Fishery Data Series No. 17-46

Updated Passage Estimates for the Pilot Station Sonar Project, 1995–2015

by

Carl T. Pfisterer

Toshihide Hamazaki

and

Bruce C. McIntosh

October 2017

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

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

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by
Carl T. Pfisterer, Bruce C. McIntosh
Alaska Department of Fish and Game, Division of Commercial Fisheries, Fairbanks
and
Toshihide Hamazaki
Alaska Department of Fish and Game, Commercial Fisheries, Anchorage

Alaska Department of Fish and Game
Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska, 99518-1565

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Carl T. Pfisterer and Bruce C. McIntosh,
Alaska Department of Fish and Game, Division of Commercial Fisheries,
1300 College Road, Fairbanks, AK 99701, USA

and

Toshihide Hamazaki,
Alaska Department of Fish and Game, Division of Commercial Fisheries,
333 Raspberry Road, Anchorage, AK 99518, USA

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ABSTRACT

Methodology used to apportion sonar counts to species at the Pilot Station sonar project was modified to limit the influence of fish with very low probability of capture. In addition, net selectivity parameters were recomputed using test gillnet data from 1990 to 2015, prior parameters only used data from 2000 to 2009. The code used to generate estimates was changed to reflect the modified methodology and the updated parameters were used to update daily estimates of fish passage by species from 1995 to 2015.

Key words sonar, dual-frequency identification sonar, DIDSON, net selectivity, Yukon River

INTRODUCTION

The Pilot Station sonar project, located on the Yukon River at river km 197 near the community of Pilot Station, is the most complex and comprehensive fish passage counting project in Alaska. The project was initiated in the 1980s and since 1995 the project has estimated passages of Chinook salmon (*Oncorhynchus tshawytscha*), summer and fall chum salmon (*O. keta*), coho salmon (*O. kisutch*), pink salmon (*O. gorbuscha*), humpback whitefish (*Coregonus pidschian*), broad whitefish (*C. nasus*), sheefish (*Stenodus leucichthys*), and cisco (*Coregonus* spp).

The sonar project consists of 2 processes: (1) estimating total fish passage (N), and (2) estimating species proportion (ps). Then, passage of fish by species (Ns) is estimated by multiplying the 2 components (i.e., $Ns = N{\cdot}ps$). The first step involves estimating total fish passage by counting migrating fish detected using split-beam and imaging sonar, and the second step estimates the relative proportion of each species from the catches of drift gillnets. Although the accuracy of enumerating total passage has been improved by advancement of sonar technologies, estimating species proportions remain very difficult because fishing gear is selective to fish of particular morphologies and behaviors, in other words, every fish has different probability of capture. To compensate for the differential probability of capture, the Pilot Station sonar program employs gillnets of varying mesh sizes (2.75 to 8.5 inches) and fishing occurs at multiple stations along the river. Probability of capture is adjusted by net selectivity for each species (for details see Maxwell et al 1997; Carol and McIntosh 2008; Lozori and McIntosh 2014).

Since initiation of the project, statistical methods for estimating species apportionment have been reviewed and revised several times (see Methods for details), mostly to improve passage estimates of Chinook salmon. Since its inception, Chinook salmon passages by Pilot Station sonar have been considered an underestimate. Chinook salmon estimates at Pilot Station were lower than those estimated by a radiotelemetry mark–recapture study conducted approximately 90 miles upstream of Pilot Station during 2000–2004 (Spencer et al. 2009) as well as those estimated by genetic mark–recapture during 2005–2010 (Hamazaki and Decovich 2014). There are undoubtedly some fish that pass beyond the counting range of the sonar, but this number is probably low based on the distribution of targets observed at the site (Schumann and McIntosh 2017) and would not explain the discrepancy given the low proportion of Chinook salmon that would be applied to these missed counts. A more reasonable explanation is error or bias in species apportionment due to non-representative sampling or problems with the selectivity model. On occasion, it has been observed that least and Bering cisco (*C. sardinella* and *C. laurettae*) have received very high weighting that in many cases appear to inflate the cisco estimates at the expense of salmon estimates. For this reason, we believe that part of the underestimation was due to the relative shape of net selectivity curves between Chinook salmon and other species migrating concurrently (Figure 1). The selectivity parameters for cisco in particular produce narrow curves resulting in low probability of capture (and hence high weighting) for fish that deviate even slightly from the mode. This prompted us to review and revise species apportionment methodologies. Additionally, historical changes in species apportionment methodologies have not been well documented. This report documents the changes made to the selectivity parameters, the methodology used to revise the historical estimates, and a summary of the revised estimates.

OBJECTIVES

- Document changes to the net selectivity parameters used at the Pilot Station sonar project.
- Document methodology used to revise historical estimates.
- Present a summary of the revised historical estimates for the Pilot Station sonar project.

METHODS

HISTORICAL CHANGES OF SPECIES APPORTIONMENT METHODOLOGY

In the Pilot Station sonar project, species proportion (p_i) at a fishing zone of a period is calculated by summing catch per unit effort (CPUE) of each length (l) of a species (i) across all mesh sizes, divided by CPUE of all species and all lengths:

$$\hat{p}_i = \frac{\sum_{l} CPUE_{il}}{\sum_{i,l} CPUE_{il}}. \qquad (1)$$

Historical changes on species apportionment methodology occurred regarding species-length specific CPUE calculation and estimation of net-selectivity (Table 1).

From 1995 to 1999, CPUE was calculated by each mesh and length and then summed across meshes by length:

$$CPUE_{il} = \sum_{m} \frac{c_{ilm}}{s_{ilm} \cdot f_m}, \qquad (2)$$

where c_{ilm} is the number of a species (i) of a length (l) caught by gillnet of a mesh size (m); s_{ilm} is the net selectivity (ranging 0 to 1.0), and f_m is a fishing effort of the gillnet mesh size (m) deployed. To prevent overinflating CPUE, fish with selectivity values less than 0.1 were censored from CPUE calculation (i.e., c_{ilm} = 0 when s_{ilm} < 0.1).

In 2000, CPUE calculation was modified to:

$$CPUE_{uil} = \frac{\sum_{m} c_{ilm}}{\sum_{m} s_{ilm} f_m}. \qquad (3)$$

In this equation, catch of a species (i) of each length (l) caught by gillnet of a mesh size (m) (c_{ilm}) was summed across all mesh sizes, and then divided by product of net selectivity (s_{ilm}), and fishing effort of the gillnet (f_m) summed across all mesh sizes. This eliminated over inflation of catches of low net selectivity, and thus, minimum cut-off net selectivity was eliminated. In 2005, minimum selectivity criteria were reinstated along with new selectivity function. Catches and selectivity less than 0.01 were censored (i.e., s_{ilm} = 0 and c_{ilm} = 0 when s_{ilm} < 0.01).

ESTIMATION OF NET SELECTIVITY

From 1995 to 2004, a modified form of Schunte and Sibert's (1983) equation was used and net selectivity parameters were estimated using all available (1990–1995) data in 1996. It is unknown how often the parameters were updated for estimation of subsequent years:

$$s_j(l) = \exp\left(-\alpha\left(\tfrac{l}{m_j} - \tau\right)\right)\cdot(1-\beta)^{\left(1-\frac{1}{\beta}\right)}\cdot\left(1-\min\left(1, \beta\exp\left(-\alpha\left(\tfrac{l}{m_j}-\tau\right)\right)\right)\right)^{-\left(1-\frac{1}{\beta}\right)} . \quad (4)$$

Net selectivity was originally estimated for 5 salmon species (Chinook, summer chum, fall chum, coho, and pink salmon), large whitefish (Broad, Humpback whitefish), cisco, and other miscellaneous species.

In 2005, the net selectivity model was revised to the Pearson model with the addition of a tangling parameter for fish caught in small mesh size (Bromaghin 2004, 2005):

$$s_j(l) = \left[1+\left(\frac{\lambda}{2\theta}\right)^2\right]^{\theta}\cdot\left[1+\left(\frac{l-\frac{\sigma\lambda}{2\theta}-\tau}{\sigma}\right)^2\right]^{-\theta}\exp\left\{-\lambda\left[\tan^{-1}\left(\frac{l-\frac{\sigma\lambda}{2\theta}-\tau}{\sigma}\right)+\tan^{-1}\left(\frac{\lambda}{2\theta}\right)\right]\right\}$$

$$s_j(l) = \begin{cases} \omega & l > \tau \text{ and } s(l) \le \omega \\ s(l) & \textit{otherwise} \end{cases} . \quad (5)$$

With the addition of more test fishery samples from 1990 to 2005, species-specific whitefish net selectivity (Broad, Humpback) was estimated. In 2009, net selectivity parameters were estimated using 2000–2009 test fishery data to reflect possible net selectivity change associated with morphological change over time.

PROPOSED REVISION 2016

The major revision implemented was to raise the minimum net selectivity to 0.1 and not censor catches (i.e., s_{ilm} = 0.1 when s_{ilm} < 0.1). This minimum threshold approach will include all captured fish in the estimation process while preventing outliers from disproportionally affecting the estimates. We also revised estimation of net selectivity parameters using all historical data (1990–2015) because limiting datasets increases fluctuations in net selectivity estimates. With the large dataset, we were also able to estimate net selectivity of sheefish.

ESTIMATION OF 2005 TOTAL SONAR

Prior to 2005, the project operated dual-beam or split-beam sonar only. In 2005, DIDSON (dual-frequency identification sonar) passage counting was introduced on the left bank for the first time on June 19, about 3 weeks after split-beam sonar counting was started. It was at about this time the left bank profile changed considerably. What was once a gradual slope (approximately 2°) was becoming a cut bank (approximately 10° slope), making it difficult to fully insonify the water column with the narrow split-beam transducers. It was believed the wider beam of the DIDSON would provide better coverage, particularly in the nearshore. For most years prior to 2005, the slope was gradual and we do not believe compromised in this way, therefore estimates from prior years were not adjusted. As expected, the DIDSON tended to count more fish than split-beam for the first 20 m of the left-bank. Thus, during the periods when both sonars were operated, DIDSON counts were used for the first 20 m, unless split-beam counts were higher – which would have occurred in the rare event the DIDSON was improperly aimed.

For the first 20 m counts during the period of June 1–June 18 when the DIDSON was not installed, we estimated DIDSON equivalent counts using a regression as:

$$\hat{N}_{D,d} = \alpha N_{S,d} \, , \tag{6}$$

where $N_{S,d}$ is counts of the first 20 m of left bank by split-beam.

Parameter α was estimated using data from June 19 to July 7. Data from later in the season was not used because the relationship changed as the season progressed and the water level decreased.

ESTIMATION OF PASSAGE BY SPECIES

Though passages of whitefish have been estimated separately, their passages have been combined as other species. This revision reports run size and trend of whitefish species for the first time.

COMPARISON WITH OTHER INDICATORS OF RUN ABUNDANCE

Unfortunately, for most species passing the sonar site, there are few estimates of run abundance that can be used to ground truth the sonar estimates. For Chinook salmon, a mark–recapture project was operated from 2000 to 2004 (Spencer et al. 2009) and the Eagle sonar project started providing estimates in 2005, which, when combined with harvest and estimates of genetic stock identification, provides an estimate of total abundance (Hamazaki and Decovich 2014). The Alaska Department of Fish and Game (ADF&G) also produces an estimate of the drainagewide run of fall chum salmon using escapement estimates on tributaries and historical relationships (Fleischman and Borba 2009; Estensen et al. 2017). All of these independent estimates have sources bias and uncertainty complicating direct comparison; however, they are the best alternative estimates available. The old and new Pilot Station estimates of Chinook and fall chum salmon passage were compared with these other estimates of run size to determine whether the previously observed biases were lessened.

RESULTS

Sample sizes for the selectivity parameters generated were 14,213 Chinook salmon, 85,669 summer chum salmon, 43,813 fall chum salmon, 22,390 coho salmon, 13,448 pink salmon, 2,798 broad whitefish, 8,830 humpback whitefish, 12,360 cisco, 3,490 sheefish, and 2,892 others. In general, the new selectivity parameters (Table 2) were similar to those generated in 2010 using the 2000–2009 data (Table 3), the exceptions are broad whitefish and cisco for which the new curves are slightly broader (Appendix B1). The new sheefish curves appear narrower, but that is only compared to the previous others category to which sheefish were previously grouped.

