



Executive Secretary's Summary of Decisions 32nd Annual Meeting

The Pacific Salmon Commission held its 32nd Annual Meeting from February 13-17, 2017 at the Embassy Suites Downtown (Portland, OR), and discussed a number of topics (see attached agenda).

The Commission AGREED:

1. The minutes from January 2017 are approved as edited by the National Sections.
2. The CTC will provide strategic advice to the Commission on 2018 Very High Priority Chinook issues during the February 2017 meeting, earlier than the anticipated May 2017 deadline.
3. The proposal dated February 14, 2017 for addressing habitat issues and the elimination of the Habitat and Restoration Technical Committee is adopted.
4. The SFEC report is adopted, with its recommendations to be taken under consideration during Annex IV renegotiation and the regular management of Treaty fisheries.
5. The Commission will publish, via the appropriate PSC report series, the Radio Frequency Identification (RFID) and environmental anomalies reports provided by independent experts.
6. The Executive Secretary will liaise with the CSC to provide a report on the International Year of the Salmon Steering Committee meeting (February 28 - March 1, 2017), and provide this to the Chair and Vice-Chair by April for review. Commission consideration of this report will occur later in 2017.
7. The protocol for chapter renegotiations is approved, as provided on February 16, 2017.
8. The CSC recommendations for considering environmental and biological anomalies in the work of the PSC are noted. While certain recommendations require relatively few resources to implement, others would take considerable time and effort. The CSC will expand on each strategy to identify mechanisms to deliver the recommendations through improved linkages and partnerships. The CSC will consider how the strategies would fit into future work plan items, and those items will be submitted for review and consideration by the Commission at the 2017 Fall Meeting.
9. The CTC review of the PSC expert panel report on forecasting methodology is received, and will require further discussion at the 2017 Fall Meeting.
10. The CTC strategic advice on 2018 Very High Priority Chinook (VHPC) projects is accepted, and will be transmitted to the Joint Fund Committee. The CTC's review of the expert panel report on forecasting methodology will also be transmitted as context for theme "E" in the CTC's strategic advice on 2018 VHPC projects.
11. The report of the F&A Committee is adopted, including the Commission budget for 2017/2018.

ATTENDANCE

PACIFIC SALMON COMMISSION
ANNUAL MEETING
FEBRUARY 13-17, 2017
DOWNTOWN EMBASSY SUITES
PORTLAND, OREGON

COMMISSIONERS

CANADA

R. Reid (Chair)
B. Assu
S. Farlinger
J. McCulloch
M. Ned
B. Riddell
P. Sprout

UNITED STATES

C. Swanton (Vice Chair)
W.R. Allen
P. Anderson
W. Auger
D. Darm
R. Klumph
M. Oatman



**Draft Agenda
32nd Annual Meeting
February 13-17, 2017
Embassy Suites Downtown; Portland, OR**

1. Adoption of agenda
2. Approval of minutes: January 2017
3. Executive Secretary's report

Chinook issues

4. CTC feasibility assessment of expert panel recommendations
5. Commission guidance to Joint Fund Committee re. 2017 VHPC projects (as needed)
6. Report from Chinook negotiation team

Other action items pending

7. Reports from Panels and Committees
 - a. Work plan progress
 - b. Status of negotiations
 1. Results of completed work
 2. Incomplete work/remaining issues
 - c. FSRC progress report
 - d. CSC
 1. Final environmental anomalies report 2015-2016 (Skip McKinnell)
 2. Radio Frequency Identification technology final report (Karl English)
 3. Options paper on environmental anomaly monitoring
 4. International Year of the Salmon: draft agenda for North Pacific Steering Committee (Feb. 28-Mar. 1, 2017)
 - e. Selective Fishery Evaluation Committee
 - f. F&A Committee report
 - g. Endowment Fund Committee report
8. Commission reconsideration of Habitat and Restoration Technical Committee
9. Presentation of Larry Rutter Award
10. Presentation of PSC service plaque – Mike Clark
11. Public comment

Economic Impacts of Pacific Salmon Fisheries

Progress Report

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I.0 Introduction

This Project Report outlines work to date on our project to analyze the economic impacts of commercial and recreational fisheries from SE Alaska down to Oregon. The work addresses the five species of salmon in total - sockeye, coho, pink, chum and Chinook - and each of the years 2012 to 2015.

Our investigations to date have included interviews with over 40 individuals and with review of a variety of reports, both government and private sector consultant studies.

Our report focuses on number of salmon caught for each sector, for each year, for each jurisdiction. However, we provide commentary on investigations as to valuation of fishing activity e.g., ex-vessel & wholesale values for salmon, angler expenditures for recreational.

The importance of the subsistence sector is addressed in a separate draft report. Discussion of subsistence will be included in our Final Report.

2.0 Commercial Sector

The key information pieces for the commercial sector in each region for each species are:

- no. fish caught
- av. weight per fish
- ex-vessel value per lb round (whole) fish
- wholesale value per lb (whole) fish

Separate fleets or fishing segments are identified in each region for catch data.

Fishing Fleets/Fleet Segments			
SE Alaska	BC	Washington	Oregon
Purse Seine	Seine	Columbia R	Columbia R
Drift Net	Gillnet	Other	Ocean Troll
Troll	Troll		
Hatchery Cost Recovery	Transboundary*		
Other	FN Commercial		

* *Stikine & Taku (no commercial harvests in Alek)*

The catch data is summarized in Exhibit I (catch data by individual fleet is given in Appendix A).

2.1 SE Alaska

The Alaska Department of Fish & Game (ADF&G) has catch numbers by species in their annual publication “Overview of the Southeast Alaska & Yukatat Commercial, Personal Use, and Subsistence Salmon Fisheries” Table 10. The publication also has average weight per fish - but the average weights refer to landed weight, based on fish tickets, and not round weight. Troll fish is usually landed dressed head on and therefore troll weight needs to be adjusted (this has not been done yet).

The same ADF&G publication and division has published average ex-vessel prices for salmon (but these prices may not necessarily be final prices).

Each processor in Alaska must complete a Commercial Operator Annual Report (COAR) detailing processed seafood quantities & sales values by species and product form. We have accessed COAR data and can calculate an overall wholesale (processed) price by species for each year.

2.2 British Columbia

DFO Policy & Economics personnel provided unpublished data on commercial salmon catch, including test fisheries catch, for the traditional outside fisheries of seine, gillnet & troll. DFO also provided information on First Nation commercial catch, a combination of Economic Opportunity (EO), Excess Surplus to Spawning Requirements (ESSR), Treaty, and Demonstration and Other.

Exhibit 1: Salmon Catch by Region - Commercial

	2012						2013						2014						2015					
	Sockeye	Coho	Pink	Chum	Chinook	All	Sockeye	Coho	Pink	Chum	Chinook	All	Sockeye	Coho	Pink	Chum	Chinook	All	Sockeye	Coho	Pink	Chum	Chinook	All
Number Caught '000 Fish																								
SE Alaska	947	2,087	21,300	12,365	280	36,978	975	3,864	94,787	12,574	241	112,440	1,670	3,790	37,194	6,680	428	49,761	1,528	2,146	35,064	11,523	351	50,612
BC	1,478	290	829	1,264	196	4,057	365	543	13,627	1,702	179	16,416	10,913	321	4,572	881	371	17,059	1,971	326	1,692	2,507	249	6,744
Washington	157	391	1	871	427	1,846	28	334	6,044	1,240	513	8,160	773	698	2	960	492	2,925	77	88	724	830	557	2,276
Oregon	1	14	<1	<1	136	152	<1	37	<1	<1	228	265	1	215	<1	<1	331	548	2	27	<1	<1	208	237
Total	2,583	2,782	22,130	14,500	1,039	43,033	1,367	4,779	114,458	15,516	1,161	137,281	13,357	5,023	41,768	8,521	1,623	70,292	3,578	2,587	37,479	14,861	1,364	59,869
RD Weight Landed '000 lbs																								
SE Alaska	5,928	13,334	76,040	112,399	3,650	211,352	5,877	22,025	333,650	102,600	3,137	467,288	9,686	25,769	130,178	60,785	5,183	231,601	6,663	12,620	134,645	97,486	3,526	254,940
BC	8,223	2,173	2,709	13,962	2,794	29,860	2,012	4,046	46,219	19,497	2,422	74,196	62,044	1,917	14,828	9,814	5,190	93,793	9,799	1,883	5,841	25,043	3,398	45,965
Washington	862	3,604	4	10,451	4,614	19,535	152	3,226	24,176	14,885	6,281	48,720	4,251	4,734	6	11,525	7,353	27,869	424	587	2,896	9,965	7,334	21,205
Oregon	3	108	<1	1	1,802	1,914	<1	276	<1	<1	3,216	3,493	5	1,611	<1	<1	4,802	6,417	7	197	<1	<1	2,926	3,130
Total	15,015	19,219	78,753	136,813	12,860	262,660	8,041	29,573	404,045	136,982	15,055	59,3697	75,985	34,032	145,012	82,123	22,527	359,680	16,894	15,287	143,382	132,494	17,184	325,240

Commercial catch data for the Stikine and Taku transboundary rivers was taken from the Transboundary Technical Committee for the Pacific Salmon Commission, “Preliminary Estimates of Transboundary River Salmon Production, Harvest & Escapement and a Review of Joint Enforcement Activities in 2015”. The biologist also provided some piece count and weight data. We used this data to estimate average weights for years 2012 to 2015 (some weights were on a dressed weight basis so we had to convert to round weight in the calculations).

Average weights from DFO data for the traditional outside fisheries was used to estimate average weights for the FN commercial fisheries.

Ex-vessel price and wholesale price data are available from the provincial “Seafood Industry Seafood Year in Review” (SYIR) report.

2.3 Washington

The Columbia River Inter-Tribal Fisheries Commission has data on commercial catch - numbers of fish and average weights on the Columbia River - but does not separate such catch between Washington and Oregon interests. The Pacific Fishery Management Council (PFMC) reports data on Columbia River commercial catch separately by Washington State and Oregon but only in weight units in their “Review of Ocean Salmon Fisheries” document. The Council also reports catch for ocean troll fisheries in Washington State and Oregon - but Washington has substantial commercial fisheries other than Columbia River and ocean troll. NOAA gives data on all commercial catch for Washington State but only in weight units and not in piece units.

As a result, we benchmarked Washington State commercial fishery catch to the NOAA catch weight units and backcalculated number of fish caught, using some average weight data from the Columbia River Inter-Tribal Fisheries Commission and professional judgement. We need to conduct further investigation of this.

The NOAA data also has ex-vessel price data for the commercial fishery overall.

Our interview with an individual from NOAA in charge of the IO-PAC model indicated that NOAA uses a common processor markup for all species of salmon for Washington State and Oregon in each year, namely 46% in 2012, 30% in 2013, and 38% in 2014. We estimate the 2015 markups as 40% (the markups are based on a limited EDC survey of groundfish processors who also process salmon).

2.4 Oregon

In Oregon there are essentially only two major types of commercial fisheries, the Columbia River (a variety of gear types) and ocean troll.

We took the PFMC data for the Oregon component of the Columbia River fishery and the Oregon ocean troll fishery. The former had catch in weight units whereas the latter had catch in both weight and numbers of fish. We then estimated an average weight to convert the Columbia River catch to pieces. Again we need to reassess the piece count calculations but the procedure does produce a total catch weight consistent with NOAA figures.

The NOAA data set provides ex-vessel prices and values.

Similar to the Washington State case, we will use the IO-PAC processor markups in our analysis.

3.0 Recreational Sector

The key information pieces for the recreational sector in each region are:

- no. fish caught
- no. of salmon angling days
- angler expenditures per day

We tried to identify four (4) separate recreational fishing segments in each region - freshwater charter (for hire) and private anglers plus saltwater charter (for hire) and private anglers.

The data challenges for the recreational sector are more daunting than for the commercial sector. One issue is identifying the share of angling activity, and hence expenditures, that is targeted at salmon rather than halibut, other bottom fish etc. In some cases we will have to use professional judgement on this matter.

