Sockeye Salmon Stock Status and Escapement Goal for Hugh Smith Lake in Southeast Alaska

RC-4

by
Harold J. Geiger,
Timothy P. Zadina,
and Steven C. Heinl

Alaska Department of Fish and Game
Division of Commercial Fisheries
Juneau, Alaska

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AUTHORS

Harold J. Geiger is the salmon stock assessment research supervisor for the Southeast Region of the Division of Commercial Fisheries, Alaska Department of Fish and Game, and he works out of the Douglas office (Douglas Island Center Building, 802 3rd Street, P.O. Box 240020, Douglas, Alaska 99824-0020).

Timothy P. Zadina is a research biologist employed by the Southeast Region of the Division of Commercial Fisheries, Alaska Department of Fish and Game, and he works out of the Ketchikan office (2030 Sea Level Drive, Suite 205, Ketchikan, Alaska 99901).

Steven C. Heinl is a research biologist employed by the Southeast Region of the Division of Commercial Fisheries, Alaska Department of Fish and Game, and he works out of the Ketchikan office (2030 Sea Level Drive, Suite 205, Ketchikan, Alaska 99901).

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ABSTRACT

Hugh Smith Lake is a meromictic sockeye salmon-producing system about 97 km southeast of Ketchikan, Alaska. This system has a history of commercial exploitation of sockeye salmon going back to the late 19th century. From 1895 to 1912, catches in the vicinity of Hugh Smith Lake varied between 42,000 and 210,000 sockeye salmon — although it is not clear what fraction of these were actually bound for Hugh Smith Lake. In recent times, the harvest of Hugh Smith bound sockeye salmon has been mostly incidental in other fisheries, with the coded wire tags originating from this system principally recovered in Districts 101 and 104 in Alaska, but there has been no sampling for these tags in Canadian fisheries. Since 1980, and in a few years before that, the escapements into this system have been estimated by means of a weir, with confirmation of these estimates by mark-recapture studies since 1992. The most recent escapement goal of 15,000 to 35,000 spawners was based on "professional judgment," and put into practice in the mid-1990s. Escapement has been below the lower end of that goal range every year since 1992. From smolt years 1980 to 1996, the estimated harvest rate of coded wire tagged groups of this stock ranged from 40 to 96% (the latter number based on very few tag recoveries), with a median value of 61%. Because of the difficulty of reconstructing the total number of adults originating from this system, a traditional Ricker analysis cannot be used to set the escapement goal. We used 3 alternate analyses, each with its own limitations, but all 3 led to remarkably similar recommendations. Combining the 3 analyses, we recommend that the Alaska Department of Fish and Game adopt a *biological escapement goal* of 8,000 to 18,000 spawners for Hugh Smith Lake sockeye salmon. We further recommend that the Alaska Department of Fish and Game reduce the incidental harvest rate on this stock of sockeye salmon. Finally, we recommend that ADF&G and SSRAA staff conduct careful reviews of the Hugh Smith Lake sockeye salmon stocking program and stock assessment programs before the summer of 2003.

KEY WORDS: sockeye salmon, *Oncorhynchus nerka*, Hugh Smith Lake, biological escapement goal, escapement trends, juvenile production, risk analysis

INTRODUCTION

Hugh Smith Lake (55°06' N., 134°40' W.; Orth 1967) is located 97 km southeast of Ketchikan, on mainland Southeast Alaska, in Misty Fjords National Monument (Figure 1). The lake is organically stained with a surface area of 320 ha, mean depth of 70 m, maximum depth of 121 m, and volume of $223 \cdot 10^6$ m^3 (Figure 2). The lake empties into Boca de Quadra inlet via Sockeye Creek (50 m; ADF&G stream number 101-30-10750). Sockeye salmon spawn in 2 inlet streams: Buschmann Creek flows northwest 4 km to the head of the lake (ADF&G stream number 101-30-10750-2006); and Cobb Creek flows north 8 km to the southeast head of the lake (ADF&G stream number 101-30-10750-2004). Cobb Creek has a barrier to anadromous migration approximately 0.8 km upstream from the lake (Figure 2). Hugh Smith Lake also has a meromictic layer located below the 60 m depth level. Water below this layer does not interact with the upper freshwater layer of the lake.

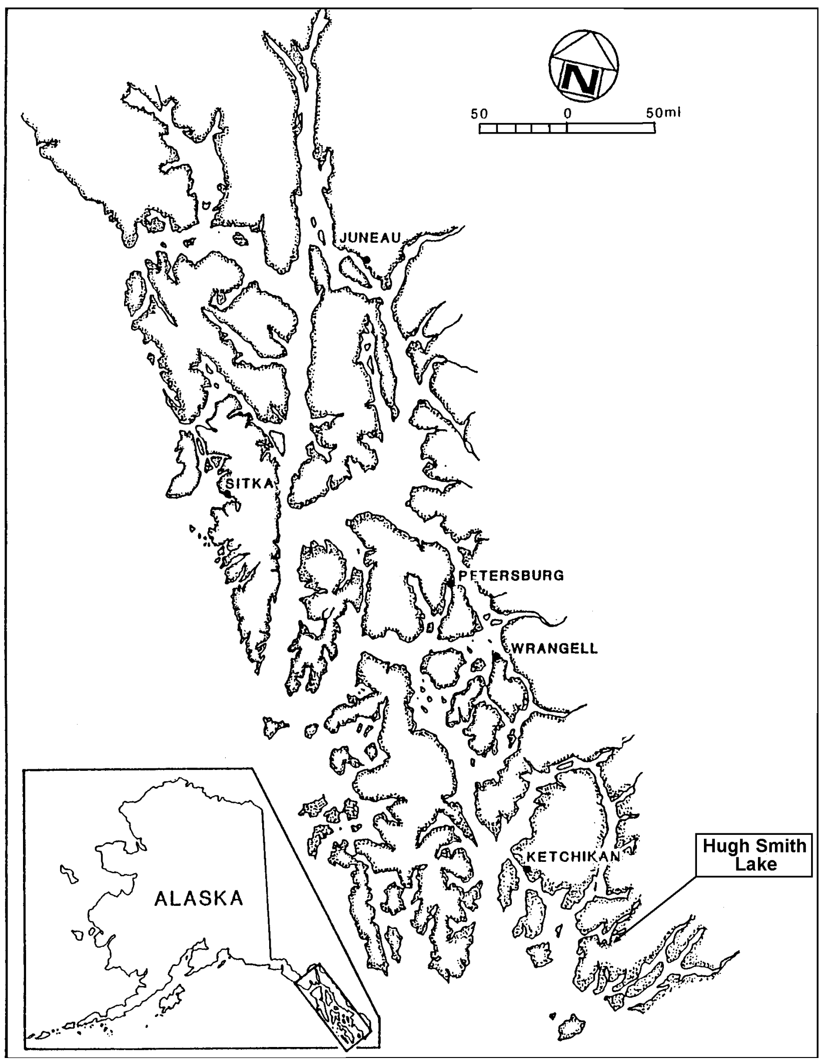

Figure 1. The location of Hugh Smith Lake in Southeast Alaska.

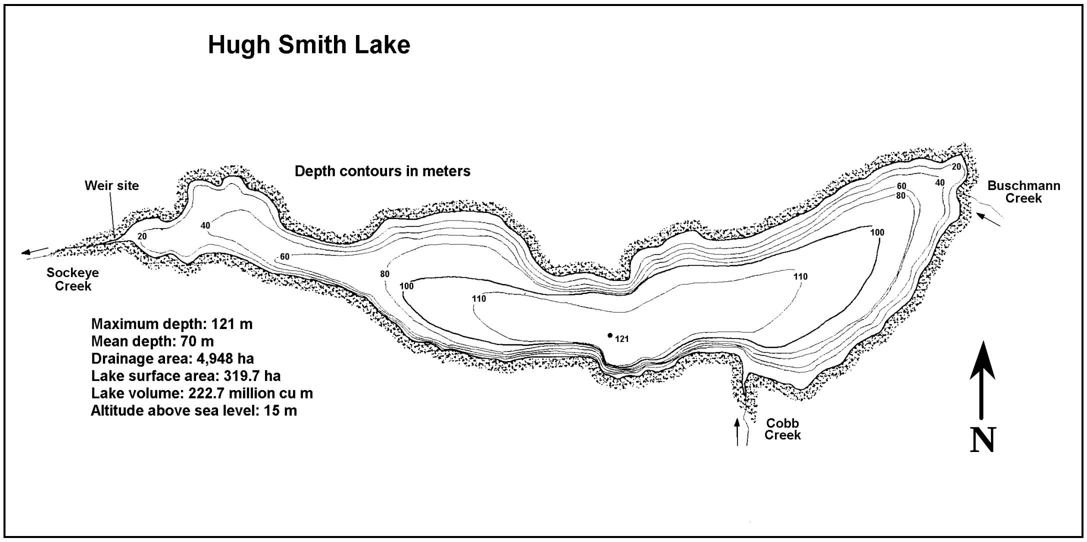

Figure 2. Bathymetric map of Hugh Smith Lake, Southeast Alaska, showing the location of the weir site, location of inlet streams, and other features of the lake system.

Historically, Hugh Smith Lake was an important sockeye salmon (*Oncorhynchus nerka*) producer in Boca de Quadra Inlet in the southern portion of Southeast Alaska. From 1895 to 1912, the sockeye salmon catch in Boca de Quadra ranged from 42,000 to 210,000 (Rich and Ball 1933). Moser (1898) gives sockeye salmon catch figures of 97,000 in 1895, 137,000 in 1896, and 65,000 in 1897 — all of which were harvested at the mouth of Hugh Smith Lake and its "approaches." It is not clear, however, what portion of those fish that were taken in the "approaches" came from the waters around the entrance of Boca de Quadra. Tagging studies have shown that sockeye salmon migrating through the waters surrounding Boca de Quadra are from highly mixed stocks (Hoffman et al. 1983 and 1984). A saltery was located near the outlet of Hugh Smith Lake in the late 1800s and 2 canneries were located nearby in Boca de Quadra in the early 1900s.

A private hatchery was operated at the head of Hugh Smith Lake from 1901 to 1903, and from 1908 to 1935, but numbers of adult sockeye salmon returning to the lake were not recorded (Roppel 1982). The hatchery operators left records of egg-take numbers that provide some idea of the minimum size of the escapement in those days. Assuming a fecundity of 3,500 eggs per female, the hatchery must have been using between about 6 thousand to 20 thousand adults — consistently for nearly 30 years. Although overfishing near the mouth of Hugh Smith Lake reduced the escapement to the point that the hatchery operators were unable to take broodstock in 1903, and the hatchery was not operated from 1904 to 1907, typically, over 10-thousand adults were used for hatchery broodstock in most years from 1901 to 1935.

The Alaska Department of Fish and Game (ADF&G) enumerated the sockeye salmon escapement at Hugh Smith Lake with a weir from 1967 to 1971, and annually since 1980. Dates of weir operation since 1982 indicate that weir counts encompass the vast majority of the returning adults, while earlier weir counts were likely biased low. Spawning escapements since 1982 have varied considerably from year to year, and have ranged from 897 fish in 1998 to 65,408 fish in 1992, averaging 12,978 fish. Sockeye salmon escapements averaged 17,671 fish from 1982–1989, 11,775 fish during the 1990s, and 3,439 fish over the past 5 years (1998–2002). The escapement record shows a long-term decreasing trend since 1982 (Spearman's rank correlation trend test, r = - 0.600, p = 0.003, n = 23; Conover 1980).

ADF&G unpublished coded wire tag data show that Hugh Smith Lake sockeye salmon are harvested primarily in the traditional Alaska commercial fisheries of Districts 101 and 104. Additionally, these fish have also been harvested at Annette Island (District 101-28), and Districts 102, 103, 106, 109, and 154; in 1994, 3 tags were even recovered in Districts 212 and 223 of Prince William Sound. Hugh Smith sockeye salmon have been captured in the early net fisheries of mid-June (Statistical Week 25) through late-September (Statistical Week 39).

Peltz and Haddix (1989) attempted to estimate harvest rates, and spatial and temporal distributions of Hugh Smith sockeye salmon in commercial fisheries using coded wire tags. Their harvest rate calculations do not include the Hugh Smith-origin sockeye salmon that were harvested in northern British Columbia since those fisheries were not sampled for coded wire tagged sockeye salmon. Joint U.S.-Canada tagging studies in 1982 and 1983 showed that Hugh Smith Lake sockeye salmon migrate through northern British Columbia waters in Dixon Entrance (e.g., in 1982, 195 adult sockeye salmon that had been tagged and released in northern British Columbia waters were recovered at the Hugh Smith Lake weir out of 386 total weir recoveries). This demonstrated an unknown, but possibly substantial Canadian harvest (Hoffman et al. 1983, 1984, and unpublished data), at least in those years. These coded wire tag and treaty tag studies demonstrated that the Hugh Smith sockeye salmon stock migrated widely and was highly susceptible to harvest from many fisheries.

As previously mentioned, Hugh Smith sockeye salmon have been the subject of various enhancement efforts, going back to the early part of the last century. In the early 1980s, the lake was the subject of lake enrichment studies, and beginning in 1987 the subject of hatchery lake-stocking efforts by the Alaska Department of Fish and Game. Currently, the Southern Southeast Regional Aquaculture Association (SSRAA) uses in-lake net pens at Hugh Smith Lake to rear pre-smolt, with an annual release of up to 500,000 hatchery-produced juvenile sockeye salmon of Hugh Smith origin (SSRAA 2002).

The Sustainable Salmon Policy defines a *management concern* as “a concern arising from a chronic inability, despite use of specific management measures to maintain escapements for a stock with the bounds of [escapement goal] ... ‘Chronic inability’ means continuing or anticipated inability to meet escapement objectives over a four- to five-year period...” The 2002 management plan for the purse seine fishery (ADF&G 2002) has this to say about Hugh Smith Lake:

> *Hugh Smith Lake sockeye salmon in Boca de Quadra (District 1) continues to be a conservation concern. The escapement goal for this system is 15,000 to 35,000 fish. The total return for Hugh Smith sockeye salmon in 2002 is forecast to be approximately 28,000 fish. SSRAA enhancement programs could possibly increase the returns to the system over past years.*
>
> *Harvest rates on Hugh Smith sockeye can range from 50 to 90%. If Hugh Smith sockeye salmon escapements in early July are inadequate, area restrictions may be implemented by mid-July in the vicinity of Boca de Quadra. The duration and the extent of the closed area will be based upon observed escapement of Hugh Smith sockeye salmon and the need to harvest surplus pink salmon stocks bound for Boca de Quadra.*

At this time, it does not appear possible to describe the origin of the escapement goal for this system as listed in the 2002 management plan. Likely, the goal of 15,000 to 35,000 spawners is based on “professional judgment.” The 1993 management plan (ADF&G 1993) uses the term “informal escapement goal for Hugh Smith sockeye salmon,” and states this goal is 27,000. Zadina et al. (1995) reported that they expected Hugh Smith to be capable of producing a maximum of 44,000 sockeye salmon annually, and they recommended an escapement goal of 16,000 to reach this maximum production, based on the euphotic volume (EV) model of Koenings and Burkett (1987) that relates physical water features of the lake to carrying capacity in other sockeye salmon lakes throughout Alaska. There was some analysis of stock-recruit data that was documented in several memoranda in the 1980s; a preliminary, undocumented spawner-recruit analysis led to an estimate that escapements between 18,000 and 35,000 sockeye salmon would produce maximum sustainable yield.

Irrespective of the origin of the goal, and irrespective of how the goal changed in the 1990s, clearly this system meets the definition of a *management concern*. The system does not meet the definition of the next most serious level of concern, which is a *conservation concern*. To be classed as a conservation concern a stock must be chronically below a *sustainable escapement threshold*, and no such threshold has been developed for Hugh Smith sockeye salmon.

Below, we wish to:

(1) summarize and analyze biological information available concerning the Hugh Smith Lake stock of sockeye salmon,

(2) make a recommendation concerning an appropriate biological escapement goal for this stock of sockeye salmon,

(3) suggest that ADF&G take actions needed to rebuild this stock of sockeye salmon (reduced harvest and a review of the supplemental stocking program),

(4) suggest the existing stock assessment program undergo review and that needed improvements be implemented.

SPAWNING ESCAPEMENT

Estimates of Escapement

The Hugh Smith Lake adult salmon counting weir is located at the outlet of the lake, approximately 50 m from saltwater at high tide (Figure 2). The weir is an aluminum bi-pod, channel, and picket design, with an upstream trap for counting and sampling salmon. From 1980 to 2002, the adult weir was operated from early or mid-June through at least late-October, the period when 99% of the sockeye salmon run enters the lake. The only exception was in 1981, when weir operations terminated early on September 8 . The integrity of the weir was verified by periodic underwater inspections, and through a two-sample mark-recapture study that was initiated in 1992 and continued each year through 2002.

The mark-recapture study was used to determine if the weir was fish tight or if sockeye salmon entered the lake before the weir was fish tight in mid-June. Fish were marked with a readily identifiable fin-clip at the weir. Marking was stratified through time, with different marks used for each average third of the run: (1) right ventral fin clip from June 16–July 18; (2) left ventral fin clip July 19–August 15; and (3) partial dorsal fin clip August 16 – to the end of weir operation in early November. Marks were applied at a constant rate throughout the season: 36% in 1992, 97 to 100% from 1993 to 1996, 67% from 1997 to 2000, and 50% from 2001 to 2002.

Stream surveys to sample for marked spawning adults in Buschmann and Cobb Creeks were conducted over the length of the spawning season, late August to early October. All dead fish were examined for fin clips, and live fish were captured and examined for marks using dip nets or a beach seine. Fish that were killed during egg-takes were also sampled for the presence or absence of fin-clips. All sampled fish (live and dead) were marked on the left operculum with a round hole punch to prevent double sampling. The number of fish sampled during these annual second events of mark-recapture experiments (1992–2002) averaged 929 fish, ranging from 226 fish in 1998 to 2,377 fish in 1993. The number of recaptured sockeye salmon first marked at the weir site and recaptured on the spawning grounds over this 11-year period averaged 659 fish and ranged from 221 sockeye salmon in 1999 to 2,029 sockeye salmon in 1993.

We used Stratified Population Analysis System (SPAS) software (Arnason et al. 1996) to generate mark-recapture estimates of the total spawning population of sockeye salmon. SPAS was designed for analysis of two-sample mark-recapture data where marks and recoveries take place over a number of strata. We used this software to calculate: (1) maximum likelihood (ML) Darroch estimates and pooled-Petersen (Chapman's modified) estimates, and their standard errors; (2) chi-square tests for goodness-of-fit based on the deviation of predicted values (fitted by the ML Darroch estimate) from the observed values; and (3) 2 chi-square tests of the validity of using fully pooled data. The latter chi-square tests for complete mixing of marked fish between release and recovery strata, and tests for equal proportions of marked fish in the various recovery strata. We assumed that passing either of those tests (that is, a significance probability of $P>0.05$) is sufficient to validate full pooling of the data (i.e., the pooled-Petersen estimate). The manipulation of release and recovery strata in calculating estimates (the method used in SPAS) is also presented and discussed at length by Schwarz and Taylor (1998).

Total sockeye salmon passage estimates at the weir site and estimates of spawning escapements to Hugh Smith Lake, from 1967 to 2002, are presented in Table 1. Mark-recapture estimates of the passage of sockeye salmon into Hugh Smith Lake from 1992 to 2002 were generally very close to the weir counts (Table 2). We deemed the weir count to be "verified" if it fell within the 95% confidence interval of the mark-recapture estimate, and if either of the chi-square tests of complete mixing or equal proportions of marked fish in the recovery strata were not statistically significant. Mark-recapture estimates in 1993, 1994, and 1995, were larger than the weir counts for those years, and chi-square tests of complete mixing of marked fish between release and recovery strata, and a test of equal proportions of marked fish in the recovery strata were statistically significant (i.e., a significance probability $P<0.05$). We chose to use the ML Darroch estimates for calculating the total escapements in 1993, 1994, and 1995. The differences between the weir counts and the mark-recapture estimates in 1993 (2,220 fish) and 1994 (580 fish), suggests that fish entered the lake before the weir was in place in mid-June, or some fish passed the weir and were not counted. In 2001, a hole was discovered in the weir in late August. Although chi-square goodness of fit tests were not significant for the test of equal proportions of marked fish in the recovery strata ($P=0.16$), we used a pooled Petersen estimate to calculate the total escapement in 2001, rather than the weir count.

Table 1. Hugh Smith Lake sockeye salmon escapement estimates and run timing, 1967–2002.