The revised estimates were generally higher for Chinook, summer chum, fall chum, coho, and pink salmon with reductions in the other species (Tables 4–13). On average, Chinook salmon passage increased by 35,000 (ranging from 4,116 in 1997 to 99,299 in 2005), which corresponds to an increase of 26%. Direction of revised summer chum salmon passage was variable. Though it increased by about 53,000 on average, it ranged from -56,524 in 1997 to 183,886 in 2008. Generally, revised passage was lower before 2005. On the other hand, fall chum passage size increased consistently, with average of 69,000 (2,295 in 1998 to 173,675 in 2006) or 12% on average. Coho salmon increased by 21,000 on average (9,459 in 1998 to 51,250 in 2014) or 16%

on average. The largest increase was pink salmon with average increase of 46,000 or increase of 81%. Those revised changes, however, did not alter overall historical abundance trends.

The effect on individual species within the other grouping (cisco, sheefish, etc.) cannot be easily determined because they were previously grouped and sheefish did not have separate parameters prior to generating these new parameters. Updated daily passage estimates by species can be obtained from the ADF&G, Division of Commercial Fisheries, Arctic-Yukon-Kuskokwim database management system (AYKDBMS)[1].

The 2005 expansion of split-beam estimates for 0–20 m (Table 14) using paired split-beam/DIDSON data resulted a significant positive relationship with DIDSON estimates 25.171 times the split-beam (Table 15). Expanding the split-beam estimates for June 1–18 by this relationship increased Chinook salmon estimates by 71,138, summer chum salmon estimates by 186,052, cisco by 14,671, humpback whitefish by 1,389, broad whitefish by 10,259, and sheefish by 36,836 (Table 16).

DISCUSSION

The combination of updated selectivity parameters and minimum selectivity threshold affected all species to varying degrees. The estimates for all salmon species increased but the combined others decreased. The salmon species least affected was summer chum which only increased 2.69% on average whereas the salmon species most affected was pink salmon at 80.68% (Tables 4–13). It should be noted that the average percent increase in pink salmon is inflated in even years when the run sizes are very small, and a small increase results in a large percentage gain. Others decreased by 31.19% on average (Table 13). Although the historical estimates for others are not broken out by species, it stands to reason the largest change was in cisco because the parameters for that species changed more dramatically than any of the others, as evidenced in the curves (Appendix C1). Specifically, the new parameters result in a much broader curve for cisco, the effect of which is that small deviations from peak efficiency will not result in large changes to selectivity; in other words, the new parameters for cisco are less sensitive to small differences in length than the old parameters were.

Overall, the updated selectivity parameters and minimum selectivity value used in estimation appears to improve the passage estimates at the Pilot Station sonar project. The concern about 1 or 2 fish disproportionally affecting estimates, particularly when in the presence of salmon, appears to be alleviated. The spikes in the daily estimates of others are much reduced, as evidenced in the 2015 field season (Figure 2). Additionally, the new estimates of Chinook and fall chum salmon are much closer to independent estimates of run size. On average, the previous estimates of Chinook salmon were 80% of the mark–recapture estimates, whereas the new estimates are 101% (Table 17). Likewise, the previous estimates of fall chum were 83% of the reconstructed run above Pilot Station whereas the new estimates are 92% (Table 18). Given the improvement in the comparisons of Chinook and fall chum salmon to independent run estimates, these changes should be incorporated into the project methodology going forward.

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[1] AYKDBMS, http://www.adfg.alaska.gov/CommFishR3/WebSite/AYKDBMSWebsite/Default.aspx.

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TABLES AND FIGURES

Table 1.–Historical changes to species apportionment methodology.

	1996-2000	2001-2004	2005-2008	2009-2015	2016
Number of unique selectivity parameters	8	8	9	9	10
	Chinook S. Chum F. Chum Coho Pink Whitefish Cisco Other		Whitefish to Broad Whitefish Humpback Whitefish		Add Sheefish
Years to estimate selectivity parameters	1990-1996	1990-2000	1990-2005	2000-2009	1990-2016
Selectivity function	Eq (4)	Eq(4)	Eq(5)	Eq(5)	Eq(5)
Minimum selectivity	0.1	None	0.01	0.01	0.1
Catches of minimum selectivity	Remove	NA	Remove	Remove	Change to 0.1
Species apportionment formula	Eq (2)	Eq (3)	Eq (3)	Eq (3)	Eq (3)

Table 2.–New net selectivity parameters derived from test fishery data, 1990–2015.

Species	Tau	Sigma	Theta	Lambda	Tangle
Chinook	1.902078925	0.186802768	0.660152352	-0.746205354	0.000000000
Jack	1.902078925	0.186802768	0.660152352	-0.746205354	0.000000000
Chum	2.043533171	0.163348896	0.771205361	0.003003834	0.042598264
Fall Chum	1.889853171	0.351076269	2.437277643	-2.657357848	0.055488254
Coho	1.942331380	0.277217781	0.831494925	-1.555546880	0.058675124
Pink	2.050473071	0.140560927	1.682653781	4.999993900	0.095370569
Broad Whitefish	1.799596516	0.192226804	0.924401709	-1.734789466	0.036245892
Humpback Whitefish	1.899857017	0.243394240	1.096037183	-1.998617643	0.030946407
Cisco	2.172545305	0.523398220	3.052048956	-2.754044551	0.016236055
Sheefish	2.113091700	0.193596124	0.755242549	-1.632160944	0.000000000
Other	2.265164567	0.325796239	0.860665310	-1.474167113	0.000000000

Table 3.–Original selectivity parameters used from 2009 to 2015 derived from 2000 to 2009 test fishery data.

Species	Tau	Sigma	Theta	Lambda	Tangle
Chinook	1.9008	0.2050	0.5923	-0.4334	0.023940
Jack	1.9008	0.2050	0.5923	-0.4334	0.023940
Chum	1.9699	0.1543	0.7504	-0.4841	0.000000
Fall Chum	1.8632	0.2330	1.1954	-1.4361	0.030340
Coho	1.9827	0.3269	0.8686	-1.4557	0.118500
Pink	1.9805	0.2598	1.5542	1.2820	0.164900
Broad Whitefish	1.7774	0.2205	1.4018	-1.9341	0.098090
Humpback Whitefish	1.9021	0.2320	1.1103	-2.0546	0.064150
Cisco	2.0830	0.2223	1.8771	-1.6381	0.180900
Other	2.2604	0.3642	0.9881	-2.2990	0.000000

Table 4.–Yearly Chinook salmon estimates with 90% confidence bounds.

Year	Previous estimates	New estimates	Variance	SE	CV	Lower 90%	Upper 90%	Percent change
1995	162,945	221,357	335,360,998	18,312.864	0.083	191,232	251,482	35.85%
1997	195,647	199,763	421,691,184	20,535.121	0.103	165,983	233,543	2.10%
1998	87,852	108,038	2,673,204,552	51,703.042	0.479	22,986	193,090	22.98%
1999	144,723	184,218	3,358,496,495	57,952.537	0.315	88,886	279,550	27.29%
2000	44,428	54,560	43,569,911	6,600.751	0.121	43,702	65,418	22.81%
2001	99,403	121,089	82,925,356	9,106.336	0.075	106,109	136,069	21.82%
2002	123,213	151,713	590,411,360	24,298.382	0.160	111,742	191,684	23.13%
2003	268,537	318,088	301,327,397	17,358.784	0.055	289,533	346,643	18.45%
2004	156,606	200,761	147,510,216	12,145.378	0.060	180,782	220,740	28.19%
2005	159,915	259,214	665,991,904	25,806.819	0.100	216,762	301,667	62.10%
2006	169,403	228,763	283,466,389	16,836.460	0.074	201,067	256,459	35.04%
2007	125,553	170,246	240,953,740	15,522.685	0.091	144,711	195,781	35.60%
2008	130,643	175,046	168,712,439	12,988.935	0.074	153,679	196,413	33.99%
2009	144,049	177,796	252,322,169	15,884.652	0.089	151,666	203,926	23.43%
2010	120,175	145,088	8,033,173,505	89,627.973	0.618	-2,350	292,526	20.73%
2011	123,369	148,797	150,398,891	12,263.723	0.082	128,623	168,971	20.61%
2012	106,731	127,555	128,570,238	11,338.882	0.089	108,903	146,207	19.51%
2013	114,424	136,805	400,021,291	20,000.532	0.146	103,904	169,706	19.56%
2014	137,755	163,895	129,716,149	11,389.300	0.069	145,160	182,630	18.98%
2015	115,907	146,859	354,178,375	18,819.627	0.128	115,901	177,817	26.70%
							Average	25.94%

Table 5.–Yearly summer chum salmon estimates with 90% confidence bounds.

Year	Previous estimates	New estimates	Variance	SE	CV	Lower 90%	Upper 90%	Percent change
1995	3,556,445	3,620,102	3,980,940,938	63,094.698	0.017	3,516,311	3,723,893	1.79%
1997	1,415,641	1,359,117	1,569,122,001	39,612.145	0.029	1,293,955	1,424,279	-3.99%
1998	826,385	824,901	1,542,144,910	39,270.153	0.048	760,302	889,500	-0.18%
1999	973,708	969,459	2,236,895,659	47,295.831	0.049	891,657	1,047,261	-0.44%
2000	456,271	448,665	207,205,857	14,394.647	0.032	424,986	472,344	-1.67%
2001	441,450	442,546	216,182,048	14,703.131	0.033	418,359	466,733	0.25%
2002	1,088,463	1,097,769	964,836,766	31,061.822	0.028	1,046,672	1,148,866	0.85%
2003	1,168,518	1,183,009	1,359,288,137	36,868.525	0.031	1,122,360	1,243,658	1.24%
2004	1,357,826	1,344,213	921,883,525	30,362.535	0.023	1,294,267	1,394,159	-1.00%
2005	2,442,285	2,572,586	2,298,581,295	47,943.522	0.019	2,493,719	2,651,453	5.34%
2006	3,767,044	3,780,760	8,930,229,537	94,499.892	0.025	3,625,308	3,936,212	0.36%
2007	1,726,885	1,875,491	2,045,252,549	45,224.468	0.024	1,801,097	1,949,885	8.61%
2008	1,665,667	1,849,553	1,736,126,408	41,666.850	0.023	1,781,011	1,918,095	11.04%
2009	1,421,646	1,477,186	1,805,363,834	42,489.573	0.029	1,407,291	1,547,081	3.91%
2010	1,405,533	1,415,027	8,816,530,953	93,896.384	0.066	1,260,567	1,569,487	0.68%
2011	1,977,808	2,051,501	2,218,765,768	47,103.777	0.023	1,974,015	2,128,987	3.73%
2012	2,131,453	2,136,476	2,308,437,662	48,046.203	0.022	2,057,440	2,215,512	0.24%
2013	2,696,939	2,849,683	4,853,505,805	69,667.107	0.024	2,735,081	2,964,285	5.66%
2014	1,926,922	2,020,309	3,615,276,638	60,127.171	0.030	1,921,400	2,119,218	4.85%
2015	1,412,861	1,591,505	3,579,063,695	59,825.276	0.038	1,493,092	1,689,918	12.64%
							Average	2.69%

Table 6.–Yearly fall chum salmon estimates with 90% confidence bounds.

Year	Previous estimates	New estimates	Variance	SE	CV	Lower 90%	Upper 90%	Percent change
1995	1,053,245	1,148,916	2,032,278,761	45,080.803	0.039	1,074,758	1,223,074	9.08%
1997	506,621	579,767	411,211,702	20,278.356	0.035	546,409	613,125	14.44%
1998	372,927	375,222	153,441,909	12,387.167	0.033	354,845	395,599	0.62%
1999	379,493	451,505	232,665,402	15,253.373	0.034	426,413	476,597	18.98%
2000	247,935	273,206	157,230,216	12,539.147	0.046	252,579	293,833	10.19%
2001	376,182	408,961	374,133,329	19,342.526	0.047	377,143	440,779	8.71%
2002	326,858	367,886	306,514,771	17,507.563	0.048	339,086	396,686	12.55%
2003	889,778	923,540	1,299,769,902	36,052.322	0.039	864,234	982,846	3.79%
2004	594,060	633,368	493,112,062	22,206.127	0.035	596,839	669,897	6.62%
2005	1,812,824	1,894,078	4,537,264,383	67,359.219	0.036	1,783,272	2,004,884	4.48%
2006	790,563	964,238	770,005,999	27,748.982	0.029	918,591	1,009,885	21.97%
2007	684,011	740,195	793,856,053	28,175.451	0.038	693,846	786,544	8.21%
2008	615,127	636,525	333,092,389	18,250.819	0.029	606,502	666,548	3.48%
2009	233,307	274,227	549,228,640	23,435.628	0.085	235,675	312,779	17.54%
2010	393,326	458,103	615,064,300	24,800.490	0.054	417,306	498,900	16.47%
2011	764,194	873,877	672,528,459	25,933.154	0.030	831,217	916,537	14.35%
2012	682,650	778,158	1,428,981,615	37,801.873	0.049	715,974	840,342	13.99%
2013	710,805	865,295	1,930,469,983	43,937.114	0.051	793,018	937,572	21.73%
2014	669,627	706,630	1,416,043,642	37,630.355	0.053	644,728	768,532	5.53%
2015	544,329	669,483	613,854,017	24,776.078	0.037	628,726	710,240	22.99%
							Average	11.79%

Table 7.–Yearly coho salmon estimates with 90% confidence bounds.