The harvest data for the recreational sector is summarized in Exhibit 2 (separate region profiles are given in Appendix B).

3.1 SE Alaska

ADF&G has recreational catch numbers and angler day figures, separately for freshwater and saltwater, based on an annual household survey in Alaska - but this survey does not ask for directed angling effort at salmon.

Charter operators must complete an annual catch report and this report has some information on directed effort for salmon which we have accessed. We also have contacted ADF&G as to their informed opinion on the share of freshwater days attributable to salmon fishing. We will follow up with them.

No recent information on angler expenditure per day exists. The detailed 2007 Southwick study has not been replicated. NOAA did conduct a nationwide analysis, with information by state, as to economic impacts from marine angling in 2011 ("The Economic Contribution of Marine Angler Expenditures in the United States 2011").

We will estimate recent angler expenditure data based on the Southwick and NOAA reports. There is also a 2011-13 Alaskan charter operator survey that is useful.

3.2 British Columbia

In mid 2012 DFO launched a pilot e-survey called "iREC" in which a sample of tidal recreational licence holders each month are asked to complete an Internet Survey as to their fishing activity in the past month. The survey results, although still preliminary and subject to further review, look promising. We have accessed them for this survey.

Exhibit 2: Salmon Catch by Region - Recreational

	2012					2013					2014					2015				
	SEAK	BC	WA	OR	Total	SEAK	BC	WA	OR	Total	SEAK	BC	WA	OR	Total	SEAK	BC	WA	OR	Total
FW Harvest '000 Fish																				
Sockeye	9	85	61	0	155	11	85	24	0	120	13	172	56	0	241	12	85	65	0	163
Coho	28	90	75	36	229	29	90	125	41	286	33	90	146	228	497	32	90	60	115	296
Pink	7	0	0	0	7	12	0	380	0	392	4	0	0	0	4	7	0	208	0	215
Chum	1	0	10	0	11	1	0	19	0	20	1	0	9	0	9	1	0	11	0	12
Chinook	1	50	143	149	343	1	50	193	173	417	1	50	143	180	373	1	50	189	333	574
SW Harvest '000 Fish																				
Sockeye	6	2	<1	<1	8	10	16	<1	<1	26	6	146	<1	<1	152	8	78	4	<1	90
Coho	180	309	209	16	714	311	368	165	15	857	260	345	266	100	969	271	278	225	28	802
Pink	50	48	<1	<1	98	87	226	135	<1	447	47	71	<1	<1	118	82	260	199	<1	541
Chum	9	13	3	<1	25	22	18	3	<1	43	9	13	3	<1	25	10	18	3	<1	31
Chinook	46	256	82	19	403	55	288	74	30	448	86	394	76	18	575	79	407	79	9	574
All Harvests '000 Fish																				
Sockeye	15	87	61	<1	163	21	101	24	<1	146	19	318	56	<1	393	20	163	69	<1	252
Coho	208	399	284	52	943	340	458	290	56	1,143	293	435	412	327	1,466	303	368	284	143	1,098
Pink	57	48	<1	<1	105	99	226	515	<1	840	51	71	<1	<1	122	90	260	407	<1	756
Chum	9	13	14	<1	36	23	18	22	<1	63	9	13	12	<1	34	11	18	15	<1	43
Chinook	46	306	225	168	745	56	338	267	203	864	87	444	219	198	948	80	457	268	342	1,147

Legend: SEAK - SE Alaska WA - Washington FW - Freshwater

BC - British Columbia OR - Oregon SW - Saltwater

Source: Appendix B

We used the iREC catch numbers for kept salmon. However, the angler days figures, not segmented by directed species, are lower than suggested by the DFO quinquennial (every 5 years) mail survey of anglers. For this report we made an estimate of marine angler days but we need to investigate this further.

We will update the angler expenditure information in the DFO quinquennial survey for this exercise. The last survey results presently available relate to the year 2010. But the 2015 results may be available for use in this study in the next 2 months.

3.3 Washington

Washington Department of Fish & Wildlife has recreational salmon catch on freshwater and saltwater available in their annual "Sport Fish Report". The report also gives marine angler trips but not freshwater angler trips.

The PFMC Report which we used to profile the commercial salmon fishery in Washington and Oregon also has some information on recreational salmon angling in marine waters, segmented by charter and non-charter (private) components.

We will update the 2011 NOAA economic profile information for this project.

3.4 Oregon

The Oregon Department of Fish & Wildlife has recreational salmon catch data on freshwater and saltwater. The database also gives marine angler days but not freshwater angler days.

The PFMC Report has data on marine angling segmented by charter and non-charter components for Oregon.

We will update the 2011 NOAA economic profile information for the project.

4.0 Next Steps

Gordon Gislason will be in Anchorage AK the week of February 6 to interview ADF&G individuals and to work with ISER. The following week he will be in Portland OR at which time he can address some of the data questions that have arisen.

We will be analyzing other reports, such as TRG reports, on the economic dimensions of commercial and recreational fisheries in Washington State and Oregon.

Appendix A

Commercial Data by Region

Exhibit A.1: Commercial Catch of Salmon - Region SE Alaska

	2012					2013					2014					2015				
	Sockeye	Coho	Pink	Chum	Chinook	Sockeye	Coho	Pink	Chum	Chinook	Sockeye	Coho	Pink	Chum	Chinook	Sockeye	Coho	Pink	Chum	Chinook
Number Caught																				
Purse Seine	170,345	275,426	19,172,555	4,826,746	21,713	282,350	545,667	88,764,579	5,797,941	24,516	900,955	388,692	33,471,883	2,384,335	28,290	908,426	283,973	32,157,211	4,817,171	30,058
Drift Net	498,100	265,327	938,892	3,517,702	26,243	456,008	441,552	1,664,045	3,422,488	34,525	497,968	554,301	1,417,432	2,381,367	27,877	389,752	251,020	1,372,627	3,287,124	29,266
Troll	3,229	1,201,520	168,539	476,520	209,023	5,019	2,392,155	684,532	1,054,735	149,472	7,289	2,243,782	75,278	199,707	355,426	6,975	1,240,163	259,409	424,230	269,750
Hatchery Cost Recovery	125,664	201,028	148,506	3,055,726	18,809	49,609	272,288	968,095	2,099,940	29,770	123,029	387,988	236,214	1,575,630	13,148	111,390	203,764	304,645	2,277,464	17,321
Other	149,661	143,404	871,210	488,439	4,147	181,667	212,297	2,705,666	198,398	2,998	140,691	214,856	1,992,939	138,608	3,588	111,762	167,302	969,818	717,184	4,134
All	946,999	2,086,705	21,299,702	12,365,133	279,935	974,653	3,863,959	94,786,917	12,573,502	241,281	1,669,932	3,789,619	37,193,746	6,679,647	428,329	1,528,305	2,146,222	35,063,710	11,523,173	350,529
RD Weight per Fish lbs																				
Purse Seine	6.260	6.390	3.570	9.090	13.040	6.030	5.700	3.520	8.160	13.000	5.800	6.800	3.500	9.100	12.100	4.360	5.880	3.840	8.460	10.060
Drift Net	6.260	6.390	3.570	9.090	13.040	6.030	5.700	3.520	8.160	13.000	5.800	6.800	3.500	9.100	12.100	4.360	5.880	3.840	8.460	10.060
Troll	6.260	6.390	3.570	9.090	13.040	6.030	5.700	3.520	8.160	13.000	5.800	6.800	3.500	9.100	12.100	4.360	5.880	3.840	8.460	10.060
Hatchery Cost Recovery	6.260	6.390	3.570	9.090	13.040	6.030	5.700	3.520	8.160	13.000	5.800	6.800	3.500	9.100	12.100	4.360	5.880	3.840	8.460	10.060
Other	6.260	6.390	3.570	9.090	13.040	6.030	5.700	3.520	8.160	13.000	5.800	6.800	3.500	9.100	12.100	4.360	5.880	3.840	8.460	10.060
RD Weight Landed '000 lbs																				
Purse Seine	1,066	1,760	68,446	43,875	283	1,703	3,110	312,451	4,7311	319	5,226	2,643	117,152	21,697	342	3,961	1,670	123,484	40,753	302
Drift Net	3,118	1,695	3,352	31,976	342	2,750	2,517	5,857	27,928	449	2,888	3,769	4,961	21,670	337	1,699	1,476	5,271	27,809	294
Troll	20	7,678	602	4,332	2,726	30	13,635	2,410	8,607	1,943	42	15,258	263	1,817	4,301	30	7,292	996	3,589	2,714
Hatchery Cost Recovery	787	1,285	530	27,777	245	299	1,552	3,408	17,136	387	714	2,638	827	14,338	159	486	1,198	1,170	19,267	174
Other	937	916	3,110	4,440	54	1,095	1,210	9,524	1,619	39	816	1461	6,975	1,261	43	487	984	3,724	6,067	42
All	5,928	13,334	76,040	112,399	3,650	5,877	22,025	333,650	102,600	3,137	9,686	25,769	130,178	60,785	5,183	6,663	12,620	134,645	97,486	3,526

Exhibit A.2: Commercial Catch of Salmon - Region BC

	2012					2013					2014					2015				
	Sockeye	Coho	Pink	Chum	Chinook	Sockeye	Coho	Pink	Chum	Chinook	Sockeye	Coho	Pink	Chum	Chinook	Sockeye	Coho	Pink	Chum	Chinook
Number Caught																				
Seine (Areas A, B)	209,680	362	609,541	540,328	0	24,061	42,936	11,559,036	751,524	110	5,228,142	29,244	3,597,103	421,786	331	599,616	9,721	1,195,732	1,304,128	5
Gillnet (Areas C, D, E)	629,837	487	85,320	462,424	14,826	151,776	6,332	345,391	664,555	16,298	3,450,559	11,774	540,138	248,811	30,469	539,546	13,089	194,827	938,894	23,627
Troll (Areas F, H)	2,158	217,558	65,370	27,755	139,693	21	405,434	110,918	42,809	103,234	387,652	212,416	37,575	2,859	279,879	2,697	261,861	46,909	49,650	160,971
Transboundary	60,571	20,372	0	363	9,187	53,761	18,364	161	461	4,877	51,358	22,211	27	24	5,842	73,523	15,536	0	0	7,175
First Nation Commercial	575,905	51,431	68,615	232,748	32,550	135,175	70,255	1,611,332	242,748	54,258	1,795,589	45,033	397,497	207,476	54,842	755,314	25,988	254,207	214,460	56,806
All	1,478,151	290,210	828,846	1,263,618	196,256	364,794	543,321	13,626,838	1,702,097	178,777	10,913,300	320,678	4,572,340	880,956	371,363	1,970,696	326,195	1,691,675	2,507,132	248,584
RD Weight per Fish lbs																				
Seine (Areas A, B)	4.472	6.007	3.113	10.850	12.000	4.500	6.000	3.357	10.851	12.000	5.767	6.000	3.115	11.519	12.000	4.642	6.000	3.356	10.181	12.000
Gillnet (Areas C, D, E)	5.987	8.012	3.778	11.588	18.254	5.698	6.074	3.897	12.733	17.039	5.606	6.481	3.901	11.048	16.378	4.523	6.717	3.983	9.676	14.642
Troll (Areas F, H)	6.226	7.390	3.815	10.593	13.667	6.000	7.565	3.865	7.671	12.402	6.169	5.363	3.315	9.664	13.581	6.161	5.385	3.459	8.649	13.152
Transboundary	5.500	8.500	3.800	7.200	15.500	5.500	8.500	3.800	7.200	15.500	5.500	8.500	3.800	7.200	15.500	5.500	8.500	3.800	7.200	15.500
First Nation Commercial	5.500	7.500	3.500	10.500	14.500	5.500	7.500	3.500	10.500	14.500	5.500	7.500	3.500	10.500	14.500	5.500	7.500	3.500	10.500	14.500
RD Weight Landed '000 lbs																				
Seine (Areas A, B)	938	2	1,898	5,863	0	108	258	38,804	8,155	1	30,151	175	11,205	4,859	4	2,783	58	4,013	13,277	0
Gillnet (Areas C, D, E)	3,771	4	322	5,359	271	865	38	1,346	8,462	278	19,344	76	2,107	2,749	499	2,440	88	776	9,085	346
Troll (Areas F, H)	13	1,608	249	294	1,909	0	3,067	429	328	1,280	2,391	1,139	125	28	3,801	17	1,410	162	429	2,117
Transboundary	333	173	0	3	142	296	156	1	3	76	282	189	0	0	91	404	132	0	0	111
First Nation Commercial	3,167	386	240	2,444	472	743	527	5,640	2,549	787	9,876	338	1,391	2,178	795	4,154	195	890	2,252	824
All	8,223	2,173	2,709	13,962	2,794	2,012	4,046	46,219	19,497	2,422	62,044	1,917	14,828	9,814	5,190	9,799	1,883	5,841	25,043	3,398