Year	1967	1968	1969	1970	1971	1980	1981	1982	1983	1984	1985
Weir Count	6,754	1,617	10,357	8,755	22,096	12,714	15,545	57,219	10,429	16,106	12,245
Total Escapement[a]								57,219	10,429	16,106	12,245
Weir Mortalities	NA	NA	NA	NA	NA	NA	NA	81	45	134	201
Adults Used for Egg Takes	0	0	0	0	0	0	0	0	0	439	798
Spawning Escapement[b]	NA	NA	NA	NA	NA	NA	NA	57,138	10,384	15,533	11,246
Weir Starting Date	1-Jun	13-Jun	11-Jun	9-Jun	20-Jun	5-Jun	7-Jun	4-Jun	30-May	1-Jun	1-Jun
Weir Ending Date	3-Sep	21-Aug	14-Aug	1-Sep	22-Aug	4-Oct	8-Sep	27-Nov	30-Nov	26-Nov	11-Nov
Total Days Elapsed	94	69	64	84	63	121	93	176	184	178	163
Date of First Sockeye	13-Jun	14-Jun	11-Jun	11-Jun	20-Jun	6-Jun	8-Jun	7-Jun	1-Jun	6-Jun	5-Jun
Date of Last Sockeye	3-Sep	21-Aug	14-Aug	1-Sep	22-Aug	4-Oct	8-Sep	25-Oct	25-Oct	19-Nov	29-Oct
No. of Days Elapsed Between First and Last Sockeye	82	68	64	82	63	120	92	140	146	166	146
10th Percentile Run Date	22-Jun	2-Jul	26-Jun	26-Jun	1-Jul	4-Jul	28-Jun	20-Jun	11-Jul	14-Jul	12-Jul
25th Percentile Run Date	28-Jun	11-Jul	9-Jul	6-Jul	9-Jul	20-Jul	7-Jul	29-Jun	17-Jul	26-Jul	25-Jul
50th Percentile Run Date	7-Jul	15-Aug	20-Jul	27-Jul	20-Jul	6-Aug	27-Jul	9-Jul	11-Aug	8-Aug	23-Aug
75th Percentile Run Date	18-Jul	19-Aug	7-Aug	6-Aug	19-Aug	26-Aug	24-Aug	18-Jul	4-Sep	26-Aug	2-Sep
90th Percentile Run Date	28-Jul	21-Aug	9-Aug	13-Aug	20-Aug	9-Sep	3-Sep	7-Aug	24-Sep	10-Sep	13-Sep

[a] The total escapement equals weir count, 1967–1985.
[b] The spawning escapement equals the total estimated escapement minus the weir mortalities (coded-wire-tagged fish) and fish killed for egg takes.

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Table 1. (page 2 of 3)

Year	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Weir Count	2,312	33,097	5,056	6,513	1,285	5,885	65,586	11,312	8,386	3,422	7,123
Total Escapement[a]	6,968	33,097	5,056	6,513	1,285	5,885	65,737	13,532	8,992	3,452	7,123
Weir Mortalities	12	0	28	32	28	33	151	278	42	11	57
Adults Used for Egg Takes	619	1,902	424	1,547	0	357	178	1,460	763	312	513
Spawning Escapement[b]	6,337	31,195	4,604	4,934	1,257	5,495	65,408	11,794	8,187	3,129	6,553
Weir Starting Date	17-Jun	3-Jun	5-Jun	3-Jun	8-Jun	17-Jun	16-Jun	17-Jun	20-Jun	17-Jun	17-Jun
Weir Ending Date	29-Oct	21-Oct	22-Oct	25-Oct	31-Oct	9-Oct	25-Oct	4-Nov	1-Nov	3-Nov	4-Nov
Total Days Elapsed	134	140	139	144	145	114	131	140	134	139	140
Date of First Sockeye	18-Jun	8-Jun	12-Jun	11-Jun	13-Jun	19-Jun	16-Jun	20-Jun	20-Jun	19-Jun	20-Jun
Date of Last Sockeye	3-Oct	4-Oct	16-Oct	18-Oct	21-Oct	11-Oct	18-Oct	3-Nov	26-Oct	1-Nov	20-Oct
No. of Days Elapsed Between First and Last Sockeye	107	118	126	129	130	114	124	136	128	135	122
10th Percentile Run Date	11-Jul	18-Jul	19-Jul	30-Jul	8-Jul	22-Jul	12-Jul	2-Jul	20-Jul	7-Jul	25-Jul
25th Percentile Run Date	15-Jul	20-Jul	24-Jul	5-Aug	23-Jul	29-Jul	19-Jul	16-Jul	1-Aug	17-Jul	11-Aug
50th Percentile Run Date	20-Jul	4-Aug	9-Aug	10-Aug	27-Aug	21-Aug	27-Jul	30-Jul	23-Aug	29-Jul	19-Aug
75th Percentile Run Date	28-Jul	30-Aug	25-Aug	14-Aug	7-Sep	12-Sep	29-Jul	14-Aug	26-Aug	9-Aug	3-Sep
90th Percentile Run Date	8-Aug	31-Aug	1-Sep	22-Aug	16-Sep	22-Sep	11-Aug	31-Aug	3-Sep	21-Aug	13-Sep

[a] The total escapement equals the mark-recapture estimate (1986, 1993, 1994, 1995) plus weir mortalities, or the weir count. (Data used to calculate a Petersen estimate in 1986 are not available.)

[b] The spawning escapement equals the total estimated escapement minus the weir mortalities (coded-wire-tagged fish) and fish killed for egg takes.

-continued-

Table 1. (page 3 of 3)

Year	1997	1998	1999	2000	2001	2002
Weir Count	12,182	1,138	3,174	4,281	3,665	6,166
Total Escapement[a]	12,182	1,138	3,174	4,281	3,825	6,166
Weir Mortalities	28	23	20	12	6	0
Adults Used for Egg Takes	0	218	276	280	268	286
Spawning Escapement[b]	12,154	897	2,878	3,989	3,551	5,880
Weir Starting Date	18-Jun	17-Jun	16-Jun	17-Jun	16-Jun	17-Jun
Weir Ending Date	5-Nov	11-Nov	8-Nov	11-Nov	11-Nov	4-Nov
Total Days Elapsed	140	147	145	147	148	140
Date of First Sockeye	18-Jun	19-Jun	22-Jun	19-Jun	19-Jun	19-Jun
Date of Last Sockeye	1-Nov	12-Oct	4-Oct	27-Oct	6-Oct	17-Oct
No. of Days Elapsed Between First and Last Sockeye	136	115	104	130	109	120
10th Percentile Run Date	3-Jul	8-Jul	7-Jul	29-Jun	2-Jul	10-Jul
25th Percentile Run Date	16-Jul	21-Jul	15-Jul	7-Jul	18-Jul	4-Aug
50th Percentile Run Date	25-Jul	30-Jul	31-Jul	20-Jul	16-Aug	7-Aug
75th Percentile Run Date	2-Aug	10-Aug	15-Aug	30-Jul	22-Aug	9-Aug
90th Percentile Run Date	15-Aug	18-Aug	22-Aug	6-Aug	23-Aug	12-Aug

[a] The total escapement equals the mark-recapture estimate (2001) plus weir mortalities, or the weir count.

[b] The spawning escapement equals the total estimated escapement minus the weir mortalities (coded-wire-tagged fish) and fish killed for egg takes.

Table 2. Mark-recapture escapement estimates for Hugh Smith Lake sockeye salmon, 1992–2002.

Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Live Weir Count[a]	65,435	11,034	8,344	3,413	7,066	12,154	1,115	3,154	4,269	3,629	5,999
Proportion Marked	36%	99%	97%	100%	99%	67%	67%	67%	67%	50%	50%
Number Released With											
Period 1 (16 Jun-18 Jul)	8,817	4,199	1,132	1,430	637	3,663	117	598	1,151	543	491
Period 2 (19 Jul-15 Aug)	11,173	4,383	1,655	1,465	1,622	3,657	496	975	1,539	317	2318
Period 3 (16 Aug-Nov)	3,800	2,391	5,339	501	4,736	780	132	530	156	947	190
Number Sampled for Marks	1,974	2,377	1,152	1,028	374	934	226	323	443	484	908
Number of Marks Recovered	814	2,029	1,041	1,006	369	638	157	221	299	230	449
Mark-Recapture Estimate[b,c,e]	57,652	**13,254**	**8,925**	**3,441**	7,090	11,853	1,071	3,070	4,213	**3,789**	6,059
Se	1,520	134	77	70	41	253	42	109	131	168	187
± 95% CI	2,979	263	151	137	80	496	82	214	257	329	367
CV	3%	1%	1%	2%	1%	2%	4%	4%	3%	4%	3%
Total Escapement[e]	65,737	13,532	8,992	3,452	7,123	12,182	1,138	3,174	4,281	3,825	6,166

[a] The weir count used for mark-recapture calculations was the number of live fish (weir count minus weir mortalities) passed through the weir.

[b] Pooled Petersen, and ML Darroch estimates and their standard errors were calculated using Stratified Population Analysis Software. Release data were stratified into 3 release periods, and recovery data were stratified by recovery days.

[c] Mark-recapture estimates for 1992, 1996, 1997, 1998, 1999, 2000, 2001, and 2002 are Pooled Petersen estimates. Chi-square tests for goodness of fit and complete mixing in 1993, 1994, and 1995 were significant ($P<0.05$), and suggested that ML Darroch estimates be used rather than a Pooled Petersen estimate for those years.

[d] The bold mark-recapture estimates in 1993, 1994, 1995, and 2001 were used to estimate total escapement, rather than the weir count. A small hole was detected in the weir in 2001, so it is known that fish escaped unsampled into the lake. In other years, the weir count fell within the confidence interval of the mark-recapture estimate, and therefore, the weir count was judged to be acceptable.

[e] The total escapement equals the mark-recapture estimate plus weir mortalities (1993, 1994, 1995, and 2001), or the live weir count plus weir mortalities (1992, 1996, 1997, 1998, 1999, 2000, and 2002).

These mark-recapture studies (1992–2002) demonstrated that the weir counts were accurate. Over the 11-year period of 1992–2002, the annual differences between the weir counts and the mark-recapture estimates only averaged 5% of the weir counts, indicating that weir counts in general, were unbiased estimates of the annual passage of sockeye salmon into Hugh Smith Lake. The largest relative difference (20%) was in 1993 when the weir count was 11,034 and the mark-recapture estimate was 13,254. From 1994-2002, the relative differences between the 2 estimates of passage never exceeded 5%. The differences in 1992, 1993, and 1994 were 12%, 20%, and 7%, respectively.

It is possible that the extensive handling of such a large proportion of the escapement (up to 100% of the escapement in 1993–1996) may have induced a level of post release mortality on these fish prior to spawning. Because the weir is located only 50 m from saltwater, the sockeye salmon so handled during the first events of the mark-recapture studies would have been actively changing their metabolism to live in freshwater instead of saltwater, making them potentially susceptible to handling induced post-release mortality. However, no evidence of major mortality was evident during the years 1997–2002, when only 50–67% of the run was marked. A stress-induced mortality of a significant number of marked fish would have caused the mark-recapture estimates to be higher than the weir counts.

The most striking features of the spawning escapement series are the 3 peaks in 1982, 1987, and 1992, the loss of this five-year pattern of peaks after 1992, and a general decrease in the remainder of the 1982-2002 escapement series (Figure 3). We used a non-parametric regression and regressed escapement on *year number* in the data set (i.e., *year number* means 1 for 1982, 2 for 1983, and so forth). We call the slope of that regression the robust estimate of decline (Geiger and Zhang 2002). If the analysis is restricted to the last 15 years, the robust estimate of decline in escapement is just over 200 fish per year. However, if 21 years of data is considered, the decline is estimated to be about 550 fish per year. Therefore, it appears that most of the decline in this stock took place in the early 1980s (Figure 3). Based upon weir counts, the run timing of sockeye salmon has been highly variable within this system throughout the historic data series (Figure 4).

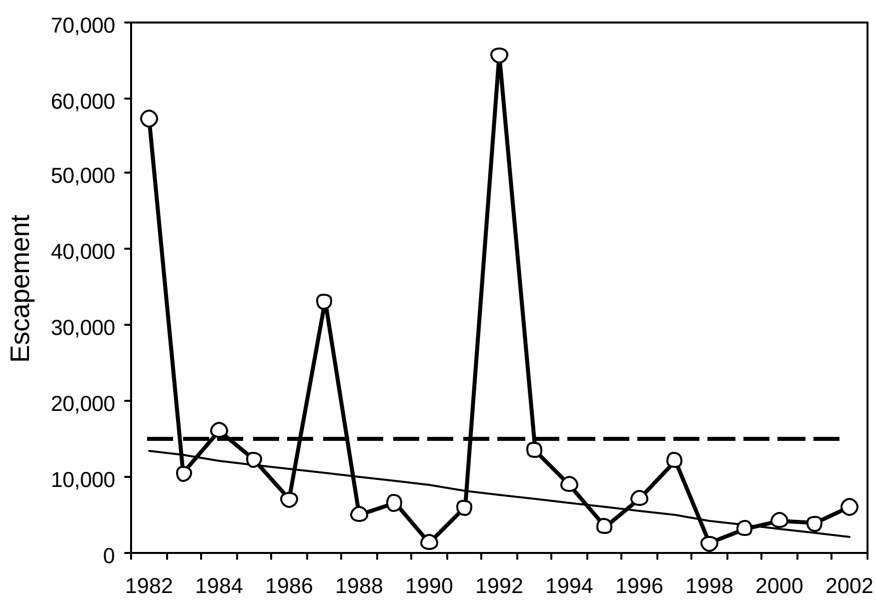

Figure 3. Escapement estimates for Hugh Smith sockeye salmon from 1982 to 2002. The thin line is the robust trend in escapement over time and the dotted line is 15,000 fish, the lower end of the previous escapement goal.

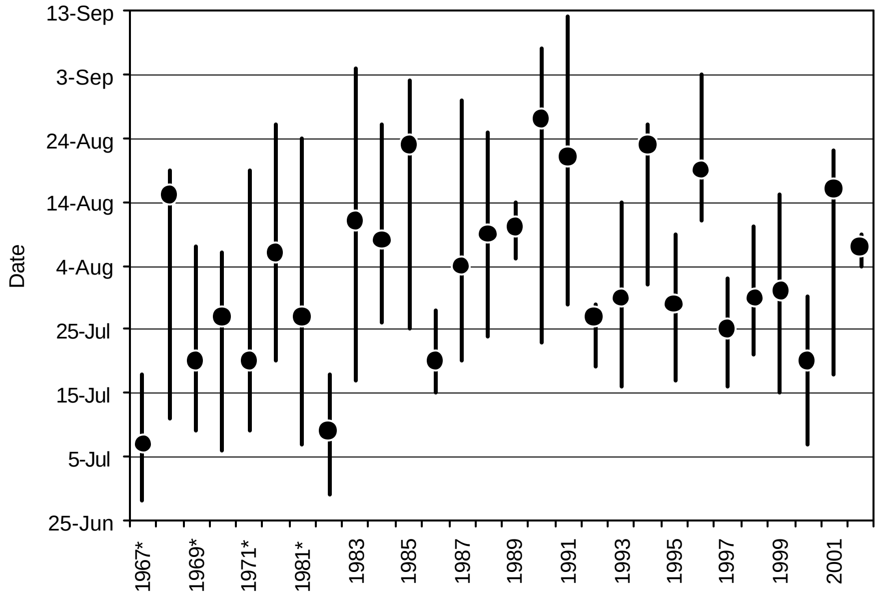

Figure 4. Timing of sockeye salmon counts at the Hugh Smith weir with the 50th percentile run date (dots) and the dates when 25 and 75% of the sockeye salmon passed through the weir (vertical bars). From 1967–1971 the weir was removed sometime between August 11 and September 3, so these years are not directly comparable to the later years. The year 1989 was the last time that the weir was operational on June 1; after 1989, the weir was not put in place until June 16.

Biological Sampling of the Escapement

The age composition of the escapement was determined from scale samples taken daily at the adult weir throughout the run. The sex of each fish was determined from external sexual maturation characteristics. Lengths were measured from mid eye to fork of the tail to the nearest millimeter. One scale was taken from the preferred area of each fish (INPFC 1963), and prepared for analysis as described by Clutter and Whitesel (1956). Scale samples were aged at the ADF&G salmon aging lab, Douglas, Alaska. The number of scale samples that could be aged from each annual sample ranged from 140 (1998) to 4,027 (1991), and depended on the size of the escapement and the sampling rate for a given year. Since 1996, the goal has been to sample up to 600 sockeye salmon for scales, with samples obtained over the course of the entire run. This sample size also yields an adequate number of scales for the major age classes that are used in scale pattern-based stock identification of sockeye salmon in southern Southeast Alaska commercial fisheries harvests (Oliver et al. 1990).

The age distribution was calculated for each week of the escapement:

$$\hat{p}_{hj} = n_{hj} \big/ n_h \; ; \qquad (1)$$

where: h = index of the stratum (week),
j = index of the age class,
p_{hj} = proportion of the sample taken during stratum h that is age j,
n_h = number of fish sampled in week h, and
n_{hj} = number observed in class j, week h.

Standard errors of the weekly age class proportions were calculated as (Cochran 1977, page 52):

$$SE(\hat{p}_{hj}) = \sqrt{\left[\frac{(\hat{p}_{hj})(1-\hat{p}_{hj})}{n_h - 1}\right][1 - n_h/N_h]}, \tag{2}$$

such that N_h = the number of fish in the escapement in week h. The age distributions for the total escapement were estimated as a weighted sum (by stratum size) of the weekly proportions. That is,

$$\hat{p}_j = \sum_h p_{hj}(N_h/N), \tag{3}$$

such that N = the total escapement. The standard error of a seasonal proportion is the square root of the weighted sum of the weekly variances (Cochran 1977, pages 107–108):

$$SE(\hat{p}_j) = \sqrt{\sum_j^h [SE(\hat{p}_{hj})]^2 (N_h/N)^2}\ . \tag{4}$$

The 4 dominant age classes of sockeye salmon returning to Hugh Smith Lake are age 1.2, age 1.3, age 2.2, and age 2.3, and they comprised over 98% of all returning adults (Table 3). Other age classes found were age 0.1, age 0.2, age 1.1, age 2.1, age 3.1, age 1.4, age 1.5, age 2.4, age 3.2, and age 3.3, but together they never constituted a significant proportion of the return.

On a brood year basis, the predominant group of returning adults to the escapement was age 1.3 (mean 50.3%; range 10.4%–89.2%). That is, most of the fish from the same brood year matured as age 1.3 fish. The other 3 age groups in order of presence were age 2.3 (mean = 22.3%; range 1.0% – 72.8%), age 2.2 (mean = 12.9%; range 0.4% - 39.7%), and age 1.2 (mean = 12.6%; range 1.0% – 33.4%). The age distribution of the escapement at Hugh Smith Lake varies on an annual basis, because of the mix of strong and weak brood years in the same annual run. In 1999, for example, age 1.2 fish from the stronger 1995 brood year outnumbered the age 1.3 fish from the weaker 1994 brood year at a rate of 3 to 1 (Table 3).

ENHANCEMENT

Hugh Smith Lake has been the site of repeated attempts at salmon enhancement, going back to the very beginning of the 20th century (Roppel 1982). A private, packing company hatchery started on Cobb Creek in 1901 but moved to Buschmann Creek in 1904 where it stayed until 1935 when it closed permanently. The hatchery was not operated from 1904–1907 but in 1907 a total of six-million sockeye salmon eggs were taken and moved to the Fortmann Hatchery located in the Naha River drainage located approximately 20 km north of Ketchikan. During this early hatchery period, 600-thousand to 34-million eggs were taken annually and emergent fry were released into Buschmann Creek. The Buschmann Creek sockeye salmon run was again used for hatchery purposes in the 1950s for the Territory's lake stocking program in the Ketchikan area, and many fish were removed from the system at that time (Roppel 1982).

A new interest in the enhancement of the Hugh Smith Lake stock of sockeye salmon started again in the late 1970s. The lake's limnological features and documented low adult escapement relative to the historical catch records initially indicated this lake was a good candidate for nutrient enrichment. ADF&G's Fisheries Rehabilitation, Enhancement, and Development Division (FRED) fertilized the lake from 1981 to 1984. The nutrient-addition project was discontinued because the investigators concluded that age-1 smolt size was constrained by the temperature regimes in the lake, rather than by a limited food supply. The investigators concluded that the low number of rearing fish was not taxing the sockeye salmon food base even without fertilization (Peltz and Koenings 1989). FRED Division began remote sockeye salmon egg incubation, with back-planting into Hugh Smith Lake in 1984 in an attempt to increase the lake rearing fry production. The eggs were incubated at the Beaver Falls Central Incubation Facility in Ketchikan. Unfed, emergent fry were returned to Hugh Smith Lake from 1986–1990. When FRED Division was constricting due to budget cuts, Southern Southeast Regional Aquaculture Association (SSRAA) took over the Hugh Smith sockeye salmon rehabilitation program in 1991, after assuming the responsibilities of the Beaver Falls facility. In 1998, SSRAA moved its sockeye salmon incubation facilities to the Burnett Inlet Hatchery located on Etolin Island.

Table 3. Age distribution of the Hugh Smith Lake sockeye salmon escapement based on scale pattern analysis, weighted by week of escapement, 1980–2002.

