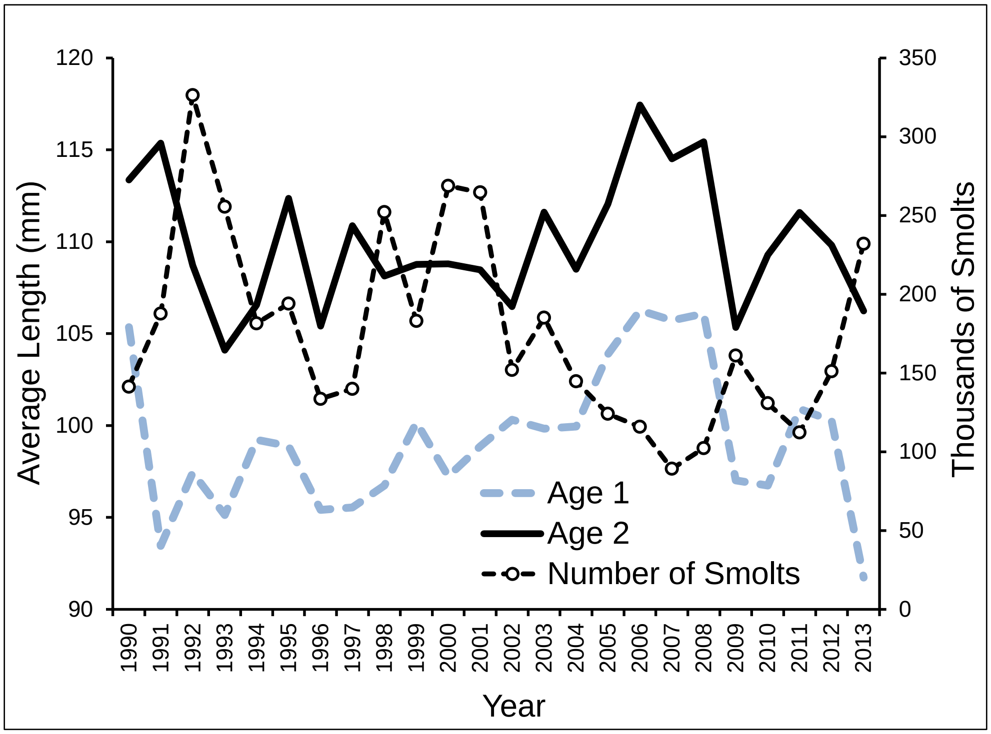

Figure 40.–Estimated total number of coho salmon smolts migrating from the Berners River and average snout to fork length of smolts migrating from Shaul Pond, 1990–2013.

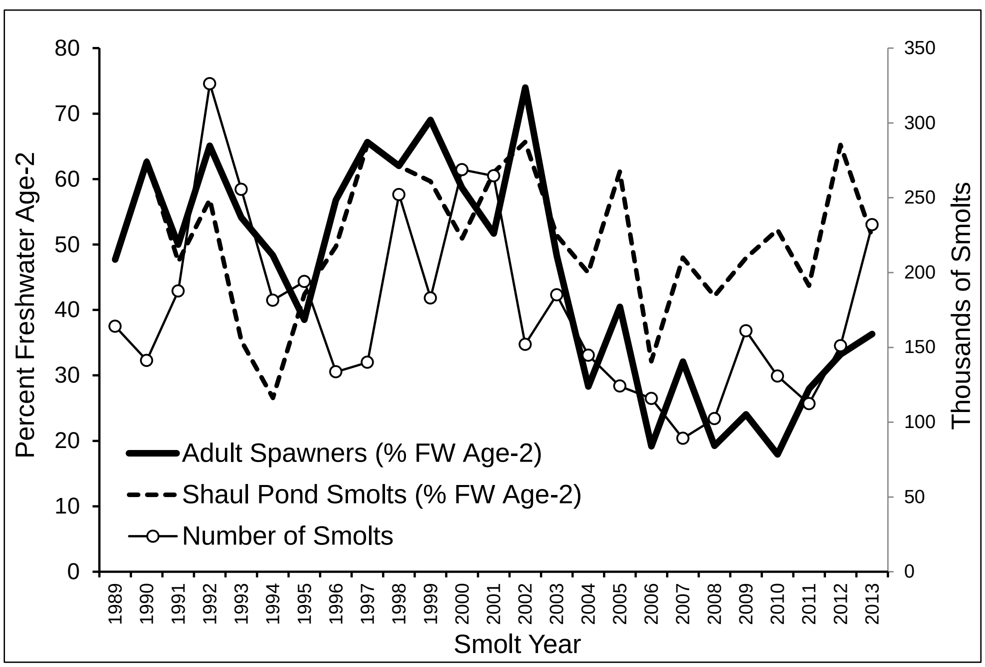

Figure 41.–Estimated total Berners River coho salmon smolt production and the proportion of Shaul Pond smolts and returning adult spawners that were freshwater age-2, by smolt migration year.

FRY MARKING AND SURVIVAL

During 1996–2012, newly emerged fry were captured with dipnets, tagged with half-length coded wire tags and released in major rearing ponds in order to generate known-age samples as part of an aging validation study. During the period, an average of 3,528 (range 2,368–5,482) valid-tagged fry with a distinct code were released annually into Shaul Pond (Appendix B3).

After including fish that were sacrificed for samples as smolts, the estimated survival rate of marked newly-emerged fry released in Shaul Pond averaged 27.5% (range 8.5–66.5%) to the smolt stage (Appendix C1) and 4.5% (range 1.0–12.8%) to the adult stage (Appendix C2). While these rates seem remarkably high for fish ≤38 mm SNF that have undergone the finclipping and tagging process, they represent fish that were released directly into highly favorable rearing habitat and may not be representative of fry survival for the overall population.

We found no significant correlations ($p = 0.05$) between survival of Shaul Pond fry to smolthood and effective parent spawning escapement (adjusted to constant PCEB) or adult return (adjusted to constant marine survival), for freshwater ages 1, 2, and both ages combined. On average, 75.5% (range 30.1–99.5%) of surviving fry marked during the 1995–2010 brood years smolted 1 year after emergence, and 24.5% (range 0.5–69.9%) smolted after 2 years.

PRODUCTION COMPARISON WITH THE CHILKAT RIVER

Coho salmon production from the Chilkat River in upper Lynn Canal was estimated during 2000–2014 (Elliott 2013; Brian Elliott, ADF&G Fishery Biologist, Haines, personal communication). The Chilkat River system, located 67 km to the northwest, is dominated by similar glacial mainland valley habitat, but it is substantially larger, and total adult coho salmon return estimates average about 6 times greater than returns to the Berners River.

Adult return estimates for the two rivers have been strongly correlated ($R^2 = 0.871$; $p<0.001$), suggesting that common regional influences (including climate) have acted similarly in affecting both smolt production and marine survival in these two stocks (Figure 42). However, estimates were not significantly correlated for either smolt production ($R^2 = 0.225$; $p = 0.074$), or marine survival ($R^2 = 0.171$; $p = 0.126$).

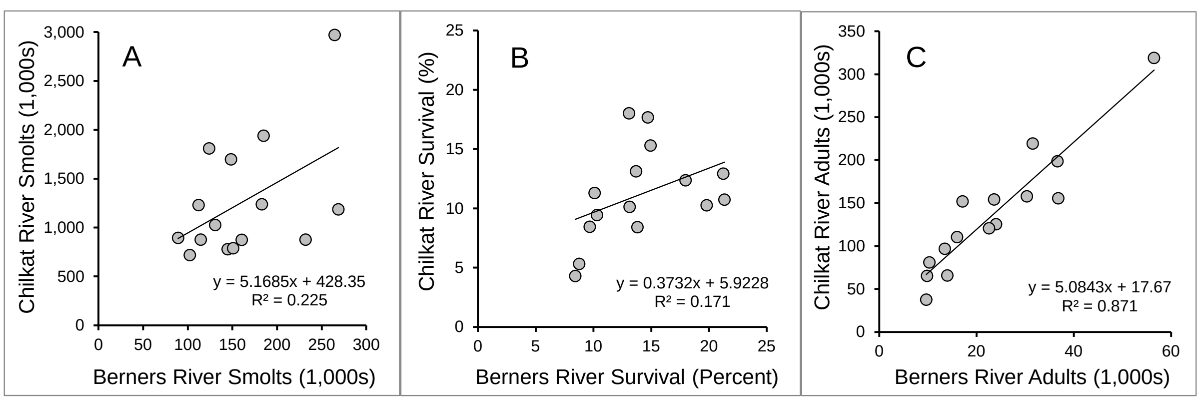

Figure 42.–Linear regression relationships between the Berners River and the Chilkat River in estimated coho salmon smolt production (A), marine survival (B), and total adult return (C). Chilkat River production estimates were provided by Brian Elliott (ADF&G Fishery Biologist, Haines, personal communication).

The contrast in correlations between adult return and smolt production and marine survival may be explained by a combination of process error and statistical error, primarily in the Chilkat River estimates. Estimates of smolt production are sensitive to both forms of error, particularly for the Chilkat River project in which a very small fraction of the population has been marked as a result of using minnow trapping methods that involve primarily capture of pre-migrating fish in early spring, which may vary in selectivity depending on location and weather. The proportion of returning adults with coded wire tags (Θ) has averaged 0.019 for the Chilkat River and 0.170 for the Berners River. Estimates of adult return are less affected by error in estimating Θ because only the harvest estimate is entirely dependent upon Θ, whereas escapement is estimated independently. Marine survival estimates are directly dependent upon estimated smolt production, such that over-estimation of smolt production will result in a proportionate under-estimate of marine survival and vice versa.

INSEASON STOCK ASSESSMENT AND MANAGEMENT

The strong positive correlation in returns to the Berners and Chilkat rivers indicates that conditions should be favorable for inseason stock assessment based on aggregate catch and effort statistics in the Lynn Canal drift gillnet fishery. However, R^2 values for linear relationships between Lynn Canal drift gillnet coho salmon CPUE and measures of abundance of Berners River coho salmon (run size in Lynn Canal and spawning escapement) are in most cases relatively weak (Appendix F1). During 1989–2014, cumulative CPUE of wild coho salmon in District 115 does not explain more than one-third of variation in Berners River run size in Lynn Canal until after the fishery has concluded for statistical week 38, at which point 97% of the troll harvest and 61% of the Lynn Canal drift gillnet harvest of the stock has already been taken, on average.

Inseason assessment based on CPUE is complicated by variation in factors related to fishery management, including predominant fishing areas and the number of boats participating, as well as variation caused by natural factors including weather and fish behavior. The number of vessels participating in the Lynn Canal drift gillnet fishery during peak fall fishing weeks (statistical weeks 36–39) decreased dramatically from an average of over 200 vessels in the 1970s and 1980s to 94 vessels in the 1990s and 55 vessels in the 2000s. Average participation increased slightly to 71 vessels during 2010–2014 (Figure 43). The decrease in effort coincided with a sharp decline in fall chum salmon abundance (Figure 13) and an increase in coho salmon returns across the region in the 1990s, that provided increased fall fishing opportunity in other drift gillnet fishing districts to the south. Although the total duration of openings in peak fall weeks was relatively stable at 180–212 hours during the 1970s–1990s, average fishing time increased markedly to 353 hours during 2000–2009 and 264 hours during 2010–2014.

The decrease in the number of vessels participating in the fishery after the 1980s likely resulted in increased CPUE relative to abundance. However, that shift did not likely have a major effect within the recent period of lower effort used to investigate relationships with Berners River run size (Appendix F1). The distribution of effort and harvest within Lynn Canal (Figure 43) has also likely had a substantial influence on the relationship between CPUE and Berners River coho salmon abundance. During the 1970s and 1980s, when the fishery was focused primarily on chum salmon, the average harvest of coho salmon during peak weeks was distributed relatively evenly across subdistricts (30% lower, 35% central, and 35% upper). Concurrent with a marked increase in coho salmon and decrease in chum salmon, the average distribution of the coho salmon harvest in the 1990s shifted dramatically to refocus on areas of typically higher coho salmon CPUE in lower Lynn Canal (71%) and away from the central subdistrict (22%) and, in particular, upper Lynn Canal (7%), where fishing was frequently restricted to protect the Chilkat River chum salmon run (Appendix F2). There was a slight shift in the coho salmon harvest back to central and northern areas during 2000–2009 and 2010–2014 as coho salmon abundance decreased and chum salmon returns exhibited minor improvement in some years.

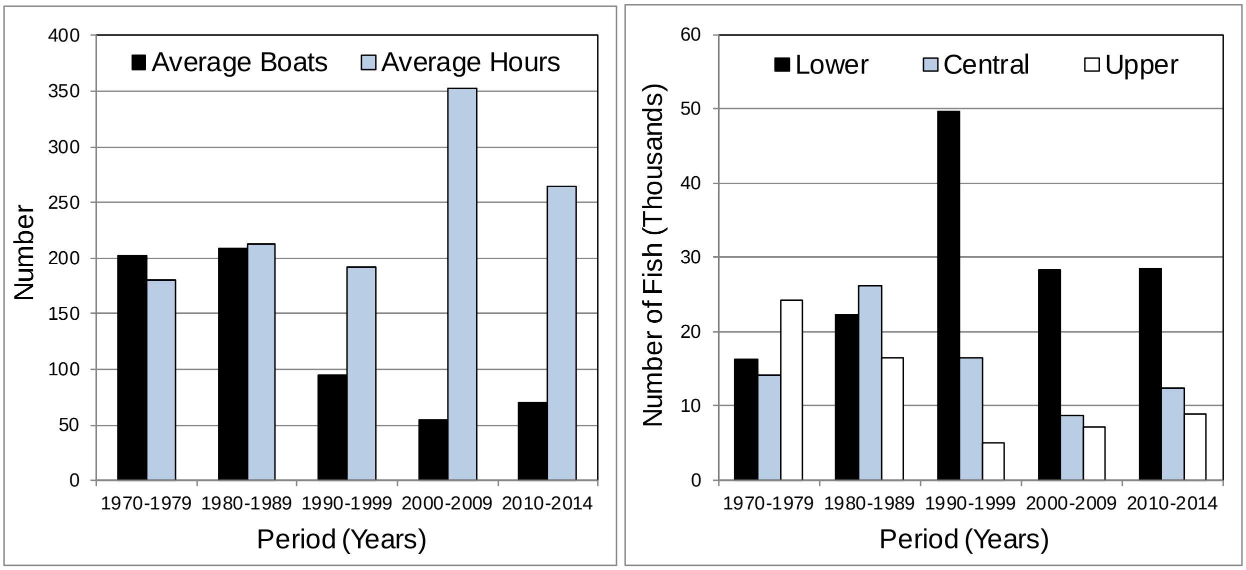

Figure 43.–Average weekly number of boats participating and total number of hours open to fishing in the Lynn Canal commercial drift gillnet fishery during four peak fall fishing weeks (statistical weeks 36–39; left graph) and the total coho salmon harvest in all weeks in in lower (subdistricts 10, 11 and 20), central (subdistrict 31) and upper (subdistricts 32, 33 and 34) Lynn Canal (right graph).

Another inconsistent variable is the hatchery contribution to the Lynn Canal drift gillnet coho salmon harvest, which averaged a moderate 4.4% during 1989–2014 but ranged from only 0.6% in 1997 to 16.6% in 1991. Macaulay Hatchery, operated by Douglas Island Pink and Chum (DIPAC), has contributed the vast majority (average 82%) of the total hatchery contribution to the Lynn Canal drift gillnet harvest since 1991, when major coho salmon production was developed at that facility. Most of the harvest of hatchery fish appears to occur in lower Lynn Canal (subdistrict 115-10), although contribution estimates are not available by subdistrict, and the harvest of returning Macaulay Hatchery coho salmon in the fishery appears to be strongly influenced by inter-annual variation in migratory behavior of returning fish, which in some years tend to approach the hatchery terminal area from a more northward direction compared with other years.

The late and variable migratory timing of Berners River coho salmon is another feature that makes it difficult to assess their return abundance and escapement during the fishing season. Protracted presence in coastal waters and broad geographic exposure to the troll fishery has made it possible to develop useful inseason CWT-based models for assessment of survival and returns of coho salmon to Hugh Smith Lake and Ford Arm Creek (Shaul et al. 2009 and 2014). Tagging rates for the Berners River stock have typically been ample for development of such models, averaging 349 unexpanded recoveries annually from the troll fishery during 1991–2014. However, the stock's particular migratory characteristics (including a late migration through areas of lighter, more variable troll effort to the northwest) as well as its variable migration timing (Figure 18), has confounded inseason assessment of marine survival from harvest of CWTs by the troll fishery. A further complication is the difficulty in estimating the proportion marked (Θ) for returning adults, without a significant jack component in the population or a weir where early returning adults can be sampled for Θ. In recent years, an effort has been initiated to address this problem by trapping smolts in large downstream minnow traps to develop provisional real-time estimates for Θ and the smolt population (Appendix B5), with limited success to date (the real-time estimate for 2010 was outside the 95% confidence bounds of the final smolt estimate). Development of a dependable real-time smolt estimate would be useful for forecasting abundance because smolt production has accounted for nearly half (48%) of variation in the adult return.

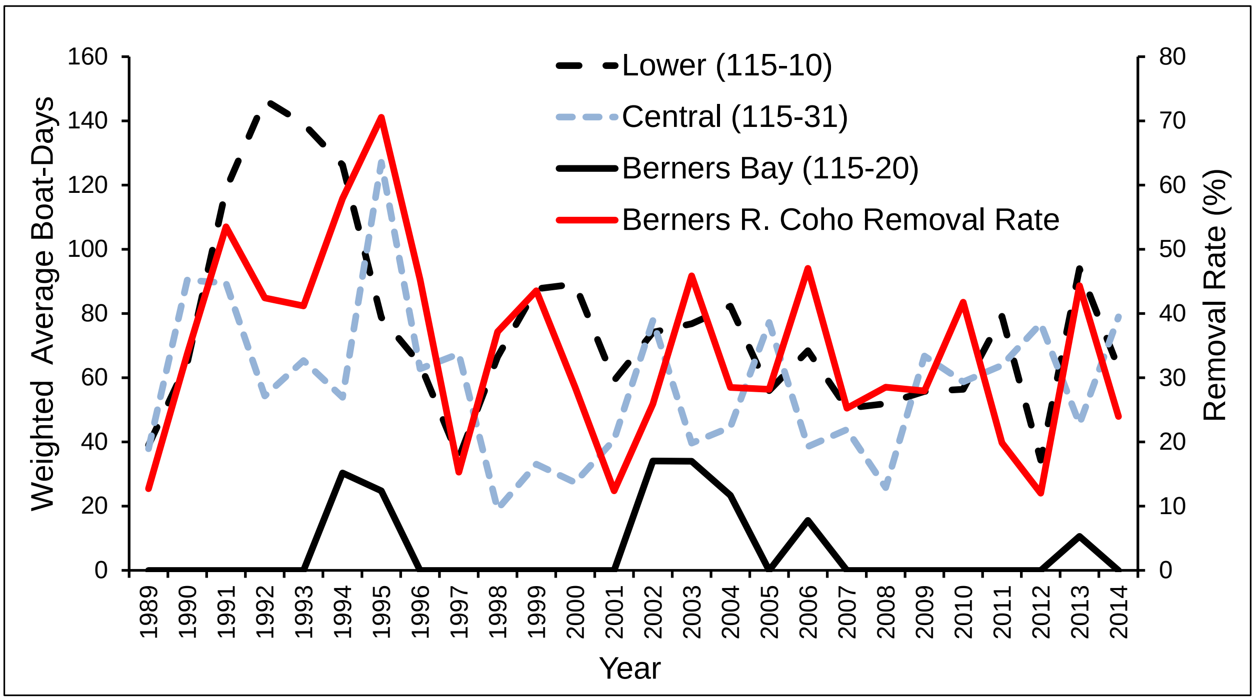

Figure 44.–Estimated removal rate for the Berners River coho salmon return by the Lynn Canal commercial drift gillnet fishery compared with the weighted weekly average number of boat-days fished by the drift gillnet fishery in three subdistricts in lower Lynn Canal. Boat-days fished in each week are weighted by the 1990–2014 average proportion of the harvest of the Berners River stock in the Lynn Canal fishery.