Exhibit A.3: Commercial Catch of Salmon - Region Washington

	2012					2013					2014					2015				
	Sockeye	Coho	Pink	Chum	Chinook	Sockeye	Coho	Pink	Chum	Chinook	Sockeye	Coho	Pink	Chum	Chinook	Sockeye	Coho	Pink	Chum	Chinook
Number Caught																				
Columbia River	0	8,800	0	0	105,500	0	28,300	0	0	206,500	0	119,100	0	0	323,500	0	9,300	0	0	316,600
Other	156,700	381,700	1,000	870,900	321,100	27,600	306,000	6,044,000	1,240,400	306,700	772,900	578,500	1,500	960,400	168,600	77,100	78,800	724,000	830,400	240,000
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
All	156,700	390,500	1,000	870,900	426,600	27,600	334,300	6,044,000	1,240,400	513,200	772,900	697,600	1,500	960,400	492,100	77,100	88,100	724,000	830,400	556,600
RD Weight per Fish lbs																				
Columbia River	5.500	7.500	4.000	12.000	15.000	5.500	7.500	4.000	12.000	15.000	5.500	7.500	4.000	12.000	15.000	5.500	7.500	4.000	12.000	15.000
Other	5.500	9.270	4.000	12.000	9.440	5.500	9.850	4.000	12.000	10.380	5.500	6.640	4.000	12.000	14.830	5.500	6.560	4.000	12.000	10.770
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
RD Weight Landed '000 lbs																				
Columbia River	0	66	0	0	1,583	0	212	0	0	3,098	0	893	0	0	4,853	0	70	0	0	4,749
Other	862	3538	4	10,451	3,031	152	3,014	24,176	14,885	3,184	4,251	3,841	6	11,525	2,500	424	517	2,896	9,965	2,585
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
All	862	3,604	4	10,451	4,614	152	3,226	24,176	14,885	6,281	4,251	4,734	6	11,525	7,353	424	587	2,896	9,965	7,334

Exhibit A.4: Commercial Catch of Salmon - Region Oregon

	2012					2013					2014					2015				
	Sockeye	Coho	Pink	Chum	Chinook	Sockeye	Coho	Pink	Chum	Chinook	Sockeye	Coho	Pink	Chum	Chinook	Sockeye	Coho	Pink	Chum	Chinook
Number Caught																				
Columbia River	800	13,700	0	100	63,300	0	36,500	100	0	115,400	1,300	204,500	0	0	123,000	2,100	24,500	0	0	104,000
Ocean Troll	0	624	0	0	73,101	200	452	0	0	112,757	0	10,998	0	0	208,096	0	2,187	0	0	104,031
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
All	800	14,324	0	100	136,401	200	36,952	100	0	228,157	1,300	215,498	0	0	331,096	2,100	26,687	0	0	208,031
RD Weight per Fish lbs																				
Columbia River	3.500	7.500	0.000	12.000	15.000	3.500	7.500	4.000	0.000	15.000	3.500	7.500	0.000	0.000	15.000	3.500	7.500	0.000	0.000	15.000
Ocean Troll	0.000	8.000	0.000	0.000	11.660	0.000	5.500	0.000	0.000	13.170	0.000	7.000	0.000	0.000	14.210	0.000	6.000	0.000	0.000	13.130
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
RD Weight Landed ('000 lbs																				
Columbia River	3	103	0	1	950	0	274	0	0	1,731	5	1,534	0	0	1,845	7	184	0	0	1,560
Ocean Troll	0	5	0	0	852	0	2	0	0	1,485	0	77	0	0	2,957	0	13	0	0	1,366
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
All	3	108	0	1	1,802	0	276	0	0	3,216	5	1,611	0	0	4,802	7	197	0	0	2,926

Appendix B

Recreational Data by Region

Exhibit B.1: Recreational Catch of Salmon - SE Alaska \$US

	2012	2013	2014	2015
Freshwater Salmon Catch (pieces)				
Sockeye	8,883	11,026	13,152	12,350
Coho	27,652	29,050	32,685	32,021
Pink	6,601	12,275	3,882	7,469
Chum	570	978	517	723
Chinook	741	919	837	873
Saltwater Salmon Catch (pieces)				
Sockeye	6,142	10,120	5,861	7,626
Coho	179,874	310,535	259,887	270,532
Pink	49,900	87,127	46,861	82,210
Chum	8,514	21,759	8,933	10,207
Chinook	45,754	55,473	86,105	78,886
Total Salmon Catch (pieces)				
Sockeye	15,025	21,146	19,013	19,976
Coho	207,526	339,585	292,572	302,553
Pink	56,501	99,402	50,743	89,679
Chum	9,084	22,737	9,450	10,930
Chinook	46,495	56,392	86,942	79,759
All Angler Days				
Freshwater for Hire	9,924	9,978	10,257	10,520
Freshwater Private	81,085	73,893	84,811	82,825
Saltwater for Hire	112,603	119,212	131,966	137,546
Saltwater Private	275,395	342,967	337,276	363,599
Salmon % of All Angler Days				
Freshwater for Hire	100%	100%	100%	100%
Freshwater Private	50%	60%	55%	55%
Saltwater for Hire	56%	57%	56%	56%
Saltwater Private	60%	70%	65%	65%
Salmon Activity (Angler Days)				
For Hire	72,982	77,929	84,158	87,546
Private	205,780	284,413	265,875	281,893
All	278,761	362,342	350,033	369,439

Exhibit B.2: Recreational Catch of Salmon - British Columbia \$CA

	2012	2013	2014	2015
Freshwater Salmon Catch (pieces)				
Sockeye	85,000	85,000	172,000	85,000
Coho	90,000	90,000	90,000	90,000
Pink	0	0	0	0
Chum	0	0	0	0
Chinook	50,000	50,000	50,000	50,000
Saltwater Salmon Catch (pieces)				
Sockeye	2,000	16,100	145,900	78,200
Coho	309,000	367,600	344,500	278,200
Pink	48,000	225,600	71,000	260,200
Chum	13,000	18,200	12,900	17,800
Chinook	256,000	288,400	394,200	407,000
Total Salmon Catch (pieces)				
Sockeye	87,000	101,100	317,900	163,200
Coho	399,000	457,600	434,500	368,200
Pink	48,000	225,600	71,000	260,200
Chum	13,000	18,200	12,900	17,800
Chinook	306,000	338,400	444,200	457,000
All Angler Days				
Freshwater for Hire	75,000	75,000	75,000	75,000
Freshwater Private	3,725,000	3,725,000	3,725,000	3,725,000
Saltwater for Hire	180,000	180,000	180,000	180,000
Saltwater Private	1,600,000	1,600,000	1,600,000	1,600,000
Salmon % of All Angler Days				
Freshwater for Hire	25%	25%	25%	25%
Freshwater Private	18%	18%	18%	18%
Saltwater for Hire	55%	55%	55%	55%
Saltwater Private	65%	65%	65%	65%
Salmon Activity (Angler Days)				
For Hire	117,750	117,750	117,750	117,750
Private	1,710,500	1,710,500	1,710,500	1,710,500
All	1,828,250	1,828,250	1,828,250	1,828,250

Exhibit B.3: Recreational Catch of Salmon - Washington \$US

	2012	2013	2014	2015
Freshwater Salmon Catch (pieces)				
Sockeye	61,395	23,744	55,591	65,336
Coho	74,973	125,261	146,164	59,517
Pink	0	380,142	0	207,582
Chum	10,332	18,932	8,807	11,351
Chinook	143,171	193,328	142,656	189,376
Saltwater Salmon Catch (pieces)				
Sockeye	58	146	355	4,090
Coho	208,792	164,656	265,532	224,878
Pink	163	134,539	52	198,931
Chum	3,492	3,487	3,073	3,288
Chinook	82,318	73,886	75,972	78,602
Total Salmon Catch (pieces)				
Sockeye	61,453	23,890	55,946	69,426
Coho	283,765	289,917	411,696	284,395
Pink	163	514,681	52	406,513
Chum	13,824	22,419	11,880	14,639
Chinook	225,489	267,214	218,628	267,978
All Angler Days				
Freshwater for Hire				
Freshwater Private				
Saltwater for Hire				
Saltwater Private	77,659	80,014	119,617	97,114
Salmon % of All Angler Days				
Freshwater for Hire				
Freshwater Private				
Saltwater for Hire				
Saltwater Private	100%	100%	100%	100%
Salmon Activity (Angler Days)				
For Hire	0	0	0	0
Private	77,659	80,014	119,617	97,114
All	77,659	80,014	119,617	97,114

Exhibit B.4: Recreational Catch of Salmon - Oregon \$US

	2012	2013	2014	2015
Freshwater Salmon Catch (pieces)				
Sockeye	0	0	0	0
Coho	36,205	41,390	227,777	114,617
Pink	0	0	0	0
Chum	0	0	0	0
Chinook	148,721	172,586	179,682	333,303
Saltwater Salmon Catch (pieces)				
Sockeye	0	0	0	0
Coho	16,079	14,536	99,507	28,282
Pink	0	0	0	0
Chum	0	0	0	0
Chinook	18,794	30,234	18,480	9,442
Total Salmon Catch (pieces)				
Sockeye	148,721	172,586	179,682	333,303
Coho	52,284	55,926	327,284	142,899
Pink	0	0	0	0
Chum	0	0	0	0
Chinook	18,794	30,234	18,480	9,442
All Angler Days				
Freshwater for Hire				
Freshwater Private				
Saltwater for Hire				
Saltwater Private	67,308	85,535	121,506	66,076
Salmon % of All Angler Days				
Freshwater for Hire				
Freshwater Private				
Saltwater for Hire				
Saltwater Private	100%	100%	100%	100%
Salmon Activity (Angler Days)				
For Hire	0	0	0	0
Private	67,308	85,535	121,506	66,076
All	67,308	85,535	121,506	66,076



**Annual Report of the
Southern Boundary Restoration and Enhancement Fund and the
Northern Boundary and Transboundary Rivers Restoration and Enhancement Fund
for the year 2016.**

Introduction

In June of 1999, the United States and Canada reached a comprehensive new agreement (the “1999 Agreement”) under the 1985 Pacific Salmon Treaty. Among other provisions, the 1999 Agreement established two bilateral funds: the Northern Boundary and Transboundary Rivers Restoration and Enhancement Fund (Northern Fund); and the Southern Boundary Restoration and Enhancement Fund (Southern Fund). The purpose of the two funds is to support activities in both countries that develop improved information for fishery resource management, rehabilitate and restore marine and freshwater habitat, and enhance wild stock production through low technology techniques. The United States agreed to capitalize the Northern and Southern Funds in the amounts of \$75 million U.S. and U.S. \$65 million respectively. Canada also contributed CAN \$500,000. The 1999 Agreement also established a Northern Fund Committee and a Southern Fund Committee, each comprised of three nationals from each country, to oversee investment of the Funds’ assets and make decisions about expenditures on projects. Only the earnings from investments can be spent on projects.