		Age Class																
Return Year		0.1	1.1	2.1	3.1	0.2	1.2	2.2	3.2	0.3	1.3	2.3	3.3	1.4	2.4	1.5	2.5	Total
1980	Number by Age Class		37				1,055	113			9,380	2,129						12,714
	SE of Number		0				16	1			150	39						
	Proportion by Age Class		0.3%				8.3%	0.9%			73.8%	16.7%						
	SE of Proportion		0.0%				0.1%	0.0%			1.2%	0.3%						
	Sample Size		3				72	12			719	175						981
1981	Number by Age Class		250				7,216	1,826			4,598	1,655						15,545
	SE of Number		1				114	32			65	30						
	Proportion by Age Class		1.6%				46.4%	11.7%			29.6%	10.6%						
	SE of Proportion		0.0%				0.7%	0.2%			0.4%	0.2%						
	Sample Size		19				502	149			338	137						1,145
1982	Number by Age Class						1,613	805		12	52,124	2,665						57,219
	SE of Number						17	7		0	183	44						
	Proportion by Age Class						2.8%	1.4%		0.0%	91.1%	4.7%						
	SE of Proportion						0.0%	0.0%		0.0%	0.3%	0.1%						
	Sample Size						174	122		1	2,305	407						3,009
1983	Number by Age Class		14	8			1,375	495		12	5,501	2,843		182				10,429
	SE of Number		0	0			20	6		0	103	44		2				
	Proportion by Age Class		0.1%	0.1%			13.2%	4.7%		0.1%	52.7%	27.3%		1.7%				
	SE of Proportion		0.0%	0.0%			0.2%	0.1%		0.0%	1.0%	0.4%		0.0%				
	Sample Size		1	1			157	57		2	565	301		23				1,107
1984	Number by Age Class		9				966	551			10,436	4,144						16,106
	SE of Number		0				14	6			95	72						
	Proportion by Age Class		0.1%				6.0%	3.4%			64.8%	25.7%						
	SE of Proportion		0.0%				0.1%	0.0%			0.6%	0.4%						
	Sample Size		1				149	56			1,007	378						1,591
1985	Number by Age Class			15			76	43			8,935	2,997	13	74	70		23	12,245
	SE of Number			0			1	0			104	55	0	1	0		0	
	Proportion by Age Class			0.1%			0.6%	0.3%			73.0%	24.5%	0.1%	0.6%	0.6%		0.2%	
	SE of Proportion			0.0%			0.0%	0.0%			0.9%	0.4%	0.0%	0.0%	0.0%		0.0%	
	Sample Size			1			10	6			856	279	2	6	7		3	1,170

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Table 3. (page 2 of 4)

Return Year		Age Class 0.1	1.1	2.1	3.1	0.2	1.2	2.2	3.2	0.3	1.3	2.3	3.3	1.4	2.4	1.5	2.5	Total
1986	Number by Age Class		5			4	5,076	780			745	305		49		5		6,968
	SE of Number		0			0	20	11			4	3		0		0		
	Proportion by Age Class		0.1%			0.1%	72.8%	11.2%			10.7%	4.4%		0.7%		0.1%		
	SE of Proportion		0.0%			0.0%	0.3%	0.2%			0.1%	0.0%		0.0%		0.0%		
	Sample Size		1			1	1,389	191			195	77		13		1		1,868
1987	Number by Age Class		147	130			626	1,030	24		29,329	1,733	61	17				33,097
	SE of Number		1	1			2	6	0		221	27	0	0				
	Proportion by Age Class		0.4%	0.4%			1.9%	3.1%	0.1%		88.6%	5.2%	0.2%	0.1%				
	SE of Proportion		0.0%	0.0%			0.0%	0.0%	0.0%		0.7%	0.1%	0.0%	0.0%				
	Sample Size		9	18			66	132	4		3,374	278	6	1				3,888
1988	Number by Age Class		5	3			1,907	1,237			1,054	782	2	67				5,056
	SE of Number		0	0			13	9			6	4	0	0				
	Proportion by Age Class		0.1%	0.1%			37.7%	24.5%			20.8%	15.5%	0.0%	1.3%				
	SE of Proportion		0.0%	0.0%			0.3%	0.2%			0.1%	0.1%	0.0%	0.0%				
	Sample Size		3	2			1,076	727			624	499	1	46				2,978
1989	Number by Age Class		0	0			163	52	1		5,808	486	1		2			6,513
	SE of Number		0	0			1	1	0		32	7	0		0			
	Proportion by Age Class		0.0%	0.0%			2.5%	0.8%	0.0%		89.2%	7.5%	0.0%		0.0%			
	SE of Proportion		0.0%	0.0%			0.0%	0.0%	0.0%		0.5%	0.1%	0.0%		0.0%			
	Sample Size		0	0			116	24	1		1,489	184	1		1			1,816
1990	Number by Age Class		12	1			52	38			658	495	1	27				1,285
	SE of Number		0	0			0	0			5	9	0	0				
	Proportion by Age Class		0.9%	0.1%			4.1%	3.0%			51.2%	38.5%	0.1%	2.1%				
	SE of Proportion		0.0%	0.0%			0.0%	0.0%			0.4%	0.7%	0.0%	0.0%				
	Sample Size		8	1			39	29			537	294	1	24				933
1991	Number by Age Class		2	26	4		1,588	2,028	2		781	1,442			13			5,885
	SE of Number		0	0	0		7	20	0		2	8			0			
	Proportion by Age Class		0.0%	0.4%	0.1%		27.0%	34.5%	0.0%		13.3%	24.5%			0.2%			
	SE of Proportion		0.0%	0.0%	0.0%		0.1%	0.3%	0.0%		0.0%	0.1%			0.0%			
	Sample Size		2	11	1		1,274	1,103	1		629	998			8			4,027

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Return Year		Age Class 0.1	1.1	2.1	3.1	0.2	1.2	2.2	3.2	0.3	1.3	2.3	3.3	1.4	2.4	1.5	2.5	Total
1992	Number by Age Class		3	3			1,587	1,262	15		60,690	1,824		336	15			65,737
	SE of Number		0	0			22	31	0		589	34		2	0			
	Proportion by Age Class		0.0%	0.0%			2.4%	1.9%	0.0%		92.3%	2.8%		0.5%	0.0%			
	SE of Proportion		0.0%	0.0%			0.0%	0.0%	0.0%		0.9%	0.1%		0.0%	0.0%			
	Sample Size		1	1			63	105	1		914	135		2	2			1,224
1993	Number by Age Class			13			1,137	1,916	10		3,055	7,038	66	285	13			13,532
	SE of Number			0			25	39	0		50	135	1	5	0			
	Proportion by Age Class			0.1%			8.4%	14.2%	0.1%		22.6%	52.0%	0.5%	2.1%	0.1%			
	SE of Proportion			0.0%			0.2%	0.3%	0.0%		0.4%	1.0%	0.0%	0.0%	0.0%			
	Sample Size			2			62	163	1		279	564	2	31	1			1,105
1994	Number by Age Class		51	41			572	625	6		6,546	1,079		66	5	2		8,992
	SE of Number		0	0			5	7	0		106	11		0	0	0		
	Proportion by Age Class		0.6%	0.5%			6.4%	7.0%	0.1%		72.8%	12.0%		0.7%	0.1%	0.0%		
	SE of Proportion		0.0%	0.0%			0.1%	0.1%	0.0%		1.2%	0.1%		0.0%	0.0%	0.0%		
	Sample Size		12	13			148	91	2		966	243		18	2	1		1,496
1995	Number by Age Class			25			902	451			802	1,226		44	1			3,452
	SE of Number			0			14	6			13	24		0	0			
	Proportion by Age Class			0.7%			26.1%	13.1%			23.2%	35.5%		1.3%	0.0%			
	SE of Proportion			0.0%			0.4%	0.2%			0.4%	0.7%		0.0%	0.0%			
	Sample Size			16			299	133			263	408		13	1			1,133
1996	Number by Age Class		12				1,012	1,654	6		3,519	904			16			7,123
	SE of Number		0				30	79	0		93	24			1			
	Proportion by Age Class		0.2%				14.2%	23.2%	0.1%		49.4%	12.7%			0.2%			
	SE of Proportion		0.0%				0.4%	1.1%	0.0%		1.3%	0.3%			0.0%			
	Sample Size		2				97	76	1		287	70			1			534
1997	Number by Age Class		18				249	403			10,791	664	20	35				12,180
	SE of Number		0				5	4			121	20	0	0				
	Proportion by Age Class		0.1%				2.0%	3.3%			88.6%	5.5%	0.2%	0.3%				
	SE of Proportion		0.0%				0.0%	0.0%			1.0%	0.2%	0.0%	0.0%				
	Sample Size		1				13	22			580	37	1	2				656

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		Age Class																
Return Year		0.1	1.1	2.1	3.1	0.2	1.2	2.2	3.2	0.3	1.3	2.3	3.3	1.4	2.4	1.5	2.5	Total
1998	Number by Age Class		27	9		3	75	49			576	332		66				1,138
	SE of Number		4	1		0	4	2			26	21		4				
	Proportion by Age Class		2.4%	0.8%		0.3%	6.6%	4.3%			50.6%	29.2%		5.8%				
	SE of Proportion		0.3%	0.1%		0.0%	0.3%	0.2%			2.3%	1.9%		0.3%				
	Sample Size		2	3		1	9	7			81	32		5				140
1999	Number by Age Class			29			1,658	538			573	363		6	7			3,174
	SE of Number			1			35	11			13	7		0	0			
	Proportion by Age Class			0.9%			52.2%	17.0%			18.1%	11.4%		0.2%	0.2%			
	SE of Proportion			0.0%			1.1%	0.3%			0.4%	0.2%		0.0%	0.0%			
	Sample Size			4			245	77			81	53		1	1			462
2000	Number by Age Class		14		13		918	302			2,251	769	14					4,281
	SE of Number		0		0		21	5			52	22	0					
	Proportion by Age Class		0.3%		0.3%		21.4%	7.1%			52.6%	18.0%	0.3%					
	SE of Proportion		0.0%		0.0%		0.5%	0.1%			1.2%	0.5%	0.0%					
	Sample Size		1		1		94	33			257	70	1					457
2001	Number by Age Class	7	60			6	162	71			2,908	598		7	6			3,825
	SE of Number	0	1			0	13	1			43	9		0	0			
	Proportion by Age Class	0.2%	1.6%			0.2%	4.2%	1.9%			76.0%	15.6%		0.2%	0.2%			
	SE of Proportion	0.0%	0.0%			0.0%	0.3%	0.0%			1.1%	0.2%		0.0%	0.0%			
	Sample Size	1	9			1	25	14			591	120		1	1			763
2002	Number by Age Class		6	21			3,981	564			1,318	263		13				6,166
	SE of Number		0	1			58	11			21	6		0				
	Proportion by Age Class		0.1%	0.3%			64.6%	9.2%			21.4%	4.3%		0.2%				
	SE of Proportion		0.0%	0.0%			0.9%	0.2%			0.3%	0.1%		0.0%				
	Sample Size		1	3			582	77			197	36		2				898

In the infancy of the Alaska sockeye salmon culture program, in the late 1980s, ADF&G had a policy that only allowed for emergent fry releases (McDaniel et al. 1994). The thinking at the time was that the risk of the spread of the IHN virus outweighed any other benefits of salmon survivability by prolonged feeding in a controlled environment. From 1987 to 1989, warm winter temperatures caused early emergence of sockeye salmon in the hatchery used to incubate Hugh Smith sockeye salmon. It appears that emergent fry were stocked before the lake's plankton production was able to handle the dramatic increase in predators. This may have caused survivability and trophic structure problems in Hugh Smith Lake as it did in Virginia Lake in 1989 (Zadina and Haddix 1993) but the extent is not known. This unfed fry stocking program was modified after 1989 but continued off and on again until 1996, and reached its peak with over 1.4 million fry released into Hugh Smith Lake in 1990. Available data indicates that post release mortality of stocked unfed fry was very high and that few of these fish survived to the smolt stage. In 1988, the sockeye salmon culture policy was modified to allow for short-term rearing of fry when emergence timing was too early. Since there were no detected pathological problems associated with this change, the policy was modified further in 1990 to allow for advanced hatchery rearing to pre-smolt size.

SSRAA evolved the program in the last 4 years into a pen-reared pre-smolt production program. SSRAA released about 202,000 pre-smolts in 1999, about 380,000 pre-smolts in 2000, about 445,000 pre-smolts in 2001, and about 468,000 pre-smolts in 2002. All of these pre-smolt releases occurred in late July each year. Since the advent of the pre-smolt program, all hatchery propagated sockeye were thermal otolith marked each year for identification. These marks were used to evaluate their contribution to the total smolt population and results indicate the program has been successful with thousands of hatchery origin smolt emigrating from the lake (Table 4).

Table 4. Minimum estimated numbers of hatchery-propagated sockeye salmon smolt emigrating from Hugh Smith Lake, by year of smolting. The estimates are based on the classification of the sampled smolts into hatchery or natural categories based on an analysis of otolith patterns. The 1999 hatchery smolt were age-2.0 fish that remained in the lake from stocking in 1997. The 2000 otolith samples were lost in transit. For each smolt year, the number of hatchery smolt is a minimum estimate because not all smolt were enumerated at the weir. Most hatchery smolt were age 1.0.

Smolt Year	Number of Smolt Sampled	Proportion of Sampled Smolt With Otolith Bands	Number of Smolt Counted at Weir Site	Minimum Number of Hatchery Origin Smolt Produced
1998	417	47%	64,667	30,257
1999	455	4%	42,397	1,611
2000			71,849	
2001	475	71%	189,323	134,975
2002	453	55%	296,203	163,752

PRODUCTION OF SMOLT

A smolt fence has been used since 1981 to sample and count sockeye salmon smolt emigrating from Hugh Smith Lake. The smolt weir is located above the lake outlet in an area having little to no current. The smolt weir consists of 6.1 m long panels that are covered with 0.6 cm mesh plastic netting (vexar). The panels are 1.2 to 2.4 m deep. Panel depths closely match the bottom contour at the lake outlet; however, gaps between the bottom of the smolt weir and the outlet bottom are blocked with a 0.6 cm mesh hardware cloth. The areas between both ends of the smolt weir and the shore are blocked using plastic netting attached to iron pipes driven into the lake bottom. A funnel shaped opening, measuring 1.7 x 0.7 m at the mouth and a 6 x 6 cm at the end and leading to a 1 x 1 x 1.2 m holding box, is located between 2 of the weir panels.

Counts of sockeye salmon smolts through the weir since 1981 have averaged 130 thousand smolt over the 22-year period, ranging from 14.9 thousand smolt counted in 1992 to 427 thousand smolt counted in 1989 (Table 5). These data represent a rough index of total smolt production, not a complete estimate of smolt production. This is because some sockeye salmon smolt emigrate from the lake before the smolt weir is operational and some emigrate after the weir is dismantled. Further, the dates of weir operation have changed over the time series. None-the-less, the large variation in smolt counts (Figure 5) from year to year likely reflect real variation in total sockeye salmon smolt production from Hugh Smith Lake. Notable in this data series is an extended period of low smolt counts beginning in the early 1990s and lasting through 2000. Smolt counts have been substantially higher in 2001 and 2002.

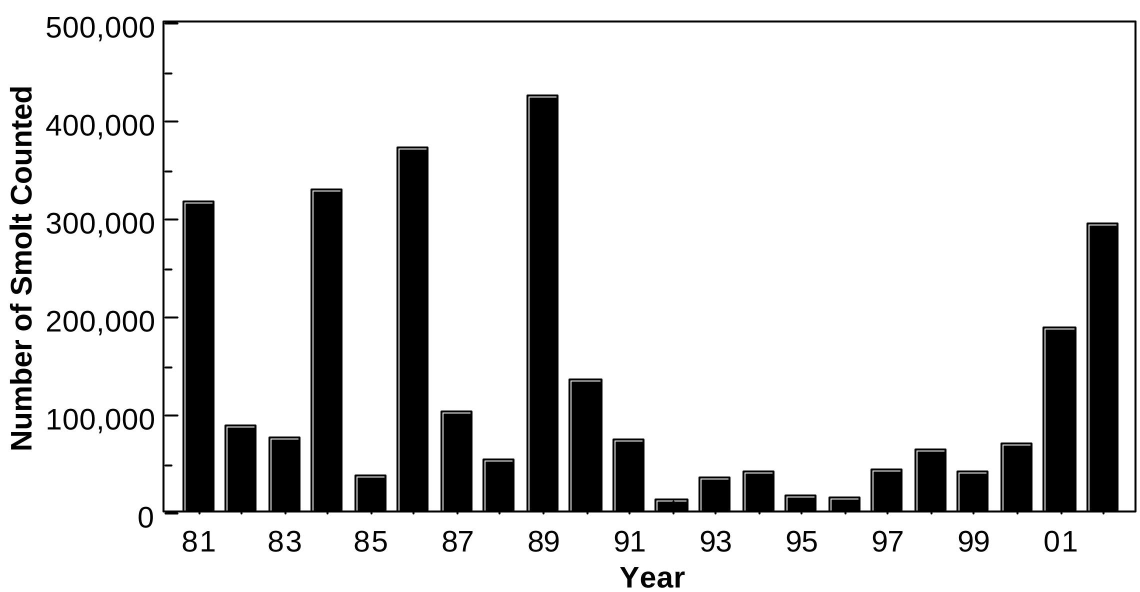

Figure 5. Number of sockeye salmon smolt counted at the Hugh Smith Lake smolt weir, 1981–2002.

Table 5. Number of sockeye salmon smolts enumerated at the Hugh Smith Lake smolt weir and the number of smolt that were coded wire tagged.

Smolt Year	Smolt Weir Count	Number of Sockeye Smolts Coded Wire Tagged
1981	318,857	28,376
1982	90,325	30,000
1983	77,096	17,032
1984	330,442	0
1985	39,692	0
1986	373,450	32,577
1987	104,776	33,032
1988	54,421	39,434
1989	427,366	0
1990	137,092	0
1991	74,655	60,888
1992	14,912	14,146
1993	35,737	34,504
1994	43,056	35,687
1995	19,212	17,503
1996	16,355	13,480
1997	44,257	0
1998	64,667	0
1999	42,397	0
2000	71,849	0
2001	189,323	0
2002	296,203	0

Several hundred smolt were sampled at the Hugh Smith smolt weir each year. On average, a little over 60% of the emigrating smolt were age 1, about 35% were age 2, and a few percent were age 3 (Table 6). On a brood-year basis, the age-1 smolt composed a slightly higher average of about 66% and age-2 smolt average 33%. Mean length of age-1 smolt has averaged about 75 mm, while age-2 and age-3 smolt have averaged about 90 mm and 112 mm, respectively.

The Hugh Smith Lake smolt weir was used to capture emigrating sockeye salmon smolts for coded wire tagging from 1980 to 1983, 1986 to 1988, and 1991 to 1996. Peltz and Haddix (1989) described methods used to capture and tag fish at the lake from 1980 to 1983, and methods used in subsequent years were generally similar. Sockeye salmon smolts were anesthetized in MS-222, adipose fins were removed with scissors, and the fish were tagged with a full-length coded wire tag as described by Koerner (1977). The anesthetic was changed to clove oil during the latter years. Prior to 1986, smolts were released immediately back into the outlet of the lake after tagging. In 1982 and 1983, a sub-sample of the tagged fish were checked for tag retention prior to release. Starting in 1986, tagged sockeye salmon smolts were held in pens in quiet water for 24 hours to recover from the effects of the anesthetic, after which a sub-sample of 100 smolts was checked for tag retention. The fraction of smolts that retained tags was multiplied by the total number that were tagged to determine the daily number of valid tags released. Tagged smolts were released in the dark of evening.

Over the 12 years that coded-wire-tagging took place at Hugh Smith Lake, an average of 29,720 sockeye salmon smolt were coded wire tagged. Numbers of sockeye salmon smolt coded-wire-tagged in these 12 years ranged from 13,480 smolt in 1996 to 60,888 smolt in 1991 (Table 5; Appendix A). In addition, smolt sampling with fyke traps was conducted at Hugh Smith Lake in 1980 and this effort resulted in 4,048 smolt being coded wire-tagged-that year.

Recovery of coded wire tagged fish (including Hugh Smith Lake sockeye salmon) was conducted annually in nearly all commercial marine fisheries in Southeast Alaska by the ADF&G Commercial Fisheries Division Port Sampling Program (briefly described by Oliver 1990 and Clark and Bernard 1987). The heads of all fish missing adipose fins were sent to the ADF&G Coded Wire Tag Laboratory for tag removal and decoding. Commercial fisheries tag recovery data were stratified by fishing district, gear, and statistical week. Only recovered tags from discrete strata were used for evaluation; i.e., tags recovered from "select" samples, or from mixed-gear or mixed-district landings, were excluded from the analysis. Alaska harvests (assumed known without error) and sample data were obtained from the ADF&G Coded Wire Tag and Otolith Processing Laboratory internet web site on January 12, 2003. Coded wire tag sampling of Canadian fishery harvests did not take place.

Table 6. Hugh Smith Lake sockeye salmon smolt average size by age, 1980–2001. Percentages are weighted by weekly smolt counts.