The proportion of the available Berners River coho salmon run removed by the Lynn Canal drift gillnet fishery has shown a similar trend to estimated fishing effort in lower and central Lynn Canal (weighted by the average harvest timing of Berners River fish in District 115; Figure 44). We examined linear regression relationships between weighted effort and the removal rate for Berners River coho salmon in order to better understand the relationship between fishing effort and the impact on harvest and escapement. In simple regression models, significant positive correlations ($p \leq 0.05$) were found with fishing effort in waters of lower Lynn Canal outside of Berners Bay (subdistrict 115-10; $R^2 = 0.35$; $p = 0.008$) and within the bay (subdistrict 115-20; $R^2 = 0.18$; $p = 0.031$), but not in central Lynn Canal north of Pt. Sherman (subdistrict 115-31; $R^2 = 0.06$; $p = 0.210$). A multiple regression with fishing effort in subdistricts 115-10 and 115-20 explained 44% of variation in the removal rate, and assigned 59% weighting to effort in the bay compared with 41% for effort outside the bay. This limited analysis is consistent with what has generally been understood by managers; i.e., that Berners Bay stocks are substantially available along the eastern shore of lower Lynn Canal, immediately north and south of Berners Bay, and potentially more so within the bay but are less available in central and upper Lynn Canal north of Pt. Sherman.

Lower Lynn Canal Drift Gillnet Fishery Management

Following statehood, lower Lynn Canal (Section 15C) was not opened to the commercial drift gillnet fishery until 1968. During 1961–1966, Berners Bay (Section 15B) was opened beginning in statistical week 35, and weekly fishing periods ranged from 3–4 days per week. These openings drew little fishing effort: the weekly number of participating boats ranged from 0 to 13, and the season total harvest of coho salmon ranged from 0 to 2,757 fish.

Fall openings in Berners Bay were re-instituted during the all-time record coho salmon return in 1994, following a series of very strong returns and large escapements during 1991–1993. The area management biologist began to look for ways to increase exploitation on the coho salmon return without substantially increasing harvest pressure on Chilkat River chum salmon. In 1994, the bay was opened in week 38 (initially only to Cove Point) for 1 day, followed by 3-day openings in the following 2 weeks, and a 2–day opening in the final week (41). These measures, along with a comparatively large fishing fleet in lower Lynn Canal, appeared to substantially increase harvest of the run in Berners Bay, resulting in an estimated removal rate of 58% (compared with a previous 5-year average of 37%) while still leaving a record number of adults to spawn. A total of 13,805 coho salmon were reported harvested inside the bay during 9 days of fishing.

In the following year (1995), the bay was opened in week 38 for only 2 days during which 50 boats reported landings from the bay that totaled 11,632 coho salmon, nearly all reportedly caught in the first night. The principal author visited with a participant in the fishery later in the week who described the opening as a slaughter and stated, “You guys never should have opened Berners Bay!” Port sampling technicians recovered heads from 603 adipose-clipped coho salmon from a sample of 6,708 fish from the Lynn Canal drift gillnet fishery that week of which 593 contained tags, including 551 tags that had been implanted in smolts from the Berners River. A substantial proportion of the week 38 catch was taken in Berners Bay, and the Berners River was estimated to have contributed 35% (7,045 fish) of the coho salmon catch in Lynn Canal for the week (20,119 fish). In retrospect, the Berners River run size in Lynn Canal (20,854 fish) in 1995 was substantially lower than during the previous 4 years (range 30,798–46,969 fish), while the removal rate by the Lynn Canal drift gillnet fishery was a record 70.6% (14,716 fish) after an estimated 30.5% (9,154 fish) of the stock had already been removed by previous fisheries. Nearly half (47%) of surviving Berners River coho salmon at the beginning of week 38 were harvested both inside and outside the bay in the single 2-day opening. The intense Lynn Canal drift gillnet fishery in 1995 had a substantially greater effect in reducing the average size of Berners River spawners compared with any other year (Figures 25 and 26).

A series of strong coho salmon returns to Lynn Canal during 2002–2004 coincided with low salmon prices, relatively low troll exploitation rates, and reduced participation in the fall drift gillnet fishery. The combination of substantial returns and low fishing effort sparked renewed interest in opening Berners Bay to fishing. During 2002–2004 and 2006, the bay was opened during peak fall fishing weeks, usually for 3 days per opening, and only moderate participation was reported by 18–28 boats during the very large return in 2002 and only 8–15 boats during peak weeks in 2003–2004 and 2006. In 2013, the bay was opened for 3 days only once in week 37, prior to typical peak abundance, and relatively few fish were caught. While the openings during 2002–2004 and 2006 likely helped increase exploitation (the estimated average removal rate in Lynn Canal was 36.8% during those years, compared with 30.2% for the 19 years during 1989–2014 when the bay was not opened), their impact on escapement appears to have been limited by relatively low participation in the openings.

Although openings inside Berners Bay (Section 15B) can be unpredictable in their effect on exploitation and escapement, management of openings outside the bay in Section 15C has had a more predictable effect and has proven amply conservative relative to the Berners River stock. Even in recent years (2005–2013) when returns were low, the harvest averaged only 10.5 thousand fish compared to 26.0 thousand fish during 1990–2004. Escapement fell below the current *BEG* in only one of those years (2007).

During the most recent 10-year period (2005–2014), openings in Section 15C during the three peak statistical weeks (that have historically accounted for an average of 70% of the harvest of the stock) have consistently been either for 2 or 3 days, and an average of 23 boats (range 16–32 boats) were reported fishing in the subdistrict in those weeks. Based on the linear relationship with boat-days fishing in Section 15C, the lower bound of the proposed *BEG* (4,500 spawners) is predicted to be achieved even under the lowest observed Lynn Canal run size since 1989 (6,502 adults in 2007) with as many as 60 boats fishing 2 days per week or 40 boats fishing 3 days per week. A Lynn Canal return that is only average for the 5 lowest return years out of 26 (7,983 adults) will more likely than not achieve the lower *BEG* threshold with up to 49 boats fishing 3 days per week.

Troll Fishery Management

Inseason information on the Berners River return is even more limited for management of the troll fishery along the primary migration approaches where harvest of the stock peaks about 2 weeks ahead of the harvest in the Lynn Canal drift gillnet fishery. Inseason assessment has depended to a large extent upon other, more general indicators of returns to northern inside systems, including, in particular, inriver run assessment for the Taku River, which has a substantial early-run component, and to a lesser extent the Chilkat River fish wheel catch. Berners and Chilkat stocks both typically peak in timing in the troll fishery well after the mid-August mid-season troll fishery closure, and reliable stock-specific data for those populations is lacking at the time when the decision must be made about implementation of the closure. Management action in the troll fishery based on inseason assessment more specifically for Lynn Canal stocks must typically be deferred until September, and is best-informed regarding potential extension of the summer troll season (for up to 10 days past the 20 September ending date specified in regulation).

A primary stated intent by the Alaska Board of Fisheries for the mid-season troll fishery closure first implemented in 1980 was to insure allocation of coho salmon to inside user groups. Mid-season closures were consistently of 10 days in duration from 1980 through 1992, but varied between 2 and 10 days during 1993–2000 in response to a period of generally greater average coho salmon returns to the region beginning in 1990 (Skannes et al. 2015). During 2001–2014, closures ranged from 0 to 5 days (average 3.6 days), and the season was extended for 10 days through 30 September in 9 out of 15 years. In 2013, trollers were allowed to harvest and retain coho salmon continuously for a period of 4 months from 1 June through 30 September, likely for the first time since the 1930s, before the coho troll fishery was fully developed.

However, despite being relatively liberal in recent years of smaller average returns, management of the troll fishery has been effective not only in achieving biological escapement needs for the Berners and Chilkat river stocks, but also in maintaining a relatively stable share of the harvest by the drift gillnet fishery (Figure 45). Actions to reduce the duration of the mid-season closures, as well as to extend the troll season for 10 days past the normal 20 September ending date, have helped compensate for a decrease in effort in the troll fishery, and have not come at the expense of the drift gillnet harvest or escapement needs for the Berners River and Chilkat River stocks, with the exception of 2007 when escapement was slightly below the current *BEG*s for both stocks. Despite the trend toward more liberal management, the average troll exploitation rate on the Berners River stock decreased from 32.7% during 1989–2000 to 25.2% during 2001–2014 (Appendix A7).

During the 1970s and 1980s, when fall drift gillnet fishing effort in Lynn Canal averaged over 200 boats, the drift gillnet fishery averaged only 34–35% of the combined troll and drift gillnet harvest of Berners River coho salmon, although the drift gillnet proportion averaged higher (47%) for Chilkat River coho salmon that had to traverse the intensive fishery in the central and upper canal that was directed at chum salmon bound for the same system (Appendix F2). After the abrupt decline in the Chilkat River chum salmon return beginning in 1990, there was a rapid shift in management from limiting fishing in the lower canal (Section 15C), where coho salmon comprised the highest proportion of the catch, to shifting fishing effort into that area in order to harvest large coho salmon returns while protecting Chilkat River chum salmon as they transited the central and upper canal (Section 15A).

This shift increased the drift gillnet proportion of the combined troll and drift gillnet harvest of Berners River fish to 47–48% during 1990–2004 when coho returns were very abundant, on average (Figure 45). As a result of less effort in upper Lynn Canal during this period, gillnetters likely took a smaller fraction of the harvest of Chilkat River coho salmon (Appendix F2). During the recent 10-year period of substantially lower average coho salmon abundance, and slight recovery in chum salmon returns, the average gillnet fraction decreased from 48% during 2000–2004 to 44% during 2005–2014 for Berners River coho salmon and increased from 39% to 49% for Chilkat River coho salmon. The recent increase in the drift gillnet proportion was also affected by lower average exploitation rates by the troll fishery during 2000–2004 (22%) and 2005–2014 (26%) compared to 1989–1999 (34%; Figure 15; Appendix A7).

Chilkat River Management

In addition to achieving the *BEG* for the Berners River coho salmon population, it is also important to meet Lynn Canal drift gillnet fishery management goals for the larger, intermixed Chilkat River coho salmon population, for which escapement estimates are available since 1987 and run reconstruction estimates are available since 2000. While coho salmon returns to both rivers have been very strongly correlated (Figure 42), it is also useful to compare the ratio of average adult returns and escapements to escapement goals to determine whether one stock or the other will more likely need to be favored in calibrating area and time fishing regulations at various levels of abundance.

The current *BEG* of 30,000–70,000 spawners for the Chilkat River drainage was established based on a Ricker analysis by Ericksen and Fleischman (2006). Estimates provided for 2000–

2014 returns by Brian Elliott (ADF&G Fishery Biologist, Haines, personal communication), indicate an average total return of 137,200 adults to the Chilkat River compared with 23,500 adults returning during the same period to the Berners River, for which we propose a *BEG* of 4,500–10,000 spawners (based on the expanded survey count). The ratio of average adult return to the *BEG* for the Chilkat River (1.96–4.57) was 12–17% lower than a comparable ratio for the Berners River stock (2.35–5.22), indicating that, on average, it will be possible to exploit the Berners River population somewhat more intensively (Figure 46).

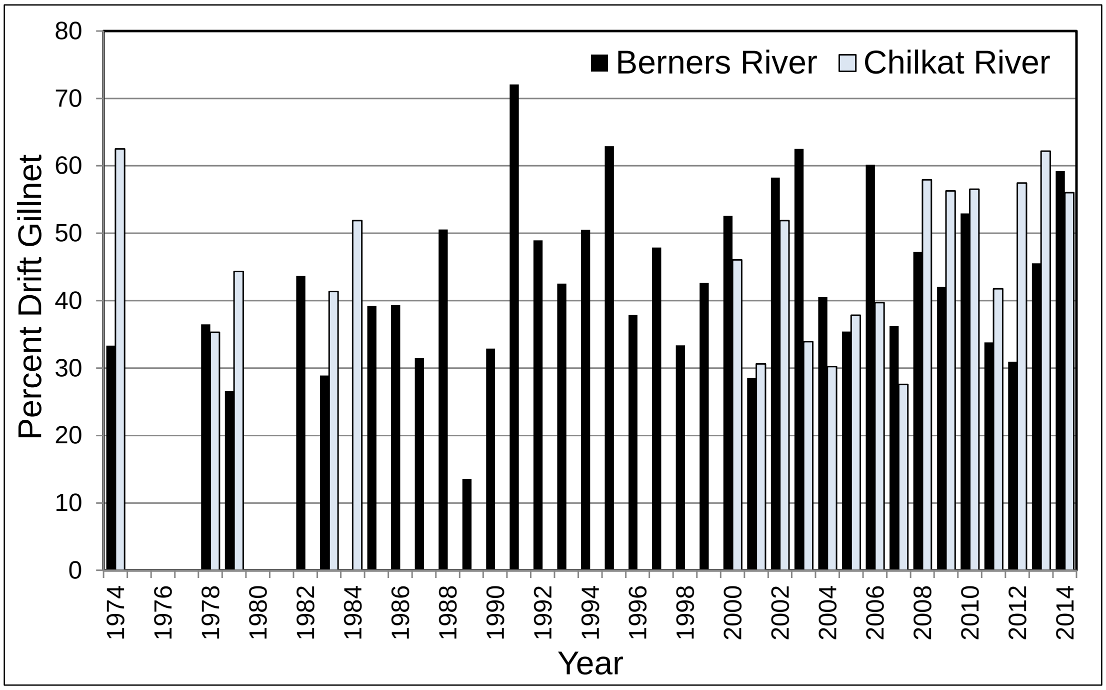

Figure 45.–Percent taken by drift gillnetters of the combined harvest by commercial troll and drift gillnet fisheries of coho salmon returning to the Berners and Chilkat rivers.

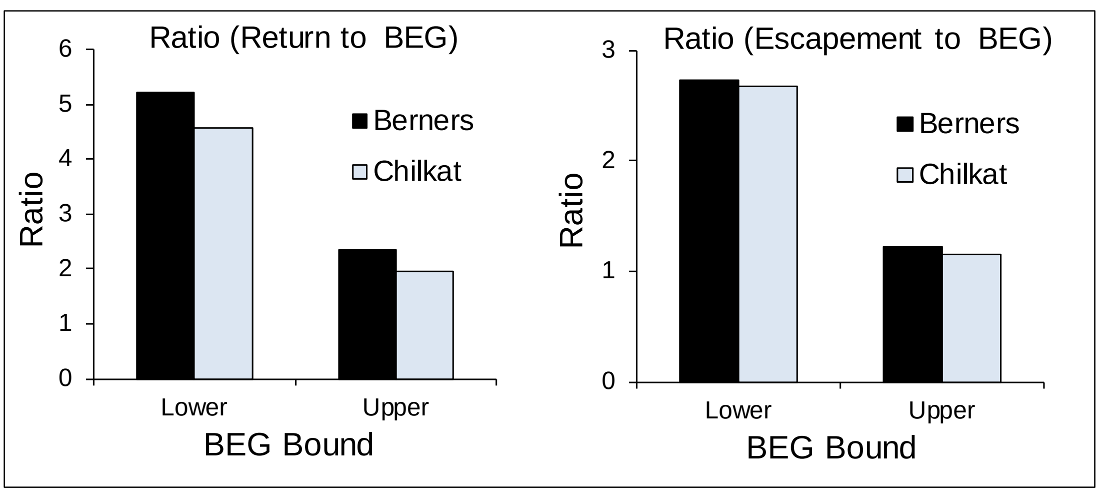

Figure 46.–Ratio of the 2000–2014 average total adult return (left graph) and spawning escapement (right graph) of coho salmon to the Berners and Chilkat rivers to the upper and lower bounds of their respective biological escapement goals (*BEG*s). Our recommendation (4,500–10,000 spawners) is the *BEG* used for the Berners River.

However, under prevailing fishing patterns over the 15-year period, the estimated average all-fishery exploitation rate has in fact averaged higher for the Berners River (48.6%) compared with the Chilkat River (41.6%), so that the ratio of average escapement to respective *BEG* bounds has been closer between the populations, and the ratios for the Chilkat River (1.15–2.68) have been only 2–7% lower than the ratios for the Berners River (1.23–2.73). Given this relatively small difference, there appears to be little reason to alter management from recent fishing patterns to favor either stock over the other.

CONCLUSIONS

CAUSES OF VARIATION IN ADULT RETURNS

Variation in adult coho salmon returns to the Berners River over a 25-year period (1990–2014) was nearly equally attributed to variation in freshwater factors (48%), including spawning escapement, and variation in marine survival (52%). The relative contribution by freshwater production to variation in adult production was substantially higher compared with Hugh Smith Lake coho salmon (35%; Shaul et al. 2009), perhaps because most juveniles in the latter system rear in a relatively stable lake environment.

Total adult returns to the Berners River showed a marked (60%) step-down from a period of peak production, from an average 38.2 thousand fish during 1990–2004 to only 15.2 thousand fish during 2005–2013, that was approximately equally attributed to a decrease in smolt production (38%) and marine survival (37%). Return estimates based on unexpanded escapement counts suggest that similarly low average returns occurred in the mid- to late 1970s (Figure 10), a period of generally lower wild coho salmon harvests in Southeast Alaska (Shaul et al. 2011).

The strong positive correlation (R^2 = 0.871) in adult return estimates between the Berners and Chilkat rivers over a 15-year period suggests that similar environmental processes affect coho salmon populations in these mainland river valleys, which are major contributors to a common drift gillnet fishery in Lynn Canal and to the troll catch in northern Southeast Alaska during the latter part of the fishing season. Coho salmon returns to other important mainland systems with a substantial amount of off-channel pond, slough, and wetland rearing habitat may have been similarly influenced by climatic variation.