Committee Members

Northern Fund Committee

Canada:

Steve Gotch
Carmel Lowe
John McCulloch

United States:

Doug Mecum
Bill Auger
Charlie Swanton

Southern Fund Committee

Canada:

Andrew Thomson
Don Hall
Mike Griswold

United States:

Larry Peck
Peter Dygert
Joe Oatman

Executive Summary

- Total contributed capital (nominal) was U.S. \$140,065,000 (the equivalent of CDN \$209,796,000 using the exchange rate at the time the last installment was made). Actual fund asset value at December 31st, 2016 was U.S. \$199,048,000 or CDN \$267,262,000.
- 2016 could be characterized as a year of uncertainty. The year began badly with concerns over the Chinese economy and low oil prices. Further volatility resulted when the U.K. surprisingly voted to leave the European Union. However, political uncertainty across the globe was shrugged off by investors after the U.S. election and through the end of the year as investors bid up stocks in anticipation of deregulation, lower taxes, inflation and infrastructure spending.
- In 2016 the Southern Fund Committee supported a total of 32 projects for U.S. \$2.83 million including U.S. \$800,000 provided to the Salish Sea Marine Survival Program.
- In 2016 the Northern Fund Committee supported a total of 81 projects for U.S. \$4.76 million.
- Responding to guidance provided by the Commission, U.S. \$956,152 was contributed to support five very high priority chinook projects in 2016. The Northern Fund contributed U.S. \$454,590 and the Southern Fund contributed U.S. \$501,563.
- Combined project spending by the Northern and Southern Funds was U.S. \$7.59 million in 2016.
- Total Northern and Southern Fund project expenditures to date are U.S. \$68.5 million, including U.S. \$2.05 million to the very high priority chinook projects, in support of 996 projects. In addition, the Funds have contributed U.S. \$10 million to the Sentinel Stocks Program. The Southern Fund has contributed U.S. \$3.4 million to the Salish Sea Marine Survival Program.
- The Northern and Southern Fund Committee members met in person jointly on three occasions, first in February 2016, then again in April 2016 and again in November 2016. In addition in 2016, the Northern Fund Committee met three times in separate session and the Southern Fund Committee met separately on three occasions and made one field trip.
- A global equities manager search sub-committee met by conference call in March 2016 and in person in April 2016. A conference call with the full joint Fund Committees was held at the end of June to recommend and select a new global equities manager.
- On the Northern Fund Canadian section Dr. Carmel Lowe replaced Mr. Tom Protheroe.
- Fund staff provided administrative services for the Yukon River Panel's annual U.S. \$1.2 million Restoration and Enhancement Fund for a sixth year in 2016.

Investment Review

Global equities got off to a rocky start in 2016 as renewed concerns over subdued Chinese economic growth, a weaker Chinese yuan, deteriorating economic data globally, and falling commodity prices spooked equity market investors. After raising interest rates for the first time last year, the U.S. Federal Reserve (Fed) turned more dovish late in the quarter signaling that further rate hikes would be delayed lending support to the U.S. equity market. In the first quarter the joint Fund's net return of +2.77% in US dollar terms (USD) trailed the Benchmark return of +3.19% in USD. The underperformance was primarily due to poor performance by the Infrastructure manager (RARE) versus its benchmark and the underweight allocation to Universe Bonds.

In the second quarter, after falling sharply on the news of the UK's surprise referendum vote to leave the EU (Brexit), and the increased risk of political and economic stability in the wider European region Global equities rebounded somewhat after a volatile first quarter. Japanese equities also fell as the stronger yen posed a threat to exporter profits. U.S. equity returns were less volatile than elsewhere globally as expectations over the timing of the next interest rate increase by the Fed got pushed back. Over the second quarter, the Total Fund's net return of +0.68% in USD trailed the Benchmark return of +1.36% in USD. The underperformance was primarily due to poor performance by the international equity manager (LSV) versus its benchmark.

A global equity manager search was completed in Q2 with a decision to replace the previous global equity manager, Brandes with the Morgan Stanley Global Franchise Fund. As a temporary allocation, assets were transferred from Brandes to BlackRock in December 2015 and will stay there until the transition to the Morgan Stanley Fund has been completed. This transition from BlackRock to Morgan Stanley got underway at the end of the second quarter with the intention of being completed in the second half of 2016.

Markets absorbed the unexpected UK decision to leave the European Union with global equities continuing on an upward path after the Brexit decision in the third quarter. Economic data pointed to a resilient economic environment. Weakness in the Canadian dollar continued over the quarter, increasing returns in Canadian dollar terms. Over the past quarter, the Total Fund's net return of +3.73% in USD exceeded the Benchmark return of +3.40% in USD. The outperformance was primarily due to strong performance by LSV, the international equity manager versus its benchmark. The outperformance was primarily due to strong stock selection across multiple sectors and an underweight allocation to the Health Care and Consumer Staples sectors.

Global Equities rallied in the fourth quarter of 2016 boosted by better than expected economic data from U.S., Europe and China; improving company earnings across many regions; expectations of greater fiscal stimulus; and the election of Donald Trump in November's U.S. election. Political uncertainty across the globe was shrugged off as investors bid up stocks in anticipation of deregulation, lower taxes, inflation and infrastructure spending.

In October 2016, the transfer of the Global Equity mandate from BlackRock (temporary manager after the termination of Brandes) to Morgan Stanley was initiated and completed in January 2017.

Total contributed capital (nominal) was U.S. \$140,065,000 (the equivalent of CDN \$209,796,000 using the exchange rate at the time the last installment was made). Actual fund asset value at December 31st, 2016 was U.S. \$199,048,000 or CDN \$267,262,000.

Contributed capital and asset value of the individual Funds as of December 31st, 2016 stood as follows:

	Contributed Capital	Asset Value
Northern:	U.S. \$75,000,000 CDN \$112,388,000	U.S. \$109,178,000 CDN \$114,095,000
Southern:	U.S. \$65,000,000 CDN \$97,408,000	U.S. \$89,870,000 CDN \$94,334,000

Note #1:

In 2003 a rescission of 0.65% applied to the FY 2003 appropriations reduced the final contribution to the Northern Fund by U.S.\$162,500 and to the Southern Fund by U.S.\$97,500. Thus the actual Contributed Capital is:

Northern:	U.S. \$74,837,500
Southern:	U.S. \$64,902,500

Note #2:

U.S. Dollar Exchange (noon) rate: per Royal Trust, December 31, 2016	1.3427	0.74477
U.S. Dollar Exchange (noon) rate: per Royal Trust, November 30, 2016	1.3426	0.74482
U.S. Dollar Exchange (noon) rate: per Royal Trust, December 31, 2015	1.3840	0.72254
U.S. Dollar Exchange (noon) rate: per Royal Trust, December 31, 2014	1.1601	0.86199

Note #3:

Cash withdrawals performed in June 2016 to a total of U.S. \$6,660,000

2016 Project Funding

In 2016 the Southern Fund Committee supported a total of 34 projects for U.S. \$2.83 million. The list included projects addressing (i) specific priorities identified by the Pacific Salmon Commission's Fraser River and Southern Panels for U.S. \$1.53 million, (ii) four very high priority chinook projects for U.S. \$501,710, and, (iii) the Salish Sea Marine Survival Program for U.S. \$800,000. Of the U.S. \$1.53 million projects directed towards specific priorities identified by the Pacific Salmon Commission's Fraser River and Southern Panels U.S. \$1.29 million was directed to projects that also met the Southern Fund Committee's goal to "improve the management of fisheries relevant to the Pacific Salmon Treaty". U.S. \$125,000 was invested in the goal to "address priority stocks of interest". And, U.S. \$118,000 was invested in two projects under the goal of "gaining a better understanding and incorporating ecosystem factors into underlying science and management processes".

In 2016 the Northern Fund Committee supported a total of 81 projects for U.S. \$4.76 million. Of these, eight projects with a total value of U.S. \$292,000 were in the Enhancement envelope with the majority dealing with sockeye enhancement in the Transboundary region and Lakelse Lake in northern BC. U.S. \$171,000 was invested in Habitat Restoration works in northern BC and also access improvement projects in the Transboundary region. U.S. \$3.85 million was directed to 67 Improved Information-type projects across South East Alaska, the Transboundary and Northern

BC. In addition, the Northern Fund provided U.S. \$454,590 in total to four very high priority chinook projects.

In the thirteen years between 2004 and 2016 the Northern Fund has granted U.S. \$37.6 million to 543 projects. Similarly, between 2004 and 2016 the Southern Fund has granted U.S. \$30.9 million to 453 projects. Total Fund project expenditures to date are U.S. \$68.5 million in support of 996 projects. Included in this total is a sum of U.S. \$2.07 million in very high priority chinook projects and U.S. \$3.4 million from the Southern Fund to the Salish Sea Marine Survival Program. In addition to these amounts, the Sentinel Stocks Program was funded jointly by the Northern and Southern Funds between 2009 and 2014 in the amount of U.S. \$10 million.

Joint Funding Initiatives

(i) Very high priority Chinook projects

Grants were awarded in 2016 to the following projects:

Very high priority chinook projects 2016			Cost	
	Title	Agency	CAD	USD
1	Canadian Mark Recovery program CWT Sampling and Coordination and Mark Recovery Program Head Lab	DFO	\$484,844	
2	Terminal Abundance of WCVI Chinook salmon	DFO	\$257,000	
3	Increased Chinook salmon stock coded-wire tagging to improve the quality of Chinook indicator stock analyses	DFO	\$239,170	
4	Genetic-based abundance estimates for Snohomish River chinook salmon	WDFW		\$231,424
5	Abundance estimates for Stillaguamish River chinook salmon using trans-generational genetic mark recapture	WDFW		\$17,809

During the latter part of 2016, the process for undertaking technical reviews of all very high priority chinook projects for the Fund Committees ahead of funding decisions in 2017 and beyond was re-examined.

(ii) Fund communications.

For a second year in February 2016 the Joint Fund Committees sponsored an evening of brief presentations followed by a networking opportunity for attendees at the Pacific Salmon Commission's annual meeting at the Hyatt Regency Hotel in Vancouver, BC. The purpose of the event was to create an Endowment Fund communications opportunity. This year the February event was planned to draw the attention of the already

assembled PSC delegates to the upcoming launch of the recently redesigned PSC website which had been funded by the Joint Fund Committees. Fund Manager Angus Mackay followed this by giving an informational presentation on Fund investments and spending patterns that have emerged over the last decade. The evening was completed with the inaugural presentation of the Annual Larry Rutter Award for Pacific Salmon Conservation to Lorraine Loomis.

Joint Fund Committee Meetings

The Northern and Southern Fund Committees have agreed that given the congruent nature of their agendas, their decision to combine the funds into a single master account for investment management purposes, and the efficiencies involved with respect to interaction with the Fund managers, it was appropriate to meet together as a Joint Fund Committee at least once a year, preferably twice, for Fund financial reviews and investment manager interviews. The Fund Committees have also determined that it is beneficial to meet jointly early in the year during their annual project selection meetings to discuss and determine co-funding arrangements for very high priority chinook projects. Thus the Joint Fund Committees met in person three times during 2016. On February 16th, 2016; again on April 27th, 2016 and finally, on November 15th and 16th, 2016.

In February the two Fund Committees met separately to select their projects for funding support in 2016. A crucial element of these discussions was the suite of very high priority chinook projects being brought to the attention of the Committees by the Commission for funding consideration. Three of these projects concerned operations or stocks of interest that spanned the geographical areas covered by both the Northern and Southern Funds. Two others up for consideration were more obviously regional in their significance. At the meeting the Committees agreed to share the cost of three of the very high priority chinook projects. In addition, the Northern Fund Committee would fund a fourth on their own and the Southern Fund Committee would fund a fifth. Following these decisions Executive Secretary Mr. John Field presented a memo detailing the Commissioners understanding of the very high priority chinook project review and selection process that had been developed a week earlier at the PSC's annual meeting in Vancouver. Some discussion followed in which Committee members gave consideration to a potential meeting with the Commissioners to discuss the role of the Funds in supporting long-running agency-led projects that were facing core funding shortfalls due to budgetary constraints in both national capitals. Mr. Field provided a second memo concerning the Annual Larry Rutter Award for Pacific Salmon Conservation. Although the idea had initially been proposed as a Fund Committee initiative, the consensus now was that the Award should henceforward become Commission business. The global manager search sub-committee members reported on progress towards the selection of a new global equities investment manager to replace Brandes. Finally the Fund Committees set a date for their forthcoming April meeting.