Year	Age 1 Mean Length	Age 1 Mean Weight	Age 1 Percent of Total	Age 2 Mean Length	Age 2 Mean Weight	Age 2 Percent of Total	Age 3 Mean Length	Age 3 Mean Weight	Age 3 Percent of Total	Overall Mean Length	Overall Mean Weight
1980	66.4	2.73	77.5%	77.1	4.06	22.5%	NA	NA	0.0%	70.8	3.31
1981	69.0	2.88	67.5%	80.7	4.53	32.5%	92.0	6.60	0.0%	73.3	3.55
1982	67.3	2.68	61.0%	75.4	3.67	39.0%	NA	NA	0.0%	70.2	3.07
1983	70.5	3.19	58.8%	79.6	4.69	41.2%	105.0	8.90	0.0%	74.7	3.89
1984	76.7	3.57	90.4%	85.0	4.68	9.6%	99.0	7.10	0.0%	77.8	3.74
1985	70.8	3.09	52.9%	85.6	5.05	46.7%	105.4	10.40	0.4%	76.7	3.88
1986	71.0	2.86	72.4%	87.3	5.08	24.8%	100.1	7.58	2.8%	76.0	3.57
1987	70.7	2.92	50.0%	84.1	4.69	49.5%	100.5	7.73	0.5%	77.4	3.81
1988	73.6	3.07	72.6%	82.9	4.31	27.4%	NA	NA	0.0%	76.6	3.48
1989	69.5	2.67	76.7%	88.4	5.62	23.3%	NA	NA	0.0%	74.9	3.52
1990	78.1	4.08	30.9%	88.4	5.85	67.6%	122.1	17.00	1.5%	85.0	5.36
1991	72.7	3.22	63.5%	90.9	6.14	36.1%	124.6	17.58	0.4%	81.2	4.64
1992	82.9	5.03	41.8%	102.3	9.25	57.2%	120.6	15.24	1.0%	94.5	7.59
1993	79.4	4.46	62.8%	95.4	7.62	35.7%	121.3	15.03	1.5%	86.1	5.84
1994	71.6	3.08	74.2%	99.3	8.35	21.6%	128.3	18.14	4.2%	82.2	5.35
1995	75.5	3.76	38.7%	91.9	6.67	61.3%				84.4	5.35
1996	76.0	3.99	40.1%	97.0	8.12	42.5%	112.8	12.58	17.4%	92.8	7.55
1997	75.8	3.73	11.7%	102.2	9.17	39.5%	123.7	16.09	8.3%	98.2	8.56
1998	74.5	3.67	80.7%	103.2	9.44	18.2%	125.0	18.55	1.1%	80.9	5.01
1999	66.6	2.50	68.7%	90.5	6.11	31.3%				75.5	3.85
2000	84.2	5.19	77.6%	84.7	5.42	21.9%	101.2	8.76	0.4%	84.4	5.27
2001	89.0	5.97	90.6%	104.4	9.71	8.3%	108.4	10.59	1.0%	90.2	6.26
80-01 Means	74.5	3.60	61.1%	90.4	6.39	35.0%	111.9	12.37	2.5%	81.6	4.91

Sampling to ascertain the proportion of the annual sockeye salmon escapement that had coded wire tags was implemented at Hugh Smith Lake. All sockeye salmon were checked for missing adipose fins at the adult weir. Prior to 1994, any fish missing an adipose fin was killed, and the head was sent to the ADF&G coded wire tag lab where the coded wire tag was removed and decoded. Beginning in 1994, however, all adipose-clipped sockeye salmon observed at the weir were checked for tags using a metal detector. In general, fish that registered a tag were released, and only a sub-sample of coded wire tagged fish were killed at the weir (2 per week). All fish that did not register a tag were killed and the head was sent to the tag lab for analysis (between 4 and 19 fish per year). The heads of spawned-out, adipose-clipped fish were recovered from the escapement to supplement the fish taken at the weir. This method provided the total number of adipose-clipped fish in the escapement, the total number that retained coded wire tags, the total number that did not retain coded wire tags, and a sub-sample of the tags by tag code. Escapement coded wire tag recovery data were obtained from the ADF&G coded wire tag and otolith processing laboratory internet web site on January 12, 2003.

Analysis of the recovery of sockeye salmon with coded wire tags from the tagging efforts of 1980–1996 cannot be used to develop total harvest estimates for the stock nor to estimate total smolt survivals. This is due to the fact that any harvests in Canadian fisheries would not be included in such estimates. However, these data can be used to estimate harvest rate in the Southeast Alaskan fisheries and to estimate survival rate of coded wire tagged fish as measured through recovery in the combined Alaskan fishery and escapement (Tables 7 and 8).

The estimated "Alaskan survival" rate for the various annual smolt out-migrations was very low prior to the 1991 tagging. Further, the first 7 annual survival estimates show much variability. We think a substantial portion of the low and variable survival rate estimates associated with these early years is at least partially attributable to the capture, handling, and tagging process itself. These low and variable survival rate estimates likely represent the effect of project maturity, rather than some large underlying change in marine conditions or marine habitat. That is, sockeye salmon smolts are very fragile, and the project crew gained experience in anesthetizing, handling, and tagging the fish. As the project matured the sampling crew learned to inflict increasingly less stress and damage on the smolts. Further, during the early years of the coded wire tagging effort, MS 222 was used as an anesthetic. This compound has been shown to interfere with the osmo-regulatory function of fish. Once released these fish have only to swim a short distance to the ocean and then need to change their osmo-regulatory system to reside in saltwater rather than freshwater. The use of MS 222 may have caused substantial added stress once these fish moved to saltwater and may have greatly increased post release mortality of coded wire tagged smolt. The survival rates of coded wire tagged smolt prior to 1991 are not considered representative of the survival rate of untagged fish from those same smolt years.

The estimated "Alaskan survival" for the smolt coded wire tagged from 1991 to 1996 increased dramatically over the earlier years, averaging about 8% with but little variability (Table 7). These survival rates seem reasonable to us, given that they still represent minimum values due to the fact that any coded wire tagged sockeye salmon that survived to adulthood and were caught in Canadian fisheries are not included. The smolt survival values associated with the 1991–1996 coded wire tagging provide a useful metric for further analysis presented later in this report.

Table 7. Estimated survival of sockeye salmon smolt from Hugh Smith Lake that were coded wire tagged, 1980–1996. The column labeled “Number Recovered in Escapement” represents the estimated number of coded-wire-tagged fish in the escapement, including age 1-ocean fish. The column labeled “Estimated Number of Tags in Alaskan Fisheries” represents the sum of the estimated harvest of coded-wire-tagged fish in all Alaskan fisheries, including age 1-ocean fish. Each tag recovery was expanded, by dividing by the fishery-sampling rate (obtained from the ADF&G coded wire tag database, summing the “fishery expansion factor”). The column labeled “Estimated Harvest Rate” represents our estimate of the Alaskan harvest rate on Hugh Smith sockeye salmon. The “Estimated Alaskan Survival” represents the survival rate of the coded-wire-tagged fish to Alaskan fisheries and the escapement. The inverse, natural mortality, in this case will include any mortality induced through handling stress and tagging, the effects of a variable marine environment, and an unknown level of fishing mortality in Canada.

Smolt Year	Life Stage When Tagged	Number Tagged (A)	Number Recovered in Escapement (B)	Estimated Number of Tags in Alaskan Fisheries (C)	Estimated Adult Tagged Fish in Return (B+C)	Estimated Harvest Rate (C/(B+C))	Estimated Alaskan Survival ((B+C)/A)
1980	smolt	4,048	24	32	56	57%	1.4%
1981	smolt	28,376	181	328	509	64%	1.8%
1982	smolt	30,000	487	535	1,022	52%	3.4%
1983	smolt	17,035	28	50	78	64%	0.5%
1986	smolt	32,577	183	712	895	80%	2.7%
1987	smolt	33,032	26	515	541	95%	1.6%
1988	smolt	39,434	103	183	286	64%	0.7%
1991	smolt	60,888	1,869	2,959	4,828	61%	7.9%
1992	smolt	14,146	778	572	1,350	42%	9.5%
1993	smolt	34,504	1,174	1,534	2,708	57%	7.8%
1994	smolt	35,687	1,111	1,719	2,830	61%	7.9%
1995	smolt	17,503	379	975	1,354	72%	7.7%
1996	smolt	13,480	565	372	937	40%	7.0%

PRODUCTION OF FRY

Estimates of the number of sockeye salmon fry residing in Hugh Smith Lake have been calculated with the aid of hydro-acoustic surveys and companion trawl surveys. The hydro-acoustic surveys provide estimates of the number of fish residing in the limnetic waters of the lake (number of targets) and the trawl surveys provide a measure of the species/age composition of these targets. A total of 28 separate hydro-acoustic surveys were conducted between 1982 and 2001, however, in some cases, companion trawl surveys were not conducted.

Table 8. Sampling statistics for adult coded wire tagged sockeye salmon returning to the Hugh Smith weir. All coded wire tagged sockeye salmon at Hugh Smith were externally marked by removing the adipose fin. A sample of returning adults were examined for missing adipose fins, and a sample of these marked fish were further examined for coded wire tags. As not all Hugh Smith sockeye salmon were tagged, in principle, each tag recovery in the commercial fishery represented anywhere from about 3.5 to over 600 untagged Hugh Smith sockeye that were not identifiable, depending on the particular release cohort.

Year	Number of Fish Examined for Missing Adipose Fin	Number of Fish Detected with Missing Adipose Fin	Number of Marked Fish Examined for Coded Wire Tags	Number of Coded Wire Tags Recovered	Average Expansion Factor for Samples
1983	9,963	82	82	42	237.2
1984	16,106	221	134	124	78.8
1985	12,245	517	203	180	26.7
1986	2,312	14	13	9	238.5
1987	Unknown	9	9	6	Unknown
1988	4,570	122	32	28	42.8
1989	6,513	166	80	70	44.8
1990	1,285	42	28	20	42.8
1991	5,885	147	31	25	49.6
1992	23,941	12	10	0	n.a. -
1993	13,530	266	239	220	55.3
1994	8,379	1,959	198	188	4.5
1995	3,413	874	97	90	4.2
1996	7,123	1,400	130	109	6.1
1997	12,182	1,242	1,242	1,231	9.9
1998	1,138	330	330	324	3.5
1999	3,174	218	218	214	14.8
2000	3,495	13	13	12	291.3
2001	3,665	6	6	6	610.8

We reviewed available hydro-acoustic surveys and selected those surveys that took place between early August and late April that had companion trawl surveys. This effort provided a set of 17 surveys, 7 of which took place in the spring (March or April) and 10 of which took place in the fall (August–November). In all but one case, the hydro-acoustic survey was repeated twice the same night and hence we were able to estimate the average number of targets for these surveys and variances of those averages. The trawl surveys were evaluated as to the number of age-0 sockeye salmon caught out of the total catch for each of the fall surveys and the number of age-1 sockeye salmon caught out of the total catch for each of the spring surveys. Variances for these estimates of the age-0 and age-1 sockeye salmon proportions were calculated using standard normal procedures. Estimates of the number of targets were multiplied by the proportional estimates to derive estimates of the total number of age-0 sockeye salmon in fall surveys and age-1 sockeye salmon in spring surveys. Age-0 juvenile sockeye salmon abundance estimates derived from the 9 fall surveys ranged from 112,979 fish in 1984, brood year 1983, to 773,197 fish (the average value) in 1983, brood year 1982 (Table 9). Age-1 juvenile sockeye salmon abundance estimates derived from the 7 spring surveys ranged from 20,778 fish in 1992, brood year 1990, to 604,985 fish in 1984, brood year 1982 (Table 9).

Table 9. Juvenile sockeye salmon abundance estimates from fall surveys (age 0) and spring surveys (age 1), Hugh Smith Lake, 1983–1998. Estimates in bold were used for the combined analysis.

Sample Year	Sample Date	Survey Type	Fall Juvenile Age 0 Estimate	Age 0 S. E.	Spring Juvenile Age 1 Estimate	Age 1 S. E.
1983	22-Mar	Spring	-	-	**43,103**	10,176
1983	21-Sep	Fall	775,082	47,796	-	-
1983	14-Nov	Fall	771,312	88,346	-	-
1983	*fall avg.*	*Fall*	*773,197*	-	-	-
1984	02-Apr	Spring	-	-	**604,985**	85,575
1984	20-Sep	Fall	112,979	21,792	-	-
1985	24-Apr	Spring	-	-	**165,660**	16,117
1985	20-Sep	Fall	822,261	45,907	-	-
1986	08-Apr	Spring	-	-	**504,978**	32,655
1986	17-Sep	Fall	444,923	64,344	-	-
1987	20-Mar	Spring	-	-	**373,419**	59,459
1987	23-Sep	Fall	**260,986**	32,002	-	-
1991	25-Apr	Spring	-	-	**149,786**	18,258
1992	23-Apr	Spring	-	-	**20,778**	9,684
1992	18-Aug	Fall	**455,743**	29,261	-	-
1993	03-Aug	Fall	**762,000**	94,748	-	-
1995	09-Aug	Fall	**334,658**	17,739	-	-
1998	03-Sep	Fall	**264,000**	46,666	-	-

Plots of the fall and spring survey estimates of juvenile sockeye salmon abundance versus spawning escapements reveals important features concerning the biology of the stock (Figure 6). Production of juveniles from spawning escapements in the range of 6,000 to 15,000 spawners was quite variable. For instance, production of age-1 juveniles for escapements that ranged from about 10,000 to 16,000 spawners resulted in age-1 juvenile production estimates that ranged from about 40,000 to about 500,000, or about 10-fold variation. Several of the age-1 juvenile estimates in this range of spawners were statistically different, so the observed variation is not due to sampling, instead it demonstrates considerable density independent mortality within Hugh Smith Lake. The same observation can be made for spawning escapements that range from about 6,000 to 15,000 relative to production of age-0 juveniles (Figure 6).

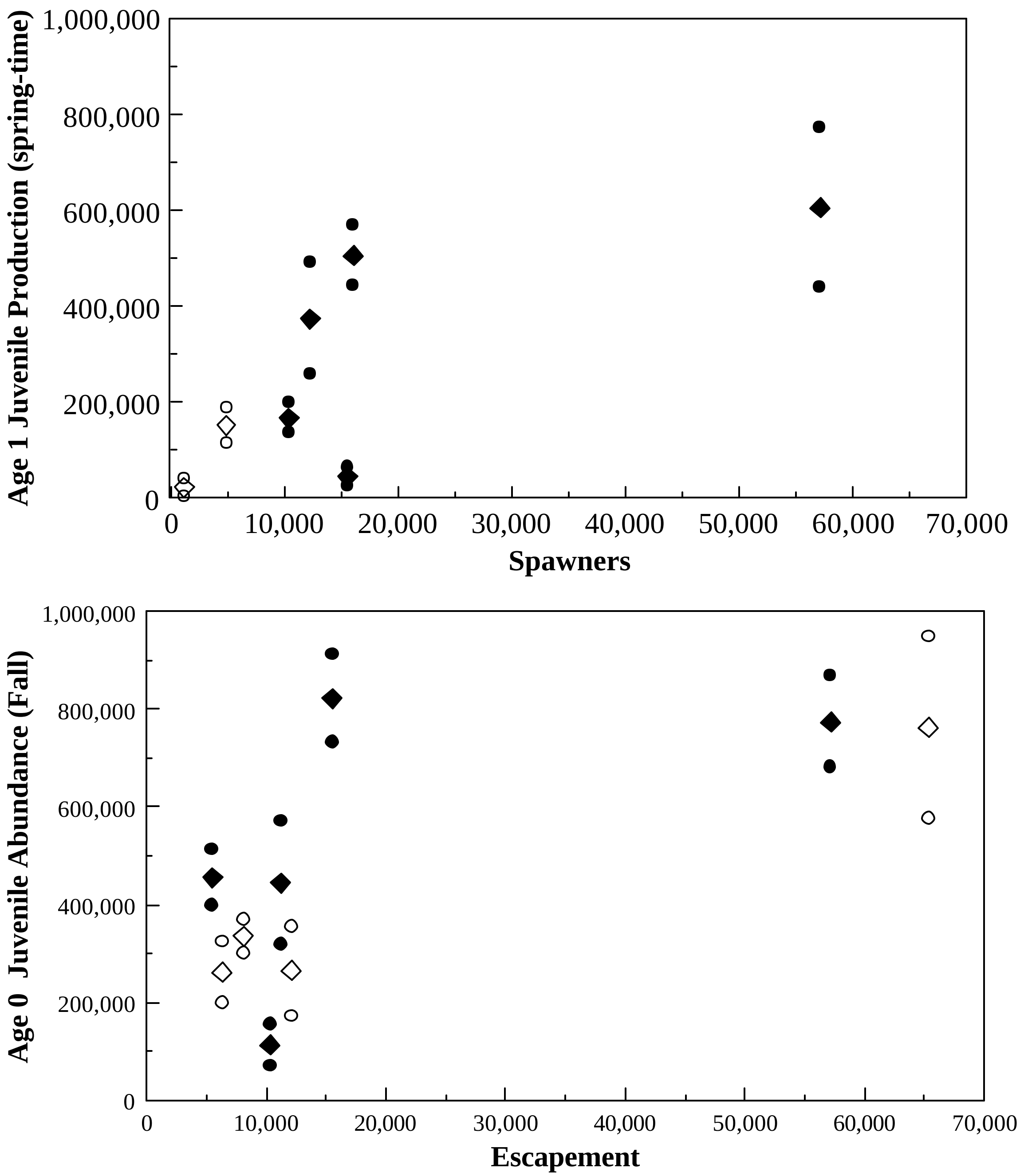

Figure 6. Plots of spawning escapement versus resultant estimated abundance of age-1 juvenile sockeye salmon in the spring (upper panel) and age-0 juvenile sockeye salmon in the fall (lower panel). Diamonds represent point estimates and the circles above and below each diamond represent 95% confidence intervals for these estimates. Solid diamonds (and circles) are for brood years without supplemental stocking; open diamonds (and circles) are for brood years when supplemental stocking took place.

A second important observation is that juvenile production estimates for brood years with and without supplemental stocking are not much different. This stocking of fry appears to have failed to increase in juvenile abundance. However, because these hatchery fish were not differentially marked we have no way to substantiate this hypothesis, just as we have no way to substantiate the hypothesis that the hatchery fish replaced the wild fish. On balance, it appears, that the hatchery-produced sockeye salmon fry released into Hugh Smith Lake probably suffered substantial mortality by the time the fall and spring hydro-acoustic estimates were conducted. If so, these annual data can be treated the same and the fact that supplemental stocking occurred in these years can be largely ignored in subsequent analysis. A third important observation is that the pattern and magnitude of the relationship between spawning escapement and juvenile production appears similar whether using the fall age-0 production data set or the spring age-1 production data set.

A fourth important observation is that whether one is looking at the fall data set or at the spring data set, production of juveniles does not appear to materially increase with very large spawning escapements. This provides evidence of density dependent mortality within Hugh Smith Lake. These data appear to follow the pattern predicted with a Beverton-Holt spawner-recruit relationship. As a result, brood year escapements and juvenile abundance estimates were used with a Beverton Holt model to evaluate carrying capacity of Hugh Smith Lake. Three data sets were used: (1) the fall surveys, (2) the spring surveys, and (3) a combined fall-spring data set as identified in bold face in Table 9 above. The combined data set was developed in an attempt to increase brood years of data and, in this case, all spring surveys were included as well as those fall surveys for brood years without a spring survey. The spring data set was fit using non-linear regression and the statistical software package SYSTAT© to the following model:

$$R(\text{age}\,1) = \frac{aS}{1+bS} + e, \qquad (5)$$

such that S = estimated spawning escapement,

R = estimated age 1 juvenile abundance,

a = intrinsic rate of population increase in the absence of density-dependent limitations;

ß= density-dependent parameter; and

e = process error with mean 0 and variance s_e^2.

The fall data set was similarly fit except that R(age 1) was R(age 0) and the combined data set was fit using R(age 1 or age 0). Estimated a, ß, and carrying capacity values are provided in Table 10 and a plot of the 3 relationships is provided in Figure 7.

Table 10. Estimates of the carrying capacity of Hugh Smith Lake based upon Beverton-Holt stock-recruit functions using 3 alternate data sets.

Data Set	Sample Size	Corrected R^2 Statistic	Estimated a	Estimated ß	Estimated Carrying Capacity
Spring Surveys	7	0.85	27.77	0.000028	991,000
Fall Surveys	9		66.01	0.000068	966,000
Combined Surveys	12	0.56	39.40	0.000043	915,000

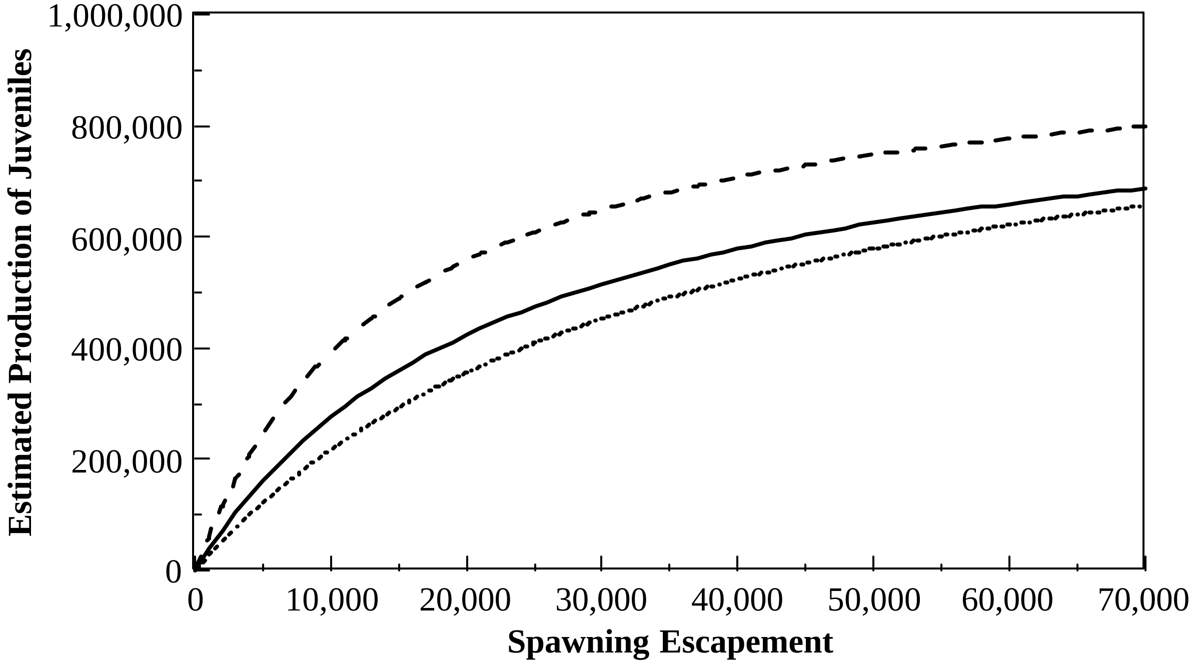

Figure 7. Estimated relationship between spawning escapement and production of juvenile sockeye salmon in Hugh Smith Lake using the Beverton-Holt model. The closely spaced dotted line is the relationship based upon just the spring surveys of age 1 juveniles and the wider spaced dashed line is the relationship based upon just the fall surveys of age 0 juveniles. The solid line is the relationship based on the combined data and is considered the best estimate of the relationship between spawning abundance and production of juveniles in Hugh Smith Lake.