Freshwater Production

Summer and fall precipitation appears to be an important factor in mainland river coho smolt production, at least during periods of warmer climate. This finding adds further support for the importance of precipitation and streamflow to survival and abundance of rearing coho salmon based on studies of populations in Oregon and Washington (Smoker 1955; Mathews and Olson 1973; Scarnecchia 1981; Lawson et al. 2004).

The decrease in smolt production relative to summer-fall precipitation in the mid- to late 2000s suggests that the decline was probably not related to summer habitat conditions. At the same time, spawner-recruit data indicates that the decline was not related to a change in spawning escapement. The strong correlation in adult returns with the Chilkat River indicates that causal factors were widespread in coho salmon populations in similar habitat, in the freshwater environment as well as in marine waters. Although the underlying cause of the decline in smolt production is not entirely clear, it appears likely that it was related to weather conditions associated with post-1998 cooling in the northeast Pacific. While we suspect that colder winter-spring weather was responsible for the decrease to an average of only 123 thousand smolts in the 2007–2013 return years, it remains to be seen if recent warm conditions in the northeast Pacific will lead to a sustained rebound in smolt production in line with the most recent (2014) return.

Our primary hypothesis for the decline in smolt production is that conditions for rearing fish between fall and spring affected movement of juveniles among habitats and their survival in isolated off-channel locations. While typical beaver ponds provide stable habitat that can support a high growth rate in rearing fish (Murphy et al. 1989), the dams associated with the ponds can restrict habitat connectivity (Malison et al. 2016). In addition, extended snow and ice cover, combined with a scarcity of winter-spring rainfall events, may result in depletion of oxygen in some off-channel habitats to lethally low levels, conditions observed by Josephson[2] in some Chilkat River Valley ponds in March 1981 and 1982.

While bacterial decomposition of plant matter in off-channel habitats consumes oxygen, deeper snow cover and later ice-out dates can reduce potential offsetting oxygen production from photosynthesis, and limit the influx of oxygen from outside sources including wind and rainwater (Greenbank 1945). Under the winter-kill hypothesis, conditions leading to potential mortality were likely most severe in spring when air temperature decreased most during the years in question and was closely linked to climate in the North Pacific. This hypothesis is consistent with observations by Josephson (*unpublished*), who found evidence that winter snow and ice cover substantially reduced oxygen levels in ponds in the Chilkat River Valley and concluded that over-winter survival was likely a critical aspect of productivity for rearing coho salmon.

The ability of fish to move between habitats, particularly to escape oxygen sensitive habitats in fall and winter, may be important to their survival. Among Chilkat River ponds, survival to adulthood averaged higher for juveniles tagged in ponds that were artificially connected with the river compared with naturally connected ponds (Josephson *unpublished*). While hindering escape from lethal oxygen levels, limitations on movement imposed by colder winter–spring weather may also reduce access to pockets of favorable off-channel habitat where potential for growth and survival may be higher.

Some aspects of the period of low smolt production appear to point to decreased access to favorable off-channel habitats as a potentially important factor, rather than simply increased winter mortality combined with an inability to escape isolated pockets. The negative correlation between total Berners River smolt production and average size of Shaul Pond smolts of both ages 1 and 2 is consistent with a density effect in the pond. The number of smolts captured from trough traps on pond spillways decreased beginning in the mid-2000s, when average smolt size was large. Increased growth of juveniles may also explain the strong negative correlation between total brood-year freshwater production (approximated by the survival-adjusted adult return) and the proportion of adults returning at age 3 (freshwater age 1) versus age 4 (freshwater age 2), pointing to a density-dependent response as a likely cause of the shift toward younger smolts.

Fry migrating downstream from headwaters spawning areas during spring and early summer actively seek out spillways and attempt to gain access to elevated beaver ponds near the margins of the main channel. Use of dip nets to capture fry concentrated in these locations has proven a

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[2] Josephson, R. *Unpublished manuscripts*: Chilkat Pond Investigations in 1982 (1983), and Chilkat Ponds Summary (1987), Alaska Department of Fish and Game, FRED Division, Juneau.

successful technique for obtaining newly emerged fry (≤38 mm SNF length) for marking as part of the multi-year aging validation study. Restriction of movement by juveniles among habitats is likely to compromise their growth and survival by restricting their ability to optimally use of all available habitats throughout the year. The peak in size-at-age of Shaul Pond smolts during 2005–2008, years of low system-wide smolt production (Figure 38), suggests that growth may have benefited from a reduction in density of juveniles, possibly as a result of restricted access to the pond complex.

Absence of significant correlation between spawning escapement (either nominal or adjusted for constant PCEB) and fry-to-smolt survival for marked fry released in Shaul Pond suggests that the number of juveniles rearing in the pond were affected more by access than by the number of fry emerging from spawning areas. It is difficult to explain the larger size-at-age of Shaul Pond smolts in colder years when abundance was low without considering access limitation, because the opportunity for a density-dependent growth response to late-winter and spring mortality from oxygen depletion would appear limited by the time available for growth following decreased density (particularly under colder spring conditions). Therefore, in the specific case of Shaul Pond, we suspect that colder winter–spring weather may have affected smolt production primarily by limiting access to the pond rather than through increased mortality within the complex, which receives input from a stream and includes some deeper basins with substantial volume.

Although the proportion of freshwater age-2 fish in the spawning escapement decreased significantly between the 1990–2003 (average 27.9%) and 2004–2013 smolt years (average 57.5%; $p < 0.001$), the age composition among smolts that migrated from Shaul Pond did not change significantly for the same sea-entry years ($p = 0.400$), which suggests that different dynamics may have prevailed in some other habitats in the system. Oddly, a reduction of freshwater age-2 production appeared to account for most of the decline in smolt production from the overall drainage, while freshwater age-1 production did not show a declining trend. If winter–spring mortality was the primary cause of the reduction in smolt production (rather than reduced access to prime off-channel rearing habitat) then it would appear necessary to explain why most of the mortality fell on older age-2 smolts, perhaps through use of different habitats or differing sensitivity to oxygen depletion. Also, if increased juvenile mortality occurred in the spring when oxygen levels should have been lowest, shortly prior to the smolt migration, then it is difficult to explain such a marked positive growth response to reduced juvenile density in Shaul Pond during a relatively short period of spring months under cold conditions that would seem more likely to retard growth. Further insight may be possible by analyzing scale growth on adults to examine size at sea-entry and growth by freshwater age.

Spring rainfall may also be important in providing access for smolts to leave some habitats. Large, bright juveniles were observed in a pond a short distance from camp that had no access to the slough during the smolt migration period (Mark Olsen, ADF&G Fishery Biologist, Juneau, personal communication). Following construction of a small ditch connecting the pond to the slough, smolts exited the pond and were captured in a trough trap for tagging.

Abundant pink salmon returns provide an influx of nutrients into freshwater systems that can provide a substantial benefit to freshwater rearing species such as coho salmon, up to a level of saturation (Wipfli et al. 2003; Shaul et al. 2014). Absence of pink salmon escapement information for the Berners River precluded evaluation of the potential benefit of marine derived nutrients (MDN) to coho salmon production. However, physical differences that involve separation of spawning and rearing habitats in mainland systems with glacial influence like the Berners River may limit benefits of salmon escapements to rearing juvenile fish, compared with streams like Ford Arm Creek, on West Chichagof Island, in which spawning salmon and rearing juveniles exhibit substantial habitat overlap (Shaul et al. 2014). Most coho salmon rearing in the Berners River drainage occurs in off-channel ponds and sloughs, while relatively little rearing occurs in mainstem channels (similar to the nearby lower Taku River drainage; Murphy et al. 1989). Most spawning by all species occurs in cooler, swifter headwaters and tributary streams whose main current bypasses off-channel rearing habitats and joins glacial waters, limiting potential transport of salmon carcasses into important rearing habitats. However, this dynamic may change under a warming climate as glacial sources from the west side of the valley diminish, and water temperatures in main channel areas of the middle and lower system potentially increase enough to provide suitable summer rearing habitat.

Marine Survival

A comparison of marine survival between the Berners River and Hugh Smith Lake, located 490 km to the southeast, suggests that climatic conditions linked to the PDO affect marine survival in different ways relative to latitude of the natal stream, likely during the early marine period (Figures 33 and 34). Several studies 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, evidence of such a period has remained elusive in studies of growth and survival of coho salmon in northern Southeast Alaska, where indirect evidence has instead favored an important late period for growth and survival after juveniles leave coastal waters late in their first summer at sea (Hobday and Boehlert 2001; Briscoe 2004; LaCroix et al. 2009; Orsi et al. 2013).

Shaul and Geiger (2016) presented evidence of an important growth-related late-marine period for survival of Berners River coho salmon that appeared linked to the effects of climate (PDO) and top-down control by pink salmon of the principal prey species of coho salmon (minimal armhook squid, *Berryteuthis anonychus*) during their final year at sea. The effect of poor marine growth conditions fell most heavily on the female component of the population, and the combined effect on growth and survival of females has had a substantial effect on the per capita reproductive potential of the Berners River population.

A positive relationship between adult size and marine survival (Figure 36) is consistent with the hypothesis that late-marine growth is an important influence on overall marine survival. An evident decrease in variation in survival at smaller adult sizes suggests that as the rate of growth slows in the offshore environment, growth-related late-marine mortality becomes a proportionately more important influence on marine survival compared with other factors. On balance, it appears likely that important periods for survival of Southeast Alaska coho salmon occur both early and late in their ocean residence.

Summary of Information from Other Publications

Below, we summarize findings from our work on Berners River coho salmon published elsewhere, including inter-system movement of fish between the Berners River and other drainages (Shaul et al. 2013) and effects of climate and competition for offshore prey on adult size, marine survival, and per-capita reproductive capacity of Berners River coho salmon (Shaul and Geiger 2016).

Inter-system Movement

Inter-system movement of juvenile coho salmon in the Lynn Canal area became evident during the course of the aging validation investigation and routine stock assessment studies (Shaul et al. 2013). Two smolts sacrificed at Det's Pond in the Berners River in May 2000 were found to contain CWTs implanted in smolts in the Chilkat River in spring 1999. Another smolt marked in the Chilkat River in May 2001 was recovered in a smolt trap the following May in lower Jordan Creek in Juneau. In addition, fish tagged in the Berners and Chilkat rivers have been recovered as fall immigrant juveniles that entered Auke Creek in September and October (Shaul et al. 2013).

Micro-probe analysis of the Sr/Ca ratio in otoliths from some of these fish pointed to substantial growth in estuarine and marine waters (Shaul et al. 2013). The analysis indicated that one of the fish, tagged in the Chilkat River and recovered the following year as a 126 mm age-2 smolt that migrated from Det's Pond, had experienced growth in marine waters during the year of emergence and again during the following year, that comprised 36% and 15%, respectively of the smolt's total growth history.

At the same time, smolts marked in the Berners River (4 total to date during 1997–2013), and one smolt marked in Jordan Creek in June 2003, moved in the opposite direction and were recovered as adults in the Chilkat River fish wheels in the year after marking. This suggests that rather than straying to a different system, these fish may have completed a round trip to their natal stream (the Chilkat River) after having smolted from a distant stream.

These inter-system movements have potential implications for most of the estimates generated in this investigation, because not all smolts marked in the Berners River may be part of that genetic population and not all adult spawners in the system may have smolted from the Berners River. This process likely acts to reduce the number of coded wire tagged fish in the Berners River escapement, while increasing the number of untagged adults, relative to the tagged rate of seaward migrating smolts in the prior year. To the extent that some fish tagged as smolts in the Berners River originated in other systems and ultimately homed back to another natal stream, resulting estimates of harvest, smolt production, exploitation rate, and removal rate are likely higher than real values, and estimates of marine survival are probably low.

The marine-rearing strategy allows fish that are surplus to the summer carrying capacity of freshwater habitat to attain a high growth rate on estuarine and marine food resources (Murphy et al. 1984; Tschaplinski 1988) before returning in the fall to suitable overwintering habitat. Although estuarine and marine waters present osmoregulatory challenges and increased predation risk, growth and survival in those environments appears to be far less compensatory than in fresh water. The successful contribution by these marine-rearing nomads to smolt and adult populations provides a plausible explanation for the significant positive linear slope observed in the spawner-recruit relationships for Southeast Alaska coho populations in Hugh Smith Lake, leading Shaul et al. (2013) to propose a modification to the logistic hockey stick (LHS) model, in which nomads entering estuarine and marine waters contribute to smolt and adult production at a constant proportion of the increase in the number of spawners at escapements above the level needed to maximize smolt production from freshwater habitat.

Their proposed modification, the bent hockey stick (BHS) model, differs little from the LHS model at S_{msy} and the lower goal bound, but the indicated *BEG* range is substantially broader due to an increase in the indicated upper (≥90% of *MSY*) goal bound. A positive population response to increasing escapement allows imprecisely but conservatively managed mixed stock fisheries to achieve a high percentage of theoretical *MSY*, with a smaller yield penalty for variable escapements above S_{msy} (Shaul et al. 2011).

While Shaul et al. (2013) hypothesized that growth and survival in estuarine and marine waters has an important influence on the spawner-recruit relationship (and optimal fishery management strategy), it is clearly secondary in importance to production of smolts reared entirely in freshwater. Although their survival may be low on average and variable, nomads' use of a different, less density-limiting environment for summer growth benefits populations with life history diversification and a potential population buffer. The strategy enables populations in wet coastal regions like Southeast Alaska to efficiently access diverse habitats for growth and over-winter refuge, connecting thousands of small anadromous streams where coho salmon populations would otherwise remain isolated and vulnerable to population shocks.

Effects of Climate and Competition with Pink Salmon on Adult Size, Sex Ratio, Reproductive Potential, and Marine Survival

Shaul and Geiger (2016) investigated the factors responsible for variation in average weight of troll-caught coho salmon during a 45-year period (1970–2014) and extended the analysis to explain variation in adult size, sex ratio, marine survival, and per capita reproductive potential of the Berners River population. This population is particularly advantageous for such analysis because the near-absence of a 0-ocean jack component in the population makes it possible to examine sex-specific survival without the complicating influence of a varying maturity schedule.

They found that about 65% of variation in coho salmon weight was explained by a model giving approximately equal weight to two variables linked to the primary squid prey species (*Berryteuthis anonychus*) of coho salmon in offshore waters. Approximately equal weight was given to a climate variable (March–April average PDO index) directed at the period of squid prey hatching and development, and another variable (catch biomass of pink salmon in the Gulf of Alaska) representing top-down control of maturing squid by a major predator. In both cases, independent variables in the best model were averaged over lags at 2-year intervals compared with the coho return year (i.e., years 0, -2, -4 for the PDO index, and years -2 and -4 for pink salmon biomass), indicating that squid prey populations are shaped by climate and pink salmon predation over a period of up to three 2-year squid life cycles.

Shaul and Geiger (2016) also presented a model based on the objective of maintaining a constant coho salmon weight, that shows how the capacity of the Gulf of Alaska to pasture pink salmon (while maintaining sufficient prey for coho growth) varies with climate. They also presented evidence from contrasting increasing size trends in flexible planktivores (pink and 2-ocean sockeye salmon) and decreasing size in nektivores (coho and 4-ocean chinook salmon) that suggests that the combined effects of climate and increasing pink salmon abundance have reduced the average trophic level in the salmon forage base to the detriment of higher trophic level feeders like coho salmon, steelhead (*O. mykiss*), and Chinook salmon.

The set of predictive variables (pink-PDO) that best explained returning adult size also explained a substantial amount of variation in per capita egg biomass, and marine survival in the Berners River population, as well as in the year-to-year change in those variables and in the ratio of females to males. These findings support conclusions from earlier research (based on juvenile salmon trawl surveys and research on the Auke Creek population) that indicate that much of the variation in growth and mortality of coho salmon in northern Southeast Alaska occurs in offshore waters of the Gulf of Alaska after the first marine summer (Hobday and Boehlert 2001; Briscoe 2004; LaCroix et al. 2009; Orsi et al. 2013). The findings also support the existence of an important late-marine period for survival at sea that is tied to offshore squid prey populations.

If Chinook salmon are influenced in a similar way during their late-marine period, when squid comprise a substantial part of their diet (Kaeriyama et al. 2004), it may help explain the improbable combination of decreasing adult size and decreasing age-at-maturity in several Alaska Chinook salmon populations (Lewis et al. 2015) and wide-spread declines in many populations (ADF&G Chinook Salmon Research Team 2013).

BIOLOGICAL ESCAPEMENT GOAL

The highly variable recruitment response (even after accounting for variation in marine survival and per capita reproductive potential) points to the advisability of a relatively broad escapement goal for the Berners River coho salmon population that will likely encompass S_{msy} under future interdecadal trends in climatic variation and related variation in freshwater and marine survival.

We have substantially more confidence in the HS model compared with the Ricker model when applied to coho salmon (Bradford et al. 2000), but find the upper bound indicated by the simple HS model to be overly constraining. In addition to addressing climatic variability, a sufficiently broad *BEG* provides a more practical target for fishery management. The HS model tends to indicate a narrow escapement range around S_{msy} predicted to produce 90% or more of *MSY*, whereas limitations in management of highly variable coho salmon returns in mixed stock fisheries point to the efficacy of a broader goal, with an upper bound at least double the lower bound (Shaul and Tydingco 2006). In this case, the indicated upper bound based on all brood years and average marine survival (6,405 spawners) is only 1.62 times the lower bound (3,952 spawners; Table 2).

Another reason to increase the upper goal bound is the potential for increased production at higher escapement levels by marine-rearing nomads that may be additive to constraints imposed by freshwater habitat capacity (Shaul et al. 2013). Survival-adjusted returns for the Ford Arm Creek and Hugh Smith Lake stocks both show positive correlation with brood year escapement at spawner abundances above S_{msy}. Although this effect was not evident in the Berners River data series, its influence on smolt production may have been masked by the influence of climatic variation.

Based on the above considerations, we recommend a rounded *BEG* of 4,500–10,000 spawners (point target 5,000) for estimated total escapement, and 3,600–8,100 spawners (point target 4,000) for the unexpanded survey count. The recommended *BEG* for the survey count is lower than the current *BEG* of 4,000–9,200 spawners (point goal 6,300), representing downward adjustments of 10% and 12%, respectively, in the lower and upper bounds.

Climatic variation affects salmon survival and adult population size at both inter-annual and inter-decadal (i.e., regime) time scales, a fact that is abundantly evident in the highly variable Berners River coho salmon data series. Ideally, a *BEG* should be sufficiently flexible to guide fishery managers toward achieving available *MSY* during extended periods of either favorable and unfavorable conditions, without the need to make an *a priori* prediction about the duration of periods of anomalous survival. The *BEG*s (for both total escapement and the unexpanded survey count) recommended above represent our attempt to balance these considerations based on analyses of data series acquired during a period of substantial variation in survival, growth, reproductive capacity, and stock productivity.