Year	Previous estimates	New estimates	Variance	SE	CV	Lower 90%	Upper 90%	Percent change
1995	101,806	115,569	296,159,202	17,209.277	0.149	87,260	143,878	13.52%
1997	104,343	118,065	117,217,481	10,826.702	0.092	100,255	135,875	13.15%
1998	136,906	146,365	88,420,292	9,403.206	0.064	130,897	161,833	6.91%
1999	62,521	76,174	28,685,196	5,355.856	0.070	67,364	84,984	21.84%
2000	175,421	206,365	104,205,159	10,208.093	0.049	189,573	223,157	17.64%
2001	137,769	160,272	139,497,066	11,810.888	0.074	140,843	179,701	16.33%
2002	122,566	137,077	59,121,205	7,689.031	0.056	124,429	149,725	11.84%
2003	269,081	280,552	412,126,229	20,300.892	0.072	247,157	313,947	4.26%
2004	188,350	207,844	142,402,268	11,933.242	0.057	188,214	227,474	10.35%
2005	184,281	194,622	317,652,857	17,822.818	0.092	165,303	223,941	5.61%
2006	131,919	163,889	121,967,005	11,043.867	0.067	145,722	182,056	24.23%
2007	173,289	192,406	137,071,776	11,707.766	0.061	173,147	211,665	11.03%
2008	135,570	145,378	71,245,969	8,440.733	0.058	131,493	159,263	7.23%
2009	206,620	240,779	315,329,147	17,757.510	0.074	211,568	269,990	16.53%
2010	155,784	177,724	57,638,106	7,591.976	0.043	165,235	190,213	14.08%
2011	124,931	149,533	159,417,647	12,626.070	0.084	128,763	170,303	19.69%
2012	108,828	130,734	92,194,074	9,601.775	0.073	114,939	146,529	20.13%
2013	86,245	110,515	200,563,120	14,162.031	0.128	87,218	133,812	28.14%
2014	232,181	283,421	292,042,750	17,089.258	0.060	255,309	311,533	22.07%
2015	94,432	121,193	78,928,608	8,884.177	0.073	106,579	135,807	28.34%
							Average	15.65%

Table 8.–Yearly pink salmon estimates with 90% confidence bounds.

Year	Previous estimates	New estimates	Variance	SE	CV	Lower 90%	Upper 90%	Percent change
1995	24,604	53,165	156,126,622	12,495.064	0.235	32,611	73,719	116.08%
1997	2,379	3,872	4,067,645	2,016.840	0.521	554	7,190	62.76%
1998	66,751	103,416	46,319,018	6,805.808	0.066	92,220	114,612	54.93%
1999	1,801	3,947	3,029,370	1,740.509	0.441	1,084	6,810	119.16%
2000	35,501	61,389	48,412,461	6,957.906	0.113	49,943	72,835	72.92%
2001	665	2,846	1,804,294	1,343.240	0.472	636	5,056	327.97%
2002	64,891	123,698	137,934,088	11,744.534	0.095	104,378	143,018	90.62%
2003	4,656	11,370	5,067,999	2,251.222	0.198	7,667	15,073	144.20%
2004	243,375	399,339	421,505,711	20,530.604	0.051	365,566	433,112	64.08%
2005	37,918	61,122	47,136,781	6,865.623	0.112	49,828	72,416	61.20%
2006	115,624	183,006	206,668,401	14,375.966	0.079	159,358	206,654	58.28%
2007	56,701	126,282	186,458,449	13,654.979	0.108	103,820	148,744	122.72%
2008	558,050	580,127	2,748,630,504	52,427.383	0.090	493,884	666,370	3.96%
2009	23,679	34,529	58,639,966	7,657.674	0.222	21,932	47,126	45.82%
2010	747,297	917,731	2,346,365,450	48,439.297	0.053	838,048	997,414	22.81%
2011	6,526	9,754	3,287,470	1,813.138	0.186	6,771	12,737	49.46%
2012	365,124	420,344	1,322,507,140	36,366.291	0.087	360,521	480,167	15.12%
2013	3,557	6,126	15,589,093	3,948.303	0.645	-369	12,621	72.22%
2014	513,599	679,126	1,329,992,116	36,469.057	0.054	619,134	739,118	32.23%
2015	22,421	39,690	57,149,553	7,559.732	0.190	27,254	52,126	77.02%
							Average	80.68%

Table 9.–Yearly cisco estimates with 90% confidence bounds.

Year	New estimates	Variance	SE	CV	Lower 90%	Upper 90%
1995	309,786	683,028,437	26,134.813	0.084	266,794	352,778
1997	214,397	331,176,898	18,198.266	0.085	184,461	244,333
1998	118,820	131,186,612	11,453.672	0.096	99,979	137,661
1999	170,377	190,259,810	13,793.470	0.081	147,687	193,067
2000	167,897	155,574,820	12,472.964	0.074	147,379	188,415
2001	150,350	106,299,598	10,310.170	0.069	133,390	167,310
2002	208,230	329,785,662	18,160.002	0.087	178,357	238,103
2003	123,129	161,414,548	12,704.903	0.103	102,229	144,029
2004	195,371	254,011,518	15,937.739	0.082	169,153	221,589
2005	209,508	225,649,516	15,021.635	0.072	184,798	234,219
2006	258,877	348,352,043	18,664.191	0.072	228,174	289,580
2007	321,498	625,113,721	25,002.274	0.078	280,369	362,627
2008	150,308	313,481,722	17,705.415	0.118	121,183	179,433
2009	257,549	466,466,952	21,597.846	0.084	222,021	293,077
2010	280,019	1,467,745,258	38,311.164	0.137	216,997	343,041
2011	242,950	274,369,495	16,564.103	0.068	215,702	270,198
2012	204,330	203,242,564	14,256.317	0.070	180,878	227,782
2013	383,326	777,472,498	27,883.194	0.073	337,458	429,194
2014	290,524	512,799,531	22,645.077	0.078	253,273	327,775
2015	438,860	724,400,450	26,914.688	0.061	394,585	483,135

Table 10.–Yearly humpback whitefish estimates with 90% confidence bounds.

Year	Season total	Variance	SE	CV	Lower 90%	Upper 90%
1995	309,786	683,028,437	26,134.813	0.084	266,794	352,778
1997	106,845	279,863,170	16,729.111	0.157	79,326	134,364
1998	57,477	774,580,262	27,831.282	0.484	11,695	103,259
1999	124,257	114,566,327	10,703.566	0.086	106,650	141,864
2000	66,479	32,986,876	5,743.420	0.086	57,031	75,927
2001	76,722	21,628,605	4,650.656	0.061	69,072	84,372
2002	130,800	74,100,967	8,608.192	0.066	116,640	144,960
2003	169,423	114,832,922	10,716.012	0.063	151,795	187,051
2004	128,092	101,118,212	10,055.755	0.079	111,550	144,634
2005	85,629	122,106,977	11,050.203	0.129	67,452	103,807
2006	188,407	187,400,646	13,689.436	0.073	165,888	210,926
2007	266,215	571,403,951	23,904.057	0.090	226,893	305,537
2008	101,799	70,773,527	8,412.700	0.083	87,960	115,638
2009	231,742	395,820,004	19,895.226	0.086	199,014	264,470
2010	175,490	448,698,817	21,182.512	0.121	140,645	210,335
2011	152,164	105,395,647	10,266.238	0.067	135,276	169,052
2012	191,732	269,771,381	16,424.719	0.086	164,713	218,751
2013	250,518	359,578,345	18,962.551	0.076	219,325	281,711
2014	191,658	150,772,157	12,278.931	0.064	171,459	211,857
2015	261,688	1,231,806,864	35,097.106	0.134	203,953	319,423

Table 11.–Yearly broad whitefish estimates with 90% confidence bounds.

Year	Season total	Variance	SE	CV	Lower 90%	Upper 90%
1995	26,146	42,380,853	6,510.058	0.249	15,437	36,855
1997	16,270	30,963,737	5,564.507	0.342	7,116	25,424
1998	6,489	2,632,832	1,622.600	0.250	3,820	9,158
1999	13,214	8,593,190	2,931.414	0.222	8,392	18,036
2000	7,362	2,887,018	1,699.123	0.231	4,567	10,157
2001	6,848	1,553,582	1,246.428	0.182	4,798	8,898
2002	16,826	17,433,365	4,175.328	0.248	9,958	23,694
2003	31,368	14,100,028	3,755.000	0.120	25,191	37,545
2004	18,062	13,467,341	3,669.788	0.203	12,025	24,099
2005	18,413	2,809,831	1,676.255	0.091	15,655	21,170
2006	18,768	11,038,987	3,322.497	0.177	13,302	24,234
2007	26,568	46,760,600	6,838.172	0.257	15,319	37,817
2008	10,104	7,678,248	2,770.965	0.274	5,546	14,662
2009	24,532	49,231,371	7,016.507	0.286	12,990	36,074
2010	20,354	19,128,342	4,373.596	0.215	13,159	27,549
2011	14,671	5,950,639	2,439.393	0.166	10,658	18,684
2012	16,814	5,124,603	2,263.759	0.135	13,090	20,538
2013	16,554	11,542,662	3,397.449	0.205	10,965	22,143
2014	19,903	21,915,969	4,681.449	0.235	12,202	27,604
2015	23,122	18,150,939	4,260.392	0.184	16,114	30,130

Table 12.–Yearly sheefish estimates with 90% confidence bounds.

Year	Season total	Variance	SE	CV	Lower 90%	Upper 90%
1995	37,139	143,484,783	11,978.513	0.323	17,434	56,844
1997	20,464	42,419,085	6,512.994	0.318	9,750	31,178
1998	13,513	650,430,607	25,503.541	1.887	-28,440	55,466
1999	11,383	5,453,791	2,335.335	0.205	7,541	15,225
2000	9,725	18,938,796	4,351.873	0.447	2,566	16,884
2001	18,894	13,891,239	3,727.095	0.197	12,763	25,025
2002	20,359	21,372,285	4,623.017	0.227	12,754	27,964
2003	20,902	6,267,050	2,503.408	0.120	16,784	25,020
2004	17,990	10,712,210	3,272.951	0.182	12,606	23,374
2005	53,953	4,895,103	2,212.488	0.041	50,314	57,593
2006	37,875	850,779,159	29,168.119	0.770	-10,107	85,857
2007	63,639	48,960,577	6,997.184	0.110	52,129	75,149
2008	32,399	1,056,843,608	32,509.131	1.003	-21,079	85,877
2009	33,424	24,558,534	4,955.657	0.148	25,272	41,576
2010	50,956	1,035,106,344	32,173.069	0.631	-1,969	103,881
2011	25,139	13,295,934	3,646.359	0.145	19,141	31,137
2012	33,246	20,496,427	4,527.298	0.136	25,799	40,693
2013	49,568	26,733,304	5,170.426	0.104	41,063	58,073
2014	25,098	13,279,352	3,644.085	0.145	19,103	31,093
2015	50,261	22,760,271	4,770.773	0.095	42,413	58,109

Table 13.–Yearly others estimates with 90% confidence bounds.