In all 3 cases, carrying capacity of Hugh Smith Lake was estimated to be between 900,000 and 1,000,000 juvenile sockeye salmon. The Beverton-Holt based spawner-recruit relationship developed with the full or combined juvenile production data set is used later in this paper as one of several means to develop a biological escapement goal for the Hugh Smith Lake stock of sockeye salmon. Food availability for juveniles rearing in Hugh Smith Lake can be ascertained from plankton sampling information as summarized in Appendix C, D, and E.

HARVEST ESTIMATES

The Hugh Smith Lake stock of sockeye salmon is harvested in a number of fisheries, both in Alaska and in Canada. As described above, ADF&G began experimenting with coded wire tagging of Hugh Smith Lake sockeye salmon smolt in 1980 (Peltz and Haddix 1989). We developed estimates of the Alaskan harvest rates on these coded wire tagged fish based on the recovery of tags in the escapement and recovery of tags in samples from Alaskan commercial fisheries and these rates ranged from 40 to 95% (Table 7). The harvest rates provided in Table 7 are germane to the smolt that were coded wire tagged and hence are not age or year specific. These estimates understate the actual total harvest rates, as an unknown number of these fish are harvested in Canada. However, this data set is useful for assessing the Alaskan harvest rate on smolts surviving handling and application of coded wire tags, and assessing spatial and temporal distribution of Hugh Smith Lake sockeye salmon in the commercial harvest (Appendix B). Hugh Smith coded wire tags have been recovered in Alaskan Districts 101–104, 106, 108, 109, 113, 154, and a very few (3 total tag recoveries) in Prince William Sound fisheries. However, when summed over all years, 76% of the expanded tag recoveries have been in District 101, 17% of the expanded coded wire tag recoveries were recovered in District 104, and 4% in District 106. All other districts had less than 2% of the total expanded tag recoveries in the database (unpublished data, Alaska Department of Fish and Game, coded wire tag laboratory). Although there is quite a bit of variation from year to year, for almost all years with Alaskan tag recoveries, District 101 has the largest proportion of the tagged recoveries, followed by District 104.

The Alaska commercial harvests of the Hugh Smith Lake sockeye salmon stock were further evaluated through various expansion methods to obtain year-specific and age-specific estimates. For some years, only 1 or 2 ocean age classes of adult sockeye salmon were represented by coded wire tagged fish. We calculated the harvest rate, fishery contribution, survival rate, and their standard errors (using formulae developed by James Blick, formerly a biometrician with ADF&G, Commercial Fisheries Division, Douglas) based on standard sampling theory (Cochran 1977). These methods are outlined in detail in Appendix 2 of Heinl et al. (2000, p.41–50). Again, the Canadian fisheries were not sampled for coded wire tagged sockeye salmon. All estimates of harvest rates, fishery contributions, and survival rates are biased low to an unknown degree, and harvest rates and fishery contributions are for Southeast Alaskan commercial fisheries only. We assumed that catches and total escapements are known without error; however, this is not completely true.

Recoveries of 1-ocean sockeye salmon, or jacks, were not included in this analysis, although there were small numbers recovered at the weir in 1987 (5), 1989 (1), 1993 (6), and 1997 (5), and even fewer recovered in the commercial fisheries in 1989 (1), 1992 (1), 1994 (1), 1995 (1), and 1997 (1). The majority of the 1-ocean fish are small males and they are probably not harvested in the commercial fisheries and not sampled from catches. An unknown number enter the lake uncounted, as they are small enough to swim between the weir pickets. For example, in 2002, all 1-ocean fish that were trapped at the weir were marked with a fin clip, 167 in all; 69 were examined for marks on the spawning grounds, of which only 4 were marked. The result is a Petersen estimate of 2,351 1-ocean fish (SE of 890). Also, we did not include 3 1994 tag recoveries in Districts 212 and 223 of Prince William Sound in this analysis.

Harvest rates of the 2-ocean and 3-ocean age classes were compared by computing the mean difference for all years with returning coded wire tagged fish of both age classes (1983–1985, 1989–1990, and 1994–1998). An approximate 95% confidence interval was computed assuming that all harvest rate estimates are independent and that the mean difference is normally distributed. Although harvest rate estimates are independent across years, they are dependent within years. However, Kish (1965, p. 135, 138) points out that the covariance term for the means (or proportions) of subpopulations is negligible. We generated an approximate 95% confidence interval by taking the mean difference +/- 1.96-times the standard error of the mean difference, where the standard error of the mean difference is the mean (across years) of the square root of the sum of the individual age-class standard errors. The estimated commercial harvest of Hugh Smith sockeye salmon ranged from 2,976 fish in 1995 to 42,510 fish in 1989 (Table 11). The harvest rate over all age classes combined averaged 60.2%, and ranged from 27.6% in 1983 to 94.3% in 1990. Age 3-ocean fish experienced an 18% (SE = 7.2%; 95% CI ± 14.0%) higher harvest rate than age 2-ocean fish.

Table 11. Estimated commercial harvest, total adult run, number of expanded coded wire tags, and harvest rate of coded wire-tagged Hugh Smith Lake sockeye salmon, by returning coded wire tagged age class, and all age classes combined, 1983–1999.

	1983	1984	1985	1986	1988	1989	1990	1991	1993	1994	1995	1996	1997	1998	1999
Harvest Age 2-Ocean	84	1,106	23		777	3,899	2,054		8,572	297	1,113	2,844	520	206	
SE	4	275	21		254	2,355	1,815		723	94	238	673	375	84	
Expanded Tags	1	40	4		29	112	40		683	63	238	340	115	89	
Total Run Age 2-Ocean	1,948	2,622	142		3,921	4,115	2,145		11,635	1,500	2,466	5,516	1,172	4,561	
SE	26	276	21		255	2,355	1,815		742	95	241	692	376	488	
Expanded Tags	23	94	27		119	1,046	42		927	319	526	660	260	144	
Harvest Rate Age 2-Ocean	4.3%	42.2%	16.3%		19.8%	94.8%	95.8%		73.7%	19.8%	45.1%	51.6%	44.4%	61.9%	
SE	0.2%	6.1%	12.5%		5.2%	3.0%	3.6%		1.6%	5.0%	5.3%	5.8%	17.8%	9.6%	
Harvest Age 3-Ocean	6,127	29,260	13,546	1,774		37,686	19,209	2,812		9,561	1,735	5,379	14,309	2,927	1,195
SE	3,046	3,099	1,399	799		5,183	3,906	723		754	237	614	3,592	478	211
Expanded Tags	16	301	485	33		794	505	120		2,298	494	1,290	1,354	858	273
Total Run Age 3-Ocean	14,486	43,830	25,506	2,829		43,981	20,363	5,034		17,186	3,764	9,802	25,784	3,836	2,131
SE	3,049	3,106	1,402	800		5,183	3,907	723		776	243	645	3,597	486	215
Expanded Tags	37	451	912	52		927	535	216		4,131	1,071	2,352	2,441	1,124	487
Harvest Rate Age 3-Ocean	42.3%	66.8%	53.1%	62.7%		85.7%	94.3%	55.9%		55.6%	46.1%	54.9%	55.5%	76.3%	56.1%
SE	12.1%	2.3%	2.6%	10.5%		1.7%	1.1%	6.3%		1.9%	3.4%	2.8%	6.2%	2.9%	4.3%
Harvest Age 4-Ocean			471	32			219	NA[a]			NA	NA	NA	NA	NA
SE			262	28			176								
Expanded Tags			24	6			14								
Total Run Age 4-Ocean			622	81			246	NA			NA	NA	NA	NA	NA
SE			262	28			176								
Expanded Tags			31	16			16								
Harvest Rate Age 4-Ocean			75.7%	39.2%			89.0%	NA			NA	NA	NA	NA	NA
SE			10.2%	21.3%			7.9%								
Harvest All Ages Combined	3,969	27,250	13,628	9,311		42,510	21,213	7,910		10,168	2,976	8,536	14,569	3,423	
SE	1,849	2,600	1,362	3,645		5,850	4,108	2,003		743	326	834	3,415	488	
Expanded Tags	17	346	510	39		907	559	128		2,361	746	1,655	1,472	966	
Total Run All Ages Combined	14,398	43,356	25,873	16,279		49,023	22,498	13,795		19,160	6,428	15,659	26,751	4,561	
SE	1,849	2,600	1,362	3,645		5,850	4,108	2,003		743	326	834	3,415	488	
Expanded Tags	47	551	969	68		1,046	593	223		4,449	1,612	3,035	2,703	1,287	
Harvest Rate All Ages Comb.	27.6%	62.9%	52.7%	57.2%		86.7%	94.3%	57.3%		53.1%	46.3%	54.5%	54.5%	75.0%	
SE	9.3%	2.2%	2.5%	9.6%		1.6%	1.0%	6.2%		1.8%	2.7%	2.4%	5.8%	2.7%	

[a] Very few recoveries (2–6 tags) of coded-wire-tagged 4-ocean fish were made in the harvests in 1991, 1995, 1996, 1997, 1998, and 1999; however, no coded-wire-tagged 4-ocean fish were recovered in the escapement in those years, and no estimates are available for 4-ocean fish.

The marine survival rates of coded wire tagged Hugh Smith Lake sockeye salmon ranged from 0.5% (1983 smolt year) to 10.0% (1992 smolt year) using these expansion methods (Table 12). This method provides slightly different estimates of survival than the more simple and direct methods associated with estimates provided in Table 7, because age 1-ocean fish were not included in the analysis. Survival rates of coded wire tagged fish from 1982 to 1988 were much lower than the survival rate of fish tagged from 1991 to 1996, likely due to post release mortality of coded wire tagged smolt as discussed earlier in this paper. The survival rates from 1982 to 1988 smolt years certainly do not represent the survival rate of untagged fish from those same smolt years. Coded wire tagged fish returned predominantly as 3-ocean fish. The tag retention was reported to be fairly good at the time tagged smolt were released (range 92 to 100%, not including 1980, Appendix A). However, escapement recoveries of adipose-clipped adult fish indicated a much higher degree of tag loss by year of tagging for fish tagged from 1982 to 1988 (average 19.2%).

Table 12. Survival and maturation rates and estimated degree of tag loss for coded wire tagged Hugh Smith Lake sockeye salmon.

Tag Year	Survival Rate	SE	Estimated Tag Loss	Maturation Rate 2-Ocean	Maturation Rate 3-Ocean	Maturation Rate 4-Ocean
1982	3.8%	0.2%	11.4%	9.2%	89.2%	1.6%
1983	0.5%	0.1%	21.5%	34.4%	65.6%	NA
1986	2.1%	0.2%	12.9%	13.5%	85.0%	1.5%
1987	2.7%	0.4%	27.3%	17.9%	80.9%	1.1%
1988	0.9%	0.1%	23.2%	16.3%	83.7%	NA
1991	8.4%	0.3%	1.0%	18.3%	81.4%	0.3%
1992	10.0%	0.6%	0.3%	22.6%	76.0%	1.4%
1993	8.4%	0.4%	1.0%	18.3%	81.7%	0.1%
1994	8.9%	0.8%	1.5%	21.2%	78.2%	0.6%
1995	8.0%	0.7%	0.9%	18.7%	80.9%	0.4%
1996	4.8%	0.4%	2.3%	22.8%	77.2%	NA
Mean				19%	80%	1%

It has been the practice for ADF&G project leaders conducting studies of this type to set objectives for the precision of estimates generated from the data. For example, Pahlke (1995) hoped to estimate the total harvest of Unuk and Chickamin River chinook salmon (*Oncorhynchus tshawytscha*) using coded wire tags to "within ± 25% of the true value 90% of the time." The coefficient of variation of our estimates of the total commercial harvest of Hugh Smith Lake sockeye salmon averaged 19.1%, but was as high as 46.6% in 1983, and 39.2% in 1986. The imprecision in the harvest estimates was likely a product of a high degree of tag loss and low survival rates of tagged fish from 1982 to 1988, and subsequent small numbers of tagged adults recovered.

Hugh Smith Lake sockeye salmon were primarily harvested in the District 101 drift gillnet fishery, the District 101 purse seine fishery, and in the outside waters of the District 104 purse seine fishery. Those combined areas accounted for an average of 86.0% (range 62.1 to 100%) of the commercial harvest of Hugh Smith Lake sockeye salmon (Table 13). Smaller numbers of Hugh Smith Lake sockeye salmon were harvested in many other commercial fishing areas in southern Southeast Alaska, with the Metlakatla Indian Community drift gillnet fishery at Annette Island (District 101-28) being the most important (mean

8.1%; range 3.0% to 25.7%; numbers of fish sampled in the traditional and Metlakatla Indian Community District 101 gillnet and seine samples were not separated by the ADF&G tag lab until after 1987). A few coded wire tagged Hugh Smith Lake sockeye salmon were recovered annually in the District 106 drift gillnet fishery. Thus, most Hugh Smith Lake sockeye salmon probably migrate to inside waters via Dixon Entrance, and only a small portion of the run migrates around the north end of Prince of Wales Island and south through inside waters to Hugh Smith Lake. Weekly distribution of harvests of Hugh Smith Lake sockeye salmon in the major fisheries are provided in Tables 14 and 15.

The Hugh Smith Lake sockeye salmon stock is not specifically targeted by any commercial fisheries. Commercial purse seine fisheries in southern Southeast Alaska primarily target pink salmon, which have contributed an average 92% of the harvest since 1984, while sockeye have contributed 2.5% of the harvest (Appendix F, which shows the southern Southeast Alaska purse seine harvest 1984–2002, for all 5 species of salmon). The majority of sockeye salmon harvested in these fisheries come from the Nass and Skeena Rivers (Van Alen 2000). Based on the contribution estimates for Hugh Smith Lake contained in Table 13, Hugh Smith sockeye typically represent well below 1% of the harvest of sockeye salmon in southern Southeast purse seine fisheries, or less than 0.02% of the total harvest of all species. Sockeye salmon are one of the target species in the District 101 drift gillnet fishery, with average annual harvests of 152,000 fish since 1984 (Appendix G, which shows the annual harvest in the District 101 drift gillnet fishery 1984–2002, for all 5 species of salmon). However, Hugh Smith Lake sockeye salmon only represent an average of about 3% of the sockeye salmon harvest based on contribution estimates in Table 13.

Run Timing in the Commercial Fisheries

The migration timing of Hugh Smith Lake sockeye salmon through the primary intercepting fisheries are outlined below, for years with at least 15 recovered fisheries tags. We used the weekly estimated harvest contributions of Hugh Smith Lake sockeye salmon to those fisheries to calculate the run timing (Appendix B). We calculated the proportion of the total estimated harvest of Hugh Smith Lake fish (in that fishery) that were harvested each week. Average run-timing through the fisheries was then estimated by plotting the mean weekly harvest proportions over all years. Run-timing was generally protracted.

District 101 Drift Gillnet: From 1989 to 1990, and from 1994 to 1998, coded wire tagged Hugh Smith Lake sockeye salmon were harvested in the District 101 drift gillnet fishery when the fishery opened in mid-June, through late September when the fishery closed (Figure 8). Tag recoveries in those years ranged from 58 (1990) to 402 (1994). Peak run timing was between late June and mid-August when about 80% of the catch of Hugh Smith Lake sockeye salmon in that fishery occurred. The mid-point of the run averaged July 23, but ranged from July 9 to August 6.

District 101 Purse Seine: From 1989 to 1990, and from 1994 to 1998, coded wire tagged Hugh Smith Lake sockeye salmon were harvested in the District 101 purse seine fishery when the fishery opened in early July, through late August when the fishery closed (Figure 9). Tag recoveries in those years ranged from 17 (1990) to 48 (1996). The mid-point of the run, and the peak, averaged July 23, but was August 6 in 1994, and August 13 in 1990 and ranged from July 9 to August 6. Peak run timing was between late June and early August when about 90% of the catch of Hugh Smith Lake sockeye salmon in that fishery occurred. Run timing was similar to the run timing through the District 101 drift gillnet fishery, in that about 90% of the catch of Hugh Smith Lake sockeye salmon occurred between early July and mid-August.

District 104 Purse Seine: In 1990, and from 1994 to 1997, coded wire tagged Hugh Smith Lake sockeye salmon were harvested in the District 104 purse seine fishery when the fishery opened in early July, through late August when the fishery closed (Figure 10). Tag recoveries in those years ranged from 19 (1995) to 176 (1994). The mid-point of the run, and the peak, averaged August 6, but ranged between July 16 and August 13. Run timing was slightly later in this fishery than in District 101, but this is probably simply a result of the reduced fishing effort in the District 104 purse seine fishery during the first 3 weeks of July. Fishing effort is reduced through Statistical Week 30, because of early season treaty obligations for conservation of Nass and Skeena River sockeye salmon.

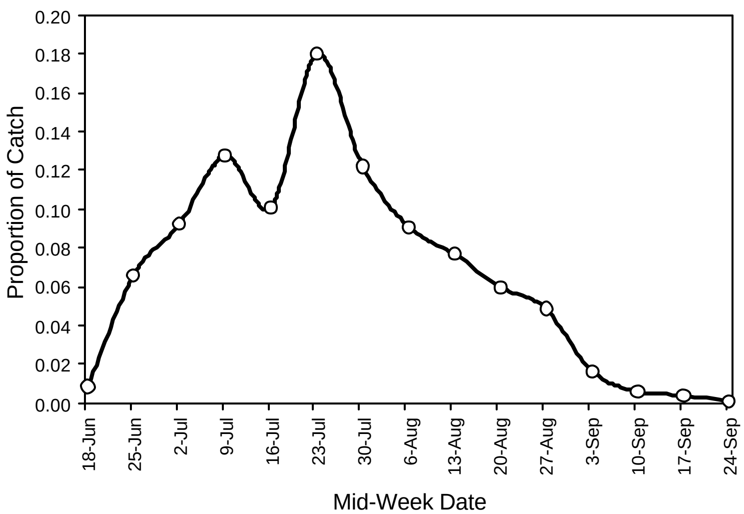

Figure 8. Mean run timing of Hugh Smith Lake sockeye salmon through the District 101-11 commercial drift gillnet fishery. The line plots the mean weekly proportion of the total annual harvest of Hugh Smith Lake sockeye salmon in the fishery from 1989 to 1990, and from 1994 to 1998.

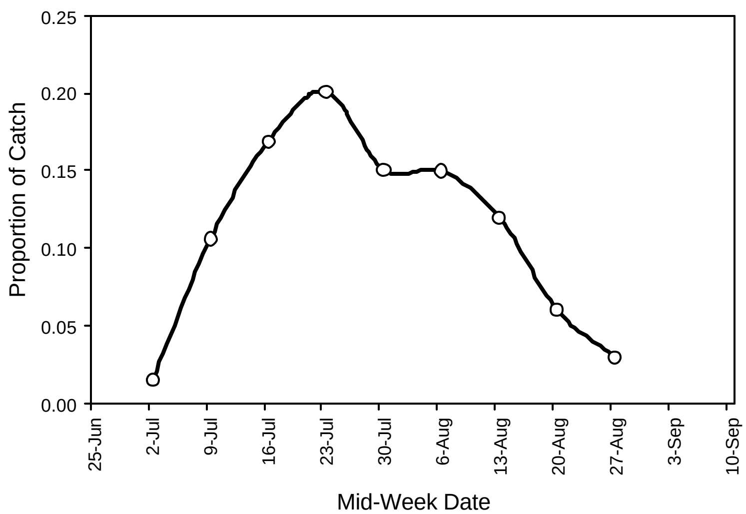

Figure 9. Mean run timing of Hugh Smith Lake sockeye salmon through the District 101 commercial purse seine fishery. The line plots the mean weekly proportion of the total annual harvest of Hugh Smith Lake sockeye salmon in the fishery from 1989 to 1990, and from 1994 to 1998.

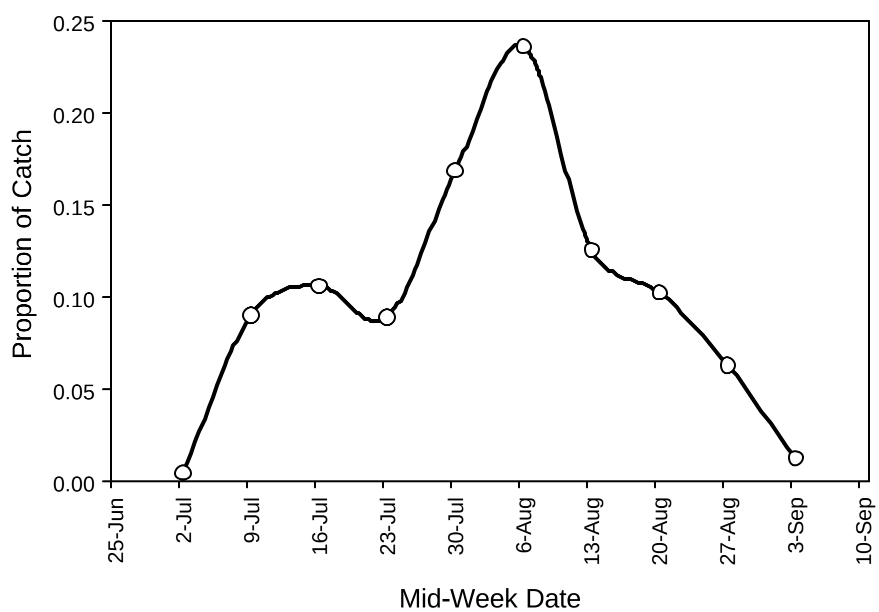

Figure 10. Mean run timing of Hugh Smith Lake sockeye salmon through the District 104 commercial drift gillnet fishery. The line plots the mean weekly proportion of the total annual harvest of Hugh Smith sockeye salmon in the fishery in 1990, and from 1994 to 1997.