The Spring meeting of the joint Northern and Southern Fund Committees was held in Vancouver on the morning of April 27th. Ms. Kamila Geisbrecht of Aon Hewitt opened the meeting by updating Committee members on the activities of the global manager search sub-committee who had held one conference call and who planned to hold in-person interviews with a short-list of selected candidature managers the following day. She recapped the closing out of the Brandes account and the temporary transfer of those assets to a BlackRock account pending selection of a new global equities manager. Ms. Geisbrecht then presented the 2015 Q4 investment performance

report and gave a preview of Q1 2016 which she described as having been markedly volatile. Responding to a question raised by Committee members on the performance of the Fund's fixed income (bonds) portfolio, Ms. Geisbrecht described strategies for active fixed income management. Following the Aon presentations, Mr. Mackay made a request for additional administrative funding in the amount of \$30,000 U.S. p.a. for a permanent part-time clerical assistant to the Fund to allow existing staff to devote more time to program enhancements and upgrades that would keep the Fund improving its service delivery standards. The request was approved. Next, PSC Secretariat Controller Ms. Ilinca Manisali presented the Fund's 2016/17 administration budget for Committee consideration. A motion to accept the budget as presented was moved and seconded. Executive Secretary Mr. John Field then recapped the very high priority chinook project process and a discussion ensued on the twin topics of ever-increasing core agency funding requests and the consequential reduction in discretionary funding opportunities for the Fund Committees. This led to a frank exchange on the advisability of supporting essential Treaty implementation activities on stock market returns. Mr. Field helped Committee members explore avenues for conveying the Fund Committees concerns on these issues to the Commissioners.

The joint Northern and Southern Fund Committees met together for the third and final time in 2016 in Vancouver on the afternoon of November 15th and all day on November 16th. The afternoon of the 15th opened with Mr. Mackay summarizing the very high priority chinook project proposal selection processes applied by the Northern and Southern Fund Committees and a review of the lists of very high priority chinook proposals selected to move to the second round of reviews. There was also a discussion on the Northern Fund's technical review process and confirmation that the Northern Fund's technical reviewers would also review the Southern Fund's very high priority chinook proposals. In the next agenda item Executive Secretary John Field reported back on his presentation at the PSC's October Executive Session of the Northern Fund Committee's update memo to the Commissioners concerning the 2017 Northern Fund process with respect to very high priority chinook projects. He reported that the Commissioners had no objection to the Northern Fund technical review process. The Commissioners agreed that the Chinook Technical Committee (CTC) were too busy to undertake a technical review of the 2017 proposals. The Chinook Interface Group (CIG) would contemplate the CTC's role going forward and develop a position for the Commissioners as to what the CTC's role in the process might be in 2018. After this agenda item the Northern and Southern Fund Committees took the opportunity to arrange to meet together in person in February 2017 to finalize very high priority chinook project funding and or shared funding as required.

Mr. Field next reported on his presentation to the Commissioners of the Northern Fund's memo on core agency funding which emphasized (i) the burgeoning annual growth of core agency funding requests being made on the Fund and, (ii) the risks associated with becoming financially dependent on support for Treaty related obligations from interest earned on unpredictable stock market investments. Mr. Field said the Commissioners noted the memo, but they had no further comment.

On the third agenda item Mr. Field reminded the Fund Committees that they had agreed, each at their separate September first round project proposal review meetings, to fund a comprehensive economic impact analysis of Pacific Salmon Treaty fisheries with grants of \$50,000 U.S. respectively North and South. The project was deemed by the Committees to be significant enough to be implemented immediately without waiting for the final conclusion of the second round 2017 project selection process in February. Mr. Field reported that a contract for the project had been

issued to Canadian and U.S. consulting experts; a progress report would be completed in February 2017; and, the final report would be delivered in May 2017.

The next agenda item concerned the honoraria paid to non-agency members of the Fund Committees, specifically the disparity between the amount paid to U.S. and Canadian Committee members. A lengthy discussion followed covering the original basis for setting national honoraria levels; the extent of the imbalance since inception; the equity principal; and, implications for other PSC related honorarium payments. Unable to reach resolution on the matter, the Committees agreed to return to the issue the following day.

Mr. Field provided an update report to the Fund Committee members on the implementation of SharePoint including hardware installation and portal development which the Funds had supported financially in 2013 and again in 2014.

Mr. Mackay asked the Committees about their interest in financially supporting a third informative evening seminar at the PSC's post-season meeting in Vancouver in January 2017. Having sponsoring successful and well attended events in 2015 and 2016, the Committees decided to waive this opportunity for 2017.

The following day, on November 16th the Committees met again in joint session for their annual financial meeting, investment manager performance review, and manager interviews. Ms. Kamila Geisbrecht of Aon Hewitt opened the meeting by describing the final transition of Fund assets to Morgan Stanley, the new global equities manager. She thanked the global manager search sub-committee for their work on the changeover. In their turn the sub-committee commended Ms. Geisbrecht to the joint Fund Committee members for her perseverance in negotiating the fee structure with Morgan Stanley. In follow up discussions the issue of fixed income assets arose again and the Committee again expressed an interest in exploring opportunities to optimize this element of the portfolio. This led to a direction from the Committee to Aon to review the current asset mix as a whole and identify opportunities to improve the risk-reward profile of the master trust by investigating the inclusion of additional asset classes and or changing the mix between fixed income and variable income asset classes. A sub-committee was struck to implement this action item.

Ms. Geisbrecht then presented the third Quarter report for 2016 (summarized in the investment review above).

The Committee then returned to the issue of non-agency member honoraria. U.S. committee members were generally of the opinion that the issue was a Canadian domestic one. Canadian Committee members accepted the need for further input on the subject at the Canadian federal level and agreed to postpone further Committee discussion on the topic until the February 2017 Fund Committee meeting.

The Committee then received the in-person presentations from the Fund managers: LSV (international equities manager), RARE (infrastructure manager), Invesco (real estate manager) and Morgan Stanley (global equity manager). The Committee was generally satisfied with the managers' reports and were interested to hear in-person from their new global manager Morgan Stanley for the first time.

Northern Fund Committee Meetings

The Northern Fund Committee met in separate session on three occasions during 2016.

February 15th to 17th, 2016

- Final selection of Northern Fund projects for funding in 2016.
- Discussions with Southern Fund on funding strategies and co-funding for the very high priority chinook projects.

April 26th (p.m. only) and 27th (p.m. only), 2016

- Performance criteria for two Northern Fund supported Canadian very high priority chinook projects as proposed by the Committee's bilateral technical support personnel.
- Potential for a Call for Proposals for 2017.
- Fund financial obligations in 2017.
- Consideration of Year 3 very high priority Chapter 3 chinook projects.
- Timetable.

September 13th to 15th, 2016 (held at the Listel Hotel in Vancouver).

- First round selection of 2017 Northern Fund project concepts to be invited to proceed to Stage Two detailed proposals.
- Review of audited financial statements.
- Consideration of proposed Fund Committee communications with the Commissioners at the Commissioner's October Executive Session.
- 2016 exchange rate report.

Southern Fund Committee Meetings

The Southern Fund Committee met in separate session four times during 2016.

February 15th and 16th 2016

- Final selection of Southern Fund projects for funding in 2016.
- Discussions with Northern Fund on funding strategies and co-funding for the very high priority chinook projects.

April 26th (p.m. only) and 27th (p.m. only), 2016.

- Annual report on Year 2 of the Salish Sea Marine Survival Program from U.S. and Canadian partners Long Live the Kings & the Pacific Salmon Foundation.
- Potential for a Call for Proposals for 2017.
- Fund financial obligations in 2017.
- Consideration of Year 3 very high priority Chapter 3 chinook projects.
- Timetable.

September 27th, 2016.

- First round selection of 2017 Southern Fund project concepts to be invited to proceed to Stage Two detailed proposals.

- Review of audited financial statements.
- Consideration of proposed Northern Fund Committee communications with the Commissioners at the Commissioner's October Executive Session.

September 28th and 29th, 2016.

- Three members of the Southern Fund Committee with Fund staff undertook a field trip to Washington State in September 2016. Driving from Port Townsend the group were met by WDFW and Olympic National Park staff in Port Angeles for a fact finding and educational tour of a number of significant sites along the Elwha River now in a state of rehabilitation following the removal of two dams on the river – possibly the largest fish habitat restoration project in the region. The following day the group were the guests of the Stillaguamish Tribe and received updates from their fisheries staff on current projects in the watershed. The group also toured the tribal hatchery site near Arlington.

Global Manager Selection Sub-Committee Meetings

The Sub-Committee met three times during 2016.

March 4th, 2016

- Conference call with Aon Hewitt staff to review the results of their research and analysis of selected global managers. Five managers were profiled and four were selected by the sub-committee to be invited to in-person interviews in Vancouver.

April 28th, 2016

- Members of the sub-committee with Fund staff and consultants from Aon Hewitt interviewed representatives from Carnegie Asset Management, Fiera Capital Corporation, Morgan Stanley Investment Management and Walter Scott & Partners Limited. Morgan Stanley were selected to be recommended to the full Joint Fund Committee as the new global assets manager for the master trust.

June 29th, 2016

- Conference call with the full Joint Fund Committee at which the global manager search sub-committee recommended hiring Morgan Stanley as the new global assets manager for the master trust. The recommendation was approved.

2016 Call for Proposals for projects in 2017/18

Both Fund Committees issued Calls for Proposals in mid-2016 for projects starting in 2017 including once again soliciting proposals for very high priority chinook projects. In the Calls, both Committees included a list of six very high priority chinook themes for projects to support the implementation of Annex IV, Chapter 3. The list of themes was recommended to the Fund Committees by the Pacific Salmon Commission in consultation with the Chinook Technical Committee (CTC).

The Northern Fund Committee received a total of 105 proposals requesting U.S. \$7.9 million. At the first round review meeting in September 2016, 76 of the proposals were selected to move to the second round detailed proposal stage having a total value of U.S. \$5.6 million. Bilateral technical reviews of the detailed proposals took place in January 2017 and a final decision on 2017 funding will be made at a meeting of the Northern Fund Committee in mid-February 2017.

The Southern Fund Committee focused its 2017 Call for Proposals on specific priorities identified by the Pacific Salmon Commission's Fraser River and Southern Panels as well as the very high priority chinook themes recommended by the Commission. The Fund Committee accepted 54 proposals requesting U.S. \$4.21 million. During the first round review meeting in September the Southern Fund Committee approved 12 multi-year, on-going proposals and 23 new proposals that together were in total requesting U.S. \$2.6 million to move to the second stage. The final decisions on 2017 funding will be made at a meeting of the Southern Fund Committee in mid-February 2017.

Committee Appointments

On the Northern Fund Committee's Canadian section, Dr. Carmel Lowe replaced Mr. Tom Protheroe who had served on the Committee for three years.

Yukon River Panel Restoration and Enhancement Fund

In March 2011, PSC Fund staff took over responsibility for the administration of the Yukon River Panel's Restoration and Enhancement Fund (R&E Fund). 2016 was the sixth year in which PSC Secretariat Fund staff have administered the R&E Fund.

The Yukon River Panel continued to place emphasis on Chinook Restoration priorities in their R&E Fund selection of projects to be funded in 2016; this in response to the decline of Yukon River Chinook salmon stocks experienced in recent years.

In 2016, a total of 31 projects were selected for R&E funding, of which, 21 were on-going multi-year projects and 10 were new. In U.S. dollar terms 69% of the funds were directed towards Conservation projects; 16% to Restoration; 10% towards Stewardship; and 5% towards Communications.