FISHERY SELECTION: INTERACTION WITH OTHER FACTORS

Although the drift gillnet fishery removed fish that were larger on average, compared with spawners, we found the effects of gillnet fishery selection on average size to be relatively minor, except in one year (1995) when the removal rate by the gillnet fishery exceeded 70%. Fishery selection was less important in females, based on the assumption that the removal rate by the drift gillnet fishery is equal for males and females of a given length. Estimated sex ratios before and after the drift gillnet fishery were not significantly different. The average female-to-male ratio during 1990–2014 decreased from an estimated 0.80 before the fishery to 0.75 in the spawning escapement. However, our estimates of the effect of the fishery on the sex ratio may be biased to the extent that morphological differences between males and females or differences in their behavior affect their vulnerability to capture by drift gillnet gear independent of their length. While the difference in girth between the sexes in larger adults would likely have only a very small effect on the post-fishery sex ratio, other morphological differences also exist (including firmness and kype development) that may also contribute to differences in retention in gillnets.

Using simple regression models, we found that the removal rate was the only significant influence on size selection by the drift gillnet fishery, and it explained 41% of variation in the linear selection differential (LSD), or difference in average length before and after the fishery. However, a multiple regression analysis that included both removal rate and CV in length as standardized variables provided a superior predictive model for LSD, and both predictive variables showed significance. These results support an interaction between variation in average adult size and removal rate as factors that determine LSD. The combined factors explained 56% of variation (with a lower AIC value), with regression coefficient weightings of 36% for CV of average length and 64% for removal rate.

The relative importance of fishery selection versus climatic variation and density dependence have been debated as potential causal factors in a multi-decadal decrease in size of coho salmon from the Columbia River to southern British Columbia, followed by rapid recovery after the early 1990s (Ricker and Wickett 1980; Ricker 1995; Weitkamp et al. 1995; Shaul et al. 2007; Ford 2011). Although density dependence and climatic variation appear to have the most support as causal factors in this decline and rebound in size (Shaul et al. 2007; Jeffrey et al. 2017), fishery selection combined with intensive exploitation may also have played a role (Knudsen et al. 2001). Determining the relative role of bottom-up ecosystem factors and fishery exploitation in the size decline is complicated because rapid recovery in size after 1993 coincided with both a marked decrease in smolt releases by hatcheries and curtailment of fisheries. The reversal and rapid recovery from the decline in body size for southern salmon coho populations (Shaul et al. 2007) suggests that, to the extent fishery selection may have been responsible for the size decline, at least it did not have an insidious lasting genetic effect on growth and adult body size.

Results of the current study show how intensive exploitation by size-selective gillnet fisheries may have worked to reinforce a decrease in adult size in southern populations caused primarily by bottom-up and density-dependent effects. For example, the comparison between even- and odd-year averages during 1998–2011 (Figure 29; Table 4) indicates that factors influencing growth reduced the average pre-gillnet length of males in poor growth (odd) years by 41 mm

(6.4%), compared with even years of good growth. In contrast, the gillnet fishery reduced average length of male spawners by only 9 mm (1.4%) in all years. However, the gillnet fishery had a slightly greater effect in odd years, when it reduced average length of spawners by 11 mm (1.8%) compared with 7 mm (1.1%) in even years. Growth was also more important in females which averaged 28 mm (4.2%) shorter in odd years, whereas the gillnet fishery reduced average female length across all years by only 3 mm (0.4%),—again with a greater effect in odd years (4 mm; 0.6%) compared with even years (1 mm; 0.2%). Our results suggest that food availability and other factors affecting growth have had a substantially more important influence on Berners River spawner length compared with fishery selection, while fishery selection increases in importance when growth is poor.

In general, results presented in this report and by Shaul and Geiger (2016) suggest that the decline in size of adult coho salmon returning to Southeast Alaska since the early 1980s was driven primarily by offshore marine prey availability rather than fishery selection. Based on extensive literature pointing to the minimal armhook squid (*Berryteuthis anonychus*) as the primary prey of coho salmon in offshore waters where most growth occurs, Shaul and Geiger (2016) inferred that the substantial (65%) variation in troll-caught coho weight explained by the PDO and GOA pink salmon catch biomass (averaged over 2-year lags) represented direct control of squid populations by bottom-up (climate) and top-down (predation by pink salmon) factors. Our findings presented here suggest that gillnet fishery selection operates in the same direction as factors that reduce growth, but is secondary to factors that operate through the food chain in reducing adult size. Size selection appears relatively low for females because of their intermediate size range and substantially lower variation in length (only 55% of variation found in males).

Gillnet fishery selection also appears to have had a relatively small effect on the sex ratio of spawners compared with the effect of differential survival between the sexes linked to growth and apparent sex-specific risk-taking in the marine environment (Holtby and Healy 1990; Spidle et al. 1998; Shaul and Geiger 2016). In the comparison between odd (poor growth) and even (good growth) years during 1998–2011, the estimated female-to-male ratio averaged 25.3% lower prior to the gillnet fishery and 30.8% lower in the escapement in odd years, whereas the gillnet fishery reduced the average female-to-male ratio by only 6.2% in all years. The effect of the gillnet fishery on the sex ratio was lower in good growth years (3.1%) compared with poor growth years (10.3%).

Shaul and Geiger (2016) found that the female-to-male ratio was positively related to marine survival during the second half of the data series (2002–2014), but not during the entire time series (1990–2014; p = 0.154). The result for the full series was strongly affected by a single major outlier in the 1991 adult return year when the female-to-male ratio was the lowest observed and marine survival was high. Returns to the Berners River and other mainland river systems in 1991 were the latest ever observed in fisheries (Figure 18); an unusually high proportion of the adults sampled in the Berners River were recently-arrived bright fish, and much of the run was distributed downstream from the pools where fish were beach seined for samples. Therefore, it is possible that the 1991 sex-ratio sample was biased toward males, which tend to migrate into freshwater slightly earlier than females (e.g., the median date of adult males at the Auke Creek weir typically precedes the median migration date of females by 1 to 4 days). With 1991 excluded, correlation between survival and sex ratio was positive during the other 24 years of the full data series (r = 0.447, p = 0.028). Sex ratio was positively correlated with mean-average length of males and females prior to the gillnet fishery when 1991 was included (r = 0.452, p = 0.023) or excluded (r = 0.502, p = 0.013) from the data series.

Overall, our observations suggest that there is a difference in response by the sexes to challenging conditions for growth. Females respond primarily through increased marine mortality (suggesting increased risk-taking in pursuit of growth) and males respond more with slower growth, smaller average size, and increased variation in size, which suggests that some males trade growth for survival while others may not. Exposure to fall drift gillnet gear tends to magnify variation in adult size while the fishery exerts a greater selective influence (i.e., harvesting larger fish and selecting for survival of smaller fish and males) in years of poor growth. Because of their more limited growth response under poor feeding conditions, females appear to have survived at a lower average rate compared with males, not only from natural mortality factors but also because they have less flexibility to return at a body size small enough to substantially improve their survival past the gillnet fishery.

Poor conditions for ocean growth lead to lower average reproductive capacity in spawners through a convergence of factors, including a sex-specific increase in female mortality, reduced egg biomass in females, and a greater fishery selection effect for smaller females. In combination, these factors substantially increase variation in effective (versus nominal) spawning escapement and should be accounted for whenever possible in spawner-recruit analysis, as we have done here. Evidence of a positive relationship between female size and egg-to-fry survival resulting from greater ability by larger females to build and defend nests (van den Berghe and Gross 1984 and 1989) is a growth-related factor that we did not account for in estimating per capita reproductive capacity in this study.

The pronounced size shift in males toward a more bimodal length-frequency distribution in odd years (Figure 29), suggests that a portion of the male population sacrifices growth for survival during poor feeding conditions at sea (Holtby and Healy 1990), thereby adopting a stealth (satellite) mating role instead of dominance in a more competitive breeding environment with a proportionately smaller female component in the spawning population (Shaul and Geiger 2016). This apparent strategy produces a further benefit in reducing vulnerability of smaller males to the capture in the gillnet fishery, thereby increasing their probability of spawning. The occurrence of two distinct breeding strategies (stealth and dominance) in 1-ocean males (Healey and Prince 1998) may tend to reduce evolutionary pressures placed on the population through fishery selection, because the mating strategy that is rarest will have the greatest advantage in a competitive breeding environment (Fleming and Gross 1994). Although returning as a smaller satellite spawner may confer a survival advantage by exposing males to fewer risks at sea (including by gillnets), the related decrease in density of larger (alpha) males should, on average, reward individuals that pursue the trade-off of increased mortality risk for growth.

Female size (both average and dominant mode) decreased markedly less than male size under poor (typically odd-year) growth conditions. A smaller decrease in adult size in females during poor growth conditions (combined with lower survival than males) supports the hypothesis that females are (on average) more willing to trade survival for growth.

Clearly, the spawning grounds have mechanisms that “push back” against the forces of fishery selection and likely explain the remarkable recovery in adult size in southern coho salmon populations after decades of declining size under exposure to intensive troll, sport, and gillnet fisheries (Shaul et al. 2007).

MANAGEMENT CONSIDERATIONS

Unfortunately, the ability to accurately manage for the proposed *BEG* is limited by a scarcity of inseason run assessment tools, such as a weir or CWT-based models, and by low to moderate correlations with drift gillnet fishery performance. In addition to drift gillnet CPUE, inseason assessment depends upon information sources from a range of indirect measures, including fish wheel catches and inseason escapement estimates for other streams in the same geographic region, including the Chilkat and Taku rivers, and a marine survival forecast for the Auke Creek population based on the average jack length and proportion of smolts that return as jacks.

Although the strong correlation between adult returns to the Berners River and the substantially larger-producing Chilkat River supports the use of inseason CPUE to assess both stocks, the utility of CPUE information is partially confounded by substantial variation in behavior of returning fish. While inseason CPUE has shown only a moderate positive correlation with Berners River run size in Lynn Canal, the correlation is relatively poor with spawning escapement. Historically, fishery managers have taken high CPUE early in the season to be a positive indicator of abundance warranting increased fishing opportunity and vice versa. However, it is also possible that CPUE (particularly early in the season) is actually a contrarian indicator. Rather than accurately pointing to high abundance, high early-season CPUE may instead indicate that a larger-than-average proportion of the run has arrived early and will likely mill in the fishing area for a longer period and accrue an above average removal rate before entering the river. On the other hand, low early CPUE that increases week-over-week to a late peak may indicate that fish have been rapidly transiting the fishing area into the stream, and will likely accrue a low removal rate. We have observed indications of this effect over time, and believe that it helps explain the relatively weak correlation between drift gillnet CPUE and spawning escapement.

Smolt abundance has accounted for nearly half of the variation in adult returns, and therefore improving real-time smolt estimates has potential to improve overall inseason assessment. We recommend that real-time smolt abundance estimation be improved by improving and increasing downstream trapping effort to estimate the marked rate of fish leaving the system. Management will likely be most successful if the manager draws a conclusion about probable return abundance based on a review of all available direct and indirect indicators of return abundance and escapement, and their relative accuracy and precision.

While there has been a very strong positive correlation in estimated adult returns between the Berners and Chilkat Rivers over a recent 15-year period (2000–2014), our recommended revised *BEG* for the Berners River of 4,500–10,000 spawners is close to the Chilkat River goal (30,000–70,000), as a proportion of average escapement to the respective systems during the period. This suggests that the Lynn Canal drift gillnet fishery can be successfully managed to achieve both goals without substantially altering the distribution of fishing time and effort to favor one stock over the other.

Experience with fishery openings inside Berners Bay in 1994 and 1995 has shown the strategy of fishing in the bay to be popular with the drift gillnet fleet because it can result in high CPUE values under some conditions. These openings have also proven useful for increasing yield when returns are clearly large like in 1994 and 2002. However, the effect on the removal rate and escapement can be unpredictable as indicated by experience from the single opening in 1995. Fishing longer openings in Section 15C may be preferred alternative unless there is evidence of either an average or larger return or a relatively small number of participating boats. This is particularly true if the fleet is already concentrated primarily in the lower canal, as increasing exploitation on smaller Berners Bay returns inside Berners Bay may come at the expense of under-harvesting the larger stock in the Chilkat River.

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APPENDIX A:
TAG RECOVERY AND ADULT RETURN ESTIMATES

Appendix A1.–Berners River coho salmon peak escapement survey counts and total escapement estimates generated based on the assumption of an equal average troll fishery exploitation rate between the Berners River and Auke Creek stocks.

	Survey Dates		Peak Escapement	Berners River Fishery Contribution		Auke Creek Troll			Implied Survey
Year	Begin	End	Count	Troll	All Gear	Exploitation	Alternative Run	Alternative Escapement	Efficiency
1982	1-Nov	9-Nov	7,505	14,140	25,104	19.6%	72,302	47,198	15.9%
1983	26-Oct	3-Nov	9,840	17,176	24,574	32.0%	53,599	29,025	33.9%
1984	23-Oct	25-Oct	2,825	-	-	32.3%	-	-	-
1985	23-Oct	29-Oct	6,169	10,861	18,167	35.9%	30,251	12,083	51.1%
1986	21-Oct	29-Oct	1,752	13,565	22,935	42.5%	31,950	9,015	19.4%
1987	20-Oct	21-Oct	3,260	7,211	10,694	36.6%	19,721	9,027	36.1%
1988	25-Oct	26-Oct	2,724	6,060	12,424	25.7%	23,615	11,190	24.3%
1989	19-Oct	20-Oct	7,509	10,583	12,247	47.9%	22,103	9,856	76.2%
1990	25-Oct	26-Oct	11,050	15,007	22,911	43.7%	34,312	11,401	96.9%
1991	22-Oct	23-Oct	11,530	6,449	23,457	16.9%	38,165	14,708	78.4%
1992	22-Oct	23-Oct	15,300	15,318	30,695	---	---	---	---
1993	24-Oct	25-Oct	15,670	19,308	33,936	38.1%	50,653	16,717	93.7%
1994	20-Oct	21-Oct	15,920	27,339	57,439	34.8%	78,587	21,148	75.3%
1995	20-Oct	21-Oct	4,945	8,766	23,870	31.4%	27,916	4,045	122.2%
1996	17-Oct	18-Oct	6,050	10,529	17,604	38.5%	27,351	9,747	62.1%
1997	20-Oct	21-Oct	10,050	2,453	5,234	12.2%	20,069	14,835	67.7%
1998	26-Oct	27-Oct	6,802	10,424	16,335	31.1%	33,518	17,183	39.6%
1999	21-Oct	22-Oct	9,920	12,876	23,225	33.6%	38,380	15,154	65.5%
2000	19-Oct	20-Oct	10,650	4,811	10,815	22.2%	21,677	10,863	98.0%
2001	19-Oct	20-Oct	19,290	8,814	12,863	30.4%	28,962	16,100	119.8%
2002	18-Oct	18-Oct	27,700[a]	8,650	22,118	17.6%	49,035	26,916	102.9%
2003	21-Oct	22-Oct	10,110	6,823	19,001	23.3%	29,282	10,281	98.3%
2004	20-Oct	23-Oct	14,450	10,792	18,724	26.6%	40,601	21,877	66.0%
2005	19-Oct	20-Oct	5,220	4,639	7,538	31.7%	14,633	7,095	73.6%
2006	19-Oct	20-Oct	5,470	4,082	10,352	22.2%	18,363	8,011	68.3%
2007	19-Oct	20-Oct	3,915	2,937	4,807	25.1%	11,705	6,898	56.8%
2008	20-Oct	21-Oct	6,870	3,878	7,497	29.8%	13,011	5,514	124.6%
2009	20-Oct	21-Oct	4,230	2,807	5,087	30.1%	9,323	4,236	99.9%
2010	19-Oct	20-Oct	7,520	6,451	14,297	25.0%	25,780	11,484	65.5%
2011	19-Oct	21-Oct	6,050	3,722	5,979	17.1%	21,733	15,754	38.4%
2012	19-Oct	20-Oct	5,480	2,071	3,051	20.1%	10,297	7,246	75.6%
2013	22-Oct	23-Oct	6,280	7,521	14,788	32.1%	23,395	8,608	73.0%
2014	22-Oct	23-Oct	15,480	4,301	11,168	13.6%	31,583	20,415	75.8%
1989–2014 Average			10,133	8,513	16,732	27.8%	28,817	12,644	80.6%

[a] The lower survey area was glacially occluded in 2002. The escapement count in the area with adequate visibility was divided by the 1990–2001 average proportion counted in that area (0.34285) to generate the expanded count of 27,700 spawners.

Appendix A2.–Escapement samples for adipose clips and coded wire tags from adult coho salmon and the number of Berners River coho tags by tagging year recovered from marine fisheries, 1974−2014.