Table 13. Estimated distribution of the Hugh Smith Lake sockeye salmon catch in the Alaskan commercial fisheries, expanded for all age classes combined, for years with returning 2-ocean and 3-ocean coded wire tagged adults, 1983–1999.

	1983	1984	1985	1986	1988	1989	1990	1991	1993	1994	1995	1996	1997	1998	1999	Mean
Dist. 101 Gillnet [a]	1,297	12,533	7,870	3,491		17,606	5,575	2,361		4,453	1,261	4,394	5,270	2,239		5,395
	32.7%	46.0%	57.7%	37.5%		41.4%	26.3%	29.8%		43.8%	42.4%	51.5%	36.2%	65.4%		39.4%
Dist 101 MIC[b] Gillnet						1,265	1,183	2,035		1,132	473	469	2,225	141		1,115
						3.0%	5.6%	25.7%		11.1%	15.9%	5.5%	15.3%	4.1%		8.1%
Dist. 101 Seine[a]		11,990	3,437	2,806		13,628	8,604	136		1,070	690	2,222	2,259	786		3,969
		44.0%	25.2%	30.1%		32.1%	40.6%	1.7%		10.5%	23.2%	26.0%	15.5%	23.0%		29.0%
Dist. 101 MIC Seine						320		62		33	57	71	46			49
						0.8%		0.8%		0.3%	1.9%	0.8%	0.3%			0.4%
Dist. 101 MIC Trap		290	210				53	78								53
		1.1%	1.5%				0.2%	1.0%								0.4%
Dist. 102 Seine		274	148			661	714			14	40	17	135			167
		1.0%	1.1%			1.6%	3.4%			0.1%	1.3%	0.2%	0.9%			1.2%
Dist. 103 Seine								821					138			80
								10.4%					0.9%			0.6%
Dist. 104 Seine	2,672	1,666	1,229			8,172	4,017	2,419		2,911	293	1,281	4,121	199		2,415
	67.3%	6.1%	9.0%			19.2%	18.9%	30.6%		28.6%	9.9%	15.0%	28.3%	5.8%		17.6%
Dist. 106 Gillnet		380	734	3,016		859	1,066	1		377	161	83	277	58		584
		1.4%	5.4%	32.4%		2.0%	5.0%	0.0%		3.7%	5.4%	1.0%	1.9%	1.7%		4.3%
Dist. 108 Gillnet										19						2
										0.2%						0.0%
Dist. 109 Seine		117														10
		0.4%														0.1%
Troll	1		1							160			98			22
	0.0%		0.0%							1.6%			0.7%			0.2%
Total	3,970	27,250	13,629	9,313		42,510	21,213	7,912		10,168	2,976	8,536	14,569	3,423		13,693
	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%

[a] Traditional and Metlakatla Indian Community District 101 gillnet and purse seine samples were not separated in 1983, 1984, 1985, and 1986. Means shown for those 2 fisheries are for 1989 and later. Three 1994 tag recoveries in Districts 212 and 223 of Prince William Sound were not expanded.

[b] Metlakatla Indian Community.

Table 14. The estimated weekly harvest of Hugh Smith Lake sockeye salmon in the commercial drift gillnet fishery of Districts 101.

		Statistical Week															
	Year	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	Total
Drift Gillnet	1989	96	334	1,201	2,296	1,252	4,967	2,395	1,705	1,467	1,067	641	184				17,606
District 101-11	1990		115	84		347	823	1,081	797	685	607	954	84				5,575
	1991	177	301	186	162	170		312	195	172	234	183	145	124			2,361
	1994		121	252	124	389	390	520	502	750	581	437	298	46	7	35	4,453
	1995	16	96	253	204	70	332	81	53	104	46				8		1,261
	1996	64	203	269	682	1,141	631	596	487	163	72	32	14	24	17		4,394
	1997	144	943	521	1,190	385	508	465	245	201	246	120	91	121	90		5,270
	1998		210	326	430	216	534	267	187	10	40	11		8			2,239
Drift Gillnet	1989				117	694	373			82			1				1,266
District 101 MIC	1990		83	160	220					277	443						1,183
	1991		142	124	62	175	533	277	126	71	341	186			1		2,035
	1994		31	41	95	82	293	79	142	156	108	87	17				1,132
	1995	31	64	76	45	62	63	75	9	6		31	10				473
	1996	6	14	51	254	79	48	8		9							469
	1997	28	265	439	530	722	30	142	50			20					2,225
	1998			38	44		10		28		21						141

Fishery sampling is based on the “statistical week”: weeks are numbered sequentially, beginning on Sunday. In 1983, for example, Statistical Week 25 began on June 12, Statistical Week 26 began on June 19, Statistical Week 27 began on June 26, Statistical Week 28 began on July 3, Statistical Week 29 began on July 10, Statistical Week 30 began on July 17, Statistical Week 31 began on July 24, Statistical Week 32 began on July 31, Statistical Week 33 began on August 7, Statistical Week 34 began on August 14, Statistical Week 35 began on August 21, Statistical Week 36 began on August 28, Statistical Week 37 began on September 4, Statistical Week 38 began on September 11, Statistical Week 39 began on September 18.

Table 15. The estimated weekly harvest of Hugh Smith Lake sockeye salmon in the commercial purse seine fisheries of Districts 101 and 104.

		Statistical Week																
	Year	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	Total
Purse Seine	1984				275	1,269	1,320	1,836	3,350	2,811	558	570					11,990
District 101	1985						360	339	975	338	914	392	118				3,437
	1986					1,323					508		975				2,806
	1989			166	671	4,808	2,542	1,911	2,966		564						13,628
	1990				51	424	536	902	904	4,406	1,382						8,604
	1991					136											136
	1994				25	243	62	129	391	219							1,070
	1995			62	80	57	155	232	19		23	62					690
	1996					885	269	498	265		264	40					2,222
	1997				1,079		673		20	111	149	228					2,259
	1998				54	56	360	99	161	56							786
Purse Seine	1983					966				1,706							2,672
District 104	1984				287	380			714		286						1,666
	1985										1,229						1,229
	1989				224	1,395	411		350	2,859	1,299	1,633					8,172
	1990				127	349		1,015	976	944	251	357					4,017
	1991					454		765	319	289	439	153					2,419
	1994				46	147	179	490	1,093	334	346	233	42				2,911
	1995			8		18	25	19	49	35	99	23	18				293
	1996				26	194	34	317	310	132	100	168					1,281
	1997				1,952	896	550	282	161	198	83						4,121
	1998					14	45	42	70	27							199

Fishery sampling is based on the “statistical week”: weeks are numbered sequentially, beginning on Sunday. In 1983, for example, Statistical Week 25 began on June 12, Statistical Week 26 began on June 19, Statistical Week 27 began on June 26, Statistical Week 28 began on July 3, Statistical Week 29 began on July 10, Statistical Week 30 began on July 17, Statistical Week 31 began on July 24, Statistical Week 32 began on July 31, Statistical Week 33 began on August 7, Statistical Week 34 began on August 14, Statistical Week 35 began on August 21, Statistical Week 36 began on August 28, Statistical Week 37 began on September 4, Statistical Week 38 began on September 11, Statistical Week 39 began on September 18.

BIOLOGICAL ESCAPEMENT GOAL

Prior escapement goals for this system were generated at a time when the analysts had relatively little data. The most recent goal of 15,000–35,000 spawners was based on the best professional judgment of the managers of this system, and on a limited analysis of what data was available at the time.

The conventional method for setting an escapement goal in a sockeye salmon producing system with 20 years of catch and escapement information, would be to do a Ricker analysis (Quinn and Deriso 1999). Unfortunately, the unknown annual Canadian harvests of the Hugh Smith Lake stock of sockeye salmon, and questions about the U.S. harvests in some years, greatly clouds the picture for an analyst attempting to conduct a Ricker stock-recruit analysis. The basic idea behind the Ricker analysis is that a stock has 2 fundamental attributes that can be viewed as forces (underlying productivity and density dependence) — although these forces act on different scales. Because female sockeye salmon usually carry in excess of 3,000 eggs, salmon stocks have the potential to expand well over a hundred times in a single generation. This potential for the population to expand is the basis of the underlying productivity. However, crowded conditions increase the chance of disease outbreaks, lead to overgrazing of scarce food resources, and generally increase overall mortality. This is the basis of the density dependence. And, density dependence within Hugh Smith Lake is evidenced in Figures 6 and 7. While we cannot develop a traditional analysis, we have developed 3 alternate means of developing a biological escapement goal for the Hugh Smith Lake stock of sockeye salmon.

Risk Approach to Defining a Threshold Spawning Escapement Level[2]

An escapement threshold for sockeye salmon from Hugh Smith Lake is derived below based on minimizing the risks of making a management error. In the context of Alaska Administrative Code 5 AAC 39.222, the 2 types of management error are having a "management concern" when the stock is not in need of protection, or not having a "management concern" when there is such a need. A "management concern" as redefined here from regulation is having escapements below a threshold over a period of 5 years.

One inarguable fact is that salmon production is variable, often temporally obscuring trends, or lack of trends, in production or in exploitation. The practicality of this variation is that given any threshold in escapement, there is a probability of triggering a management concern without a downward trend in escapements. Conversely, there is a probability of not meeting the criterion for calling a management concern when there has been such a meaningful lessening in productivity (or increase in exploitation), again given a specific escapement threshold. These 2 probabilities, along with a decision on what constitutes a meaningful drop in mean escapements, are the risks of management error associated with a particular threshold.

These risks of management error can be estimated from the same year-to-year variation in escapements that is so troublesome. Variation experienced in past escapements is assumed to continue into the future.

[2] This section was developed by David R. Bernard, Alaska Department of Fish and Game, Division of Sport Fisheries, Anchorage Alaska.

For estimating the risk of an unwarranted management concern, the average of past escapements is also assumed to continue into the near future. For estimating the risk of not having a management concern when warranted, the past average escapement is discounted according to what is considered a meaningful drop in productivity, or increase in exploitation, as manifested by a trend downward in escapements. Either calculation begins with estimating the probability of escapements being below a threshold in a single year. Methods used to estimate this probability depend on whether variation in escapements is, or is not, serially correlated. Because there is strong evidence that escapements from Hugh Smith Lake are serially correlated, at least for those years in the analysis, methods relevant to the contrary case are not provided here.

All but 3 years of estimated escapements as listed in Table 1 were used to establish a threshold. Data for the years 1982, 1987, and 1992 were excluded from the analysis because they were judged atypical. The five-year spacing of these excluded years are evidence of a density-independent "ripple" moving through the recent history of the stock. This phenomenon largely disappeared after 1992. Because escapements are often log normally distributed, the remaining escapements were log-transformed. Subsequent hypothesis testing failed to indicate that these log-transformed data are not normally distributed (one-sample Simrnov test, Conover 1980, n = 20, P = 0.920). Further investigation provided evidence of serial correlation in the log time series (Figure 11). Inspection of autocorrelation and partial autocorrelation functions indicates that this correlation follows an auto-regressive process with a lag of 1 year, a common occurrence for salmon populations that return as adults in more than 1 year. Exclusion of data for years 1982, 1987, and 1992 were treated as "missing" data with the resulting gaps in the series filled through quadratic interpolation using the statistical software package SYSTAT©.

Simulations based on modeled variation in escapements were used to estimate the probability p_k of observing k (=5) consecutive years in which escapements would be below a threshold. With escapements x_t expressed as logs, the auto-regressive process was modeled as:

$$e_t = f e_{t-1} + a_t \, , \tag{6}$$

where e_t is the deviation from the mean m in year t ($e_t = \ln x_t - m$), f is the parameter for autocorrelation ($0 \le f < \left|1\right|$) (from Abraham and Ledolter, 1983, p. 199, equation 5.10), and a is normally distributed with mean 0 and variance s^2. For species with brood years that mature in more than 1 calendar year, e_t and e_{t-1} tend to be related such that $0 \le f < 1$, especially when 2 or more age groups dominate returns, exploitation rates are similar across years, and maturation schedules vary little from brood year to brood year. In terms of escapements with log-normal distributions, Equation 6 becomes:

$$\ln x_t = f(\ln x_{t-1}) + m(1 - f) + a_t . \tag{7}$$

The statistical software package SYSTAT© was used to estimate parameters for the ARIMA (Auto Regressive Integrated Moving Average) model described in Equation 7. Estimates for f, s^2, and c {where $c \equiv m(1 - f)$] for the series from Hugh Smith Lake are 0.52675, 0.435449, and 4.09904, respectively). All estimates were statistically significant (P < 0.05). The series showed no signs of non-stationarity.

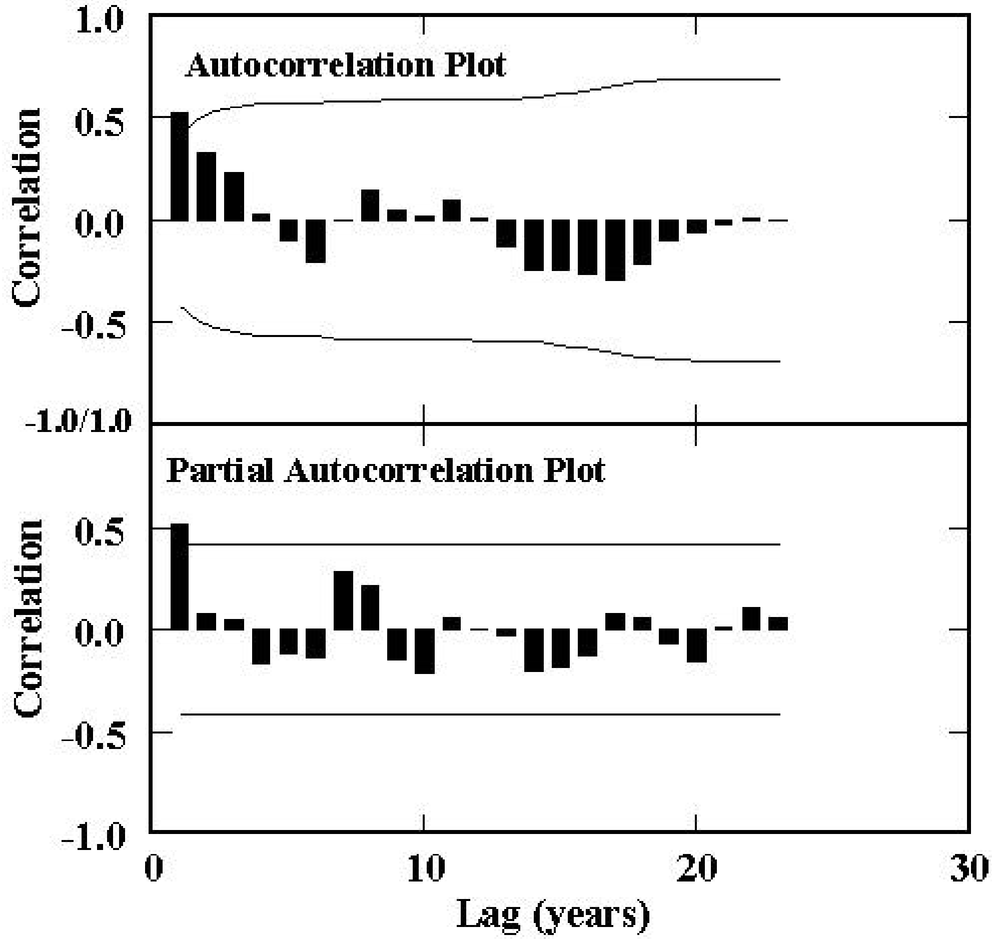

Figure 11. Auto-correlations and partial auto-correlations for log annual escapements of sockeye salmon in Hugh Smith Lake (1980–2002) excluding data for years 1982, 1987, and 1992. Correlations are based on quadratic interpolations for "missing" data. Horizontal thin lines correspond to 95% confidence intervals for correlations. Significant values at lag 1 year for both types of auto-correlation functions indicates an auto-regressive process with lag 1 year.

Simulations were conducted in a spreadsheet with each simulation forecasting escapements forward for 10,000 (= M) years. An initial value ln x_o [= $\hat{c}(1-\hat{f})^{-1}$] was chosen to start each simulation. Log escapement for year i was generated with Equation 7 as a function a of estimated parameters, predicted log escapement for year i-1, and a pseudo random number ~ Norm$(0,\hat{s}^2)$. Over the resulting simulated time series, the estimate of p_k was calculated as per the decision rule:

$$\hat{p}_k = \frac{\sum_{i=k}^{M} y_i}{M-k+1}, \text{ such that } y_i = \begin{cases} 1 & \textit{if} \ \max(\ln x_i, \ln x_{i-1} \ldots \ln x_{i-k+1}) \le \ln X, \\ 0 & \textit{otherwise.} \end{cases} \quad (8)$$

M is the number of simulated years, y a counter, and X is a threshold. No anti-log transformation from ln x to x is needed because $\Pr[x_i \le X] = \Pr[\ln x_i \le \ln X]$ with a log-normal distribution. By making M large, most likely values of escapements are represented in the predicted series with the consequence that

$\hat{p}_k$ becomes negligibly conditioned on prior escapement. The estimated probability of not observing k consecutive years with escapements below a threshold would be $1-\hat{p}_k$. A postulated reduction in average escapements of (Δ x 100) per cent was attained by adding $(1-\hat{f})\ln\Delta$ to $\hat{c}$.

The results of simulations show that risks of both types of a management error are equal with a threshold escapement level of about 8,000 sockeye salmon in Hugh Smith Lake (Figure 12). A meaningful drop in mean escapements was set at 50%. The relatively high risk estimated for this threshold (about 30%) results from the high degree of inherent variability in observed past escapements. If more than a 50% drop in average escapements is to be detected, the "thin" curve in Figure 12 would have to shift left, moving the threshold and estimated risk lower. If a smaller than a 50% drop is to be detected, the thin curve would have to shift right, increasing both estimated risk of error and the threshold escapement value. Conversely, management concerns are more likely than expected to be triggered if the threshold escapement level is set at 8,000 and mean escapement drops more than 50%; fewer than expected at 8,000 if mean escapement drops less 50%.

Assumptions behind estimating risk of management error from a time series of escapement observations with the methods described above are that observations are log-normally distributed and have a stationary mean, that is, there is no past temporal trend in m. Appropriate statistical tests failed to detect evidence to the contrary for sockeye salmon in Hugh Smith Lake. Excluding years 1982, 1987, and 1992 from the analysis, though for good reason, produced a series whose remaining elements are serially correlated. The intact series showed no evidence of serial correlation. As more data are interpolated in a time series of escapements, there is a tendency for $\hat{f} \geq f$, that is, serial correlation is suggested when it's not there. In general, if 20% or less of a series is missing, inflation in $\hat{f}$ from interpolation or deleting years should have negligible consequences. Only 3 of 23 data were excluded from the series for Hugh Smith Lake, indicating that inflation in $\hat{f}$ is an unlikely reason for detecting serial correlation. More likely the "ripple" of an unusually strong brood line through the series obscured the underlying serial correlation; removing the "ripple" revealed the correlation.

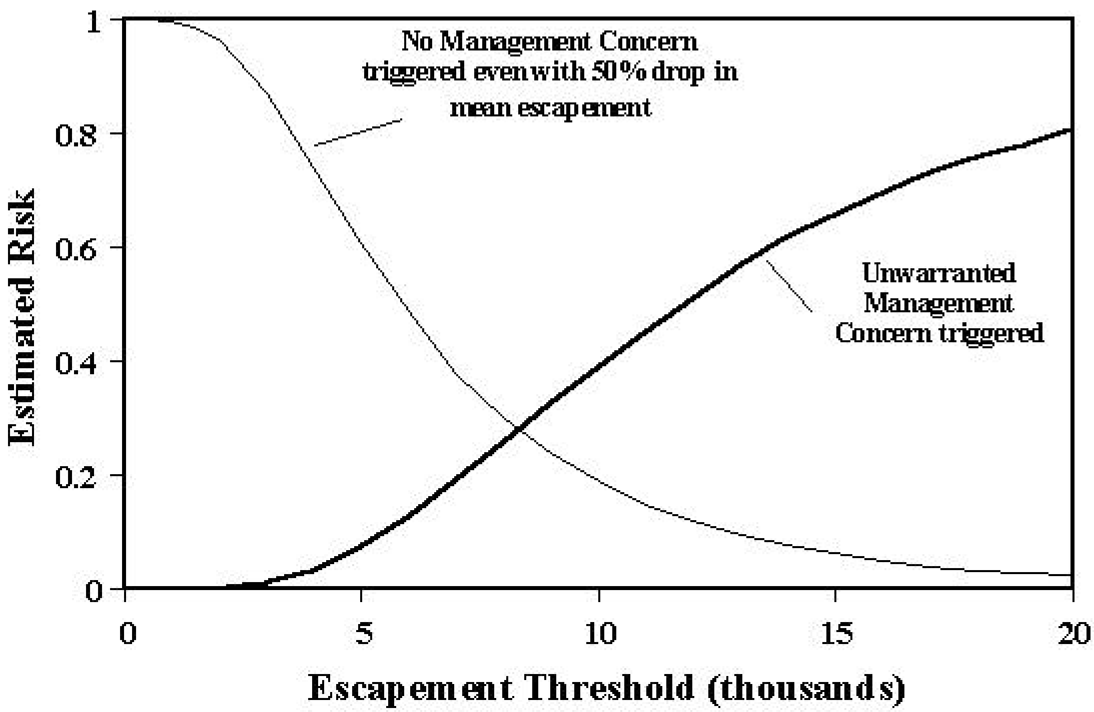

Figure 12. Estimated risk of management error associated with escapement thresholds for sockeye salmon in Hugh Smith Lake. If mean escapements remain unchanged into the future, management error occurs in a year with a management concern (thick line); if mean escapement drops 50% into the future, management error occurs in a year without a management concern (thin line).