Funds in the amount of U.S. \$1,672,890 were allocated to projects. This sum was comprised of the annual U.S. \$1.2 million disbursement supplemented by unspent funds held by the Panel from previous years.

Attachment E to the diplomatic notes dated June 30, 1999 includes the following:

“Desiring to cooperate so as to achieve optimum production, the Parties agree:

1. *To use their best efforts, consistent with applicable law, to:*
 - (a) *protect and restore habitat so as to promote safe passage of adult and juvenile salmon and achieve high levels of natural production,*
 - (b) *maintain and, as needed, improve safe passage of salmon to and from their natal streams, and*
 - (c) *maintain adequate water quality and quantity.*

2. *To promote these objectives by requesting the Commission to report annually to the Parties on:*
 - (a) *naturally spawning stocks subject to the Treaty for which agreed harvest controls alone cannot restore optimum production,*
 - (b) *non-fishing factors affecting the safe passage of salmon as well as the survival of juvenile salmon which limit production of salmon identified in sub-paragraph 2(a) above,*
 - (c) *options for addressing non-fishing constraints and restoring optimum production, and*
 - (d) *progress of the Parties’ efforts to achieve the objectives of this agreement for the stocks identified in sub-paragraph 2(a) above.*

The provisions of Attachment E described above are met by the Parties, in part, through habitat and restoration activities carried out by responsible jurisdictions and through the exchange of relevant information and reports. In addition, in 20xx, a Habitat and Restoration Technical Committee was established with a mandate to: (a) facilitate information sharing between the Parties and among agencies involved in the Commission process and (b) upon request from the Northern and Southern Fund Committees, provide advice to assist in making project funding decisions.

As part of ongoing activities undertaken to fulfill habitat and restoration provisions of Attachment E, it is proposed that the Commission adopt the following measures:

- To improve information sharing between the Parties, direct the Commission staff to construct a page on its web site that maintains citations, references or links to publically-accessible information maintained by the Parties, management entities or

others related to habitat protection and restoration projects and programs of importance to Pacific salmon subject to the Pacific Salmon Treaty.

- Eliminate the Habitat and Restoration Technical Committee which has been in abeyance for several years and is no longer required.

Protocol for PST Chapter Renegotiations

Agenda Item 7.b. Reports from Panels and Committees: Status of Negotiations 29 October 2015, adopted in bilateral session Updated, February 16, 2017 Final, Adopted

The Parties wish to provide guidance to ensure clarity for well-functioning process for negotiations. Should both parties agree, the protocol language can change.

The Commission will establish a Negotiating Team and specify its membership. The negotiating team may identify a subset of Commissioners, advisors, or technical support to work bilaterally on particular issues. The Negotiating Team will meet *in camera*, no minutes will be taken, and the decisions will be read into the record at the next opportunity. The Parties intend to remain flexible in administering the process of the negotiations.

Each Section will keep its government apprised of the negotiations and, when appropriate, raise to its government issues it believes require further support.

The full Commission will approve proposed chapter language to be recommended to the Parties.

Chapter 3, Chinook:

The negotiations will be led by Commissioners and supported by advisors as identified by the Parties.

- US negotiating team: 8 Commissioners (lead contact/spokesperson) and supported by 8 advisors.
- Canadian negotiating team: 8 Commissioners (lead contact/spokesperson) supported by 9 advisors.

Both teams are supported by technical advisors, including CTC co-chairs.

Chapters 1,2,5,6

Lead negotiators are Panel Chairs and Vice-Chairs, supported by advisors (Panel members).

The Negotiating Team will hear panel reports on chapter negotiations and address outstanding issues brought forward by the Panel Chairs.

Negotiating Team members and other invitees to Negotiating Team meetings

Canadian Commissioners

Rebecca Reid

Murray Ned

Chief Brian Assu

John McCulloch

Bob Rezansoff

Susan Farlinger (Lead Negotiator)

Brian Riddell

Paul Sprout

Canadian Advisors

Paul Macgillivray, DFO Advisor

Larry Neilson, Government of British Columbia

Russ Jones, Advisor to First Nations Commissioners

Derek Mahoney, Senior Policy Analyst*

U.S. Commissioners

Charlie Swanton

Bill Auger

Donna Darm

Department of State point of contact**

McCoy Oatman

W. Ron Allen

Phil Anderson (Lead Negotiator)

Rick Klumph

U.S. Shadows

Bob Clark, Shadow to Commissioner Swanton

Jennifer Yuhas, Shadow to Alternate Auger***

Bob Turner, Shadow to Commissioner Darm

Peter Dygert, Shadow to Alternate Department of State point of contact

Mike Matylewich, Shadow to Commissioner Oatman

Craig Bowhay, Shadow to Alternate Allen

Jim Scott, Shadow to Commissioner Anderson

Christine Mallette, Shadow to Alternate Klumph

U.S. subject matter expert

Susan Bishop, NOAA Fisheries Puget Sound/Washington Coastal Harvest Team Lead

Jim Unsworth, Director of Washington Department of Fish and Wildlife

Secretariat Staff

John Field, Executive Secretary

National Correspondents

Kirsten Ruecker, Alison Agness

**Panel Chairs and Alternates, and Technical Committee Co-Chairs, as needed for
Negotiation Team meetings specific to respective Chapters**

As needed, the relevant Panel Chair will be accompanied by their Alternate, and their respective Committee Co-Chairs.

Chinook Technical Committee (Chapter 3)

Gayle Brown and Chuck Parken

John Carlile and Robert Kope

Fraser River Panel and Technical Committee (Chapter 4)

Jennifer Nener, Les Jantz and Ann-Marie Huang

Lorraine Loomis, Kirt Hughes, Robert Conrad

Southern Panel and Technical Committees (Coho and Chum; Chapters 5 and 6)

Andrew Thomson, Brigid Payne, Arlene Tompkins and Pieter van Will

Laurie Peterson, Terry Williams, Gary Morishima, and Bill Patton

Northern Panel and Technical Committee (Chapter 2)

Mel Kotyk, Barry Rosenberger and Steve Cox-Rogers

Lowell Fair and Bo Meredith

Transboundary Panel and Technical Committee (Chapter 1)

Steve Gotch and Steve Smith

John H. Clark and Ed Jones

*Note: At the February 2017, Annual meeting Derek will be represented by Roger Wysocki, Manager, Manager, Fisheries Science - Pacific and Arctic Section

**The Department of State alternate Commissioner seat is vacant, and a point of contact will be identified by meeting. At the February 2017, Annual meeting Rebecca Dorsey will represent the Department of State.

*** Jennifer Yuhas and Mitch Eide may alternate, to be determined by meeting. At the February 2017, Annual meeting Jennifer will represent the Shadow to Alternate Auger.

Committee on Scientific Cooperation (CSC)

Annual Report to the Commission

February 16, 2017

The document provides a progress report on the three approved elements of the 2017 CSC annual work plan.

1. International Year of the Salmon (IYS)

The IYS is an international framework for collaborative outreach and research to be implemented over the period 2017-2022. It was initiated by the North Pacific Anadromous Fish Commission (NPAFC) and the North Atlantic Salmon Conservation Organization (NASCO) and planning is underway with potential partners including ICES/PICES, government agencies, First Nations, NGOs, universities and industry. The IYS will stimulate an investment in outreach and research and leave a legacy of knowledge, data/information systems, analytical tools, management systems and a new generation of scientists and managers better equipped to deal with rapidly changing environmental and social conditions. The IYS may have the potential to enhance the PSC's capacity to address a number of science and management issues.

The inaugural meeting of the North Pacific Steering Committee for the IYS initiative will take place in Vancouver, B.C. on Feb 28 – Mar 01, 2017. The agenda for this meeting as well as a list of participants are attached for the Commission's consideration (Appendix 1). The PSC Executive Secretary will participate in the meeting and submit a report on the proceedings to the Commission Chair and Vice-Chair by late March (Note: Canadian members of the CSC will also participate as representatives of other organizations).

2. Radio Frequency Identification (RFID) Tag Review

As a follow-up to the 2005 CWT Expert Panel Review, the CSC initiated a review of the current status of RFID (micro and PIT tag) technology and its potential to replace the PSC's coast-wide Chinook and coho CWT program. With funding from the Northern Endowment Fund, the CSC initiated the project: *"The Feasibility of Radio Frequency Identification Tags for Marking Juvenile Salmon for Pacific Salmon Commission Management Applications"*.

The project went to competitive bid and a contract was awarded to LGL Ltd. The CSC provided support and guidance to LGL Ltd. by participating in iterative teleconferences and arranging for reviews of their draft report by the CoTC and other science experts. The final LGL Ltd. report was submitted on February 8, 2017 and a presentation of the report and its recommendations were delivered at the Annual Meeting of the Commission on February 14, 2017.

The CSC found the report to be a very well done, comprehensive review of the current status of different types of RFID tags for application to fish and the use of RFID PIT tags for salmon. It also included a cost-benefit evaluation of the potential for the replacement of CWTs with PIT tags for PSC management.

Based on a review of the report and comments from the PSC science community, the CSC drew the following nine conclusions:

1. RFID Microchips do not have sufficient detection range for use as a replacement for CWTs.
2. Current generation RFID tags for fish (PIT tags) can provide opportunities for live sampling and individual-based identification, and could thus enhance the level of information available for stock assessment. Applications include repeat mark-recapture to better define distribution, migration, and life-stage survival.
3. PIT tags have been highly successful in population assessment of Fraser River sturgeon, dam-passage and in-river distribution of Columbia River salmon and steelhead, and a wide variety of research for migration, hatchery genetics, and survival.
4. PIT tag information can be recovered from fish released due to size- or species non-retention regulations. PIT tag information can also be recovered from landed catch without removing the head.
5. Electronic sampling wands may be feasible that would allow for detection of both CWTs and PIT tags.
6. To achieve the sample numbers and ancillary benefits detailed in the RFID report, sampling of some commercial fisheries (e.g. troll fisheries) would need to shift to or include an on-board, fisher-based sampling system.
7. Comparisons of survival and tag loss for PIT-tagged coho and Chinook salmon relative to CWT-salmon over the fish's entire life history are scarce, and there are results indicating substantially lower survival and higher tag-loss especially for smaller fall Chinook salmon.
8. Coho salmon are the species with the highest potential for using PIT tags for PSC application, because of their large smolt size and relatively smaller number of fish tagged.
9. PIT tags are more expensive than CWTs by an order of magnitude. For a given suite of indicator stocks, costs of tagging and tag information recovery with PIT tags are substantially higher than for coded-wire tags.

Based on their analysis, the CSC provides the following recommendations for the consideration of the Commission:

1. At this time, transition to the current generation of RFID tags (microchips or PIT tags) is not warranted for assessment of the PSC Coho and Chinook fisheries.
2. The CSC should revisit the potential for RFID *microchips* as an alternative for CWTs in 3-5 years. Although the detection limit is currently too small, the continued development of RFID tags for labeling and tracking things may change this situation.

3. The CSC should track the on-going studies on the effects of PIT tags on survival and tag loss of Chinook salmon to better assess their feasibility for full life cycle tagging.
4. Advocates of PIT tags should run comparison tests of PIT tags relative to CWTs on survival and tag loss for coho salmon smolts.
5. Manufacturers of PIT tags should develop a prototype dual sampling wand for testing on board research vessels and fishing vessels (e.g., the NBC troll freezer boats).
6. The CSC should discuss with CoTC and CTC how much the “added value” of PIT tags in terms of the individual-based information and other advantages could benefit current or alternative management models for PSC fisheries management.

The CSC requests approval to include the LGL Ltd. report in the PSC Technical Report Series.

3. Documenting Environmental Anomalies

At its January 2016 Post-season Meeting, the Commission directed the CSC to develop a plan for documenting environmental conditions and evaluating their implications for salmon production under the Treaty: *“By the 2016 Annual Meeting, the CSC shall collaborate with appropriate experts and develop a proposal for annual collation of data on the environment, run size, fish condition, and other metrics that may reveal anomalies in salmon survival.”* In response, the CSC developed an outline of actions that could be undertaken to address this directive.