	No. of Spawners		Sampled			Ad Clips		Prop.	Percent				Percent
	Survey	Expanded	for	Ad	Prop.	Sampled	Tags	Tagged	of Clips	Fishery Recoveries			from
Year	Count	Estimate	Ad Clip	Clips	Clipped	for Tag	Recovered	Θ	w/Tags	Smolt (X-1)	Other	Tota1	Year X-1
1974	4,124	-	733	19	0.0259	19	19	0.0259	100.0	-	-	-	-
1978	3,119	-	404	18	0.0446	7	7	0.0446	100.0	-	-	-	-
1979	3,460	-	1,008	44	0.0437	10	10	0.0437	100.0	-	-	-	-
1982	7,505	-	885	9	0.0102	9	8	0.0090	88.9	-	-	-	-
1983	9,840	-	1,366	21	0.0154	21	21	0.0154	100.0	-	-	-	-
1984	2,825	-	-	-	-	-	-	-	-	-	-	-	-
1985	6,169	-	1,532	39	0.0255	39	28	0.0183	71.8	-	-	-	-
1986	1,752	-	538	17	0.0316	17	15	0.0279	88.2	-	-	-	-
1987	3,260	-	1,501	39	0.0260	39	31	0.0207	79.5	-	-	-	-
1988	2,724	-	1,186	36	0.0304	36	32	0.0270	88.9	-	-	-	-
1989	7,509	9,320	2,462	60	0.0244	60	37	0.0150	61.7	-	-	-	-
1990	11,050	13,715	1,495	140	0.0936	139	136	0.0916	97.8	266	379	645	41.2
1991	11,530	14,311	1,694	303	0.1789	298	296	0.1777	99.3	1,026	76	1,102	93.1
1992	15,300	18,991	1,518	192	0.1265	191	186	0.1232	97.4	714	80	794	89.9
1993	15,670	19,450	1,552	250	0.1611	249	248	0.1604	99.6	1,726	11	1,737	99.4
1994	15,920	19,760	1,512	319	0.2110	319	317	0.2097	99.4	2,892	1	2,893	100.0
1995	4,945	6,138	1,006	238	0.2366	238	236	0.2346	99.2	238	0	238	100.0
1996	6,050	7,509	1,565	209	0.1335	209	208	0.1329	99.5	209	0	209	100.0
1997	10,050	12,474	1,079	330	0.3058	324	324	0.3058	100.0	330	0	330	100.0
1998	6,802	8,443	1,088	132	0.1213	132	132	0.1213	100.0	647	14	661	97.9
1999	9,920	12,313	1,506	213	0.1414	211	211	0.1414	100.0	1,000	18	1,018	98.2
2000	10,650	13,219	1,201	224	0.1865	222	222	0.1865	100.0	733	2	735	99.7
2001	19,290	23,943	1,448	323	0.2231	318	313	0.2196	98.4	759	24	783	96.9
2002	27,700	34,382	1,242	163	0.1312	163	161	0.1296	98.8	875	34	909	96.3
2003	10,110	12,549	1,273	262	0.2058	262	256	0.2011	97.7	1,322	30	1,352	97.8
2004	14,450	17,936	1,506	329	0.2185	316	302	0.2088	95.6	732	46	778	94.1
2005	5,220	6,479	1,100	228	0.2073	228	226	0.2055	99.1	408	4	412	99.0
2006	5,470	6,789	819	222	0.2711	211	211	0.2711	100.0	734	12	746	98.4
2007	3,915	4,859	1,034	237	0.2292	237	236	0.2282	99.6	563	8	571	98.6
2008	6,870	8,527	1,202	264	0.2196	260	260	0.2196	100.0	422	15	437	96.6
2009	4,230	5,250	708	81	0.1144	81	79	0.1116	97.5	201	5	206	97.6
2010	7,520	9,334	1,700	159	0.0935	158	155	0.0918	98.1	285	44	329	86.6
2011	6,050	7,509	830	89	0.1072	89	88	0.1060	98.9	177	6	183	96.7
2012	5,480	6,802	1,396	270	0.1934	270	264	0.1891	97.8	163	3	166	98.2
2013	6,280	7,795	1,127	105	0.0932	105	104	0.0923	99.0	392	14	406	96.6
2014	15,480	19,214	2,528	224	0.0886	223	214	0.0850	96.0	282	6	288	97.9
Avg.	8,562	12,577	1,278	166	0.1306	163	160	0.1283	95.6	684	33	717	94.8

Appendix A3.–Estimates of the age .0 jack component of coho salmon returns and escapements to the Berners River as a percent of males only and all fish returning to the fisheries and escapement, 1990–2014.

	Escapement Sample			Jack Escapement		Total Adult Return[a]			Jack Total Return[b]		
Return Year	Adult Female	Adult Male	Jack Male	Percent of Spawners	Percent of Males	Females	Males	Total	Jack Male Return	Percent of Return	Percent of Males
1990	212	288	0	0.00	0.00	15,566	21,059	36,626	0	0.00	0.00
1991	204	424	1	0.16	0.24	13,729	24,039	37,768	23	0.06	0.09
1992	312	318	0	0.00	0.00	24,661	25,025	49,686	0	0.00	0.00
1993	273	390	4	0.60	1.02	22,891	30,495	53,386	117	0.22	0.38
1994	309	339	1	0.15	0.29	37,368	39,841	77,209	30	0.04	0.08
1995	219	394	6	0.97	1.50	12,568	17,440	30,008	60	0.20	0.34
1996	268	339	2	0.33	0.59	11,786	13,326	25,113	25	0.10	0.19
1997	288	297	2	0.34	0.67	8,577	9,131	17,708	43	0.24	0.46
1998	253	344	2	0.33	0.58	10,395	14,383	24,778	28	0.11	0.20
1999	221	414	0	0.00	0.00	13,201	22,337	35,538	0	0.00	0.00
2000	253	347	0	0.00	0.00	10,276	13,757	24,034	0	0.00	0.00
2001	241	358	0	0.00	0.00	15,085	21,721	36,806	0	0.00	0.00
2002	257	266	0	0.00	0.00	28,177	28,323	56,500	0	0.00	0.00
2003	252	340	5	0.84	1.45	14,453	17,097	31,550	106	0.34	0.62
2004	280	320	0	0.00	0.00	17,602	19,058	36,660	0	0.00	0.00
2005	209	374	1	0.17	0.27	5,389	8,628	14,017	11	0.08	0.13
2006	312	288	0	0.00	0.00	9,117	8,024	17,141	0	0.00	0.00
2007	231	370	0	0.00	0.00	4,192	5,473	9,666	0	0.00	0.00
2008	325	275	0	0.00	0.00	8,884	7,139	16,024	0	0.00	0.00
2009	233	366	1	0.17	0.27	4,259	6,079	10,337	9	0.08	0.14
2010	254	346	0	0.00	0.00	10,058	13,573	23,631	0	0.00	0.00
2011	223	376	1	0.17	0.27	5,264	8,224	13,488	13	0.09	0.15
2012	246	354	0	0.00	0.00	4,184	5,668	9,853	0	0.00	0.00
2013	245	355	0	0.00	0.00	9,379	13,204	22,583	0	0.00	0.00
2014	237	406	0	0.00	0.00	11,525	18,857	30,382	0	0.00	0.00
Average	254	348	1	0.17	0.29	13,143	16,476	29,620	19	0.06	0.11

[a] Estimated total adult returns by sex are based on estimates of the pre-gillnet sex ratio.

[b] Age .0 jacks are assumed to be unexploited by the fisheries.

Appendix A4.–Estimated harvest by gear type, escapement and total run of coho salmon returning to the Berners River, 1974–2014, based on the unexpanded escapement survey count.

		Number of Fish								
Year	Fishery Sample Size	Troll	Purse Seine	Drift Gillnet	Sport	B.C. Net	Cost Recovery	Total Catch	Escapement Survey Count	Total Run
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	1,384	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	313	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
Average		8.904	195	7,223	295	0	1	16,618	8,562	25,344

Appendix A5.–Estimated percent harvest by gear type, escapement and total run of coho salmon returning to the Berners River, 1974–2014, based on the unexpanded escapement survey count.

	Fishery	Percent of Total Run								
Year	Sample Size	Troll	Purse Seine	Drift Gillnet	Sport	B.C. Net	Cost Recovery	Total Catch	Escapement	Total Run
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	1,384	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
Average		35.5	0.8	26.7	1.2	0.0	0.0	64.2	35.8	100.0

Appendix A6.–Estimated harvest by gear type, escapement and total run of coho salmon returning to the Berners River, 1989–2014, based on the expanded escapement survey count.

	Fishery	Number of Fish								
Year	Sample Size	Troll	Purse Seine	Drift Gillnet	Sport	B.C. Net	Cost Recovery	Total Catch	Total 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	1,384	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	313	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	17,935	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
Average		8.904	195	7,223	295	0	1	16,618	12,577	29,310

Appendix A7.–Estimated percent harvest by gear type, escapement, and total run of coho salmon returning to the Berners River, 1989–2014, based on the expanded escapement survey count.

	Fishery	Percent of Total Run								
	Sample		Purse	Drift		B.C.	Cost	Total		Total
Year	Size	Troll	Seine	Gillnet	Sport	Net	Recovery	Catch	Escapement	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	1,384	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	313	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
Average		28.7	0.7	24.0	1.2	0.0	0.0	54.6	45.4	100.0

Appendix A8.–Estimated exploitation rate by fishery and removal rate by the Lynn Canal (District 115) drift gillnet fishery for the Berners River coho salmon population, 1989–2014.

	Exploitation Rate						Removal Rate
		Purse	Marine	Drift gillnet			Drift Gillnet
Year	Troll	Seine	Sport	Other	District 115	Total	District 115
1989	49.1	0.0	0.0	1.4	6.3	56.8	12.8
1990	41.0	0.5	1.0	1.0	19.1	62.6	33.7
1991	17.1	0.8	0.2	0.4	43.7	62.1	53.5
1992	30.8	1.0	0.4	1.4	28.2	61.8	42.4
1993	36.2	0.3	0.3	1.2	25.5	63.6	41.2
1994	35.4	1.8	1.0	0.9	35.2	74.4	57.9
1995	29.2	0.1	0.7	0.5	49.0	79.5	70.6
1996	41.9	0.9	1.6	0.8	24.8	70.1	45.3
1997	13.9	1.3	1.6	0.0	12.7	29.6	15.3
1998	42.1	1.6	1.2	0.9	20.2	65.9	37.2
1999	36.2	0.6	1.6	0.2	26.7	65.4	43.6
2000	20.0	0.7	2.1	0.2	22.0	45.0	28.5
2001	23.9	0.5	0.9	0.4	9.2	34.9	12.4
2002	15.3	0.6	1.9	0.1	21.3	39.1	25.9
2003	21.6	0.8	1.7	2.4	33.7	60.2	45.9
2004	29.4	0.2	1.4	0.6	19.5	51.1	28.5
2005	33.1	0.9	1.7	0.0	18.2	53.8	28.2
2006	23.8	0.0	0.6	0.7	35.2	60.4	47.0
2007	30.4	0.4	1.7	0.3	17.0	49.7	25.3
2008	24.2	0.0	0.9	0.4	21.3	46.8	28.5
2009	27.2	0.6	1.7	0.0	19.7	49.2	28.0
2010	27.3	0.5	2.0	2.4	28.4	60.5	41.8
2011	27.6	1.9	0.8	0.3	13.8	44.3	19.9
2012	21.0	0.0	0.5	0.0	9.4	31.0	12.0
2013	33.3	1.6	2.7	0.3	27.5	65.5	44.4
2014	14.2	0.0	2.1	0.6	20.0	36.8	24.0
Average	28.7	0.7	1.2	0.7	23.4	54.6	34.4

Appendix A9.–Average weekly percent of total catch and weekly exploitation rate (percent) for the Berners River coho salmon return in the Alaska troll fishery and Lynn Canal (District 115) drift gillnet fishery, and removal rate (percent) by the gillnet fishery, during 1990–2014.

	Average	Troll Fishery		District 115 Drift Gillnet Fishery		
Statistical Week	Mid-week Date	Percent of Catch	Exploitation Rate	Percent of Catch	Exploitation Rate	Removal Rate
26	25-Jun	0.0	0.0	0.0	0.0	0.0
27	2-Jul	0.4	0.1	0.0	0.0	0.0
28	9-Jul	1.2	0.3	0.0	0.0	0.0
29	16-Jul	3.0	0.8	0.0	0.0	0.0
30	23-Jul	4.4	1.3	0.0	0.0	0.0
31	30-Jul	5.5	1.6	0.0	0.0	0.0
32	6-Aug	7.3	2.1	0.1	0.0	0.0
33	13-Aug	4.6	1.4	0.3	0.1	0.1
34	20-Aug	9.2	2.7	1.4	0.3	0.5
35	27-Aug	15.3	4.3	4.8	1.1	1.7
36	3-Sep	16.7	4.7	9.2	2.0	2.9
37	10-Sep	17.2	4.6	20.8	4.8	6.9
38	17-Sep	12.1	3.1	24.8	6.6	9.6
39	24-Sep	2.6	0.7	24.5	5.7	8.3
40	1-Oct	0.3	0.1	11.9	3.0	4.3
41	8-Oct	0.0	0.0	2.1	0.5	0.8
42	15-Oct	0.0	0.0	0.0	0.0	0.0
Total		100.0	27.8	100.0	24.0	35.2

Appendix A10.–Berners River escapement adult coho salmon age composition sample, estimated adult return by age class and return by age adjusted to a constant average marine survival rate of 16.28%.

	Number of Samples (Age)				Total Adult Return (Age)				Return at Average Survival (Age)			
Year	1.1	2.1	3.1	Total	1.1	2.1	3.1	Total	1.1	2.1	3.1	Total
1985	145	191	2	338	---	---	---	---	---	---	---	---
1986	111	168	1	280	---	---	---	---	---	---	---	---
1987	139	370	2	511	---	---	---	---	---	---	---	---
1988	197	275	2	474	---	---	---	---	---	---	---	---
1989	154	264	0	418	7,946	13,622	0	21,568	---	---	---	---
1990	214	197	2	413	18,978	17,471	177	36,626	13,838	12,738	129	26,705
1991	197	335	3	535	13,907	23,649	212	37,768	8,472	14,407	129	23,008
1992	231	231	0	462	24,843	24,843	0	49,685	15,281	15,281	0	30,562
1993	178	332	0	510	18,633	34,753	0	53,386	18,545	34,590	0	53,136
1994	250	295	0	545	35,417	41,792	0	77,209	19,086	22,522	0	41,608
1995	234	220	1	455	15,433	14,509	66	30,008	15,200	14,290	65	29,555
1996	321	201	0	522	15,443	9,670	0	25,113	19,428	12,165	0	31,594
1997	167	221	1	389	7,602	10,061	46	17,708	9,342	12,362	56	21,760
1998	169	325	1	495	8,460	16,268	50	24,778	7,781	14,963	46	22,790
1999	181	299	2	482	13,345	22,045	147	35,538	15,420	25,472	170	41,062
2000	159	357	1	517	7,391	16,596	46	24,034	9,166	20,579	58	29,803
2001	211	301	1	513	15,138	21,596	72	36,806	18,002	25,680	85	43,767
2002	189	202	0	391	27,311	29,189	0	56,500	20,827	22,259	0	43,086
2003	115	330	1	446	8,135	23,344	71	31,550	6,381	18,311	55	24,748
2004	267	251	2	520	18,823	17,695	141	36,660	15,478	14,551	116	30,145
2005	370	146	0	516	10,051	3,966	0	14,017	16,905	6,671	0	23,576
2006	302	206	1	509	10,170	6,937	34	17,142	11,987	8,177	40	20,204
2007	413	98	0	511	7,812	1,854	0	9,666	15,247	3,618	0	18,865
2008	355	168	0	523	10,877	5,147	0	16,024	9,857	4,665	0	14,521
2009	427	102	1	530	8,329	1,990	20	10,338	13,424	3,207	31	16,662
2010	417	132	0	549	17,949	5,682	0	23,630	19,927	6,308	0	26,235
2011	421	92	0	513	11,069	2,419	0	13,488	17,479	3,820	0	21,299
2012	333	130	2	465	7,056	2,754	42	9,852	13,096	5,113	79	18,287
2013	343	172	3	518	14,953	7,498	131	22,582	16,283	8,165	142	24,591
2014	368	210	0	578	19,344	11,039	0	30,382	24,055	13,727	0	37,781
Average	253	227	1	481	14,401	14,861	48	29,310	14,820	13,746	48	28,614

Appendix A11.–Berners River adult coho salmon estimated effective escapement and brood year returns by age class, both observed and adjusted for a constant average marine survival rate of 16.28%.

Bood Year	Effective Escapement[a]	Total Adult Return (Age) 1.1	2.1	3.1	Total	Return at Average Survival (Age) 1.1	2.1	3.1	Total
1987	---	18,978	23,649	0	42,627	13,838	14,407	0	28,244
1988	---	13,907	24,843	0	38,750	8,472	15,281	0	23,753
1989	10,819	24,843	34,753	0	59,596	15,281	34,590	0	49,871
1990	15,074	18,633	41,792	66	60,491	18,545	22,522	65	41,132
1991	11,243	35,417	14,509	0	49,926	19,086	14,290	0	33,377
1992	22,011	15,433	9,670	46	25,148	15,200	12,165	56	27,421
1993	17,145	15,443	10,061	50	25,554	19,428	12,362	46	31,837
1994	24,014	7,602	16,268	147	24,018	9,342	14,963	170	24,475
1995	5,038	8,460	22,045	46	30,551	7,781	25,472	58	33,311
1996	7,361	13,345	16,596	72	30,013	15,420	20,579	85	36,084
1997	15,528	7,391	21,596	0	28,987	9,166	25,680	0	34,846
1998	9,580	15,138	29,189	71	44,399	18,002	22,259	55	40,316
1999	9,302	27,311	23,344	141	50,796	20,827	18,311	116	39,254
2000	14,389	8,135	17,695	0	25,830	6,381	14,551	0	20,932
2001	22,929	18,823	3,966	34	22,823	15,478	6,671	40	22,189
2002	41,089	10,051	6,937	0	16,988	16,905	8,177	0	25,082
2003	13,004	10,170	1,854	0	12,024	11,987	3,618	0	15,605
2004	21,477	7,812	5,147	20	12,979	15,247	4,665	31	19,943
2005	4,926	10,877	1,990	0	12,866	9,857	3,207	0	13,063
2006	8,918	8,329	5,682	0	14,010	13,424	6,308	0	19,732
2007	3,952	17,949	2,419	42	20,410	19,927	3,820	79	23,825
2008	11,764	11,069	2,754	131	13,955	17,479	5,113	142	22,734
2009	4,059	7,056	7,498	0	14,554	13,096	8,165	0	21,261
2010	9,781	14,953	11,039	69	26,100	16,283	13,727	108	30,118
Average	13,791	14,464	14,804	39	29,308	14,435	13,788	44	28,267

[a] Total escapement estimate adjusted to constant average per capita egg biomass.

APPENDIX B:
SMOLT AND MARINE SURVIVAL ESTIMATES

Appendix B1.–Number of coho salmon smolts captured in the Berners River by location and starting and ending dates when traps were operational.

Year	Trapping Dates Start	End	Shaul Pond	Det's Pond	Brown Slough	Total
1989	12-May	8-Jun	908	5,530	-	6,438
1990	6-May	10-Jun	18,415	5,183	-	23,598
1991	8-May	12-Jun	14,966	6,490	-	21,456
1992	7-May	9-Jun	35,861	15,950	595	52,406
1993	6-May	8-Jun	35,439	17,823	761	54,023
1994	7-May	8-Jun	33,694	9,390	-	43,084
1995	7-May	10-Jun	19,152	6,871	-	26,023
1996	5-May	10-Jun	32,430	8,592	-	41,022
1997	7-May	12-Jun	12,403	-	4,330	16,733
1998	7-May	11-Jun	25,978	-	9,201	35,179
1999	13-May	16-Jun	23,691	-	10,506	34,197
2000	8-May	7-Jun	27,064	-	31,281	58,345
2001	8-May	10-Jun	24,522	-	9,093	33,615
2002	10-May	10-Jun	25,265	-	4,715	29,980
2003	7-May	10-Jun	29,843	-	8,305	38,148
2004	7-May	10-Jun	24,512	-	5,552	30,064
2005	7-May	8-Jun	24,726	-	8,526	33,252
2006	8-May	11-Jun	17,358	8,698	-	26,056
2007	15-May	21-Jun	13,257	5,713	-	18,970
2008	12-May	19-Jun	8,494	2,491	-	10,985
2009	15-May	17-Jun	7,322	-	5,780	13,102
2010	10-May	11-Jun	9,726	-	3,810	13,536
2011	12-May	13-Jun	14,482	-	7,250	21,732
2012	10-May	12-Jun	11,498	-	2,200	13,698
2013	11-May	17-Jun	14,172	-	6,019	20,191

Appendix B2.–Berners River coho salmon smolt abundance and marine survival estimates, with Hugh Smith Lake marine survival estimates shown for comparison, 1989–2013.