Approach Based Upon Approximating Ricker Alpha and Beta Values

If we assume that the stock is controlled by the Ricker Law (Quinn and Deriso 1999), the 2 parameters of this relationship can be approximated with 2 important observations: the return per spawner at very low stock size, and the escapement that produces the maximum recruitment. In Appendix H we show that the peak of the curve is found at $S = 1/\boldsymbol{b}$, and the slope of the curve near the origin is equal to Ricker's $\boldsymbol{a}$. In other words, the peak in recruitment is at an escapement of $1/\boldsymbol{b}$, so that $\boldsymbol{b}$ is approximately the inverse of escapements that have consistently resulted in the highest recruitments. In this same appendix we show that $\boldsymbol{a}$ is the slope of the Ricker curve at the origin. This means the average or median return per spawner statistics for very low stock sizes provides an approximation to Ricker's $\boldsymbol{a}$ parameter.

We don't have a lot of recent experience at high-stock sizes for this system, and we have not consistently observed a peak in recruitment at a particular escapement level at Hugh Smith Lake. However, even though we do not have a complete brood year based history of recruitment, we can reasonably start by assuming $1/\boldsymbol{b}$ is in the neighborhood of 30 thousand spawners. The 1987 escapement of just over 30 thousand resulted in the largest recruitment of adult salmon in recent history, and that observation provides the justification for using 1/30,000 as a starting value to approximate $\boldsymbol{b}$. Because we do not have consistent observations of the return per spawner at Hugh Smith Lake, we are forced to start by assuming that Ricker's a is approximately 4 or slightly greater, which is near values for other small coastal lakes, including Redoubt Lake, another meromictic lake in Southeast Alaska. From our experience, an a parameter between about 3 to 8 might be considered typical for coastal sockeye salmon systems. Assuming values in this range, and assuming values of 1/20,000, 1/25,000, and 1/30,000 for the b, the escapement that would produce maximum sustained harvest would be between 9,000 and 22,000 (Table 16).

Table 16. Estimated approximate spawning escapements of Hugh Smith Lake sockeye salmon expected to produce maximum sustained yield to fisheries assuming 3 alternate values for the Ricker alpha parameter and 3 alternate values for the Ricker beta parameter.

Alternate Assumed Beta Values	MSY Escapement if a = 3 is Assumed	MSY Escapement if a = 4 is Assumed	MSY Escapement if a = 8 is Assumed
$1/b$ = 20,000	9,000	11,000	15,000
$1/b$ = 25,000	12,000	15,000	18,000
$1/b$ = 30,000	14,000	17,000	22,000

It is important to consider the cost of mistakes in assumptions about Ricker's parameters. There are 2 principal losses that follow from an error in setting an escapement goal too high or too low for this system. If an escapement goal is set too high for the Hugh Smith Lake stock of sockeye salmon, there may be significant costs to the commercial fishing industry from constraining fisheries that incidentally harvest Hugh Smith Lake sockeye salmon. Alternatively, if a less-than-optimal number of Hugh Smith sockeye salmon are passed through to the escapement, there will also be a loss of future yield from the stock. The difference between the realized yield and the potential yield, added to losses from other fisheries to pass an excess of Hugh Smith sockeye salmon, can be considered the overall cost of inaccuracy in the escapement goal. If the stock size is allowed to drop to very low levels, there are other costs that need to be considered, but we assume that the escapement goal will be large enough that the risk of extinction, and so forth, can be ignored.

To evaluate the effect of an error in assumptions about either parameter, we looked at potential loss of yield from this one stock only. Potential loss was defined to be the expected yield from this one stock with perfect information and perfect management precision minus this expected yield from this one stock under a Ricker recruitment law when a was incorrectly assumed (example values found in Table 17) and when $ß$ was incorrectly assumed (example values found in Table 18).

Overall, an escapement goal based on assumptions of a = 8, and $1/b$ = 25,000 seems to provide the best mix of an agreement with professional judgment and experience with the a parameter, and relative risk of choosing a value of $1/b$ that is too high. These assumed parameters lead to a goal centered around 18,000 spawners. If the overall intent of setting an escapement goal is to generate the maximum sustained yield from this stock, given the uncertainty in the available data, an escapement goal in this region seems to be a slightly aggressive way to balance that uncertainty and make use of the data that is available.

Table 17. The expected average loss to yield under a Ricker analysis with b = 1/30,000, assuming the a value given by the column heading, when the true a is the one given by the row. The largest expected loss (of 6,300 fish in the harvest), occurs when a high productivity stock (a = 8) is assumed to be a low productivity stock (a =3).

True Alpha Values	Average Loss if a = 3 is Assumed	Average Loss if a = 4 is Assumed	Average Loss if a = 8 is Assumed
True a = 3	0	400	2,638
True a = 4	467	0	1,317
True a = 8	6,300	2,365	0

Table 18. The expected average loss to yield under a Ricker analysis with a = 8, assuming the b value given by the column heading, when the true b is the one given by the row. The largest expected loss of nearly 5,000 fish in the harvest, occurs when either a high carrying capacity is assumed (1/b = 30,000) when the true carrying capacity is much lower (1/b = 20,000), or *vice versa.*

True Beta Values	Average Loss if 1/b = 20,000 is Assumed	Average Loss if 1/b = 25,000 is Assumed	Average Loss if 1/b = 30,000 is Assumed
1/b = 20,000	0	1,138	5,099
1/b = 25,000	1,235	0	1,091
1/b = 30,000	4,750	1,505	0

Alternatively, imagine we chose entirely the wrong parameter values with which to set an escapement goal, within the range of values we considered (i.e., consider the minimum expected yield from each of the 9 Ricker models we considered, and then consider this minimum yield as a function of the escapement goal). Now consider the "worst-case" expected yield that results from that mistake. If we look for the escapement goal that produces the maximum of this "worse-case-scenario" expected yield (just over 8,000 fish), is found at an escapement level of about 9,000. In some sense, setting the escapement goal at 9,000 is the "safest" approach in terms of protecting yield in the face of mistakes about choosing the wrong parameter values (Berger 1980), given the parameter values we considered.

In summary, a range of 9,000 to 18,000 spawners is probably the best way to tradeoff risk and uncertainty, given the limitations of this analysis. And, hence, for that reason, the definition of a *biological escapement goal* of 9,000 to 18,000 is the best we can do when attempting to solve the problem through the approach of approximating Ricker alpha and beta values.

Approach Based Upon Beverton-Holt Juvenile Production Relationship[3]

Earlier, 3 alternate Beverton-Holt stock-recruit relationships were described (Table 10; Figure 7). These relationships relate spawning escapement strength to expected production of juvenile sockeye salmon under a Beverton-Holt approach to density dependence. As earlier concluded, the combined data set (fall and spring survey estimates; $n = 12$) likely represents the best available information.

The Beverton Holt spawning abundance-juvenile production relationship for the combined data set (spring and fall surveys) can be converted into spawner abundance versus estimated adult recruits, given an assumption concerning survival rate from the juvenile to adult stage. Table 7 provides estimates of survival from the smolt to adult stage and the estimates for the 1991–1997 smolt years averages about 8% with little interannual variability. Table 12 provides alternate survival-rate estimates; the 1991–1996 smolt years using that method also average 8%, but with more inter-annual variability. Both of these estimates only include Alaskan harvests and the Hugh Smith Lake escapement; any smolt surviving to adulthood and caught in Canadian fisheries are not included. As a result, these are minimum estimates. We conclude that 8% is a reasonable recent average minimum survival rate from the smolt to adult stage.

We attempted to develop total smolt estimates using the number of smolt coded wire tagged as first events in mark-recapture experiments and the numbers caught and proportions with coded wire tags in the harvests and escapements as second events. After doing so, we concluded that the estimates were not useable after various technical analyses and evaluation. We had hoped to use these data to further evaluate the carrying capacity of Hugh Smith Lake and to gain an understanding of the survival rate from the juvenile to smolt life history stages. Although the results were deemed not fully useable, these results indicated survival from the juvenile to smolt stage averaged about 20% for brood years 1991, 1992, and 1994. While we consider this survival rate to be too low, it demonstrated that significant mortality may occur between the juvenile and smolt life history stages.

While we do not know what portion of the total smolt emigration is counted (Figure 5), the highest annual counts have been around 400,000 smolt while the highest numbers of juveniles has been about 800,000 fish (Figure 6), or twice the maximum number of smolt counted. Hence if only about one-half of the smolt are counted at the fence, survival between the juvenile and smolt stage is high. If, on the other hand, more than one-half of the emigrating smolt are counted, significant mortality takes place between the juvenile and smolt life history stages. We do not think the smolt counts represent all smolt emigrating in a given year, and hence, by default conclude that a significant, but unknown level of mortality takes place between the juvenile and smolt life history stages. As a result of this logic, we concluded that use of 8% as an estimate of juvenile to adult survival could be used as a maximum value.

We used a series of alternate assumptions concerning average survival from the juvenile to adult life history stage of 5%, 6%, 7%, and 8% with the Beverton-Holt stock recruit relationship earlier described for the combined spring and fall juvenile data set to construct 4 alternate spawner-adult recruit data sets. Each of these was iteratively evaluated to estimate the spawning escapement level predicted to provide for maximum sustained yield fisheries. Estimates of the spawning escapement level that was predicted to provide for maximum sustained yield fisheries ranged from about 9,000 to 18,000 spawners for these 4 data sets (Table 19). The 4 alternate stock-recruit relationships are plotted and provided in Figure 13.

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[3] This section was developed by John H. Clark, Alaska Department of Fish and Game, Division of Commercial Fisheries.

Table 19. Estimated maximum sustained yield spawning escapement level and replacement level for the Hugh Smith Lake stock of sockeye salmon under 4 alternate assumed average values for the juvenile to adult survival rate.

Assumed Average Survival Rate from the Juvenile to the Adult Life History Stage	Estimated Escapement Level Predicted to Provide for Maximum Sustained Yield Fisheries	Estimated Approximate Replacement Value in the Stock-Recruit Relationship
5%	9,219	22,500
6%	12,319	32,000
7%	15,169	41,000
8%	17,822	50,000

If we had a solid technical basis for a specific average survival rate from the juvenile to adult life history stage for the Hugh Smith Lake stock of sockeye salmon, a specific biological escapement goal could be defined with this methodology. Unfortunately we do not, and hence suggest the values presented above represent a reasonable range of the escapement level that is expected to provide for maximum sustained yield fisheries.

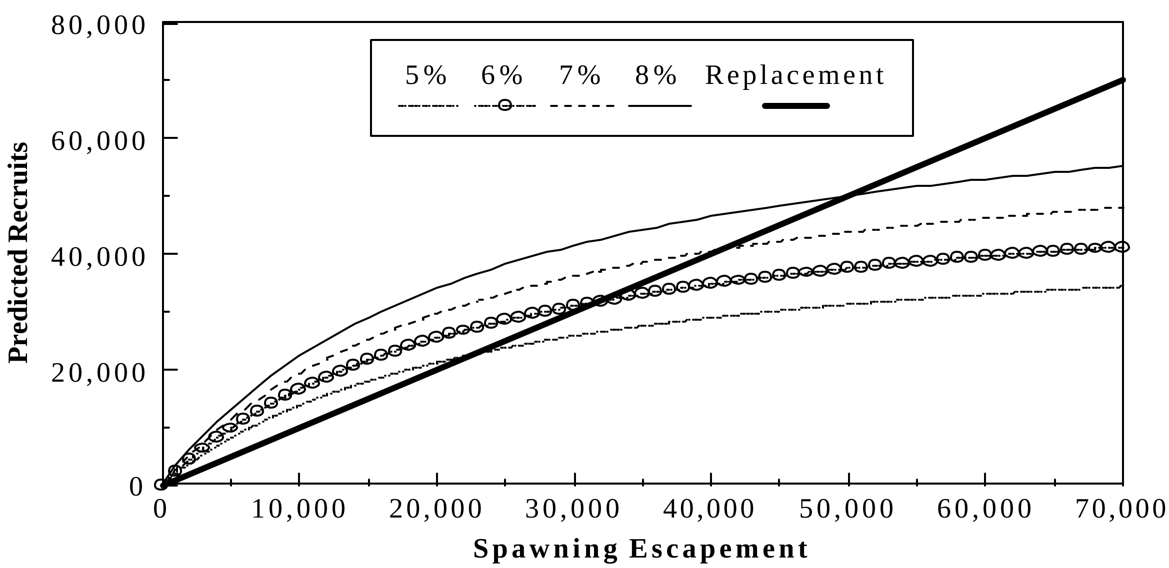

Figure 13. Alternate Beverton-Holt stock-recruit relationships for the sockeye salmon stock of Hugh Smith Lake under 4 assumptions concerning the average survival rate from the juvenile to adult life history stage.

Recommended Biological Escapement Goal and Discussion

In the 3 analyses presented above:

(1) The "risk" analysis leads to a conclusion on an escapement level of about 8,000 spawning sockeye salmon in Hugh Smith Lake was a reasonable threshold level to minimize making fishery management errors.

(2) The Ricker approach, using reasonable assumed values for alpha and beta, leads to the conclusion that a biological escapement goal range of from 9,000 to 18,000 spawning sockeye salmon in Hugh Smith Lake was probably the best way to tradeoff risk and uncertainty, given the limitations of the analysis.

(3) The Beverton-Holt spawner-juvenile production relationship for Hugh Smith Lake sockeye salmon, once adjusted for assumed juvenile to adult survival rates, identified a range of from about 9,000 to 18,000 spawners as a potential range of values associated with the maximum sustained yield spawner escapement level.

From these diverse analyses, **we recommend that the *biological escapement goal* for the Hugh Smith Lake stock of sockeye salmon be defined as 8,000 to 18,000 spawners**. While none of these lines of analyses are as technically strong as we would like, the convergence of the results is encouraging enough for us to make this recommendation to the Alaska Department of Fish and Game. We also recommend that this biological escapement goal be reevaluated in 2005.

DISCUSSION

Stabilizing the escapement level in Hugh Smith Lake — that is holding the line on further stock decline — should be the most important fishery management goal for this system. The cost to the fishing industry that follows from a less-than-optimal escapement goal may be very low, especially when compared to the cost of forgone harvest in fisheries that must be closed to pass a large number of Hugh Smith Lake sockeye salmon into the escapement. The Hugh Smith stock of sockeye salmon is not a stock that a whole community is depending upon as their only source of sockeye salmon, and the marginal benefits from this system's yield are relatively minor. In other words, the cost of underestimating the escapement that will produce maximum sustained yield are small, until the size of the mistake is very large. Underestimating the escapement that produces maximum sustainable yield by, say, half, is a mistake with low-cost consequences given the way this stock is used. On the other hand, setting an escapement goal that is far too high has increasingly costly consequences, with the cost increasing dramatically as the magnitude of the error increases far above the optimum level.

For that reason, if an error must be made, it is important to error on setting a goal that is too low rather than too high in this situation. However not meeting the goal is also costly if the stock is required to return to some higher level at a later time — as required by the Sustainable Salmon Fisheries Policy —

allowing the stock to drop to low levels creates the same kind of expensive problem as over estimating the escapement goal.

Usually, there is an additional cost to having a goal that is too low. That cost comes from the fact that stock-recruit observations at low stock sizes are less informative about the underlying stock-recruit relationship, and setting a low escapement goal compromises any future stock-recruit analyses. For this stock, the difficulty is in estimating total stock size, including the Canadian harvest, makes this consideration moot. In any event, considering all of the problems of estimating total stock size, it appears to us that stability of escapements for this system is probably far more important than yield.

If the Alaska Department of Fish and Game adopts our recommendation to define the biological escapement goal for the Hugh Smith Lake stock of sockeye salmon as 8,000–18,000 spawners per year, and if the escapement level of the recent past were realized under this escapement goal, the stock would then meet the definition of a stock of concern. After brood stock removals, the natural spawning escapements over the past 5 years were 897 spawners in 1998, 2,878 spawners in 1999, 3,989 spawners in 2000, 3,551 spawners in 2001, and 5,880 spawners in 2002 (Table 1). The five-year average is 3,439 or 42% of the lower end of the recommended range. Thus to fully address the concern, future escapements will need to be more than double the recent five-year average.

Considering the length of time escapements have been below the escapement goal, we believe the Hugh Smith Lake stock of sockeye salmon should be classified as a *stock of concern*. There are many factors that may have influenced the current state of this stock. There may be a few that are the primary cause of the downward escapement trend, but it may also be the sum of several factors. This stock has already become a "weak stock" from the point of view of management, a very troubling situation as the stock is contributing to a number of large and valuable mixed-stock fisheries. To recover from this situation, harvest rates must be reduced, and we must take steps to prevent taking any actions that would further reduce the fundamental productivity of the stock.

We have an imperfect measure of the harvest rate, but considering all that we do know, the harvest rate on this stock has been high. Most of the harvest of this stock is controlled by decisions made for distant fisheries. The managers of fisheries that affect this stock have limited inseason information to go on about the occurrence of this stock in the fisheries they control. Because the Hugh Smith stock is such a small component of the catch, these managers receive little information of the effectiveness of their actions in passing Hugh Smith sockeye salmon through their fisheries.

It appears to us that the fry stocking program used to enhance production of sockeye salmon in Hugh Smith Lake during most of the years from 1986–1997 likely failed to add significant production. On the other hand, the current enhancement program of stocking pre-smolts as has been done in most years since 1996 has the potential to improve production**. We recommend that a careful review of the Hugh Smith Lake sockeye salmon stocking program be conducted before the summer of 2003 by ADF&G and SSRAA staff**.

We have considered the possibility that the stock assessment program, including the coded wire tagging, could have negatively affected smolt survival, induced some level of mortality burden on the stock. We noticed that in some years in the 1980s, an apparent large proportion of the smolts were tagged (Table 5). Smoltification renders salmon more susceptible to stress caused by trapping, handling, tagging, and associated scale loss; in turn leading to possible osmo-regulatory problems and increased vulnerability to disease and predation (Bouck and Smith 1979; Wedemeyer 1972; Peltz and Haddix 1989). In our experience, sockeye salmon smolts seem to be much more sensitive to handling compared to coho salmon smolts. More importantly, the anesthetic MS-222, which is no longer used, is known to interfere with the osmo-regulatory ability of smolts (Bouck and Johnson 1979). The tagging site at Hugh Smith Lake was approximately 50 m from salt water, and fish were expected to enter saltwater shortly after release. Tagged smolts must have experienced some mortality associated with the use of MS-222 and handling, especially in the early years of the program. Another potential source of mortality induced to the stock through the stock assessment program was the adult mark-recapture experiment, where up to 100% of the escapement was fin clipped while passing upstream of the counting weir. If this were a major source of mortality, we would expect a large difference between the mark rate at the weir and the mark rate in the escapement — which we did not find. Even so, **we suggest a careful review of the stock assessment program implemented by ADF&G and SSRAA take place before summer of 2003 to ensure a useful stock assessment program is continued while minimizing negative effects on the stock**. This will be particularly important as additional funds have been set aside from the Southeast Sustainable Fisheries Fund for improved stock assessment of the Hugh Smith Lake stock of sockeye salmon over the coming 3 years.

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APPENDICES

Appendix A. The number of Hugh Smith Lake sockeye salmon smolt coded wire tagged by tag code, and reported tag retention at time of release, 1980–1996.