Year	Previous estimates	New estimates	New with other non-salmon	Variance	SE	CV	Lower 90%	Upper 90%	Percent change
1995	1,011,855	33,344	716,201	1,591,303,646	39,891.147	0.056	650,221	782,181	-29.22%
1997	621,857	18,865	376,841	703,947,857	26,532.016	0.070	332,957	420,725	-39.40%
1998	277,566	14,378	210,677	1,566,124,295	39,574.288	0.188	145,221	276,133	-24.10%
1999	465,515	18,470	337,701	326,489,378	18,069.017	0.054	307,815	367,587	-27.46%
2000	361,222	11,164	262,627	215,946,489	14,695.118	0.056	238,321	286,933	-27.29%
2001	353,431	12,935	265,749	145,818,946	12,075.552	0.045	245,776	285,722	-24.81%
2002	557,779	29,319	405,534	451,387,514	21,245.882	0.052	370,393	440,675	-27.29%
2003	502,878	34,829	379,651	309,890,062	17,603.695	0.046	350,534	408,768	-24.50%
2004	637,257	32,424	391,939	395,001,633	19,874.648	0.051	359,066	424,812	-38.50%
2005	594,318	57,027	424,531	404,655,553	20,116.052	0.047	391,259	457,803	-28.57%
2006	875,899	27,120	531,047	1,414,492,962	37,609.746	0.071	468,840	593,254	-39.37%
2007	1,085,316	83,737	761,657	1,380,393,963	37,153.653	0.049	700,205	823,109	-29.82%
2008	585,303	11,615	306,225	1,454,062,209	38,132.168	0.125	243,154	369,296	-47.68%
2009	765,140	42,669	589,916	984,237,062	31,372.553	0.053	538,026	641,806	-22.90%
2010	862,034	43,086	569,905	4,022,734,577	63,425.031	0.111	465,000	674,810	-33.89%
2011	694,700	18,613	453,537	404,530,427	20,112.942	0.044	420,270	486,804	-34.71%
2012	655,520	17,936	464,058	505,174,915	22,476.097	0.048	426,883	501,233	-29.21%
2013	1,020,417	32,043	732,009	1,192,658,700	34,534.891	0.047	674,888	789,130	-28.26%
2014	945,153	57,648	584,831	739,417,974	27,192.241	0.046	539,855	629,807	-38.12%
2015	1,199,082	80,058	853,989	2,064,797,272	45,440.040	0.053	778,831	929,147	-28.78%
								Avg	-31.19%

Table 14.–Paired HTI and DIDSON data for 0–20 m on the left bank of the Yukon River, 2005.

Date	HTI	DIDSON
6/19/2005	683.13	18,206.96
6/20/2005	656.23	25,271.00
6/21/2005	2,142.90	52,780.63
6/22/2005	3,410.45	112,217.49
6/23/2005	920.29	34,750.84
6/24/2005	462.19	19,296.00
6/25/2005	770.23	72,711.13
6/26/2005	548.38	48,888.09
6/27/2005	584.17	16,298.66
6/28/2005	824.33	13,922.96
6/29/2005	819.01	14,323.77
6/30/2005	517.68	10,738.11
7/1/2005	506.62	9,826.23
7/2/2005	275.14	5,142.84
7/3/2005	418.28	7,834.45
7/4/2005	1,520.65	13,447.19
7/5/2005	1,528.53	7,946.12
7/6/2005	1,016.37	15,324.90
7/7/2005	1,636.71	4,893.50

Table 15.–Regression summary for estimating DIDSON counts based on observed split-beam counts.

```
   Min     1Q Median     3Q    Max
-36305  -6559  -1783   8207  53323

Coefficients:
          Estimate Std. Error t value  Pr(>|t|)
Splitbeam   25.171      3.886   6.478 0.0000043 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 21250 on 18 degrees of freedom
Multiple R-squared:  0.6998, Adjusted R-squared: 0.6832
F-statistic: 41.97 on 1 and 18 DF,  p-value: 0.000004298
```

Table 16.–Additional sonar estimates by species for period before DIDSON was operational, 2005.

Date	Chinook	Jack	Summer chum	Fall Chum	Pink	Coho	Cisco	Humpback whitefish	Broad whitefish	Sheefish	Other	Total
6/1/05	0	0	0	0	0	0	0	0	5,257	13,154	0	18,411
6/2/05	0	0	0	0	0	0	0	0	2,259	5,652	0	7,910
6/3/05	0	0	0	0	0	0	0	0	1,989	4,976	0	6,965
6/4/05	497	0	0	0	0	0	2,351	0	0	2,228	0	5,077
6/5/05	946	0	0	0	0	0	1,840	402	338	2,279	0	5,804
6/6/05	1,166	0	0	0	0	0	2,269	495	417	2,810	0	7,157
6/7/05	2,592	876	0	0	0	0	1,636	0	0	1,667	0	6,771
6/8/05	2,382	370	2,985	0	0	0	2,025	0	0	1,136	0	8,899
6/9/05	2,475	484	4,276	0	0	0	0	0	0	1,470	0	8,705
6/10/05	2,068	356	4,160	0	0	0	461	0	0	632	0	7,676
6/11/05	2,035	394	5,211	0	0	0	2,522	493	0	679	0	11,333
6/12/05	7,295	292	8,747	0	0	0	0	0	0	0	0	16,334
6/13/05	3,674	990	16,788	0	0	0	1,568	0	0	0	0	23,020
6/14/05	16,875	4,198	57,472	0	0	0	0	0	0	0	0	78,545
6/15/05	15,730	1,107	47,234	0	0	0	0	0	0	0	0	64,071
6/16/05	2,261	0	11,572	0	0	0	0	0	0	94	0	13,927
6/17/05	467	267	12,360	0	0	0	0	0	0	59	0	13,153
6/18/05	1,342	0	15,246	0	0	0	0	0	0	0	0	16,588
Total	61,805	9,333	186,052	0	0	0	14,671	1,389	10,259	36,836	0	320,346

Table 17.–Mark–recapture estimates of Chinook salmon with new and old Pilot Station sonar estimates.

Year	Eagle sonar estimates	Canadian proportion	Canadian origin harvest	Mark–recapture	Old Chinook estimates	New Chinook estimates
2002				202,678 [a]	123,213	151,713
2003				309,887 [a]	268,537	318,088
2004				229,739 [a]	156,606	200,761
2005				255,121 [b]	159,915	259,214
2006				237,678 [b]	169,403	228,763
2007				185,548 [b]	125,553	170,246
2008				157,746 [b]	130,643	175,046
2009				222,402 [b]	144,049	177,796
2010				128,859 [b]	120,175	145,088
2011				191,155 [b]	123,369	148,797
2012	34,844	0.435	10,700	104,819 [c]	106,731	127,555
2013	31,140	0.520	10,700	80,462 [c]	114,424	136,805
2014	64,564	0.500	5,000	139,128 [c]	137,755	163,895
2015	83,246	0.426	5,000	206,956 [c]	115,907	146,859
			Average proportion of mark–recapture		0.8012	1.0117
			Median proportion of mark–recapture		0.6972	0.9893

[a] Radiotelemetry mark recapture estimate (Spencer et al. 2009).

[b] Genetic mark–recapture estimate (Hamazaki and DeCovich 2014).

[c] Eagle sonar plus estimated Canadian origin harvest divided by Pilot Station genetic proportion.

Table 18.–Reconstructed fall chum salmon run above Pilot Station with new and old Pilot Station sonar estimates.

Year	Harvest below Pilot Station	Total run reconstruction	Reconstruction above Pilot	Old PS Fall chum	New fall chum estimates
1995	177,183	1,613,147	1,435,964	1,053,245	1,148,916
1997	62,834	705,179	642,345	506,621	579,767
1998	6,424	350,923	344,499	372,927	375,222
1999	27,436	418,275	390,839	379,493	451,505
2000	6,293	252,153	245,860	247,935	273,206
2001	4,929	376,926	371,997	376,182	408,961
2002	2,818	424,085	421,267	326,858	367,886
2003	9,821	792,279	782,458	889,778	923,540
2004	4,303	653,396	649,093	594,060	633,368
2005	135,619	2,167,418	2,031,799	1,812,824	1,894,078
2006	148,273	1,194,186	1,045,913	790,563	964,238
2007	81,195	1,119,467	1,038,272	684,011	740,195
2008	113,431	822,504	709,073	615,127	636,525
2009	25,986	604,719	578,733	233,307	274,227
2010	2,888	569,905	567,017	393,326	458,103
2011	222,557	1,216,866	994,309	764,194	873,877
2012	279,381	1,080,189	800,808	682,650	778,158
2013	219,823	1,241,226	1,021,403	710,805	865,295
2014	119,352	960,063	840,711	669,627	706,630
2015	179,832	843,452	663,620	544,329	669,483
Average proportion of reconstruction above Pilot Station				0.8314	0.9240
Median proportion of reconstruction above Pilot Station				0.8084	0.9122

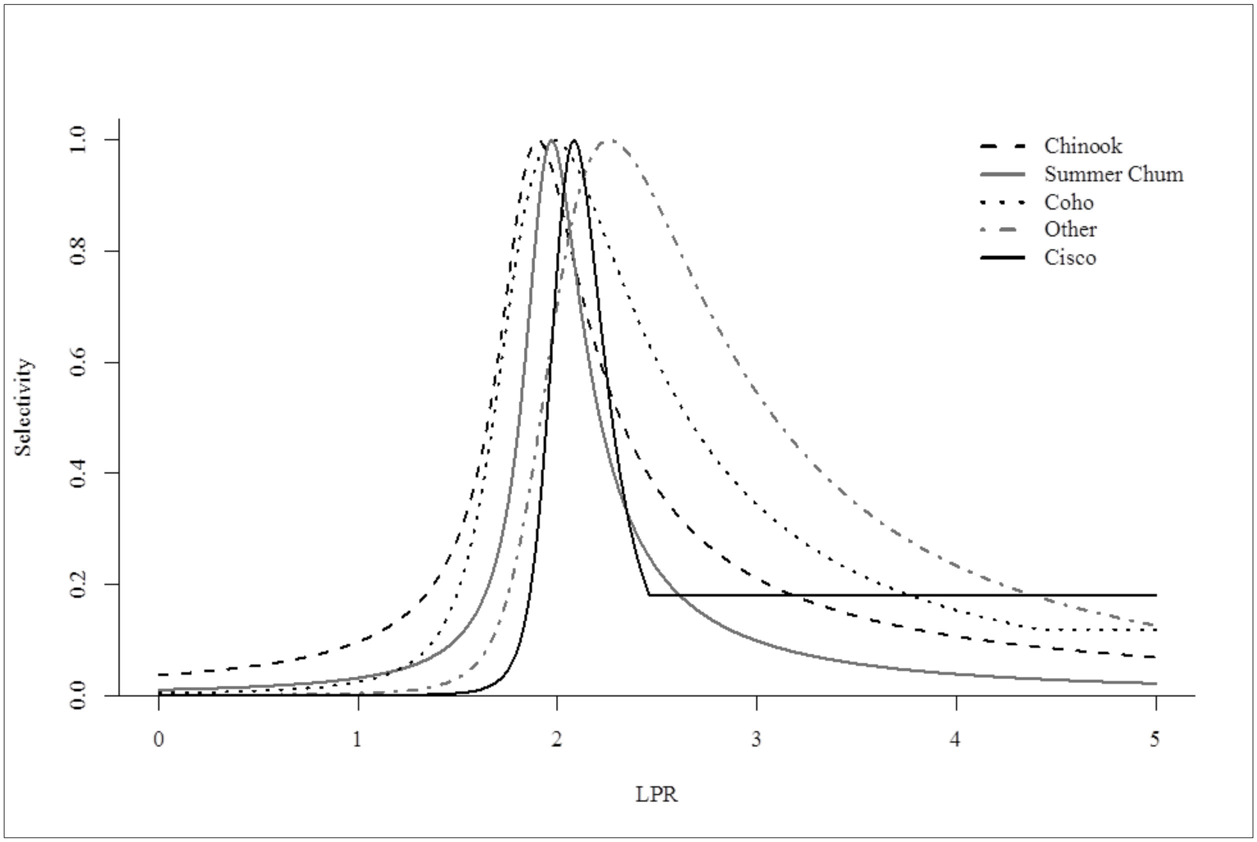

Figure 1.–Selectivity curves for Chinook, summer chum and coho salmon, cisco, and other species.

Note: Parameters derived from 2000 to 2009 test fish catches at the Pilot Station sonar project.