Sea-Migration Year	Number Marked (M)	Returns Sampled (C)	Marks Recovered (R)	Smolt Estimate (N)	95% Confidence Lower Bound	95% Confidence Upper Bound	Adult Return	Marine Survival (%) Berners River	Marine Survival (%) Hugh Smith Lake
1989	6,438	1,495	58	163,998	130,805	219,767	36,626	22.33	18.01
1990	23,598	1,694	282	141,291	126,565	159,896	37,768	26.73	17.42
1991	21,456	1,518	173	187,688	163,433	220,398	49,686	26.47	20.94
1992	52,406	1,552	248	326,312	290,329	372,477	53,386	16.36	12.99
1993	54,023	1,512	319	255,519	230,304	286,935	77,209	30.22	19.54
1994	43,077	1,006	238	181,503	161,101	207,823	30,008	16.53	13.55
1995	26,017	1,565	209	194,019	170,939	224,305	25,113	12.94	17.73
1996	40,954	1,079	330	133,629	120,639	149,752	17,708	13.25	8.35
1997	16,733	1,088	129	139,959	119,493	168,884	24,778	17.70	11.68
1998	35,179	1,506	209	252,168	222,185	291,505	35,538	14.09	14.13
1999	34,166	1,201	223	183,023	161,872	210,531	24,034	13.13	6.77
2000	58,262	1,448	313	268,777	242,034	302,164	36,806	13.69	13.37
2001	33,615	1,242	157	264,599	228,970	313,359	56,500	21.35	14.82
2002	29,980	1,273	256	148,513	132,355	169,164	31,550	21.24	13.70
2003	38,148	1,506	310	185,125	166,612	208,268	36,660	19.80	10.83
2004	29,821	1,100	226	144,778	128,124	166,409	14,017	9.68	9.15
2005	33,200	819	218	124,070	109,586	142,967	17,141	13.82	6.83
2006	25,995	1,034	234	114,648	101,657	131,447	9,666	8.43	8.88
2007	18,970	1,202	255	89,169	79,447	101,604	16,024	17.97	13.11
2008	10,945	708	75	102,318	83,600	131,836	10,337	10.10	18.26
2009	13,100	1,700	138	160,627	137,769	192,578	23,631	14.71	20.99
2010	13,535	830	85	130,727	108,009	165,547	13,488	10.32	10.43
2011	21,532	1,396	267	112,305	100,306	127,565	9,853	8.77	12.82
2012	13,698	1,127	101	151,016	126,585	187,132	22,583	14.95	16.71
2013	20,191	2,528	219	232,019	204,986	267,263	30,382	13.09	16.32
Average	28,602	1,325	211	175,512	153,908	204,783	35,560	16.31	13.89

Appendix B3.–Number of coho salmon emergent fry, pre-smolts, and smolts marked in the Berners River during 1972–2013 and Chapman estimates of pre-smolt and smolt production. Also shown in bold italics is projected smolt abundance based on estimated pre-smolt abundance multiplied by 0.4449, the 1989 smolt estimate as a proportion of the 1988 pre-smolt estimate. Fish were coded-wire-tagged in all years except 1972 when they were marked with fluorescent pigment (Gray et al. 1978).

	Number of Fish Tagged										
	Fry (Pond)		All Areas			Presmolt	Confidence Bounds		Smolt	Confidence Bounds	
Year	Shaul	Other	Presmolts	Smolts	Mix	Estimate	Lower	Upper	Estimate	Lower	Upper
1972	---	---	8,066	---	---	296,058	207,352	517,409	---	---	---
1973	---	---	---	---	---	---	---	---	***131,714***	---	---
1974	---	---	---	---	---	---	---	---	---	---	---
1975	---	---	---	---	---	---	---	---	---	---	---
1976	---	---	11,343	---	---	241,805	168,063	430,858	---	---	---
1977	---	---	11,138	---	---	249,760	193,729	351,392	***107,577***	---	---
1978	---	---	---	---	---	---	---	---	***111,116***	---	---
1979	---	---	---	---	---	---	---	---	---	---	---
1980	---	---	10,929	---	---	968,397	609,546	2,354,580	---	---	---
1981	---	---	7,826	---	---	486,340	345,261	822,377	***430,832***	---	---
1982	---	---	---	---	---	---	---	---	***216,369***	---	---
1983	---	---	10,348	---	---	402,481	307,607	581,980	---	---	---
1984	---	---	15,326	---	---	466,903	321,233	854,303	***179,061***	---	---
1985	---	---	10,110	---	---	390,764	298,165	566,789	***207,721***	---	---
1986	---	---	8,740	---	---	282,534	214,154	415,067	***173,848***	---	---
1987	---	---	10,349	---	---	450,482	357,989	607,420	***125,697***	---	---
1988	---	---	9,926	---	---	368,626	282,434	530,530	***200,416***	---	---
1989	---	---	---	6,438	6,681	---	---	---	163,998	130,805	219,767
1990	---	---	---	23,598	2,781	---	---	---	141,291	126,565	159,896
1991	---	---	---	21,456	5,083	---	---	---	187,688	163,433	220,398
1992	---	---	---	52,406	---	---	---	---	326,312	290,329	372,477
1993	---	---	---	54,023	---	---	---	---	255,519	230,304	286,935
1994	---	---	---	43,077	---	---	---	---	181,503	161,101	207,823
1995	---	---	---	26,017	---	---	---	---	194,019	170,939	224,305
1996	5,351	0	---	40,954	---	---	---	---	133,629	120,639	149,752
1997	5,040	0	---	16,733	---	---	---	---	139,959	119,493	168,884
1998	5,482	0	---	35,179	---	---	---	---	252,168	222,185	291,505
1999	5,341	0	---	34,166	---	---	---	---	183,023	161,872	210,531
2000	2,815	2,588	---	58,262	---	---	---	---	268,777	242,034	302,164
2001	2,979	2,969	---	33,615	---	---	---	---	264,599	228,970	313,359
2002	2,939	3,100	---	29,980	---	---	---	---	148,513	132,355	169,164
2003	2,905	2,134	---	38,148	---	---	---	---	185,125	166,612	208,268
2004	2,892	2,621	---	29,821	---	---	---	---	144,778	128,124	166,409
2005	2,697	3,481	---	33,200	---	---	---	---	124,070	109,586	142,967
2006	2,368	0	---	25,995	---	---	---	---	114,648	101,657	131,447
2007	3,565	0	---	18,970	---	---	---	---	89,169	79,447	101,604
2008	5,009	0	---	10,945	---	---	---	---	102,318	83,600	131,836
2009	2,906	0	---	13,100	---	---	---	---	160,627	137,769	192,578
2010	2,584	0	---	13,535	---	---	---	---	130,727	108,009	165,547
2011	2,553	0	---	21,532	---	---	---	---	112,305	100,306	127,565
2012	2,547	0	---	13,698	---	---	---	---	151,016	126,585	187,132
2013	1,340	0	---	20,191	---	---	---	---	232,019	204,986	267,263

Appendix B4.–Total catch and estimated age composition (percent of total) and average length-at-age (mm) of coho salmon smolts migrating from Shaul Pond.

			Age (Percent)			Age (Average Length in mm)			
Year	Catch	Sample	1	2	3	1	2	3	Combined
1990	18,415	452	36.7	62.8	0.4	105	113	123	110
1991	14,966	344	52.6	47.4	0.0	93	115	---	104
1992	35,861	872	43.1	56.9	0.0	97	109	---	104
1993	35,439	882	64.7	35.3	0.0	95	104	---	98
1994	33,694	742	73.2	26.5	0.3	99	107	131	101
1995	19,152	460	57.2	42.4	0.4	99	112	126	105
1996	32,430	521	50.3	49.7	0.0	95	105	---	100
1997	12,403	309	34.3	65.4	0.3	96	111	116	106
1998	25,978	583	37.5	62.0	0.5	97	108	124	104
1999	23,691	513	39.8	59.6	0.6	100	109	149	106
2000	27,064	432	49.1	50.9	0.0	97	109	---	103
2001	24,522	395	39.0	61.0	0.0	99	108	---	105
2002	25,265	434	33.6	65.7	0.7	100	106	125	105
2003	29,843	498	48.6	51.4	0.0	100	112	---	106
2004	24,512	534	54.3	45.7	0.0	100	109	---	104
2005	24,726	571	38.9	61.1	0.0	104	112	---	109
2006	17,358	398	67.8	32.2	0.0	106	117	---	110
2007	13,257	348	52.0	48.0	0.0	106	115	---	110
2008	8,494	304	57.9	42.1	0.0	106	115	---	110
2009	7,322	265	52.1	47.9	0.0	97	105	---	101
2010	9,726	265	47.7	52.3	0.0	97	109	---	103
2011	14,482	302	56.3	43.7	0.0	101	112	---	106
2012	11,498	276	34.8	65.2	0.0	100	110	---	106
2013	14,172	352	48.9	51.1	0.0	92	106	---	99
Average	21,011	461	48.8	51.1	0.1	99	110	128	105

Appendix B5.–Estimated Berners River smolt production based on inseason downstream recovery samples compared with the final estimate generated from a sample of adult spawners in the year following sea migration.

	Final Smolt Estimate			Inseason Estimate (Smolt Recovery Sample)								Percent
Smolt	Point	95% C. I. Bounds		Number	Recovery	Number	Point	95% C. I. Bounds		Percent Marked		Difference
Year	Estimate	Lower	Upper	Marked	Sample	of Marks	Estimate	Lower	Upper	Adults	Smolts	in Estimates
2009	160,627	137,769	192,578	13,100	1,247	109	148,636	125,305	182,642	8.1%	8.7%	-7.5%
2010	130,727	108,009	165,547	13,535	675	42	212,798	164,213	302,209	10.2%	6.2%	62.8%
2011	112,305	100,306	127,565	21,532	769	130	126,567	108,101	152,641	19.1%	16.9%	12.7%
2012	151,016	126,585	187,132	13,698	182	17	139,272	95,953	253,895	9.0%	9.3%	-7.8%
2013	232,019	204,986	267,263	20,191	115	6	334,609	197,777	1,085,877	8.7%	5.2%	44.2%
Avg.	157,339			16,411	598	61	192,376			11.0%	9.3%	20.9%

APPENDIX C:
FRY-TO-SMOLT AND FRY-TO-ADULT SURVIVAL

Appendix C1.–Estimated Berners River coho salmon spawning escapement, escapement adjusted to constant per capita egg biomass, and estimated fry-to-smolt survival for half-length tagged newly-emerged fry released in Shaul Pond.

Brood Year	Number of Spawners	PCEB Index	Adjusted Spawners	Fry-to-Smolt Percent Survival (Smolt Age) 1	2	3	Total
1995	6,138	0.992	6,090	12.7	10.3	0.0	23.0
1996	7,509	1.039	7,803	6.4	2.1	-	8.5
1997	12,474	1.147	14,307	2.8	6.5	-	9.3
1998	8,443	1.092	9,222	31.4	2.1	0.0	33.6
1999	12,313	0.775	9,543	47.5	12.9	-	60.4
2000	13,219	1.051	13,892	18.3	25.7	-	44.0
2001	23,943	0.937	22,428	63.4	3.1	-	66.5
2002	34,382	1.170	40,220	11.8	5.0	-	16.8
2003	12,549	1.070	13,427	21.5	6.2	-	27.7
2004	17,936	1.195	21,431	11.8	0.3	-	12.0
2005	6,479	0.800	5,183	34.6	0.2	-	34.7
2006	6,789	1.284	8,714	10.0	0.1	-	10.1
2007	4,859	0.909	4,415	39.1	3.3	-	42.4
2008	8,527	1.362	11,617	12.8	7.4	-	20.2
2009	5,250	0.821	4,311	4.9	3.9	-	8.9
2010	9,334	0.977	9,118	17.7	3.7	-	21.4
2011	7,509	0.739	5,547	14.6	-	-	-
Average	11,627	1.021	12,192	21.2	5.8	0.0	27.5

Appendix C2.–Estimated Berners River coho salmon spawning escapement, escapement adjusted to constant per capita egg biomass, and estimated fry-to-adult survival for half-length tagged newly-emerged fry released in Shaul Pond.

Brood Year	Number of Spawners	PCEB Index	Adjusted Spawners	Fry-to-Adult Percent Survival (Smolt Age) 1	2	3	Total
1995	6,138	0.992	6,090	2.3	1.5	0.0	3.7
1996	7,509	1.039	7,803	0.9	0.3	-	1.2
1997	12,474	1.147	14,307	0.4	0.9	-	1.3
1998	8,443	1.092	9,222	4.3	0.5	0.0	4.8
1999	12,313	0.775	9,543	10.2	2.7	-	12.8
2000	13,219	1.051	13,892	3.8	5.1	-	8.9
2001	23,943	0.937	22,428	12.5	0.3	-	12.8
2002	34,382	1.170	40,220	1.1	0.7	-	1.8
2003	12,549	1.070	13,427	3.0	0.5	-	3.5
2004	17,936	1.195	21,431	1.0	0.0	-	1.0
2005	6,479	0.800	5,183	6.2	0.0	-	6.2
2006	6,789	1.284	8,714	1.0	0.0	-	1.0
2007	4,859	0.909	4,415	5.7	0.3	-	6.1
2008	8,527	1.362	11,617	1.3	0.7	-	2.0
2009	5,250	0.821	4,311	0.4	0.6	-	1.0
2010	9,334	0.977	9,118	2.7	0.5	-	3.1
2011	7,509	0.739	5,547	1.9	-	-	-
Average	11,627	1.021	12,192	3.5	0.9	0.0	4.5

APPENDIX D:
DETAILED TAG RECOVERIES AND HARVEST ESTIMATES BY FISHERY

Appendix D1.–Number of observed recoveries of tagged Berners River coho salmon from random fishery samples, 1989−2014.

Fishery	Area	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Alaska Troll	NW	48	284	308	332	734	1,313	436	372	218	337	465	355	573	307
	NE	1	15	13	9	20	39	36	8	9	21	6	7	5	8
	SW	0	5	3	1	0	9	1	1	0	1	0	1	1	0
	SE	0	0	1	0	0	9	0	0	0	1	0	1	0	0
	Subtotal	49	304	325	342	754	1,370	473	381	227	360	471	364	579	315
Alaska Seine	SA12	0	2	5	3	11	21	0	5	9	7	4	5	14	2
	SA13	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	SA14	0	0	6	7	0	63	0	0	7	0	1	1	2	6
	SACO	0	1	2	0	0	3	1	2	2	2	2	0	1	0
	SASI	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	SASO	0	1	1	1	0	0	0	1	0	0	0	1	1	0
	Subtotal	0	4	14	11	11	87	1	8	18	9	7	8	18	9
Alaska Gillnet	101	0	0	0	1	0	2	0	0	0	0	0	0	0	0
	106	0	1	1	1	0	0	0	0	0	1	0	1	0	0
	107	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	108	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	111	1	6	3	22	11	43	10	7	0	10	6	2	10	2
	113	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	115	8	146	678	321	699	1,092	891	193	53	218	452	303	127	436
	182	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	200	0	0	0	0	8	0	0	0	0	0	0	0	0	0
	212	0	1	1	0	5	0	0	0	0	0	0	0	0	0
	223	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Subtotal	9	154	683	345	725	1,137	901	200	53	229	458	306	137	438
Cost Recovery	111	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	112	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	Total	0	0	0	0	0	0	0	0	1	0	0	1	0	0
BC Net		0	0	0	0	0	1	0	0	0	0	0	0	0	0
Alaska Sport	Elfin Cove	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Gustavus	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Juneau	0	0	0	0	0	0	0	0	0	0	0	0	0	7
	Sitka	0	9	3	3	8	49	9	12	14	14	11	12	9	15
	Yakutat	0	0	0	0	0	0	0	0	0	1	1	1	4	2
	Total	0	9	3	3	8	49	9	12	14	15	12	13	13	25
Total Catch		58	471	1,025	701	1,498	2,644	1,384	601	313	613	948	692	747	787
Escapement		37	136	296	186	248	317	236	208	324	132	211	222	313	161
Total Run		95	607	1,321	887	1,746	2,961	1,620	809	637	745	1,159	914	1,060	948

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Appendix D1.–Page 2 of 2.

Fishery	Area	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Average
Alaska Troll	NW	382	480	257	252	162	223	99	137	98	100	140	71	326
	NE	16	6	0	14	2	2	3	3	1	5	8	0	10
	SW	0	0	1	0	0	0	1	2	0	0	0	0	1
	SE	0	0	0	0	0	0	0	0	0	1	0	0	1
	Subtotal	398	486	258	266	164	225	103	142	99	106	148	71	338
Alaska Seine	SA12	11	4	3	0	2	0	2	0	3	0	10	0	5
	SA13	0	0	0	0	0	0	0	0	0	0	0	0	0
	SA14	0	0	1	0	0	0	0	0	2	0	3	0	4
	SACO	1	0	0	0	0	0	0	1	0	0	0	0	1
	SASI	0	0	0	0	0	0	0	1	0	0	0	0	0
	SASO	0	0	0	0	0	0	0	0	0	0	0	0	0
	Subtotal	12	4	4	0	2	0	2	2	5	0	13	0	10
Alaska Gillnet	101	0	0	0	0	0	0	0	1	0	0	0	0	0
	106	0	0	0	0	0	0	0	0	0	0	0	0	0
	107	0	0	0	0	0	0	0	1	0	0	0	0	0
	108	1	0	0	0	0	0	0	0	0	0	0	0	0
	111	17	7	0	13	2	5	0	8	1	0	3	4	7
	113	0	0	0	0	0	0	0	0	0	0	0	0	0
	115	879	240	119	415	119	188	92	160	65	51	197	201	321
	182	0	0	0	0	0	0	0	0	0	0	0	0	0
	200	0	0	0	0	0	0	0	0	0	0	0	0	0
	212	0	0	0	0	0	0	0	0	0	0	0	0	0
	223	0	0	0	0	0	0	0	0	0	0	0	0	0
	Subtotal	897	247	119	428	121	193	92	170	66	51	200	205	329
Cost Recovery	111	0	0	0	0	0	0	0	0	0	0	0	0	0
	112	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0	0	0	0	0	0
BC Net		0	0	0	0	0	0	0	0	0	0	0	0	0
Alaska Sport	Elfin Cove	0	0	0	0	0	0	0	0	0	0	0	0	0
	Gustavus	2	3	1	2	1	1	2	2	2	0	1	7	1
	Juneau	4	2	4	1	3	2	0	0	1	1	1	0	1
	Sitka	14	13	5	2	2	2	2	8	1	1	6	2	9
	Yakutat	1	1	1	2	0	0	0	0	0	0	5	2	1
	Total	21	19	11	7	6	5	4	10	4	2	13	11	11
Total Catch		1,328	756	392	701	293	423	201	324	174	159	374	287	688
Escapement		256	302	226	211	236	260	79	155	88	264	104	214	209
Total Run		1,584	1,058	618	912	529	683	280	479	262	423	478	501	897

Appendix D2.–Number of expanded recoveries of tagged Berners River coho salmon from random fishery samples, 1989−2014.