The CSC envisioned a two-phase approach to considering and evaluating environmental and biological anomalies as outlined in its Work Plan to the Commission. Phase 1 involved a contract to Dr. Skip McKinnell to: a) document environmental anomalies observed in 2015 and, where feasible, 2016; and, b) assess the anomalies and their implications for PSC management of its fisheries in view of historical patterns of anomalous observations.

At its October 2016 meeting the Commission instructed the CSC to complete the documentation of anomalies by the January 2017 Post-season Meeting and present a strategy for Phase 2 at the February 2017 Annual Meeting.

At the January meeting, the CSC submitted to the Commission part a) of Dr. McKinnell’s report, which provided the documentation of environmental and salmon metric anomalies in 2015 and, where available, 2016. Phase 1 was then completed at the 2017 PSC Annual Meeting with the submission of part b) of Dr. McKinnell’s report and a presentation of his findings to the PSC community on February 15, 2017.

As per the Commission instruction for Phase 2, the CSC also provided the Commission with a document *“Developing a strategy for on-going consideration of annual*

environmental variability and its impact on salmon production and management" (Appendix 2). The CSC developed this strategy based on the findings and recommendations in Dr. McKinnell's report, previous input from the 2015 CSC meeting with Chairs and interested members of the PSC's Technical Committees and Panels, as well as consultation with the Executive Secretary and comments from reviewers of earlier drafts of the Phase 2 approach.

This strategy identifies four objectives and provides options to address them based on different levels of institutional and funding support:

- A) Improve information sharing and access to measures of environmental and biological variability, including salmon population metrics;
- B) Develop a capacity for compiling and evaluating annual variability in environmental and salmon indicators to provide an improved information base for forecasting and managing salmon populations;
- C) Inform the Commission and its science community annually on observations of changing environmental conditions and their relation to salmon production; and,
- D) Engage other international organizations through initiatives such as the International Year of the Salmon to enhance and leverage PSC capacity and efforts to address A) to C).

The CSC requests Commission direction on implementation of the strategy. This direction will determine CSC activity for the remainder of this year and inform the development of its Work Plan for the next cycle.

The CSC also requests approval to include the McKinnell report (combining parts a and b) in the PSC Technical Report Series.

Appendix 1:

International Year of the Salmon **North Pacific Steering Committee Meeting** February 28- March 1, 2017 | Richmond, BC

Location: Vancouver Airport Marriott Hotel, 7571 Westminster Highway, Richmond, B.C.

Tuesday, February 28, 2017

9:00am- 4:15pm: Steering Committee Meeting Day One

6:30pm- 9:30pm: Stand-up reception with food at [Catch Kitchen + Bar](#) (dress: business casual). Bus transportation from the hotel, and back again, will be provided.

Wednesday, March 1, 2017

9:00am- 3:00pm: Steering Committee Meeting Day Two

Hosted by: North Pacific Anadromous Fish Commission

Phone: 604-775-5550 | email: secretariat@npafc.org

Purpose and Goals

The purpose of the two-day North Pacific Steering Committee meeting is to convene government, academic, NGO, First Nations and industry partners to engage in planning towards implementation of the International Year of the Salmon in the North Pacific. Participants will consider proposed governance arrangements and engage in the continued development of planning for the International Year of the Salmon.

Meeting Goals

- 1- Give an update on the IYS initiative, scope and purpose
- 2- Confirm the IYS governance arrangements, including the process for formalizing membership of the IYS North Pacific Steering Committee
- 3- Consider approaches to and engagement of partners in planning, communications and fund development.

Tuesday, February 28 - DAY ONE

9:00 – 10:00	Agenda Review & Introductions
10:00 - 10:45	Update on the status of the IYS
10:45 - 11:00 – Break	
11:00 - 12:00	Presentation: Increasing variability in environmental conditions and salmon fisheries in the North Pacific in 2015 and 2016. Presentation by Skip McKinnell
12:00 - 1:00 – Lunch	
1:00 - 2:00	Review and discussion of the IYS and North Pacific Steering Committee governance
2:00 - 2:15 – Break	
2:15- 3:15	IYS Funding Strategy review and discussion
3:15 - 4:15	Planning for the IYS – Overview of impact planning
4:15 – 6:15 – Free time for participants	
6:15 – Bus for reception	

Wednesday, March 1 - DAY TWO

9:00 - 9:30	Welcome and Review of Day 1
9:30 – 10:45	Planning for the IYS: developing actions through a ‘turning the curve’ exercise
10:45 – 11:00 – Break	
11:00 - 12:15	Planning for the IYS – Next steps and discussion
12:15 - 1:15 – Lunch	
1:15 - 2:00	2018 Kick-off event/symposium
2:00 - 2:45	Concluding roundtable
2:45 - 3:00	Wrap up and Next steps

IYS North Pacific Steering Committee Meeting – List of Participants

February 28-March 1, 2017

Richmond, B.C. Canada

Last Name	First Name	Affiliation
Saunders	Mark	NPAFC IYS WG Chairperson, DFO
Lowe	Carmel	NPAFC President, DFO
Radchenko	Vladimir	NPAFC Secretariat
Park	Jeongseok	NPAFC Secretariat
Young	Madeline	NPAFC Secretariat
Mecum	Doug	NPAFC, NOAA, NMFS
Stegemann	Andrew	Contracted Facilitator
Sato	Shunpei	NPAFC IYS WG, FRA
Suzuki	Kengo	NPAFC IYS WG, FRA
Urawa	Shigehiko	NPAFC IYS WG, FRA
Kim	Ju Kyoung	NPAFC IYS WG, FIRA
Lee	Do Hyun	NPAFC IYS WG, FIRA
Melnikov	Igor	NPAFC IYS WG, TINRO-Center
Oxman	Dion	NPAFC IYS WG, ADF&G
Farley	Ed	NPAFC IYS WG, AFSC, NOAA, USA
Gray	Andrew	NPAFC IYS WG, NMFS, NOAA, USA
Irvine	Jim	DFO
Brodeur	Richard	NWFSC, NOAA, USA
Batchelder	Hal	PICES, Canada
Field	John	PSC, Canada
Beamish	Dick	DFO, Emeritus
Day	Andrew	Vancouver Aquarium
Iwama	George	UBC, IOF
Berezny	Allan	UBC, IOF
Pakhomov	Evgeny	UBC, IOF
Juanes	Francis	UVic
Laborde	Sara	Wild Salmon Center
Sloat	Matthew	Wild Salmon Center
McPhee	Megan	UAF
Moran	Kate	Ocean Networks
Sastri	Akash	Ocean Networks
Hunt	Brian	UBC, Tula Foundation
Peterson	Eric	Tula Foundation
Ritchie	Rachael	Genome BC
Riddell	Brian	Pacific Salmon Foundation
White	Jacques	Long Live the Kings
Machin	Deana	First Nations Fisheries Council
Schmidt	Michael	Long Live the Kings
Stephens	Craig	Can. Wildlife Health Cooperative

Grant	Sue	DFO
Holmes	John	DFO
Nener	Jennifer	DFO

Appendix 2:

A strategy for consideration of annual variation in environmental indicators and salmon production and its implications for fisheries management under the Pacific Salmon Treaty

**Provided by the Committee on Scientific Cooperation to the Pacific Salmon Commission
15 February 2017**

The Pacific Salmon Treaty is based on the mutual interest of Canada and the United States in the conservation and management of Pacific salmon stocks and in the optimum production of such stocks. As a result of changing climate, the business of the Pacific Salmon Commission (PSC) is increasingly influenced by anomalous environmental conditions. Achieving conservation and optimal production goals now and in the future will require the Commission to actively manage processes at all levels to ensure the organization is as prepared and as a result as resilient as possible to rapidly changing environmental conditions.

At its January 2016 Post-season Meeting, the Commission directed the Committee on Scientific Cooperation (CSC) to develop a plan for documenting these conditions and evaluating their implications for salmon production under the Treaty: “By the 2016 Annual Meeting, the CSC shall collaborate with appropriate experts and develop a proposal for annual collation of data on the environment, run size, fish condition, and other metrics that may reveal anomalies in salmon survival.” In response, the CSC developed an outline of actions that could be undertaken to address this directive. The CSC envisioned a two-phase approach to considering and evaluating environmental and biological anomalies as outlined in its workplan to the PSC. Phase 1 involved a contract let to Dr. Skip McKinnell in an effort to a) document variation in these parameters observed in 2015 and, where feasible, 2016; and b) assess this variation and its implications for PSC management of its fisheries in view of historical patterns of anomalous observations.

At its October 2016 meeting the Commission instructed the CSC to complete Phase 1 by the January 2017 Post-season Meeting and present the strategy for Phase 2 at the February 2017 Annual Meeting.

Phase 1 was completed by the 2017 PSC Annual Meeting, where Dr. McKinnell presented his findings to the PSC community. Dr. McKinnell’s analysis described in detail a number of anomalies, including extreme values relative to the available historical record, for both environmental and salmon indicators in both years. The salmon anomalies included unusual observations of abundance, phenology, and adult size, and

included a number of extrema. Indeed, 2015 and 2016 were noteworthy for both the number and the magnitude of anomalies in environmental and salmon population indices in the Northeastern Pacific Ocean.

Part of Dr. McKinnell's task was to identify approaches to monitoring of anomalies, storage of related data, and communication of information to the PSC community. He concluded that ocean-climate environmental information is readily available, but that comprehensive information on salmon biology is much more challenging to find, access, and utilize. He provided eight recommendations directed towards the development of an automated system of data retrieval and analysis to provide "real time access to salmon data coastwide, in-season." Among these recommendations is the formation of expert groups to design this system, select appropriate metrics, and determine the predictive value of the information for various aspects of salmon biology.

Dr. McKinnell identified a number of challenges to achieving these objectives. Foremost among them is the absence of a cohesive international body with the responsibility, authority, and resources to manage coast-wide salmon and environmental data. These data are obtained from various sources, are not standardized (which would thereby readily permit comparisons among years and locations), and are often limited or restricted in access. Furthermore, no consensus has been reached on how best to advise fishery management in light of this information. That being said, a careful survey of how other organizations have approached similar problems has not yet been conducted. It is important to recognize that addressing these issues is limited less by available tools and technology than by communication and effective coordination among parties, which will be key to success.

With Phase 1 now complete, the CSC has been tasked with Phase 2, "*Developing a strategy for on-going consideration of annual environmental variability and its impact on salmon production and management.*" The CSC used the findings and recommendations from Dr. McKinnell's report, previous input from the 2015 CSC meeting with Chairs and interested members of the PSC's Technical Committees and Panels, consultation with the Executive Secretary, and comments from reviewers of earlier drafts of the Phase 2 approach.

This strategy identifies means to:

- A) Improve information sharing and access to measures of environmental and biological variability, including salmon population metrics;
- B) Develop a capacity for compiling and evaluating annual variability in environmental and salmon indicators to provide an information base to assist in forecasting and managing salmon populations;
- C) Inform the Commission and its science community annually on observations of changing environmental conditions and their relation to salmon production; and,

- D) Engage other international organizations through initiatives such as the International Year of the Salmon to enhance and leverage PSC capacity and efforts to address A) to C).

These elements are detailed below. The CSC considers such a strategy important to the Commission because anomalous conditions can have profound impacts on the management of PSC salmon fisheries, and because the relationships between large-scale variation in environmental features and fluctuations in salmon abundance and life history are poorly understood. The degree and number of strong anomalies and extrema observed in 2015 and 2016 were remarkable, and they may be indicative of greater uncertainty and variability in the coming years. There is an increasing recognition by technical experts and managers of the value and need to consider environmental variation in forecasting and managing salmon populations. Examples of the importance of monitoring and measuring environment and biological parameters for forecasting salmon survival, year-class strength, run-timing, or distribution include NOAA's Ocean Ecosystem Indicators program off the Oregon/Washington coast, CDFO's Fraser River sockeye forecast program, and NOAA's Southeast Alaska Coastal Monitoring program. As was done in 2015 and 2016, annual observations of environmental and salmon production indicators should be systematically collated and analyzed to better inform the management of PSC salmon fisheries.