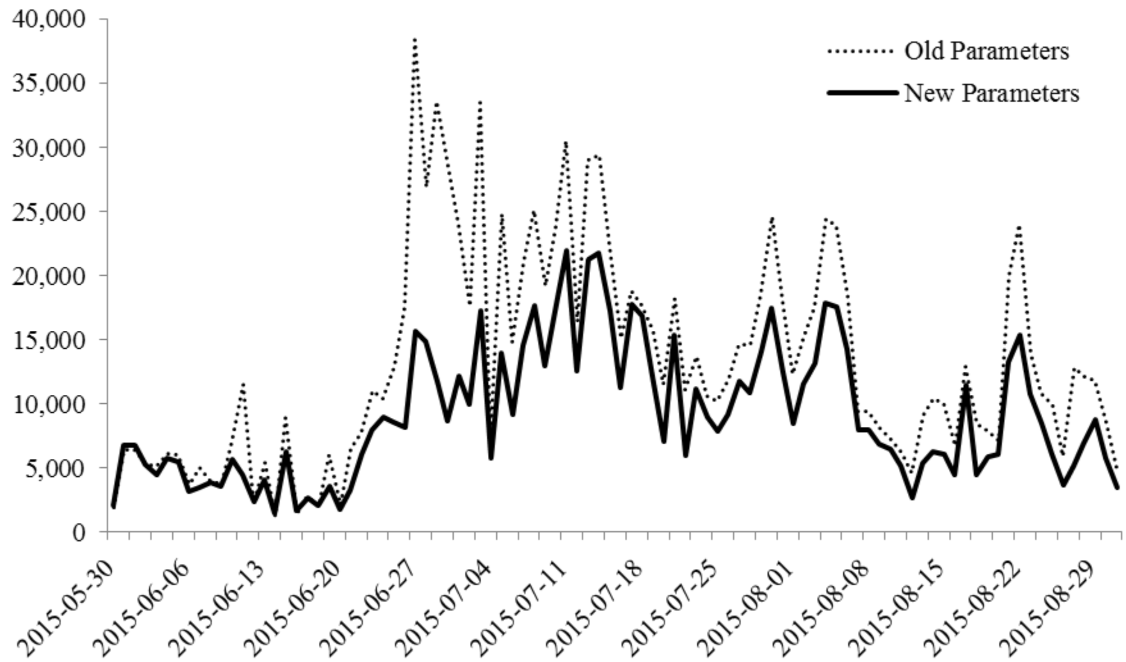

Figure 2.–Daily passage for other species using old and new selectivity parameters, Pilot Station, 2015.