Fishery	Area	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Alaska Troll	NW	155	1,291	1,076	1,853	3,027	5,599	1,952	1,374	714	1,201	1,804	883	1,916	1,097
	NE	4	69	57	31	70	87	103	23	36	60	17	12	17	24
	SW	0	16	8	3	0	24	2	2	0	2	0	1	2	0
	SE	0	0	5	0	0	22	0	0	0	2	0	1	0	0
	Subtotal	159	1,375	1,146	1,887	3,098	5,732	2,056	1,399	750	1,265	1,821	897	1,935	1,121
Alaska Seine	SA12	0	9	21	18	27	124	0	13	48	39	15	15	27	17
	SA13	0	0	0	0	0	0	0	0	0	0	0	3	0	0
	SA14	0	0	13	41	0	135	0	0	14	0	2	11	1	9
	SACO	0	3	12	0	0	30	6	11	9	9	11	0	4	0
	SASI	0	0	0	0	0	0	0	0	0	0	0	0	0	15
	SASO	0	4	4	4	0	0	0	7	0	0	0	3	6	0
	Subtotal	0	17	51	63	27	290	6	31	71	48	28	32	39	40
Alaska Gillnet	101	0	0	0	2	0	6	0	0	0	0	0	0	0	0
	106	0	5	5	2	0	0	0	0	0	2	0	3	0	0
	107	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	108	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	111	5	26	20	80	27	141	36	28	0	26	10	7	29	6
	113	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	115	20	639	2,929	1,724	2,185	5,705	3,452	827	689	606	1,344	984	745	1,560
	182	0	0	0	0	39	0	0	0	0	0	0	0	0	0
	200	0	0	0	0	21	0	0	0	0	0	0	0	0	0
	212	0	3	1	0	17	0	0	0	0	0	0	0	0	0
	223	0	0	0	0	2	0	0	0	0	0	0	0	0	0
	Subtotal	25	673	2,956	1,808	2,291	5,851	3,488	855	689	634	1,354	994	773	1,565
Cost Recovery	111	0	0	0	0	0	0	0	0	6	0	0	0	0	0
	112	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	Total	0	0	0	0	0	0	0	0	6	0	0	1	0	0
BC Net		0	0	0	0	0	2	0	0	0	0	0	0	0	0
Alaska Sport	Elfin Cove	0	0	0	0	0	0	0	0	0	0	0	0	0	57
	Gustavus	0	0	0	0	0	0	0	0	0	0	0	0	0	31
	Juneau	0	34	15	23	29	170	49	54	85	30	57	87	63	46
	Sitka	0	0	0	0	0	0	0	0	0	4	5	3	13	6
	Yakutat	0	0	0	0	0	0	0	0	0	1	20	3	0	0
	Total	0	34	15	23	29	170	49	54	85	36	82	93	76	140
Total Catch		184	2,099	4,167	3,781	5,444	12,045	5,600	2,340	1,601	1,982	3,285	2,017	2,824	2,867
Escapement		140	1,257	2,543	2,339	3,120	4,143	1,440	998	3,815	1,024	1,741	2,465	5,257	4,457
Total Run		324	3,356	6,710	6,120	8,565	16,187	7,040	3,338	5,416	3,006	5,026	4,483	8,081	7,324

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Fishery	Area	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Average
Alaska Troll	NW	1,322	2,223	948	1,052	663	845	301	577	392	375	656	366	1,295
	NE	50	30	0	54	8	7	10	10	3	14	38	0	32
	SW	0	0	5	0	0	0	2	5	0	0	0	0	3
	SE	0	0	0	0	0	0	0	0	0	3	0	0	1
	Subtotal	1,372	2,253	953	1,106	670	852	313	592	395	392	694	366	1,331
Alaska Seine	SA12	28	17	19	0	9	0	7	0	17	0	28	0	19
	SA13	0	0	0	0	0	0	0	0	0	0	0	0	0
	SA14	0	0	6	0	0	0	0	0	10	0	6	0	10
	SACO	23	0	0	0	0	0	0	6	0	0	0	0	5
	SASI	0	0	0	0	0	0	0	4	0	0	0	0	1
	SASO	0	0	0	0	0	0	0	0	0	0	0	0	1
	Subtotal	50	17	25	0	9	0	7	10	27	0	34	0	35
Alaska Gillnet	101	0	0	0	0	0	0	0	0	0	0	0	0	0
	106	0	0	0	0	0	0	0	0	0	0	0	0	1
	107	0	0	0	0	0	0	0	5	0	0	0	0	0
	108	29	0	0	0	0	0	0	0	0	0	0	0	1
	111	120	42	0	35	6	14	0	47	4	0	7	15	28
	113	0	0	0	0	0	0	0	0	0	0	0	0	0
	115	2,139	1,493	523	1,635	375	748	227	615	197	176	574	516	1,255
	182	0	0	0	0	0	0	0	0	0	0	0	0	1
	200	0	0	0	0	0	0	0	0	0	0	0	0	1
	212	0	0	0	0	0	0	0	0	0	0	0	0	1
	223	0	0	0	0	0	0	0	0	0	0	0	0	0
	Subtotal	2,288	1,535	523	1,670	381	762	227	666	201	176	580	531	1,288
Cost Recovery	111	0	0	0	0	0	0	0	0	0	0	0	0	0
	112	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0	0	0	0	0	0
BC Net		0	0	0	0	0	0	0	0	0	0	0	0	0
Alaska Sport	Elfin Cove	29	21	7	11	4	5	10	9	5	0	6	30	7
	Gustavus	11	11	12	6	13	12	0	0	4	4	7	0	4
	Juneau	67	66	24	7	13	16	10	35	2	6	26	15	40
	Sitka	4	6	5	6	0	0	0	0	0	0	17	9	3
	Yakutat	0	0	0	0	6	0	0	0	0	0	0	0	1
	Total	111	104	48	30	37	33	20	44	11	10	56	53	55
Total Catch		3,821	3,909	1,549	2,806	1,097	1,647	568	1,312	634	577	1,365	950	2,710
Escapement		2,524	3,745	1,331	1,840	1,109	1,873	586	856	796	1,286	719	1,634	2,040
Total Run		6,345	7,654	2,880	4,646	2,206	3,519	1,153	2,168	1,430	1,863	2,084	2,583	4,750

Appendix D3.–Estimated number of adult Berners River coho salmon harvested by fishery and estimated adult escapement, 1989–2014.

Fishery	Area	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Alaska Troll	NW	10,306	14,087	6,058	15,047	18,869	26,706	8,319	10,341	2,335	9,899	12,757	4,733	8,728	8,465
	NE	277	748	319	251	439	414	437	176	118	493	120	65	78	185
	SW	0	172	44	21	0	114	9	12	0	19	0	7	8	0
	SE	0	0	28	0	0	105	0	0	0	13	0	7	0	0
	Subtotal	10,583	15,007	6,449	15,318	19,308	27,339	8,766	10,529	2,453	10,424	12,876	4,811	8,814	8,650
Alaska Seine	SA12	0	100	117	143	166	592	0	100	157	318	108	79	125	131
	SA13	0	0	0	0	0	0	0	0	0	0	0	16	0	0
	SA14	0	0	73	337	0	646	0	0	45	0	13	58	3	69
	SACO	0	35	70	0	0	143	25	84	30	77	79	0	20	0
	SASI	0	0	0	0	0	0	0	0	0	0	0	0	0	112
	SASO	0	48	25	29	0	0	0	50	0	0	0	18	30	0
	Subtotal	0	184	285	508	166	1,381	25	234	231	395	200	171	178	312
AK Gillnet	101	0	0	0	13	0	29	0	0	0	0	0	0	0	0
	106	0	58	30	18	0	0	0	0	0	18	0	17	0	0
	107	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	108	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	111	302	285	115	650	170	671	153	209	0	210	69	35	130	43
	113	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	115	1,362	6,978	16,487	13,998	13,621	27,209	14,716	6,225	2,254	4,995	9,503	5,278	3,393	12,034
	182	0	0	0	0	242	0	0	0	0	0	0	0	0	0
	200	0	0	0	0	130	0	0	0	0	0	0	0	0	0
	212	0	30	8	0	106	0	0	0	0	0	0	0	0	0
	223	0	0	0	0	14	0	0	0	0	0	0	0	0	0
	Subtotal	1,665	7,351	16,640	14,679	14,282	27,909	14,869	6,434	2,254	5,223	9,572	5,330	3,523	12,077
Cost Rec.	111	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	112	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BC Net		0	0	0	0	0	10	0	0	0	0	0	0	0	0
Alaska Sport	Elfin Cove	0	0	0	0	0	0	0	0	0	0	0	0	0	438
	Gustavus	0	0	0	0	0	0	0	0	0	0	0	0	0	238
	Juneau	0	369	84	189	180	810	210	406	278	251	402	464	286	358
	Sitka	0	0	0	0	0	0	0	0	0	33	34	15	61	47
	Yakutat	0	0	0	0	0	0	0	0	0	9	142	18	0	0
	Total	0	369	84	189	180	810	210	406	278	293	578	497	347	1,080
Total Catch		12,247	22,911	23,457	30,695	33,936	57,449	23,870	17,604	5,216	16,335	23,225	10,809	12,863	22,118
Escapement		9,320	13,715	14,311	18,991	19,450	19,760	6,138	7,509	12,474	8,443	12,313	13,219	23,943	34,382
Total Run		21,567	36,626	37,768	49,686	53,386	77,209	30,008	25,113	17,690	24,778	35,538	24,028	36,806	56,500

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Fishery	Area	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Average
Alaska Troll	NW	6,573	10,648	4,614	3,883	2,903	3,848	2,700	6,289	3,694	1,984	7,109	4,301	8,277
	NE	250	144	0	199	34	30	85	107	28	72	411	0	211
	SW	0	0	25	0	0	0	21	56	0	0	0	0	20
	SE	0	0	0	0	0	0	0	0	0	15	0	0	6
	Subtotal	6,823	10,792	4,639	4,082	2,937	3,878	2,807	6,451	3,722	2,071	7,521	4,301	8,513
Alaska Seine	SA12	138	83	91	0	40	0	63	0	158	0	306	0	116
	SA13	0	0	0	0	0	0	0	0	0	0	0	0	1
	SA14	0	0	31	0	0	0	0	0	93	0	63	0	55
	SACO	112	0	0	0	0	0	0	67	0	0	0	0	29
	SASI	0	0	0	0	0	0	0	44	0	0	0	0	6
	SASO	0	0	0	0	0	0	0	0	0	0	0	0	8
	Subtotal	251	83	121	0	40	0	63	110	251	0	369	0	214
AK Gillnet	101	0	0	0	0	0	0	0	0	0	0	0	0	2
	106	0	0	0	0	0	0	0	0	0	0	0	0	5
	107	0	0	0	0	0	0	0	50	0	0	0	0	2
	108	146	0	0	0	0	0	0	0	0	0	0	0	6
	111	597	202	0	128	26	63	0	508	38	0	73	176	187
	113	0	0	0	0	0	0	0	0	0	0	0	0	0
	115	10,635	7,150	2,546	6,032	1,643	3,406	2,037	6,699	1,862	929	6,216	6,065	7,434
	182	0	0	0	0	0	0	0	0	0	0	0	0	9
	200	0	0	0	0	0	0	0	0	0	0	0	0	5
	212	0	0	0	0	0	0	0	0	0	0	0	0	6
	223	0	0	0	0	0	0	0	0	0	0	0	0	1
	Subtotal	11,377	7,352	2,546	6,161	1,668	3,469	2,037	7,258	1,900	929	6,289	6,241	7,655
Cost Rec.	111	0	0	0	0	0	0	0	0	0	0	0	0	0
	112	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0	0	0	0	0	0
BC Net		0	0	0	0	0	0	0	0	0	0	0	0	0
Alaska Sport	Elfin Cove	145	99	36	41	19	21	92	98	49	0	63	347	56
	Gustavus	56	51	59	20	57	56	0	0	35	21	73	0	26
	Juneau	331	316	115	27	58	72	88	379	22	29	285	173	238
	Sitka	18	31	22	22	0	0	0	0	0	0	188	106	22
	Yakutat	0	0	0	0	27	0	0	0	0	0	0	0	8
	Total	550	497	232	110	161	149	180	477	106	51	609	626	349
Total Catch		19,001	18,724	7,538	10,352	4,807	7,497	5,087	14,297	5,979	3,051	14,788	11,168	16,732
Escapement		12,549	17,936	6,479	6,789	4,859	8,527	5,250	9,334	7,509	6,802	7,795	19,214	12,577
Total Run		31,550	36,660	14,017	17,141	9,666	16,024	10,337	23,631	13,488	9,853	22,583	30,382	29,310

Appendix D4.–Estimated percent of the total Berners River coho salmon return harvested by fishery and escaping to spawn, 1989–2014.

Fishery	Area	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Alaska Troll	NW	47.8	38.5	16.0	30.3	35.3	34.6	27.7	41.2	13.2	40.0	35.9	19.7	23.7	15.0
	NE	1.3	2.0	0.8	0.5	0.8	0.5	1.5	0.7	0.7	2.0	0.3	0.3	0.2	0.3
	SW	0.0	0.5	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
	SE	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
	Subtotal	49.1	41.0	17.1	30.8	36.2	35.4	29.2	41.9	13.9	42.1	36.2	20.0	23.9	15.3
Alaska Seine	SA12	0.0	0.3	0.3	0.3	0.3	0.8	0.0	0.4	0.9	1.3	0.3	0.3	0.3	0.2
	SA13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
	SA14	0.0	0.0	0.2	0.7	0.0	0.8	0.0	0.0	0.3	0.0	0.0	0.2	0.0	0.1
	SACO	0.0	0.1	0.2	0.0	0.0	0.2	0.1	0.3	0.2	0.3	0.2	0.0	0.1	0.0
	SASI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
	SASO	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.1	0.1	0.0
	Subtotal	0.0	0.5	0.8	1.0	0.3	1.8	0.1	0.9	1.3	1.6	0.6	0.7	0.5	0.6
Alaska Gillnet	101	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	106	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0
	107	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	108	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	111	1.4	0.8	0.3	1.3	0.3	0.9	0.5	0.8	0.0	0.8	0.2	0.1	0.4	0.1
	113	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	115	6.3	19.1	43.7	28.2	25.5	35.2	49.0	24.8	12.7	20.2	26.7	22.0	9.2	21.3
	182	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	200	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	212	0.0	0.1	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	223	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Subtotal	7.7	20.1	44.1	29.5	26.8	36.1	49.6	25.6	12.7	21.1	26.9	22.2	9.6	21.4
Cost Recovery	111	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	112	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BC Net		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alaska Sport	Elfin Cove	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
	Gustavus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
	Juneau	0.0	1.0	0.2	0.4	0.3	1.0	0.7	1.6	1.6	1.0	1.1	1.9	0.8	0.6
	Sitka	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.1
	Yakutat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.1	0.0	0.0
	Total	0.0	1.0	0.2	0.4	0.3	1.0	0.7	1.6	1.6	1.2	1.6	2.1	0.9	1.9
Total Catch		56.8	62.6	62.1	61.8	63.6	74.4	79.5	70.1	29.5	65.9	65.4	45.0	34.9	39.1
Escapement		43.2	37.4	37.9	38.2	36.4	25.6	20.5	29.9	70.5	34.1	34.6	55.0	65.1	60.9
Total Run		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

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Fishery	Area	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Average
Alaska Troll	NW	20.8	29.0	32.9	22.7	30.0	24.0	26.1	26.6	27.4	20.1	31.5	14.2	27.9
	NE	0.8	0.4	0.0	1.2	0.4	0.2	0.8	0.5	0.2	0.7	1.8	0.0	0.7
	SW	0.0	0.0	0.2	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.1
	SE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
	Subtotal	21.6	29.4	33.1	23.8	30.4	24.2	27.2	27.3	27.6	21.0	33.3	14.2	28.7
Alaska Seine	SA12	0.4	0.2	0.6	0.0	0.4	0.0	0.6	0.0	1.2	0.0	1.4	0.0	0.4
	SA13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SA14	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.3	0.0	0.1
	SACO	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.1
	SASI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
	SASO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Subtotal	0.8	0.2	0.9	0.0	0.4	0.0	0.6	0.5	1.9	0.0	1.6	0.0	0.7
Alaska Gillnet	101	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	106	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	107	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
	108	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	111	1.9	0.6	0.0	0.7	0.3	0.4	0.0	2.1	0.3	0.0	0.3	0.6	0.6
	113	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	115	33.7	19.5	18.2	35.2	17.0	21.3	19.7	28.4	13.8	9.4	27.5	20.0	23.4
	182	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	212	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	223	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Subtotal	36.1	20.1	18.2	35.9	17.3	21.7	19.7	30.7	14.1	9.4	27.8	20.5	24.0
Cost Recovery	111	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	112	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BC Net		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alaska Sport	Elfin Cove	0.5	0.3	0.3	0.2	0.2	0.1	0.9	0.4	0.4	0.0	0.3	1.1	0.2
	Gustavus	0.2	0.1	0.4	0.1	0.6	0.4	0.0	0.0	0.3	0.2	0.3	0.0	0.1
	Juneau	1.0	0.9	0.8	0.2	0.6	0.4	0.9	1.6	0.2	0.3	1.3	0.6	0.8
	Sitka	0.1	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.3	0.1
	Yakutat	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total	1.7	1.4	1.7	0.6	1.7	0.9	1.7	2.0	0.8	0.5	2.7	2.1	1.2
Total Catch		60.2	51.1	53.8	60.4	49.7	46.8	49.2	60.5	44.3	31.0	65.5	36.8	54.6
Escapement		39.8	48.9	46.2	39.6	50.3	53.2	50.8	39.5	55.7	69.0	34.5	63.2	45.4
Total Run		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

APPENDIX E:
COHO SALMON SIZE DATA

Appendix E1.–Mean-average weekly dressed weight of troll-caught coho salmon, estimated average length, coefficient of variation of length and sex ratio of Berner River spawners and average length and sex ratio of the stock prior to exposure to the drift gillnet fishery.