Year of Tagging	Tagging Dates	Tag Code	Total Tagged	Tag Retention	Valid Tagged Released	Adult Return Years
1980	17-19 May 31 May-3 Jun	4-19-06	4,836	83.7%	4,048	1982–1984
1981	13 May-10 Jun	4-19-25	7,621	100.0%	7,621	1983–1985
		4-20-46	10,528	100.0%	10,528	
		4-20-47	10,227	100.0%	10,227	
		Total			28,376	
1982	17 May-9 Jun	4-21-61	30,000	100.0%	30,000	1984–1986
1983	10 May-30 May	4-22-52	18,802	90.6%	17,035	1985–1987
1986	26 Apr-8 Jun	4-24-42	10,643	98.5%	10,483	1988-1990
		4-24-43	3,215	98.7%	3,173	1988-1990
		4-24-45	8,983	97.2%	8,731	1988-1990
		4-24-49	10,430	97.7%	10,190	1988-1990
		Total			32,577	
1987	1 May-8 Jun	4-26-54	9,380	97.7%	9,164	1989-1991
		4-26-55	2,932	98.7%	2,894	1989-1991
		4-27-23	11,209	98.9%	11,086	1989–1991
		4-27-24	10,059	98.3%	9,888	1989–1991
		Total			33,032	
1988	13 Apr-24 May	4-29-58	10,420	97.7%	29,254	1990–1992
		4-29-25	30,761	95.1%	10,180	1990–1992
		Total			39,434	
1991	23 Apr-29 May	4-31-24	7,126	100.0%	10,525	1993–1995
		4-31-27	10,525	100.0%	10,401	1993–1995
		4-31-29	10,401	100.0%	10,918	1993–1995
		4-31-30	10,918	100.0%	11,051	1993–1995
		4-35-53	11,051	100.0%	10,867	1993–1995
		4-26-58	10,889	99.8%	7,126	1993–1995
		Total			60,888	
1992	30 Apr-28 May	4-38-16	14,146	100.0%	14,146	1994–1996
1993	25 Apr-26 May	4-38-17	12,401	99.0%	12,277	1995–1997
		4-38-18	22,249	99.9%	22,227	1995–1997
		Total			34,504	
1994	26 Apr-26 May	4-37-27	10,434	100.0%	10,434	1996–1998
		4-40-25	21,823	100.0%	21,823	1996–1998
		4-42-03	3,430	100.0%	3,430	1996–1998
		Total			35,687	
1995	26 Apr-28 May	4-43-54	17,521	99.9%	17,503	1997–1999
1996	21 Apr-29 May	4-43-53	13,480	100.0%	13,480	1998–1900

Appendix B. The estimated harvest of coded wire tagged Hugh Smith Lake adult sockeye salmon, expanded for fishery sample size, by year, statistical week, district, and gear group, 1983-1999. Numbers are rounded to the nearest whole tag. (Note additional information about statistical weeks can be found in Tables 14 and 15.)

		STATISTICAL WEEK															
Year	Gear/District	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	Grand Total
1983	Drift Gillnet 101[a]										2	3					5
	Setnet 104					4				7							11
	Troll 101[b]																
1984	Drift Gillnet 101	2				3	50	22	27	22	10	12	6	4			158
	Drift Gillnet 106								2	2							4
	Setnet 101				3	16	17	23	43	36	7	7					152
	Setnet 102										3						3
	Setnet 104				4	5			9		4						22
	Setnet 109								1								1
	Trap 101 Metlakatla Indian Community								2	1	1						4
1985	Drift Gillnet 101[c]		18	22	7		11	15	50	71	54	30	9	3	2		292
	Drift Gillnet 106				4	3	5		3	6	3		3				27
	Setnet 101						13	13	37	13	34	15	4				129
	Setnet 102											6					6
	Setnet 104										46						46
	Trap 101 Metlakatla Indian Community					5			1	1		1					8
	Troll 101[d]																
1986	Drift Gillnet 101[e, f]			3	3						2		1				9
	Drift Gillnet 106[g]						5				7						12
	Setnet 101					6					2		4				12
1988	Drift Gillnet 101-11						4		2	4	1						11
	Setnet 101						4	6			4						14
	Setnet 104								4								4
1989	Drift Gillnet 101 Metlakatla Indian Community[h]				2	15	8			2							27
	Drift Gillnet 101-11	2	7	26	49	27	106	51	36	31	23	14	4				376
	Drift Gillnet 106[i]			2				6		3		6	1				18
	Setnet 101			4	14	103	54	41	63		12						291
	Setnet 101 Metlakatla Indian Community				2	5											7
	Setnet 102						11				3						14
	Setnet 104				5	30	9		7	61	28	35					175

[a] The expanded number of tags for District 101-11 gillnet in week 35 was reduced to 3, so that the estimated contribution of Hugh Smith Lake fish would not exceed the commercial harvest.
[b] A District 101 troll recovery in week 30 was not expanded.
[c] The expanded number of tags for District 101 Metlakatla Indian Community gillnet in week 38 was reduced to 2, so that the estimated contribution of Hugh Smith Lake fish would not exceed the commercial harvest.
[d] A District 101 troll recovery in week 29 was not expanded
[e] The expanded number of tags for District 101 gillnet in week 36 was reduced to 1, so that the estimated contribution of Hugh Smith Lake fish would not exceed the commercial harvest.
[f] A District 101 gillnet recovery in week 37 was not expanded
[g] A District 106 gillnet recovery in week 38 was not expanded.
[h] The District 101 Metlakatla Indian Community gillnet recovery in week 36 was not expanded.
[i] The expanded number of tags for District 106 gillnet in week 36 was reduced to 1, so that the estimated contribution of Hugh Smith Lake fish would not exceed the commercial harvest.

Appendix B. (page 2 of 3)

		STATISTICAL WEEK															
Year	Gear/District	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	Grand Total
1990	Drift Gillnet 101 Metlakatla Indian Community		2	4	6					7	12	2	2				35
	Drift Gillnet 101-11		3	2		9	22	28	21	18	16	25	2				146
	Drift Gillnet 106			3	2		6	3	3	11							28
	Setnet 101				1	11	14	24	24	116	36						226
	Setnet 102											19					19
	Setnet 104				3	9		27	26	25	7	9					106
	Trap 101 Metlakatla Indian Community								1								1
1991	Drift Gillnet 101 Metlakatla Indian Community[a]		2	2	1	3	9	4	2	1	6	3					33
	Drift Gillnet 101-11[b]	3	5	3	3	3		5	3	3	4	3	2	2			39
	Drift Gillnet 106[c]																
	Setnet 101					2											2
	Setnet 101 Metlakatla Indian Community									1							1
	Setnet 103									13							13
	Setnet 104					7		12	5	5	7	2					38
	Trap 101 Metlakatla Indian Community				1												1
1993	Drift Gillnet 101 Metlakatla Indian Community		2	4	5	2	1	3	6	6	12						41
	Drift Gillnet 101-11		4		8	19	20	23	29	75	49	30	21	2		1	281
	Drift Gillnet 106									3	5			4			12
	Setnet 101				7	19	34	15	40		43	21	14				193
	Setnet 101 Metlakatla Indian Community							5		2	7	1					15
	Setnet 102							14									14
	Setnet 104						6	6	20	11	13	38	19				113
	Trap 101 Metlakatla Indian Community					1				1							2
1994	Drift Gillnet 101 Metlakatla Indian Community		7	10	22	19	68	18	33	36	25	20	4				262
	Drift Gillnet 101-11		25	56	29	88	88	121	114	174	132	101	69	11	2	8	1,018
	Drift Gillnet 106		6		5	20	26	15	6	9							87
	Drift Gillnet 108			4													4
	Setnet 101				6	56	14	27	91	51							245
	Setnet 101 Metlakatla Indian Community									3	5						8
	Setnet 102										3						3
	Setnet 104				11	34	41	114	254	78	80	54	10				676
	Troll 101							5									5
	Troll 113							33									33

[a] A District 101 Metlakatla Indian Community gillnet recovery in week 38 was not expanded.
[b] The expanded number of tags for District 101-11 gillnet in week 37 was reduced to 2, so that the estimated contribution of Hugh Smith Lake fish would not exceed the commercial harvest.
[c] A District 106 gillnet recovery in week 38 was not expanded.

Appendix B. (page 3 of 3)

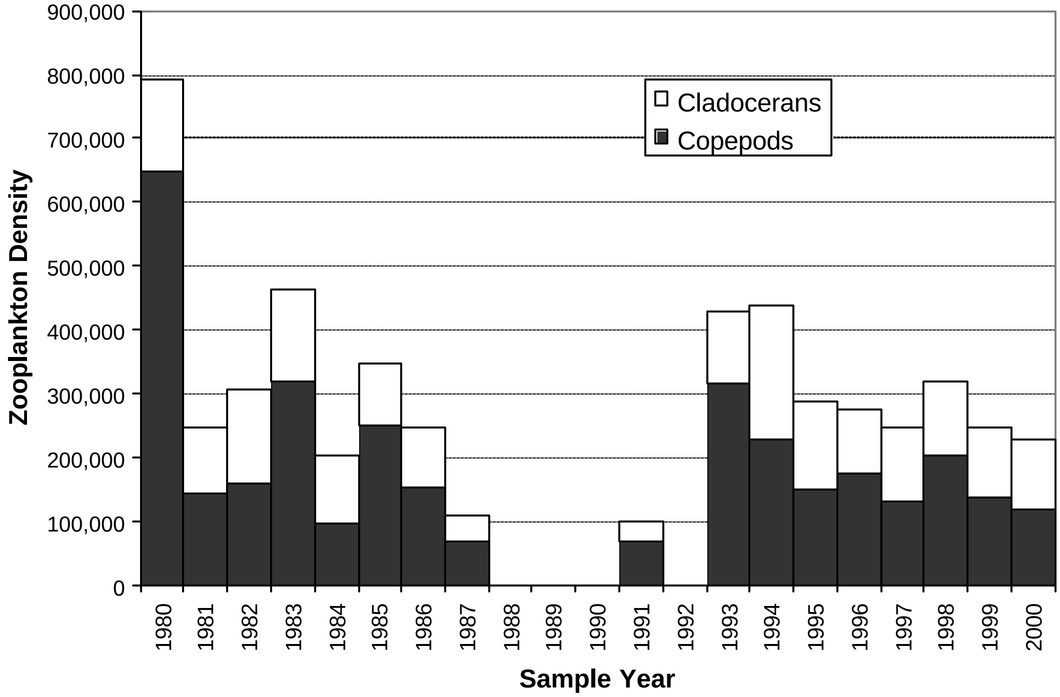
		STATISTICAL WEEK															
Year	Gear/District	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	Grand Total
1995	Drift Gillnet 101 Metlakatla Indian Community	8	16	19	11	16	16	19	2	1		8	2				118
	Drift Gillnet 101-11	4	24	63	51	18	83	20	13	26	11				2		315
	Drift Gillnet 106		10	6			9	3	3	4			6				41
	Setnet 101			16	20	14	39	58	5		6	16					174
	Setnet 101 Metlakatla Indian Community							3	1			11					15
	Setnet 102									10							10
	Setnet 104			2		5	6	5	12	9	25	6	4				74
1996	Drift Gillnet 101 Metlakatla Indian Community	1	3	10	49	15	9	1		2							90
	Drift Gillnet 101-11	12	39	52	132	221	122	115	94	32	14	6	3	5	3		850
	Drift Gillnet 106					6	6		4								16
	Setnet 101					172	52	97	51		51	8					431
	Setnet 101 Metlakatla Indian Community						14										14
	Setnet 102											3					3
	Setnet 104				5	38	7	61	60	26	19	33					249
1997	Drift Gillnet 101 Metlakatla Indian Commu nity[a]	3	27	44	54	73	3	14	5			2					225
	Drift Gillnet 101-11	15	95	53	120	39	51	47	25	20	25	12	9	12	9		532
	Drift Gillnet 106		7	5				3	9				2			2	28
	Setnet 101				109		68		2	11	15	23					228
	Setnet 101 Metlakatla Indian Community[b]										4						4
	Setnet 102					14											14
	Setnet 103									14							14
	Setnet 104				197	90	56	28	16	20	8						415
	Troll 113												7				7
	Troll 154											2					2
1998	Drift Gillnet 101 Metlakatla Indian Community			11	12		3		8		6						40
	Drift Gillnet 101-11		59	92	121	61	151	75	53	3	11	3		2			631
	Drift Gillnet 106				6	3	3	3	3								18
	Setnet 101				15	16	102	28	45	16							222
	Setnet 104					4	13	12	20	8							57
1999	Drift Gillnet 101 Metlakatla Indian Community			8	2		12										22
	Drift Gillnet 101-11			23	30	20	51	15	12	23	8			3			185
	Drift Gillnet 106										2						2
	Setnet 101						18	17									35
	Setnet 104				2	3		4	3	15		7					33

[a] Reported sample for District 101 Metlakatla Indian Community drift gillnet in week 35 was changed from 2,719 to 2,396, so that the sample size would not exceed the catch.
[b] No reported catch for District 101 Metlakatla Indian Community seine in week 26, tag not expanded.

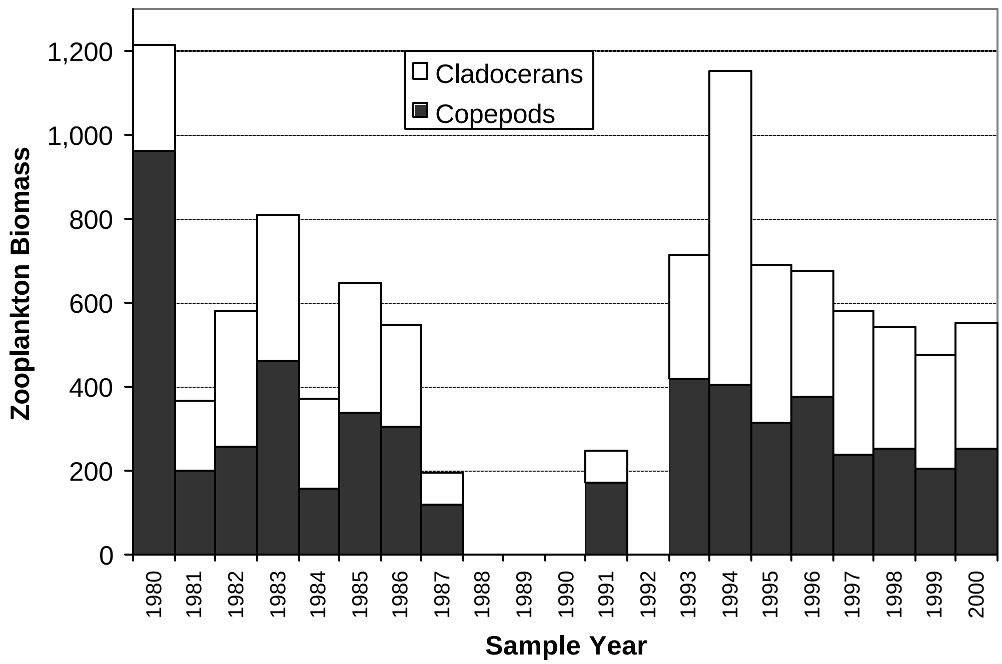
Appendix C. Zooplankton densities and biomass by order for Hugh Smith Lake from 1980–2000.

Year	Mean Seasonal Density of All Species	Mean Weighted Biomass of All Species	Seasonal Mean Density of Copepods	Percent of Total Density in Copepods	Mean Weighted Biomass of Copepods	Percent of Total Biomass in Copepods	Seasonal Mean Density of Cladocerans	Percent of Total Density in Cladocerans	Mean Weighted Biomass of Cladocerans	Percent of Total Biomass in Cladocerans
1980	790,619	1,212.8	648,041	82.0%	958.8	79.1%	142,578	18.0%	254.0	20.9%
1981	246,393	364.2	143,136	58.1%	198.0	54.4%	103,257	41.9%	166.2	45.6%
1982	305,927	581.6	160,830	52.6%	255.9	44.0%	145,097	47.4%	325.7	56.0%
1983	464,146	808.2	318,115	68.5%	460.4	57.0%	146,031	31.5%	347.8	43.0%
1984	202,620	368.5	98,052	48.4%	157.1	42.6%	104,568	51.6%	211.4	57.4%
1985	345,965	646.7	249,317	72.1%	336.3	52.0%	96,648	27.9%	310.4	48.0%
1986	245,769	545.7	153,917	62.6%	302.0	55.3%	91,852	37.4%	243.7	44.7%
1987	108,975	197.0	67,046	61.5%	120.7	61.3%	41,929	38.5%	76.3	38.7%
1988	No data collected these years									
1989	No data collected these years									
1990	No data collected these years									
1991	99,125	244.5	68,348	69.0%	168.5	68.9%	30,777	31.0%	75.9	31.1%
1992	Incomplete data only 1 sample taken for year in August									
1993	428,129	712.0	315,348	73.7%	417.2	58.6%	112,781	26.3%	294.8	41.4%
1994	439,489	1,149.5	226,964	51.6%	403.6	35.1%	212,525	48.4%	745.8	64.9%
1995	286,709	688.0	150,842	52.6%	314.7	45.7%	135,867	47.4%	373.3	54.3%
1996	276,408	675.2	174,091	63.0%	377.5	55.9%	102,317	37.0%	297.7	44.1%
1997	246,341	578.5	130,349	52.9%	239.6	41.4%	115,992	47.1%	339.0	58.6%
1998	319,833	542.7	203,557	63.6%	249.7	46.0%	116,276	36.4%	293.0	54.0%
1999	247,665	476.9	136,188	55.0%	204.6	42.9%	111,478	45.0%	272.2	57.1%
2000	226,986	552.3	117,353	51.7%	249.7	45.2%	109,632	48.3%	302.6	54.8%
1980-2000 Mean	310,653	570.7	197,735	61.1%	278.5	50.4%	112,918	38.9%	292.2	49.6%

Appendix D. Hugh Smith Lake zooplankton densities (number/m^2) by the 2 major orders (*Cladocera* and *Copepoda*) that are important to sockeye salmon production.



Appendix E. Hugh Smith Lake zooplankton biomass (mg/m^2) by the 2 major orders (*Cladocera* and *Copepoda*) that are important to sockeye salmon production.



Appendix F. Southern Southeast Alaska Salmon Purse Seine Harvest 1984 – 2002

YEAR	Chinook	Sockeye	Coho	Pink	Chum
1984	18,954	403,852	301,334	16,909,603	960,116
1985	13,536	616,950	335,353	27,879,795	769,866
1986	11,201	569,146	533,340	41,838,834	1,158,271
1987	3,791	232,994	84,618	3,162,722	283,428
1988	10,314	639,858	128,439	7,480,098	753,643
1989	10,667	724,451	273,088	40,000,082	681,734
1990	8,372	927,309	328,372	23,831,432	444,047
1991	8,532	978,456	296,761	41,614,565	1,013,729
1992	16,304	1,228,496	325,084	17,198,725	1,227,723
1993	5,677	1,527,873	357,655	36,439,429	1,563,714
1994	9,542	1,249,212	499,818	19,881,726	1,448,926
1995	42	836,802	392,863	38,026,474	1,966,640
1996	93	1,402,350	302,742	52,081,986	2,220,313
1997	3,038	1,524,961	114,200	12,985,553	1,830,126
1998	7,371	622,562	301,496	21,713,975	3,150,772
1999	3,284	320,317	183,376	36,768,033	2,701,328
2000	1,305	413,808	143,117	10,826,499	1,908,532
2001	3,329	841,716	425,654	48,611,955	2,155,230
2002	3,839	98,940	206,696	21,328,513	983,756
Average Annual Harvest	**7,326**	**797,898**	**291,263**	**27,293,684**	**1,432,731**

Appendix G. Annual Harvest in District 101 (Tree Point) Drift Gillnet Fishery 1984–2002.

Year	District	Chinook	Sockeye	Coho	Pink	Chum
1984	101	1,485	88,386	35,342	720,528	225,137
1985	101	2,787	173,096	50,967	691,155	233,824
1986	101	1,034	145,699	61,567	906,366	272,870
1987	101	1,785	107,503	36,644	583,145	157,856
1988	101	1,807	116,110	16,847	229,716	500,241
1989	101	1,808	144,936	32,485	1,347,857	299,798
1990	101	1,710	85,691	42,893	580,586	173,986
1991	101	2,077	131,492	70,319	600,530	183,894
1992	101	1,059	244,649	40,001	581,208	282,075
1993	101	1,249	394,098	32,508	481,172	383,317
1994	101	957	100,377	47,013	264,424	489,480
1995	101	1,023	164,294	53,674	789,507	633,903
1996	101	1,257	212,403	33,169	371,035	602,079
1997	101	1,606	169,474	25,687	380,693	351,230
1998	101	1,098	160,506	60,265	649,679	521,397
1999	101	1,844	160,028	64,526	611,445	178,795
2000	101	1,183	94,651	18,209	423,983	199,076
2001	101	1,379	80,041	35,504	517,737	219,716
2002	101	828	120,353	33,516	512,536	144,920
Annual Average Harvest		**1,472**	**152,305**	**41,639**	**591,753**	**318,610**

Appendix H. Derivations of formulas used in the "Ricker" approach to estimated the escapement level expected to provide for maximum sustained yield fisheries.

First, ignore the stochastic features of the Ricker Law. Note that if we take the derivative of the Ricker curve with respect to stock size we get

$$dR/dS = a \exp(-bS) - a\,bS \exp(-bS).$$

To find a maximum or a minimum or a minimum of a function, the usual procedure is to set the derivative of the function equal to zero, and solve for all element in the domain of the function (e.g., Barle and Sherbert 1999). Maxima or the minima of the function are in the values in the range of the function that map from those domain values.

By setting this derivative equal to zero, we find the peak of the curve:

$$\begin{aligned}
&dR/dS = a \exp(-bS) - a\,bS \exp(-bS) = 0,\\
&a \exp(-bS) = a\,bS \exp(-bS),\\
&1 = bS,\\
&S = 1/b.
\end{aligned}$$

By inspection we can see this is a global maximum of the function, and this tells us that an escapement that consistently produces maximum recruitment is near 1 over the *ß* parameter, or more to the point, the *ß* parameter is near 1 over the escapement value that consistently produces the maximum recruitment.

To find the slope of a line tangent to a function at some point in the domain, the usual procedure is to evaluate the derivative of the function at that element of the domain.

By setting $S = 0$ and evaluating the derivative, we find:

$$\begin{aligned}
&slope = a \exp(-b\,0) - a\,b\,0 \exp(-b\,0),\\
&slope = a.
\end{aligned}$$