APPENDIX A: CODE USED IN ESTIMATING NET SELECTIVITY PARAMETERS

Appendix A1.–Original SAS code for estimating net selectivity parameters..

```
******************************************************************************
******************************************************************************
**                                                                          **
**  FILE: Net-selectivity.sas                                               **
**  TTITLE: Yukon River Pilot Station Net-Selectivity Parameter             **
**            Estimation Program                                            **
**  PLATFORM: SAS                                                           **
**  DATE: Jan 27 2005                                                       **
**  AUTHOR: TOSHIHIDE "HAMACHAN" HAMAZAKI                                   **
**  UPDATED: 05/24/06 - B. McINTOSH                                         **
******************************************************************************
******************************************************************************;

******************************************************************************
* THIS PROGRAM READS HISTORICAL PILOT STATION TEST-FISHERY CSV OUTPUT   *
*   DATA AND CONDUCT ESTIMATE PEARSON-T NET-SELECTIVITY MODEL PARAMETERS *
******************************************************************************;

******************************************************************************
*  1.0 READ TEST FISHERY DATA FROM ACCESS TEST-FISHERY EXPORTED TO CSV    *
******************************************************************************;

filename tfdat 'D:\Yukon Sonar 2006\SAS06\net_selectivity\fishdat90_05.dat';

*****************************************************************************
* dat: Day of test fishery                                                  *
* startout: time net was deployed                                           *
* fullout: time net was completely deployed                                 *
* startin: time net was retrieved                                           *
* fullin: time net was completely retrieved                                 *
* fathoms: net fathoms                                                      *
* species: fish species                                                     *
* length: length of the fish                                                *
* tfperiods: test fishery period                                            *
*****************************************************************************;

data temp;
  infile tfdat dlm =' ,';
  informat dat dm2 dm3 dm4 dm5 mmddyy. startout fullout startin fullin dm1 time8.;
  input id dat dm1 tfperiod zone $ bank $ mesh fathoms dm2 startout dm3 fullout
       dm4 startin dm5 fullin gmethod $ captain $ spcode length sex $;
 method = upcase(substr(gmethod,2,1));
 if method ne 'D' then delete;

/* This file imput format is exactly the same as the Pilot Station Species
Apportionment test fishery data input form */

drop id gmethod captain sex method dm1-dm5;


data correctd;
 set temp;
  year = year(dat);
  month = month(dat);
```

```
 day = day(dat);
 bank = upcase(substr(bank,2,1));
        zone = upcase(substr(zone,2,1));
 * DEFINE ZONE VARIABLE;
 if bank eq 'R' then
   lzone = 1;
 else if bank eq 'L' and zone eq 'N' then
   lzone = 2;
 else if bank = 'L' and zone eq 'F' then
   lzone = 3;
 else
   lzone = .;

 * COMPUTE DRIFT TIME IN MINUTES AND EFFORT IN FATHOM HOURS;
 if fullout lt startout then
   do;
     t1 = startout;
     t2 = fullout + 86400;
     t3 = startin + 86400;
     t4 = fullin + 86400;
   end;
 else if startin lt fullout then
   do;
     t1 = startout;
     t2 = fullout;
     t3 = startin + 86400;
     t4 = fullin + 86400;
   end;
 else if fullin lt startin then
   do;
     t1 = startout;
     t2 = fullout;
     t3 = startin;
     t4 = fullin;
   end;
 else
   do;
     t1 = startout;
     t2 = fullout;
     t3 = startin;
     t4 = fullin;
   end;
 driftmin = (t3 + t4 - t1 - t2)/120;
 effort = fathoms*driftmin/60;
if (year(dat)  = 1992 ) then delete;
/* Remove data from 1992 because it was an experimental year
 and often times drifts were not done at the present day sonar site */
format dat mmddyy8.;
  drop fullout startin fullin driftmin t1-t4;

*************************************************************************;
*  2.0 EXTRACT UNIQUE DRIFT NET COMBINATIONS (SUITESET)                  *;
*************************************************************************;
*************************************************************************;
*  2.1 EXTARCT UNIQUE DRIFT SET PER DAY                                  *;
*************************************************************************;
```

```
proc summary data=correctd nway;
 class dat mesh;
 var fathoms; *: USE AS A DUMMY VARIABLE;
   output out = mesh1 n=ndrfish;
/* ndrfish = number of drifts used for each mesh per day */
run;

***************************************************************************
*  2.2 INSERT DUMMY COUNT VARIABLE                                              *
*  This variable will be used to identify mesh used for each day               *
***************************************************************************;
data mesh1; set mesh1;
  count = 1;

***************************************************************************
*  2.3 TRANSPOSE DATA AND INSERT DUMMY COUNT VARIABLE                          *
*  Add dummy bariable count2                                                    *
***************************************************************************;
proc transpose data=mesh1 out = mesh2;
  by dat;
  id mesh;
  var count;
run;
/* The transposed data show which net was used in each day by count.
If the mesh was used, it is identified as 1 otherwise .*/
/* Each column represent mesh size */
/* Column name will be  _2d75 _4 _5 _5d25 _5d5 _5d75 _6d5 _7d5 _8d5,
by way of SAS conversion from numerical to nominal data. For instance
mesh 2.75 is converted _2d75, 4.0 is converted to _4
Since this is a temporary file, don't bother to rename the column */

data mesh2; set mesh2;
  count2=1;
/* This dummy variable will be used to count how many times a particular
  mesh size combination was used. */

***************************************************************************;
*  2.4 SUMMARIZE THE UNIQUE NET COMBINATION                                    *;
***************************************************************************;
proc sort data=mesh2;
  by _2d75 _4 _5 _5d25 _5d5 _5d75 _6d5 _7d5 _8d5;
proc means data=mesh2 sum noprint;
  by  _2d75 _4 _5 _5d25 _5d5 _5d75 _6d5 _7d5 _8d5;
  var count2;
  output out = mesh3 n=numday;
run;
/* Make sure this class statment includes all mesh sizes used.  This should
  match with colum title of the mesh2*/
/*numday = number of days the particular mesh combination (suiteset) is used */


***************************************************************************;
*  2.5 ASSIGN UNIQUE SUITESET MUNBER                                           *;
***************************************************************************;
data suiteset (drop = _freq_ _type_);
 set mesh3;
```

```
        suiteset = _n_;
    nummesh = sum(_2d75,_4,_5,_5d25,_5d75,_5d5,_6d5,_7d5,_8d5);
  id = sum(_2d75*100000000,_4*10000000,_5*1000000,_5d25*100000,_5d5*10000,_5d75*1000,
        _6d5*100,_7d5*10,_8d5);
/* suiteset = particular mesh combination
   numesh = number of mesh used in each suiteset
   id = suiteset id number */

*****************************************************************************
*  2.6  ASSOCIATE SUITESET DATA INTO TEST-FISH DATA                          *
*****************************************************************************;
proc sort data = suiteset;
  by  _2d75 _4 _5 _5d25 _5d5 _5d75 _6d5 _7d5 _8d5;
proc sort data = mesh2;
  by  _2d75 _4 _5 _5d25 _5d5 _5d75 _6d5 _7d5 _8d5;

data allfish;
  merge mesh2 suiteset;
  by  _2d75 _4 _5 _5d25 _5d5 _5d75 _6d5 _7d5 _8d5;
  drop _2d75 _4 _5 _5d25 _5d5 _5d75 _6d5 _7d5 _8d5 _name_;
proc sort data = allfish;
  by dat;
proc sort data = correctd;
  by dat;
data allfish;
  merge correctd allfish;
  by dat;
run;


*****************************************************************************
*****************************************************************************
*  3.0: NET-SELECTIVITY CALCULATION PORTION                                  *
*****************************************************************************
*****************************************************************************;

*****************************************************************************
*  3.1    COMBINE SPECIES CLASS AND LENGTH CLASS                             *
*****************************************************************************;

*****************************************************************************
*        ORIGINAL SPECIES CODES                                              *
*  1: CHINOOK SALMON        2: SOCKEYE SALMON     3: COHO SALMON             *
*  4: PINK SALMON        5: SUMMER CHUM SALMON        6: FALL CHUM SALMON *
*  7: CISCO                    8: BRD WHITEFISH              9: HMP WHITEFISH   *
* 10: BURBOT                      11: SHEEFISH                    12: CHAR       *
* 13: SMELT                        14: PIKE                          15: SUCKER   *
* 16: OTHER                                                                  *
*****************************************************************************;
data spdata1;
    set allfish;
   if length = . or length = 0 then delete;   *: DELETE DATA WITH NO LENGTH INFO;
     if spcode >= 10 then spcode = 10; *: COMBINE OTHER FISH;
     if spcode = 2 then spcode = 10;   *: COMBINE SOCKEYE TO OTHERS;
  *: CATEGORIZE FISH LENGTH (FOR CHINOOK AND OTHERS);
  if spcode = 1 then lencat = round(length,20);
```

```
        *: CATEGORIZE FISH LENGTH (FOR COHO, PINK, CHUM);
 if (2 <= spcode) then lencat = round(length,10);
/* lencat = length category by 20 mm increment for chinook,
 and 10 mm increment for others*/

*************************************************************************
*  REFINED SPECIES CODES                                                *
*  1: CHINOOK SALMON          3: COHO SALMON          4: PINK SALMON    *
*  5: SUMMER CHUM SALMON      6: FALL CHUM SALMON     7: CISCO          *
*  8: BRD WHITEFISH        9: HMP WHITEFISH     10: OTHERS              *
*************************************************************************;

* DEFINE SPECIES NAMES;
 if spcode = 1 then
   species = 'CHINOOK';
  else if spcode = 3 then
   species = 'COHO';
  else if spcode = 4 then
   species = 'PINK';
  else if spcode = 5 then
   species = 'SCHUM';
  else if spcode = 6 then
   species = 'FCHUM';
  else if spcode = 7 then
   species = 'CISCO';
  else if spcode = 8 then
 species = 'BRDWF';
  else if spcode = 9 then
 species = 'HMPWF';
  else
   species = 'OTHER';

*************************************************************************;
*  3.1    COMBINE CLASS AND LENGTH CLASS                                *;
*************************************************************************;
proc summary data = spdata1 nway;
 class species lencat;
 var length;
 output out = mlength mean(length)= mlength;
run;
/* mlength = mean lengtha at each length class */

proc sort data = spdata1;
 by species lencat;
run;

/* add mlength to the data */
data spdata1;
 merge spdata1 mlength (drop = _type_ _freq_);
 by species lencat;

*************************************************************************
*  3.2  CALCULATE NUMBER OF FISH IN EACH LENCAT AND DRIFT               *
*       PER DAY.                                                        *
*************************************************************************;
proc summary data = spdata1 nway;
```

```
 class species year suiteset dat mesh mlength;
 var effort;
 output out = fish n(effort)=numfish;
/* numfish = number of fish captured */
/* data set fish contain number of fish for each lencat */
run;

*****************************************************************************;
*  3.3        TRANSPOSE DATA                                                 *;
*****************************************************************************;
proc sort data = fish;
 by species year suiteset dat mlength;
run;
proc transpose data = fish out=fish2;
 by species year suiteset dat mlength;
   id mesh;
 var numfish;
run;
/* Rename column into other name indicating mesh size */
data fish2;
  rename _2D75 = m275 _4 = m400 _5 = m500 _5D25 = m525 _5D5 = m550
  _5D75 = m575 _6D5 = m650 _7D5 = m750 _8D5 = m850;
  set fish2;
proc sort data = fish2;
 by suiteset;
run;

*****************************************************************************;
*  3.4        MERGE DATA WITH SUITESET DATA                                  *;
*                  AND DIFFERENTIATE MISSING AND REAL ZERO (0) DATAPOINTS    *;
*****************************************************************************;
data fish2;
  merge fish2 suiteset;
  by suiteset;

data fish2; set fish2;
  if (m275 = . and _2d75 = 1) then m275=0;
  /* this indicate that net was used but the fish was not caght */
  if (m400 = . and _4 = 1) then m400=0;
  if (m500 = . and _5 = 1) then m500=0;
  if (m525 = . and _5d25 = 1) then m525=0;
  if (m550 = . and _5d5 = 1) then m550=0;
  if (m575 = . and _5d75 = 1) then m575=0;
  if (m650 = . and _6d5 = 1) then m650=0;
  if (m750 = . and _7d5 = 1) then m750=0;
  if (m850 = . and _8d5 = 1) then m850=0;
 drop _name_ _2d75 _4 _5 _5d25 _5d5 _5d75 _6d5 _7d5 _8d5 numday nummesh;
run;

*****************************************************************************;
*  3.5        TRANSPOSE DATA BACK TO THE ORIGINAL FORM                       *;
*                  REMOVE MISSING VALUE SECTION                              *;
*****************************************************************************;
proc sort data=fish2;
 by species year suiteset dat mlength;
proc transpose data = fish2 out=fish3;
```

```
 by species year suiteset dat mlength;
run;
/* convert nominal mesh size data to numerical one */
data fish3;
 set fish3;
  if _name_ = 'm275' then mesh=2.75;
  if _name_ = 'm400' then mesh=4.0;
  if _name_ = 'm500' then mesh=5.0;
  if _name_ = 'm525' then mesh=5.25;
  if _name_ = 'm550' then mesh=5.5;
  if _name_ = 'm575' then mesh=5.75;
  if _name_ = 'm650' then mesh=6.5;
  if _name_ = 'm750' then mesh=7.5;
  if _name_ = 'm850' then mesh=8.5;
  if col1 = . then delete;
  numfish = col1;
  drop _name_ col1;

****************************************************************************
*  3.6        IDENTIFY UNIQUE SET OF EFFORT DATA                           *
****************************************************************************;
proc summary data = spdata1 nway;
 class year suiteset dat tfperiod startout mesh;
 var effort;
 output out = eff  min(effort)=effort;
run;

****************************************************************************
*  3.7        SUMMARIZE EFFORT DATA PER DATE                               *
****************************************************************************;
proc summary data = eff nway;
 class year suiteset dat mesh;
 var effort;
 output out = eff2  sum(effort)=effort;
run;

****************************************************************************
*  3.8        MERGE EFFORT DATA WITH NUMFISH DATA PER DATE                               *
*                   SPDATA2 IS THE REFINED ORIGINAL DATA FOR FURTHER ANALYSES    *
****************************************************************************;
proc sort data = fish3;
 by year suiteset dat mesh;
proc sort data = eff2;
 by year suiteset dat mesh;
data spdata2;
 merge fish3 eff2;
 by year suiteset dat mesh;
 cpue = numfish/effort;
/* cpue = catch per effort unit */
 lpr = mlength/(mesh*25.4*2);
/* lpr = ratio betwen fish length and mesh size in mm */
 drop _type_ _freq_;

****************************************************************************
*      3.9 GET SUITESET MESH NUMBER DATA                                   *
*     AND ADD BACK TO THE DATA                                             *
```

```
***************************************************************************;
data meshnum;
 set suiteset;
 keep id suiteset nummesh;
proc sort data = spdata2;
 by suiteset;
proc sort data = meshnum;
 by suiteset;
data spdata2;
 merge spdata2(in=a) meshnum;
 by suiteset;
 if a;
proc sort data = spdata2; *: SPDATA2 IS A REFINED ORIGINAL DATA;
 by species year id suiteset dat mlength mesh;
run;

***************************************************************************
*       3.10   CALCULATE CPUE BY ANNUAL                                   *
***************************************************************************;

***************************************************************************
*       3.11 SUMMARIZE DATA BY SPECIES SUITESET MESH MLENGTH              *
***************************************************************************;
proc summary data = spdata2 nway;
 class species suiteset nummesh mlength mesh lpr;
 var cpue;
 output out = spdata3 sum(cpue)= ;
run;
/* spdata3 is summrized cpue per mesh & lenght*/
proc summary data = spdata2 nway;
 class species suiteset nummesh mlength;
 var cpue;
 output out = temp2 sum(cpue)= sumcpue;
run;
/* temp2 is summrized cpue per mesh */

***************************************************************************
*       3.12 FIND NUMBER OF ZEROS IN EACH CATEGORY                        *
***************************************************************************;
data temp21;
 set spdata3;
 if cpue =0;
proc summary data = temp21 nway;
 class species suiteset mlength;
 var cpue;
 output out = temp21 n = n0;
/* n0: number of zero catches */
run;

***************************************************************************
*       3.13 CALCULATTE LPR, TYPE B SELECTIVITY VALUE (SELECTS)           *
*        AND NUMBER OF NON-ZEROS TO CALCULATE THE SELECTS                 *
***************************************************************************;
proc sort data = spdata3;
 by species suiteset mlength;
data spdata3;
```

```
 merge spdata3 temp2 temp21;
 by species suiteset mlength;
 selects = cpue/sumcpue;
/* selects = empirical net-selectivity */
 if n0 = . then n0 = 0;
 nonzero = nummesh - n0;
 drop _type_ _freq_ n0;
run;

/*
**************************************************************************
*       3.14 OUTPUT FILES FOR SELECTIVITY FUNCTION CALCULATION              *
**************************************************************************;
filename lpr 'e:\Projects\Net_Selectivity\Pilot_Station\tfishdata\lpr.dat';
data asciiout; set temp2;
file lpr;
 put species suiteset lencat numfish efforts lpr select;
run;
*/

**************************************************************************
*       3.15 FINAL TABLE REFORMAT FOR NETSELECTIVITY PARAMETER ESTIMATION    *
**************************************************************************;
proc sort data = spdata3;
 by species suiteset mlength;

proc transpose data = spdata3 out=tempt;
 var lpr;
 by species suiteset mlength;
 id mesh;
data tempt;
   set tempt;
   rename _2D75 = m275 _4 = m400 _5 = m500 _5D25 = m525 _5D5 = m550
   _5D75 = m575 _6D5 = m650 _7D5 = m750 _8D5 = m850;
data spdata3;
 merge spdata3 tempt;
 by species suiteset mlength;
    drop _type_ _freq_;


**************************************************************************
**************************************************************************
**  4.0     NET SELECTIVITY ANALYSES                                          **
**  Parameter Estimation: Pearson T model                                     **
**************************************************************************
**************************************************************************;
data spdata4;
 set spdata3;

proc sort;
 by species;

**************************************************************************
*  4.1  Maximum likelihood estimation                                        *
**************************************************************************;
/* proc nlmixed is used to do a maximum likelihood estimation of netselectivity
```

```
 parameters */
proc nlmixed data=spdata4 tech= dbldog;
 by species;
   title1 'Gillnet Selectivity: Person T';
 parms  tau = 2 sigma = .5 theta = 1 lamda = -1 w = 0.15;
 bounds 0<tau<3, 0<sigma<5, 0<theta<10, -3<lamda<5, 0<= w <=0.5;
/* original, default values:

 parms  tau = 2 sigma = 1 theta = 4 lamda = 0 w = 0.15;
 bounds 0<tau<3, 0<sigma<5, 0<theta<10, -3<lamda<5, 0<= w <=0.5;*/

/* parms = initial value for maximum likelihood estimation */
/* bounds = possible range each parameter can take */
/* Maximum likelihood parameter estimation is often influenced by initial parameter
   value and parameter bounds.  When estimates do not seem right, tweak values of
   parms and bounds */

   dum1 = lamda/(2.0*theta);
   dum2 = (lpr - sigma*dum1 - tau)/sigma;
   dum3 = (1 + dum1**2)**theta;
   g = dum3*((1 + (((lpr - sigma*dum1 - tau)/sigma)**2))**(-theta))
              *exp(-lamda*(atan((lpr - sigma*dum1 - tau)/sigma) + atan(dum1)));
   g275 =  dum3*((1 + (((m275 - sigma*dum1 - tau)/sigma)**2))**(-theta))
              *exp(-lamda*(atan((m275 - sigma*dum1 - tau)/sigma) + atan(dum1)));
   g400 = dum3*((1 + (((m400 - sigma*dum1 - tau)/sigma)**2))**(-theta))
              *exp(-lamda*(atan((m400 - sigma*dum1 - tau)/sigma) + atan(dum1)));
 g500 = dum3*((1 + (((m500 - sigma*dum1 - tau)/sigma)**2))**(-theta))
              *exp(-lamda*(atan((m500 - sigma*dum1 - tau)/sigma) + atan(dum1)));
 g525 = dum3*((1 + (((m525 - sigma*dum1 - tau)/sigma)**2))**(-theta))
              *exp(-lamda*(atan((m525 - sigma*dum1 - tau)/sigma) + atan(dum1)));
 g550 = dum3*((1 + (((m550 - sigma*dum1 - tau)/sigma)**2))**(-theta))
              *exp(-lamda*(atan((m550 - sigma*dum1 - tau)/sigma) + atan(dum1)));
 g575 = dum3*((1 + (((m575 - sigma*dum1 - tau)/sigma)**2))**(-theta))
              *exp(-lamda*(atan((m575 - sigma*dum1 - tau)/sigma) + atan(dum1)));
 g650 = dum3*((1 + (((m650 - sigma*dum1 - tau)/sigma)**2))**(-theta))
              *exp(-lamda*(atan((m650 - sigma*dum1 - tau)/sigma) + atan(dum1)));
 g750 = dum3*((1 + (((m750 - sigma*dum1 - tau)/sigma)**2))**(-theta))
              *exp(-lamda*(atan((m750 - sigma*dum1 - tau)/sigma) + atan(dum1)));
 g850 = dum3*((1 + (((m850 - sigma*dum1 - tau)/sigma)**2))**(-theta))
              *exp(-lamda*(atan((m850 - sigma*dum1 - tau)/sigma) + atan(dum1)));
 f = max(sign(tau-lpr)*g,g,min(w,sign(lpr-tau)*w));
 f275 = max(sign(tau-m275)*g275,g275,min(w,sign(m275-tau)*w));
 f400 = max(sign(tau-m400)*g400,g400,min(w,sign(m400-tau)*w));
 f500 = max(sign(tau-m500)*g500,g500,min(w,sign(m500-tau)*w));
 f525 = max(sign(tau-m525)*g525,g525,min(w,sign(m525-tau)*w));
 f550 = max(sign(tau-m550)*g550,g550,min(w,sign(m550-tau)*w));
 f575 = max(sign(tau-m575)*g575,g575,min(w,sign(m575-tau)*w));
 f650 = max(sign(tau-m650)*g650,g650,min(w,sign(m650-tau)*w));
 f750 = max(sign(tau-m750)*g750,g750,min(w,sign(m750-tau)*w));
 f850 = max(sign(tau-m850)*g850,g850,min(w,sign(m850-tau)*w));
 sums = sum(f275,f400,f500,f525,f550,f575,f650,f750,f850)-(9-nummesh)*w;
 phi = f/sums;
 ll = cpue*log(phi);
id f sums phi;
model selects ~ general(ll);
predict phi out = resid;
```

```
/* resid is used for diagnosis */
run;

****************************************************************************
*  4.2  MODEL PARAMETER DIAGNOSIS                                          *
****************************************************************************;
data resid;
 set resid;
 if selects > 0 then do;
 ll = cpue*log(phi);
 cl = cpue*log(selects);
 end;
 resid = phi*sumcpue - cpue;
 v = selects*sums;
data temp;
 set resid;
 if nonzero > 1;
proc summary data = temp nway;
 class species;
 var ll cl;
 output out = temp sum =;
data temp;
 set temp;
 d = 2*(cl-ll);
/* d = deviande: The smaller deviance the better model */
proc print data = temp;
run;

****************************************************************************
*  4.3  MODEL PARAMETER DIAGNOSIS SCATTER PLOT                             *
****************************************************************************;
goptions reset=global gunit=pct border cback=white
        colors=(black blue green red)
        ftitle=swissb ftext=swiss htitle=6 htext=4;
symbol1
 color=black value = dot;
symbol2
 color=blue value = dot;
symbol3
 color=red value = dot;

proc gplot data=resid;
   bubble v*lpr = cpue;
   plot v*lpr f*lpr /overlay;
  by species;
run;
/* Look at the graph if the line (model) is going through center of
clouds */
quit;
```