		Berners River (Spawners)							Berners River (Pre-Gillnet Adults)		
	Troll	Length (mm)		CV of Length		Sample		Females	Length (mm)		Sex Ratio
Year	Weight (kg)	Males	Females	Males	Females	Males	Females	Per Male	Males	Females	Females/Male
1970	3.23	---	---	---	---	---	---	---	---	---	---
1971	3.16	---	---	---	---	---	---	---	---	---	---
1972	2.85	---	---	---	---	---	---	---	---	---	---
1973	3.28	---	---	---	---	---	---	---	---	---	---
1974	3.16	---	---	---	---	---	---	---	---	---	---
1975	2.95	---	---	---	---	---	---	---	---	---	---
1976	3.14	---	---	---	---	---	---	---	---	---	---
1977	3.64	---	---	---	-----	---	---	---	---	---	---
1978	2.96	---	---	---	---	---	---	---	---	---	---
1979	3.15	---	---	---	---	---	---	---	---	---	---
1980	3.19	---	---	---	---	---	---	---	---	---	---
1981	3.38	---	---	---	---	---	---	---	---	---	---
1982	3.28	642	660	0.0901	0.0459	239	145	0.607	---	---	---
1983	3.18	628	654	0.1058	0.0533	465	235	0.505	---	---	---
1984	3.75	---	---	---	---	---	---	---	---	---	---
1985	3.46	647	670	0.0979	0.0539	246	154	0.626	---	---	---
1986	3.46	611	656	0.1298	0.0539	78	51	0.654	---	---	---
1987	3.08	633	640	0.0896	0.0641	336	262	0.780	---	---	---
1988	3.44	628	660	0.1016	0.0563	357	233	0.653	---	---	---
1989	3.02	640	656	0.0912	0.0503	259	217	0.838	---	---	---
1990	3.10	644	659	0.1060	0.0592	288	212	0.736	649	660	0.739
1991	2.95	605	646	0.1090	0.0526	424	204	0.481	626	652	0.571
1992	3.16	611	640	0.1142	0.0590	318	312	0.981	621	644	0.985
1993	2.57	591	623	0.1134	0.0603	390	273	0.700	612	630	0.751
1994	3.34	633	656	0.1044	0.0593	339	309	0.912	649	662	0.938
1995	3.33	585	636	0.1176	0.0678	394	219	0.556	634	651	0.721
1996	3.17	578	630	0.1421	0.0690	339	268	0.791	605	638	0.884
1997	3.10	635	655	0.0903	0.0548	297	288	0.970	632	652	0.939
1998	3.46	643	666	0.0978	0.0465	344	253	0.735	657	669	0.723
1999	2.54	588	626	0.1017	0.0515	414	221	0.534	598	627	0.591
2000	3.15	637	659	0.1008	0.0547	347	253	0.729	638	658	0.747
2001	2.89	618	643	0.1118	0.0725	358	241	0.673	621	644	0.694
2002	3.14	631	647	0.1084	0.0649	266	257	0.966	637	649	0.995
2003	2.94	603	647	0.1093	0.0568	340	252	0.741	614	649	0.845
2004	3.05	623	657	0.1105	0.0594	320	280	0.875	632	661	0.924
2005	2.63	579	621	0.1073	0.0603	374	209	0.559	594	627	0.625
2006	3.04	626	654	0.0949	0.0545	288	312	1.083	634	655	1.136
2007	2.73	551	621	0.1260	0.0742	370	231	0.624	567	628	0.766
2008	3.44	626	656	0.1189	0.0573	275	325	1.182	636	658	1.244
2009	2.69	574	610	0.1203	0.0769	366	233	0.637	590	619	0.701
2010	3.17	602	650	0.1069	0.0509	346	254	0.734	602	645	0.741
2011	2.45	564	607	0.1180	0.0630	376	223	0.593	569	610	0.640
2012	2.69	575	618	0.1149	0.0618	354	246	0.695	581	620	0.738
2013	2.60	578	604	0.1192	0.0669	355	245	0.690	601	613	0.710
2014	2.93	604	633	0.1066	0.0618	406	237	0.584	611	635	0.611
Average	3.09	610	643	0.1086	0.0592	333	239	0.732	616	642	0.798

Appendix E2.–Estimated Per Capita Egg Biomass (PCEB) and PCEB Index, for adult coho salmon returning to the Berners River prior to exposure to the drift gillnet fishery. These estimates were used in the analysis presented by Shaul and Geiger (2016).

Brood Year	Proportion Females	Female Average MEF Length (mm)	Egg Biomass Per Female (g)	PCEB	PCEB Index
1990	0.4250	660	867	369	1.052
1991	0.3635	652	831	302	0.862
1992	0.4963	644	798	396	1.131
1993	0.4288	630	740	317	0.906
1994	0.4840	662	878	425	1.213
1995	0.4188	651	830	348	0.992
1996	0.4693	638	776	364	1.039
1997	0.4844	651	830	402	1.147
1998	0.4195	670	912	383	1.092
1999	0.3715	627	731	272	0.775
2000	0.4276	658	861	368	1.051
2001	0.4098	644	801	328	0.937
2002	0.4987	649	822	410	1.170
2003	0.4581	649	818	375	1.070
2004	0.4801	661	872	419	1.195
2005	0.3845	627	729	280	0.800
2006	0.5319	655	846	450	1.284
2007	0.4338	628	734	318	0.909
2008	0.5545	658	861	477	1.362
2009	0.4120	619	698	288	0.821
2010	0.4256	645	804	342	0.977
2011	0.3902	610	663	259	0.739
2012	0.4247	620	701	298	0.850
2013	0.4153	613	676	281	0.801
2014	0.3793	635	763	289	0.826
Average	0.4395	642	794	350	1.000

APPENDIX F:
INSEASON ABUNDANCE INDICATORS

Appendix F1.–R^2 values for the linear relationship between the abundance of Berners River coho salmon (number entering Lynn Canal and number of adult spawners) versus cumulative drift gillnet CPUE in Lynn Canal (wild fish only in all of District 115, and all fish in Subdistrict 115-10) and the total catch of coho salmon in the Chilkat River fish wheels through various statistical weeks.

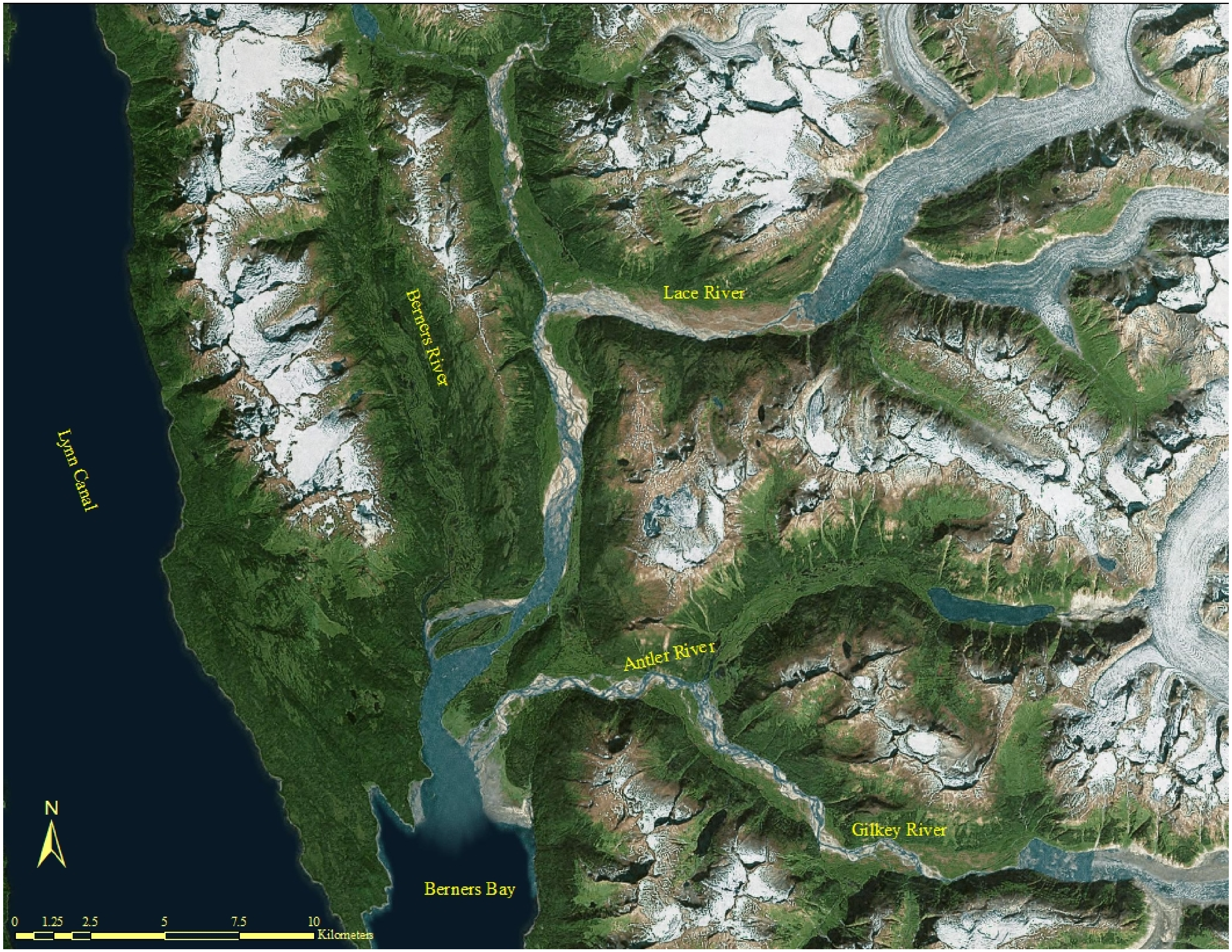
Lynn Canal Drift Gillnet Fishery (1989–2014)	District 115 Gillnet Wild CPUE		Subdistrict 115-10 Total CPUE	
Stat. Weeks	Lynn Canal Run Size	Spawning Escapement	Lynn Canal Run Size	Spawning Escapement
35	0.113	0.006	0.424	0.148
35–36	0.179	0.047	0.474	0.307
35–37	0.257	0.107	0.429	0.258
35–38	0.360	0.149	0.506	0.276
35–39	0.485	0.223	0.463	0.250
35–40	0.544	0.258	0.464	0.249
Chilkat Fish wheel Catch (1997–2014)				
Ending Stat. Week				
36	0.395	0.296	---	---
37	0.368	0.262	---	---
38	0.432	0.355	---	---
39	0.379	0.330	---	---
40	0.325	0.267	---	---
41	0.281	0.207	---	---

Appendix F2.–Lynn Canal Fall drift gillnet fishery effort statistics (total days fished and weekly average boats fishing) during statistical weeks 36–40, fall chum salmon harvest (statistical weeks 35–42) and season coho salmon harvest in Lynn Canal by fishing area. Also shown is the estimated gillnet share (percent of total) of the combined troll and drift gillnet catch in all fishing districts for the coho salmon returning to the Berners and Chilkat Rivers based on CWT recoveries (MTA Lab database) for all years except 1974 when fluorescent pigment marking was used (Gray et al. 1978).

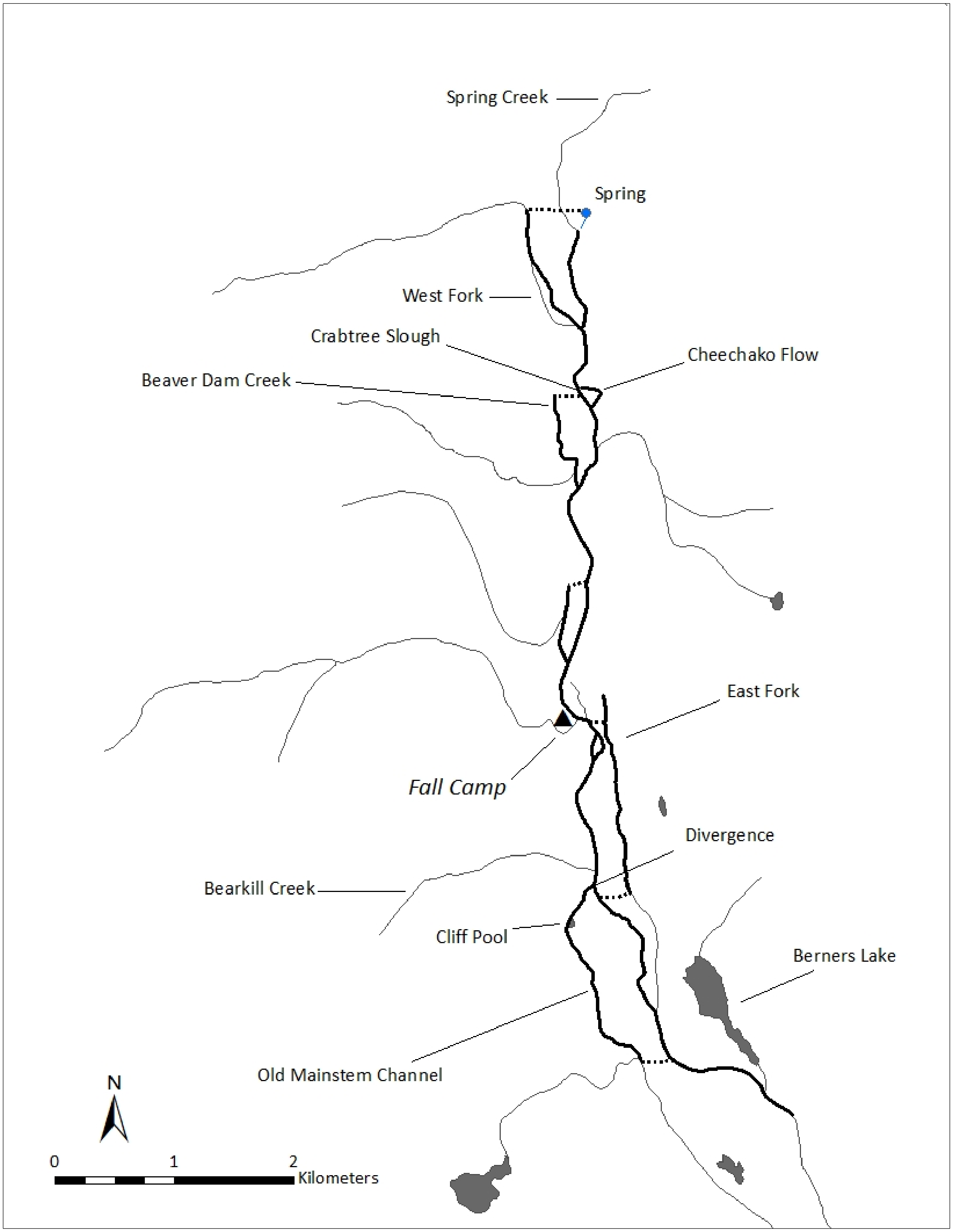
	Drift Gillnet Effort (Statistical Weeks 36–40)		Catch (1,000s of Fish) Coho Salmon (Fishing Area)				Fall Chum	Gillnet Percent of Combined Troll & Gillnet Coho Catch	
Year	Days	Average Boats	Lower	Central	Upper	Total	Total	Berners River	Chilkat River
1974	7.0	218	20.1	21.5	23.3	64.9	424.2	33.3	62.5
1975	4.0	261	14.0	17.8	25.8	57.6	235.3	-	-
1976	8.0	247	22.3	24.9	24.3	71.5	364.2	-	-
1977	7.0	253	41.0	34.2	16.3	91.5	191.6	-	-
1978	5.0	261	27.1	9.9	16.2	53.2	102.6	36.5	35.3
1979	5.0	274	3.6	17.6	5.8	27.0	209.5	26.6	44.3
1980	6.0	204	2.8	21.6	4.5	28.9	149.0	-	-
1981	6.5	169	14.2	23.2	7.3	44.7	95.6	-	-
1982	10.0	153	24.6	29.4	18.3	72.3	291.5	43.7	-
1983	13.0	212	15.9	24.1	29.6	69.5	298.3	28.9	41.4
1984	18.0	203	24.5	23.7	20.0	68.2	547.3	-	51.9
1985	14.0	233	33.7	28.4	36.2	98.3	597.2	39.2	-
1986	13.0	217	34.1	32.1	16.0	82.1	327.6	39.4	-
1987	11.0	246	22.6	23.1	8.1	53.8	355.1	31.5	-
1988	10.0	254	30.6	32.5	18.5	81.5	286.3	50.6	-
1989	4.0	181	20.8	23.4	6.3	50.5	76.0	13.6	-
1990	5.0	196	26.8	22.5	13.9	63.2	107.0	32.9	-
1991	10.0	107	106.2	15.9	7.2	129.3	89.5	72.1	-
1992	10.0	112	78.9	24.4	5.9	109.2	74.3	48.9	-
1993	12.0	86	52.5	6.7	0.8	60.0	56.2	42.5	-
1994	15.0	83	84.8	47.0	9.0	140.8	107.1	50.5	-
1995	8.0	88	55.3	21.1	3.5	79.9	57.1	62.9	-
1996	9.0	71	29.9	16.5	6.2	52.7	45.3	37.9	-
1997	4.0	78	12.6	2.0	1.0	15.6	16.4	47.9	-
1998	9.0	50	19.1	5.9	1.1	26.1	17.6	33.4	-
1999	13.0	54	30.9	2.7	1.8	35.4	46.4	42.6	-
2000	10.0	65	28.0	6.4	1.2	35.6	53.4	52.6	46.0
2001	13.0	59	23.6	7.1	3.9	34.6	65.4	28.6	30.6
2002	14.0	41	54.1	18.8	5.0	77.9	23.3	58.3	51.9
2003	20.0	43	42.0	8.9	8.9	59.8	34.1	62.5	33.9
2004	23.5	43	38.6	6.9	6.4	52.0	48.0	40.5	30.2
2005	16.0	44	17.5	4.8	5.6	27.9	67.1	35.4	37.8
2006	16.0	41	29.3	9.9	16.0	55.1	54.8	60.2	39.7
2007	13.0	46	11.0	2.6	4.6	18.2	66.0	36.2	27.6
2008	13.0	57	21.4	16.3	9.2	46.9	71.4	47.2	57.9
2009	15.0	62	17.8	6.3	11.7	35.8	55.6	42.1	56.3
2010	11.0	67	34.6	17.0	14.3	65.9	64.4	52.9	56.5
2011	14.0	74	21.0	7.9	4.9	33.8	61.4	33.8	41.8
2012	13.0	53	12.2	4.8	6.3	23.3	72.1	31.0	57.5
2013	15.0	79	36.4	14.6	17.0	68.0	97.3	45.5	62.2
2014	16.0	52	38.7	17.4	2.0	58.1	17.6	59.2	56.0
1974-1984	8.1	223	19.1	22.5	17.4	59.0	264.5	33.8	47.1
1985-1989	10.4	226	28.4	27.9	17.0	73.2	328.4	34.9	-
1990-1999	9.5	92	49.7	16.5	5.0	71.2	61.7	47.2	-
2000-2004	16.1	50	37.3	9.6	5.1	52.0	44.9	48.5	38.5
2005-2014	14.2	57	24.0	10.2	9.2	43.3	62.8	44.4	49.3
All Years	11.2	130	31.1	17.1	10.8	59.0	146.8	42.9	46.1

APPENDIX G:
MAPS AND SATELLITE PHOTOS

Appendix G1.–Berners River drainage with locations of spring and fall research camps.



Appendix G2.–Primary river systems in upper Berners Bay.



Appendix G3.–Upper Berners River drainage with thicker lines denoting stream reaches that were routinely surveyed to count adult coho salmon by foot.