Appendix A2.–*R* code used to generate new selectivity parameters.

```
###########################################################################################
#  Net Selectivity parmaeter estimates R code
#
#  Developed by:  Toshihide Hamachan Hamazaki
#  Modified by:       Carl Thomas Pfisterer 11/3/2015
###########################################################################################
library(gplots)
library(data.table)
library(stringr)
rm(list=ls(all=TRUE))
source('~/Documents/RWork/TestFishQuery.R')      #Needed for functions to query database for test fish data

###########################################################################################
#
#        This first section contains all the functions used to process the data and for the selectivity
#        model.  The section after the functions are the commands to read and process the data, optimize
#        selectivity parameters, and produce the plots.
#
###########################################################################################

#        ***************************                  FUNCTIONS        ******************************   #

###########################################################################################
#   dataclean()
#        Computes the effort in fathom hours
###########################################################################################
dataclean<-function(tfdata){
 # convert time factor to numeric and calculate effort
   t1 <- strptime(tfdata$startin,format="%H:%M:%S")
   t2 <- strptime(tfdata$startout,format="%H:%M:%S")
   t3 <- strptime(tfdata$fullin,format="%H:%M:%S")
   t4 <- strptime(tfdata$fullout,format="%H:%M:%S")
 # Calculate minutes nets are in the water: t5 is soak time.
   t5 <- (t1-t4)/2+(t3-t2)/2
 # Special converstion case when netting goes to next day
   t5[which(t4<t2)] <- (t1-t4)/2+(t3+84600-t2)/2
   t5[which(t1<t4)] <- (t1+84600-t4)/2+(t3+84600-t2)/1
 # Add effort data to the file: Effort is calculated as soak time*net fathom
   tfdata$effort <- as.numeric(tfdata$netlength*t5)/60/60
   #tfdata$effort <- as.numeric(tfdata$fathoms*t5)/60
   tfdata$date = as.Date(tfdata$date,format="%Y-%m-%d")
   #tfdata$date <- strptime(tfdata$date,format="%m/%d/%Y")
 # Remove unnecessary data
   # Keep only drift data
   tfdata <- tfdata[which(tfdata$method=='D'),]
   # Remove if effort is NA
   tfdata <- tfdata[which(tfdata$effort !='NA'),]
   # For all species other then Chinook, Jack, Summer Chum, Fall Chum, Coho, Pink, Broad Whitefish, Humpback
 Whitefish and Cisco to Other
   tfdata$species[which(tfdata$species!="Chinook" & tfdata$species!="Jack" & tfdata$species!="Chum" &
 tfdata$species!="Fall Chum" & tfdata$species!="Coho" & tfdata$species!="Pink" & tfdata$species!="Broad
 Whitefish" & tfdata$species!="Humpback Whitefish" & tfdata$species!="Cisco" & tfdata$species!="Sheefish" &
 tfdata$species!="Longnose Sucker" & tfdata$species!="No Catch")]='Other'
   # Keep only columns necessary
```

```
   tfdata <- tfdata[c("date","period","zone","bank","mesh","startout","species","length","sex","effort")]
   tfdata
}

######################################################################################################
#       netsuite()
#       Determine the unique netsuite fished for each catch
######################################################################################################
 netsuite = function(data){
 tp1 = unique(data.frame(date=data$date,mesh=data$mesh));
 #      Add dummy variable
 tp1$d = 1;
 #      Transpose data to give each net fished each day
 tp2 = reshape(tp1,idvar='date',timevar='mesh',direction='wide');
 #      Extract unique net combimation used: allused nets are 2.75, 4.0, 5.25,5.5,5.75,6.5,7.5,8.5
 suiteset = unique(tp2[,2:length(tp2)])
 #      Calculate total number of meshizes used (nnets)
   suiteset$nnets <- rowSums(suiteset,na.rm = TRUE)
 #      Assign a unique netset combination number (netset)
   suiteset$netset <- 1:length(suiteset$d.2.75)
 #      Merge netset combination number
 tp2 = merge(tp2,suiteset,by=names(tp2)[2:length(names(tp2))])
 #      Keep only variables necessary
 #   suiteset <- suiteset[c('date','nnets','netset')]
 #      Convert date variable, so that it can be joined
   tp2$date <- as.POSIXct(tp2$date)
   data$date <- as.POSIXct(data$date)
 # Merge nnets and netset to each date
   data <- merge(data,tp2, by='date')

   list(data=data,suiteset=suiteset)
}

######################################################################################################
#       binlengths()
#       Bins fish by length in 20mm bins for Chinook, 10mm bins for other species. Computes the mean
#       length within each bin and the total number.
######################################################################################################
binlengths = function(data){
 data$lencat=                                                                         ifelse(data$species
 =='Chinook',round(data$length/20+0.0001)*20,round(data$length/10+0.0001)*10)
 # create temporal data without zero catch info
   spdata1 <- data[which(data$length != 0),]
   attach(spdata1)
   mlength <- aggregate(length, by = list(species, lencat), FUN = "mean")
   names(mlength) <- c('species','lencat','mlength')
   spdata1 <- merge(spdata1,mlength, by = c('species','lencat'))
   detach()

   spdata1
}

######################################################################################################
#       numfishbyspecies()
#       Returns the number of fish by species
######################################################################################################
```

```
numfishbyspecies = function(data,suiteset){
   #    transpose catch data to get how many fish caught by species
   #    calculate the number of fish caught by day and mesh
   fish1 <- aggregate(sex~species+date+netset+mesh+mlength,data=data,FUN='length')
   fish2 <- reshape(fish1,idvar=c('species','date','netset', 'mlength'), timevar='mesh',direction='wide')
 # merge to netset
   fish2 <- merge(fish2,suiteset, by = 'netset')
   fish2 = fish2[,c(1:4,length(fish2),(order(names(fish2)[5:(length(fish2)-1)])+4))]      #Reorder columns and sort by
 mesh size
 # add zero to fish without
 numNets = (length(fish2)-1-4)/2;        #Determine the number of mesh sizes present
 for(i in 1:numNets){       #Loop though each mesh size
        index1 = i+5;
        index2 = numNets+i+5;
        name = paste('m',substr(names(fish2)[index1],3,20),sep='.')
        fish2[,(length(fish2)+1)] = ifelse(is.na(fish2[,index2])& fish2[,index1]==1,0,fish2[,index2])
        names(fish2)[length(fish2)] = paste('m',substr(names(fish2)[index1],3,20),sep='.')
 }
 # Keep only variables necessary
 fish2 = fish2[,c(3,2,1,5,4,(numNets*2+6):(length(fish2)))]
 # Change to the long form.
   fish3<-reshape(fish2,idvar=c('species','date','netset','mlength'),varying=
 list(names(fish2)[6:length(fish2)]),timevar='mesh',times  =  as.numeric(substr(names(fish2)[6:length(fish2)],3,20)),
 direction='long',v.name='nfish')
 # Delete row name
   row.names(fish3) <- NULL
 # Remove nfish = na: nfish =NA means that the net set was not used on the day of fishing.
   fish3 <-fish3[which(fish3$nfish !='NA'),]
   fish3$date = as.POSIXct(fish3$date);

   fish3
}

###############################################################################################
#       computeuniqueeffort()
###############################################################################################
computeuniqueeffort = function(data){
 # Extract unique effort data
   eff <- aggregate(effort~date+netset+period+startout+mesh, data=data, FUN = "min")
 # Add names to the eff data
   names(eff) <- c('date','netset','period', 'startout', 'mesh','effort')
 # Summarize to
   eff2 <- aggregate(effort ~ date + netset + mesh,data=eff,FUN = "sum")
   names(eff2) <- c('date','netset','mesh','effort')
   eff2 <- eff2[order(eff2$date,eff2$mesh), ]
   eff2$date <- as.POSIXct(eff2$date)

   eff2
}

###############################################################################################
#       summarizedata()
#       Combines cpue by species, length, and net suite and computes empirical net selectivity
###############################################################################################
summarizedata = function(data){
 # Summarize cpue by combining by species, length, suiteset meshsize
```

```
  mlcpue <- aggregate(cpue~species+netset+nnets+mesh+mlength+lpr, data=data, FUN = 'sum')
 # Summarize cpue by combining by species, length, suiteset
  lcpue <- aggregate(cpue~species+netset+nnets+mlength, data=data, FUN = 'sum')
  names(lcpue)[length(names(lcpue))] <- 'Scpue'
 # Calculate the number of zero catch days for
   n0 <- mlcpue[which(mlcpue$cpue ==0),]
   n.0 <- aggregate(cpue~species+netset+nnets+mlength, data=data, FUN = 'length')
 # Merge the 2 data to calculate empirical net selectivity
  names(n.0)[length(names(n.0))] <- 'n0'
 # Merger
  spdata3 <- merge(mlcpue, lcpue, by=c('species','netset','nnets','mlength'))
  spdata3$select <- spdata3$cpue/spdata3$Scpue
  spdata3 <- merge(spdata3, n.0, by = c('species','netset','nnets','mlength'))
  spdata3$nonzero <- spdata3$nnets - spdata3$n0

 #   Summarize data by combining all by suiteset
 # Add transpose data, so that which nets are used each day
   spdata4  <-  reshape(spdata3,idvar=c('species','netset','nnets','mlength'),drop=c('cpue','Scpue','select','n0','nonzero')
 ,timevar='mesh',direction='wide')
   spdata4 <- merge(spdata3, spdata4, by = c('species','netset','nnets','mlength'))

   spdata4
}

##########################################################################################
#        likelihood()
#   Net Selectivity Model
##########################################################################################
likelihood <- function(par,likedat){
   tau <- par[1]
   sigma <- par[2]
   theta <- par[3]
   lamda <- par[4]
   tangle <- par[5]
   dm1 <- lamda/(2.0*theta)
   dm2 <- (likedat[,'lpr'] - sigma*dm1 - tau)/sigma
   dm3 <- (1 + dm1^2)^theta
   g    <-    dm3*((1+(((likedat[,'lpr']-sigma*dm1    -    tau)/sigma)^2))^(-theta))*exp(-lamda*(atan((likedat[,'lpr']    -
 sigma*dm1 - tau)/sigma)+atan(dm1)))
 # Add tangle parameter
   f <- pmax((tau<likedat[,'lpr'])*tangle,g)
   matrixNames = colnames(likedat);
   for(i in 1:(length(matrixNames)-10)){
         g=dm3*((1+(((likedat[,matrixNames[i+10]]-sigma*dm1                -                tau)/sigma)^2))^(-theta))*exp(-
 lamda*(atan((likedat[,matrixNames[i+10]] - sigma*dm1 - tau)/sigma)+atan(dm1)))
         if(i==1){sumValue=pmax((tau<likedat[,matrixNames[i+10]])*tangle,g)}
         else{sumValue = sum(sumValue,pmax((tau<likedat[,matrixNames[i+10]])*tangle,g),na.rm=TRUE)}
   }
 #### Likelihood calculation  ##############################################################
 loglink = -sum(likedat[,'cpue']*log(f/sumValue));
 return(loglink)
}

##########################################################################################
#        select()
#        Calculates the selectivity from known (or previously derived) parameter values
```

```
##########################################################################################
select <- function(par,lpr){
   tau <- par[1]
   sigma <- par[2]
   theta <- par[3]
   lamda <- par[4]
   tangle <- par[5]
   dm1 <- lamda/(2.0*theta)
   dm2 <- (lpr - sigma*dm1 - tau)/sigma
   dm3 <- (1 + dm1^2)^theta
   g   <-   dm3*((1+(((lpr-sigma*dm1   -   tau)/sigma)^2))^(-theta))*exp(-lamda*(atan((lpr   -   sigma*dm1   -
 tau)/sigma)+atan(dm1)))
   f <- pmax((tau<lpr)*tangle,g)
   return(f)
}

##########################################################################################
#       computeParameters()
#       Function sets intial values and calculates maximum likelihood for the species parameter passed.  Returns
#       the net selectivity parameters obtained.
##########################################################################################
computeParameters = function(data,species){
 ### set  initial values and bounds ##########################################################
 init <- c(2.0,0.2,0.6,-0.5,0.15)
 lb <-  c(0,0.1,0,-4.0,0)
 ub <-  c(3.0,1.5,20.0,5.0,1.0)
 ########## Calculate Likelihood ##############################################################
 nll <- optim(par=init,fn=likelihood,method="L-BFGS-B",lower=lb, upper = ub, likedat=data, hessian = T)
 min_NLL <- nll$value
 #      Plot the data and curves
 lpr <- seq(0,8,by=0.05)
 lpr.r <- data[,'cpue']/20
 lpr.r = lpr.r/max(lpr.r)
 lpr.r[which(lpr.r<.3)] = .3
 #symbols(data[,'lpr'],   data[,'select'],circles=lpr.r,inches   =   TRUE,ylim=c(0,1),xlab='LPR',ylab='Net   Selectivity'
 ,main = species);
 #ramp = rainbow(255,start=.7,end=.1)
 ramp = heat.colors(255)
 #colors = ramp[255*(lpr.r/max(lpr.r))]
 #colors = rgb(lpr.r/max(lpr.r),0,1-lpr.r/max(lpr.r),1)
 #colors = rgb(log10(lpr.r+1),0,log10(max(lpr.r+1))-log10(lpr.r+1),maxColorValue=log10(max(lpr.r+1,na.rm=T)))
 #colors=rgb(0,0,0,log10(lpr.r+1),maxColorValue=log10(max(lpr.r+1,na.rm=T)))
 colors=rgb(0,0,0,lpr.r,maxColorValue=max(lpr.r,na.rm=T))
 plot(data[,'lpr'],data[,'select'],col=colors,ylim=c(0,1),xlab='LPR',ylab='Net Selectivity',main = species,bty='l');
 lines(lpr,select(nll$par,lpr),col='black',lwd=2,lty='solid')
 lines(lpr,select(oldParameters(species),lpr),col='black',lwd=2,lty="dotted")
 legend('topright',c("New Parameters","Old Parameters"),col='black',lwd=2,lty=c("solid","dotted"),bty='n')

 nll$par
}

##########################################################################################
#       oldParameters()
#       Returns the net selectivity parameters for the species specified.  These parameters were obtained using
#       the SAS code and older likelihood model.
##########################################################################################
```

```
oldParameters = function(species){
 #The following are the parameters using TF data 2000-2009 and were used in 2009-2015
 data = data.frame(
	Species = c("Chinook","Jack","Chum","Fall Chum","Coho","Pink","Broad Whitefish","Humpback
 Whitefish","Cisco","Sheefish","Other"),
	TAU = c(1.9008,1.9008,1.96990,1.8632,1.9827,1.9805,1.7774,1.9021,2.083,2.2604,2.2604),
	SIGMA = c(0.205,0.205,0.1543,0.233,0.3269,0.2598,0.2205,0.232,0.2223,0.3642,0.3642),
	THETA = c(0.5923,0.5923,0.7504,1.1954,0.8686,1.5542,1.40180,1.1103,1.8771,0.98810,0.98810),
	LAMDA = c(-0.4334,-0.4334,-0.4841,-1.43610,-1.4557,1.282,-1.9341,-2.0546,-1.6381,-2.299,-2.299),
	TANGLE = c(0.02394,0.02394,0.0,0.03034,0.1185,0.1649,0.09809,0.06415,0.18090,0,0)
 )
 parameters = as.vector(data[which(data$Species==species),-1],mode="numeric")

 parameters
}

##############################################################################################
#	empiricalSelectivity()
#	Computes an empirical selectivity by binning lpr values and taking the average of the select value
#	within each bin.
##############################################################################################
empiricalSelectivity = function(data,species){
 for (s in species){
	increment=0.25
	d = data.matrix(data[which(data$species==s & data$select>0),-1]);
	bins = seq(0,max(d[,"lpr"]),by= increment);
	meanSelect = 0;
	for (b in 1:(length(bins)-1)){
		meanSelect = c(meanSelect,mean(d[which(d[,"lpr"]>=bins[b] & d[,"lpr"]<bins[b+1]),"select"]))
	}
	d2=data.frame(lpr=bins,meanSelect=meanSelect)
	d2 = d2[-1,]
	plot(d2$lpr,d2$meanSelect,type='l',bty='l',xlab="LPR",ylab="Mean
 Selectivity",ylim=c(0,1),main=paste(s,"Min=",round(min(d2$meanSelect,na.rm=TRUE),digits=4)))
	points (d[,'lpr'],d[,'select'],col=rgb(0,0,0,0.4,maxColorValue=1))
	cat(s," Min Select=",round(min(d2$meanSelect,na.rm=TRUE),digits=4),"\n")
	#cat(s,"\n")
	#cat("lpr",bins)
	#cat("msel",meanSelect)
	#cat("\n\n\n")
 }
}

##############################################################################################
#	empiricalSelectivityPoints()
#	Plots the empirical selectivity points - essentially a subset of the previous
#	function empiricalSelectivity()
##############################################################################################
 empiricalSelectivityPoints = function(data,species,add=FALSE,col='blue'){
 for (s in species){
	increment=0.25
	d = data.matrix(data[which(data$species==s & data$select>0),-1]);
	bins = seq(0,max(d[,"lpr"]),by= increment);
	if(add==FALSE){

	plot(d[,'lpr'],d[,'select'],col=col,type='p',bty='l',xlab="LPR",ylab="Selectivity",ylim=c(0,1),main="Empirical
```

```
 Selectivity")
        }
        else{
                points (d[,'lpr'],d[,'select'],col=col)
        }
 }
}

#       ******************************** END OF FUNCTIONS ****************************       #

startTime = proc.time();
allspecies = c("Chinook","Chum","Fall Chum","Coho","Pink","Broad Whitefish","Humpback
 Whitefish","Cisco","Sheefish","Other")
tfdata = testFishQuery(Year=1990:2015,Species='ALL',LowerMesh=2.5,Table="PSTFish"); #Query the
 database for all test fish records between 1995 and 2015
#tfdata = read.table('~/Documents/Work/Eagle/2013/Eagle Selectivity/Eagle_Testfish.csv',sep=',',header=T) #Read
 data from comma delimited text file
names(tfdata) = str_to_lower(names(tfdata));  #Convert column labels to lower case
wkdata = dataclean(tfdata);
wkdata = netsuite(wkdata);
suiteset = wkdata$suiteset;
wkdata = wkdata$data;
spdata2 =
 merge(numfishbyspecies(binlengths(wkdata),suiteset),computeuniqueeffort(binlengths(wkdata)),by=c('date',
 'netset','mesh'))
spdata2$cpue = spdata2$nfish/spdata2$effort
spdata2$lpr = spdata2$mlength/(spdata2$mesh*25.4*2)
data = summarizedata(spdata2);
params = data.frame(Species=NA,TAU=NA,SIGMA=NA,THETA=NA,LAMDA=NA,TANGLE=NA)

#bg='transparent';fg='white'
bg='white';fg='black'
pdf("~/Desktop/Selectivity Plots.pdf",width=7,height=9.5)
par(col.axis=fg,col.lab=fg,col.main=fg,col.sub=fg,fg=fg,bg=bg,cex=1.0,mfrow=c(2,1),family='serif')
for (s in allspecies){
 if(s != "Other"){
        specData <- data.matrix(data[which(data$species == s),-1])
        cat("Processing Species:",s," n=",length(tfdata[which(tfdata$species==s),1]),  "\n")
 }
 else{
        specData <- data.matrix(data[which(data$species == s | data$species == "Sockeye" | data$species ==
 "Burbot" | data$species == "Smelt" |
                                        data$species == "Dolly Varden" | data$species ==
 "Pike" | data$species == "Longnose Sucker"),-1]);
        cat("Processing Species:",s," n=",length(tfdata[which(tfdata$species == s | tfdata$species == "Sockeye" |
 tfdata$species == "Burbot" |
                                                        tfdata$species ==
 "Smelt" | tfdata$species == "Dolly Varden" |
                                                        tfdata$species ==
 "Pike" | tfdata$species == "Longnose Sucker"),1]),  "\n")
 }
 params = rbind(params,c(s,computeParameters(specData,s)))
}
dev.off()
params[-1,1] = str_to_upper(params[-1,1]);   #Convert species names to uppercase to make it easier to add to
 netsel.dat text file
```

```
print(params[-1,])

pdf("~/Desktop/Empirical Selectivity Plots.pdf",width=8,height=6)
empiricalSelectivity(data,allspecies)
dev.off()
endTime = proc.time()
cat("\n\n","Time Elapsed=",endTime[3]-startTime[3])
```

APPENDIX B: TIMELINE OF PROJECT CHANGES

Appendix B1.–Timeline of project changes.

Year	Event
1980-1983	Early feasibility studies.
	Operated Bendix fan scan (300 kHz) and BioSonics single-beam sonar (420 kHz).
	Direction of travel determined from slant of fish traces (transducers were aimed 45 deg downstream).
1985	BioSonics 420 kHz.
	20 min sampling duration.
	4 Mesh sizes utilized 101.6 mm (4.0 in), 139.7 mm (5.5 in), 162.0 mm (6.38 in), and 215.9 mm (8.5 in) 45.7 m (150 ft)
	Report periods were 3-9 days to obtain minimum sample of 120 fish at each site.
	Utilized a -32 dB detection threshold.
	Transducers were aimed 15 deg downstream to determine direction of travel.
	Counts within sectors were expanded for the proportion of the water column covered.
	Sampled 4 strata, left bank nearshore, left bank offshore, right bank bottom, right bank surface. Left bank strata required 2 transducers deployed at different ranges.
1986	6 Mesh sizes utilized 101.6 mm (4.0 in), 127.0 mm (5.0 in), 139.7 mm (5.5 in), 165.1 mm (6.5 in), 190.5 mm (7.5 in), and 215.9 mm (8.5 in). All were 45.7 m (150 ft) long and 7.6 m (25 ft) deep.
1987	No substantial changes.
1988	Did not adjust catches for selectivity (this was 1988 only)
1989	Methodology consistent with 1986.
1990	Spatial expansion based on the proportion of the water column insonified was discontinued.
	8.5″ and 7.5″ drifted twice per bank per period, other nets drifted once per bank.

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	Stopped fishing 8.5″ and 7.5″ nets after July 25
	Net selectivity methodology improved from previous, used McCombie and Fry method (1960) for Chinook and chum salmon and Holt (Peterson 1966) for coho salmon, pink salmon, and whitefish. Began computing sample variance for the estimates. SAS used to generate estimates.
1991	First year 70 mm (2.75 in) net fished.
1992	Project only operated a partial season and savings used to purchase 120kHz equipment.
1993	Sonar frequency changed from 420 kHz to 120 kHz to detect fish at greater ranges.
	Individual sonar stratum were sampled in 15 min periods (was 20 min previously). Sonar operated 24 hrs/day 4 times during the season.
	No expansion for fish beyond the counting range using down looking fathometer. Log-normal curves used to describe selectivity.
1994	No substantial changes.
1995	Utilized a single stratum on the right bank No longer used the angle of traces to distinguish downstream from upstream fish. All traces were considered upstream.
1996	Project did not produce estimates and operated for training purposes only.
1997	140 mm (5.5 in) mesh added in the fall when 7.5 in and 8.5 in discontinued.
1998	Sampled 3 sonar strata on right bank.
	Dropped the 127.0 mm (5.0 in) and 165.1 mm (5.5 in) nets, used 133 mm (5.25 in).

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1999	In the fall season, dropped215.0 mm (8.5 in) and 133 mm (5.25 in) nets and added 146 mm (5.75 in) and 127 mm (5.0 in).
2000	No substantial changes.
2001	Transitioned to HTI split-beam equipment. Frequency kept at 120 kHz and still marked fish using paper charts.
2002	No substantial changes.
2003	No substantial changes.
2004	Changed selectivity model to use Pearson-T curve.
2005	Incorporated the DIDSON into left bank sampling for the first 20m.
2006	No substantial changes.
2007	No substantial changes.
2008	No substantial changes.
2009	Transitioned from marking fish on paper charts to electronic echograms
2010	Tested 50 fathom nets during summer season. Alternated 25 fathom and 50 fathom by test fishing period.
	Preliminary testing of side-scan sonar for use offshore during periods of extreme turbidity.
2011	Dropped the 50 fathom nets and resumed normal test fishing operations. Final year of side-scan testing.
2012	No substantial changes.

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2013	No substantial changes.
2014	No substantial changes.
2015	No substantial changes.
2016	Switched from DIDSON to ARIS on the left bank sampling the entire stratum 3 (0-50 m).
	Updated selectivity parameters for all species and implemented a minimum selectivity threshold of 0.1.