A) Improve information sharing and access to measures of environmental and biological variability, including salmon population metrics.

The CSC recommends that a web portal be developed to facilitate the gathering and exchange of relevant data and information. The portal development and maintenance can be incorporated into the existing website using current PSC staff expertise. Minimal new funds would be required. The portal should have the following functionality:

1. Establishment of a web-based forum for sharing information among the Technical Committees and Panels. The forum would provide the opportunity for posting in-season and post-season observations; physical and biological environmental indices; estimates of salmon survival and production; salmon life history characteristics such as run timing and size at age; relevant citations and technical reports; and discussion of implications of anomalies and environmental trends for management of PSC fisheries and forecast models. Information would depend on voluntary participation by the PSC science community.
2. Identification of web links to existing digital data sets and search engines. The CSC would coordinate collecting the relevant links for posting on the web portal. Link fields would be developed for: environmental and salmon data sets relevant to PSC Technical Committee activities, e.g., ARMIS, PDO, NPI, ONI, CUI, ENSO, Columbia River dam counts, and Fraser River hydro-acoustic counts; reference sources for publications and data, e.g., NPAFC,

PSC, CDFO, NOAA, ADFG, WDFW, and ODFW; and search engines, e.g., Google Scholar, Web of Science.

3. Development of a searchable bibliography for the PSC science community. This will require collaboration between the CSC and PSC staff for initial design and the input process, and the participation of Secretariat staff (IT and Library Science) for maintenance and oversight.
4. Discussion between the CSC and the PSC's Data Sharing Committee on mechanisms to improve information sharing and access among the Technical Committees.

B) Develop a capacity for compiling and evaluating annual variability in environmental and salmon indicators to provide an information base to assist in forecasting and managing salmon populations.

This task would require active data acquisition, management, and evaluation, and specific expertise for the analyses of the data. This task would require identifying indicators and metrics of environmental and salmon variability for coast-wide annual tracking; collating information on these indicators and metrics, and provide annual summaries; and analyzing trends in variability at the appropriate spatial and population scales in the context of the historical record. Outcomes would include a searchable, coast-wide information system coordinated between the U.S. and Canada, facilitating assessment of annual data; annual evaluation of the covariation of environmental variation and salmon production; and timely reporting of analyses to the PSC community.

To achieve this capacity the PSC would need to identify funding for a dedicated staff position and support for ad-hoc working groups of appropriate experts to design the framework, identify suitable indices and analytical approaches. Our preliminary estimate of costs for implementation is approximately \$200-300K annually. This funding could be identified in the budget development for the next PSC agreement.

C) Inform the Commission and its science community annually on observations of changing environmental conditions and their relation to salmon production.

1. The CSC would summarize development and activity of the communication forum as part of the CSC annual report. This task could be incorporated into the CSC's work plan with minimal new funding.
2. The CSC would organize and manage an annual mini-workshop of 2 hours duration at which invited experts present perspectives on the state of the ocean and the state of salmon from different regions across the North Pacific Rim. The

workshop would be scheduled as an open session at the PSC Annual Meeting. The workshop would require an annual budget for coordination and invitational travel for speakers of \$10-20 K.

- The CSC could pursue support from the Fund Committees as part of the 2017 solicitation for supporting a workshop series beginning in 2019.
- For the 2018 Annual Meeting, the CSC would organize a meeting with Technical Committee and Panel Chairs and interested members to provide review and input on information sharing, workshop development, and solicit one or more annual presentation addressing the subject of environmental variability and salmon population responses.

3. Contingent on funding for component B, the dedicated staff person would provide an annual report to the CSC, summarizing data management and analyses. The CSC would review and include in its annual report.

D) Engage other international organizations to enhance and leverage PSC capacity and efforts to address A) to C).

The PSC is not alone in needing to monitor and understand a rapidly changing environment and the impacts on fisheries management. This understanding will come from observations on salmon stocks and associated environmental indicators at the local, North Pacific Ocean, and hemispheric scales and the CSC recommends PSC seek to exploit the efforts on these matters being undertaken by international organizations. At this time, the CSC recommends PSC participation in the NPAFC/NASCO/PICES Year of the Salmon initiative as the preferred approach to doing this.

**Feasibility of Radio-Frequency Identification Tags for Marking Juvenile
Salmon for Pacific Salmon Commission Management Applications**

Final Report

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for

Pacific Salmon Commission

5 February 2017

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Executive Summary

LGL Limited was contracted by the Pacific Salmon Commission (PSC) to assess the current state of RFID technology, its suitability for application to juvenile Chinook and Coho salmon, and its potential to provide more useful and reliable information than the current CWT program. The PSC identified the following five objectives:

1. Review the current application of RFID tags for animal identification and management, including their advantages and limitations over current technologies.
2. Compare sizes, tag costs, and tag application costs of RFID tags (including PIT tags) with those of CWTs.
3. Review detection capabilities of RFID tags, including detection distances when embedded in animal tissue and when animals are moving through freshwater or seawater.
4. Evaluate the feasibility for mass screening for detection and reading of RFID tags in landings of Pacific salmon.
5. Evaluate the feasibility and cost of incorporating RFID microchips to replace CWT in marking juvenile salmon for coastwide Coho and Chinook salmon management.

These objectives were addressed by combining the information obtained through our review of the pertinent literature, CWT and RFID tagging programs; and structured inquiries of manufacturers of RFID tags used for tagging fish and detecting recoveries in marine fisheries, freshwater fisheries and spawning areas.

A summary of our findings and recommendations regarding each of the above objectives is provided in the following paragraphs:

Objective 1 – There are a wide variety of RFID tags (size, shape, operating frequency, performance) and applications, although their common use is to provide the unique identification of live beings or material assets. The numerous types of RFID tags developed for hard goods are not suitable for application to fish. Physical laws strictly govern the tag size and detection range. The frequency at which a RFID tag and respective reader operate is one of the parameters which directly influences the size of tags and the distance from the reader that the tag can be energized and reliably decoded. Passive Integrated Transponder (PIT) tags are the most commonly used and effective RFID technology suitable for fish. Application of PIT tags to fish over the past 25 years has shaped the physical specifications of tags and readers produced today to provide the best characteristics of application and performance that can be achieved (i.e., 134.4 KHz) using currently available technology. The major advantage of current RFID (PIT tag) technology over CWTs for fish studies are:

- a. PIT tag codes can be recovered from alive or dead fish in seconds by passing a scanner over the fish, whereas for CWT fish must be killed in order to extract and visually decode the tag. The ability to decode a PIT tag with a scanner eliminates collecting heads from fish that may or may not contain CWTs, extracting the CWT,

- decoding the CWT, recording the data and analytically handling errors and tags lost in this process. Therefore, PIT tags provide more opportunity for recoveries and a process that is substantially more timely and efficient;
- b. PIT tags can be detected in fish as they pass in proximity to a scanning device, including when the fish is in fresh water. CWT detectors can only be used in air. Further, standard PIT tags have a broader detection range than CWT. Therefore, PIT tags can be detected in more situations and conditions; and
 - c. Release and recovery data is higher quality in that there are significantly fewer errors in reading, recording, and exchange. Therefore, quality control of data requires less effort, data analyses are more reliable, and require less time and costs for analysis.

The major limitation of current RFID (PIT tag) technology relative to CWTs for fish studies is cost. PIT tags are approximately 11 times more costly than CWTs, and it can take approximately 2 to 8 times longer to tag a fish with a PIT versus a CWT.

Objective 2 – Biomark produces three sizes of PIT tags applicable to juvenile salmon (8, 9, and 12 mm in length, 1.0-1.4 mm in diameter). Read range for a 8 mm PIT tag (50 cm) is approximately half that for a 12 mm PIT tag (100 cm). The cost for these PIT tags are approximately CAD \$1.95 per tag, *preloaded in a needle*. Comparable tags without the needle can be obtained from HID Global for approximately CAD \$1.30 for bulk orders of 1 million tags. These tags are currently applied using manual (non-automated) techniques involving needles needle insertion or micro-surgery. A single trained staff using preloaded needles and a continuous supply of fish can tag approximately 100 fish per hour. Several other likely costs (e.g., location, mobile reader, available infrastructure and services, fish anesthesia method, and related data management) would need to be considered to provide an all-inclusive estimate of producing tagged fish for release. Assuming that these “other” costs are similar with CWT, then PIT application would cost approximately 11 times more for tags, and 8 times as much in technician labor for the same number of tagged fish. A broader programmatic comparison of PIT and CWT costs is provided in the section on Objective 5.

Objective 3 – There are two aspects of detection capability for RFID tags; Read Range and Read Speed. Read Range of a tag is directly related to the physical quantity and quality of core components (ferrite and windings), and influenced by the quality of the Reader and a host of environmental factors. Assuming optimal orientation in the antenna field, the smallest ultra and micro tags (2.5-6 mm) have a Read Range of 1 cm or less. Standard 12 mm tags can have a Read Range up to 100 cm (antenna array dependent), and 8 mm tags is less than 50 cm. In general, Read Range is the same in air and freshwater and is not appreciably effected by body tissue. Bit specification (e.g., 32 or 64 bit) of a Reader effects the Read speed, or how quickly a tag can be accurately scanned in the antenna field. Typically, tags can be read on the order of milliseconds. Tags passing through a field

quickly (e.g., through the spillway of dam) require a faster processing speed compared to those scanned using a hand wand.

Objective 4 – It is technically feasible to design and implement a mass screening program that could include a variety of landing locations for Pacific Salmon. A large portion of the catch of Chinook and Coho are harvested by commercial trollers, recreational anglers, and First Nation fishers. All commercial trollers process their catch at-sea such that PIT tags in the abdominal cavity would likely be removed and lost before reaching a shore based processing facility. However, currently available PIT tag scanners are suitable for use by fishers on vessels to scan a fish before at-sea processing. On shore, creel surveyors and “fish pit” workers at fishing lodges can scan fish caught by anglers. If necessary, monitoring systems can be developed for fish processing plant operations too. There are off-the-shelf reader/antenna products that could be applicable to scanning landings, and custom applications can also be designed and fabricated.

Objective 5 – RFID (PIT) technology possesses several attributes which are preferable compared to CWT (see section on Objective 1). However, there is insufficient data at this time to determine if existing RFID (PIT tag) technology can successfully replace CWT for the purposes of the PSC. Basically, there are too few robust juvenile-to-adult-return PIT evaluation studies providing information on PIT tag loss rates and effects of PIT tagging on long term survival to confidently support the estimation of exploitation rates (see Appendix D). More specifically: there is a lack of evidence that PIT tagged subyearling Chinook have long term survival rates and tag loss rates on par with CWT subyearling Chinook.

With regard to the cost of replacing CWTs with PIT tag technology, it would not be possible to replace the coastwide CWT marking and recapture system for all Chinook and Coho stocks using currently available PIT tag technology without a very substantial increase in funding. For example: CAD \$80.6 M would be required to purchase the PIT tags needed to replace the CWTs applied to 8.1 M Coho and 53.9 M Chinook for a single recent brood year (e.g., 2009). Consequently, we focused our assessment efforts on the feasibility using existing PIT tag technology to improve the tag recovery (detection) process and estimate the costs associated with replacing CWT with PIT tags for the Chinook and Coho exploitation rate (ER) indicator stocks, where CWT data has been important for management of Canadian and US fisheries for these species. Our calculations for Chinook suggest that the costs of replacing the CWT program for the Chinook indicator stocks with existing PIT tag technology would be roughly twice the cost of the current CWT program for the Chinook indicator stocks and roughly half the current costs for the entire CWT program for Chinook salmon. Our calculations for Coho suggest that that the costs of replacing the CWT program for the Coho indicator stocks with existing PIT tag technology, while tripling the number of

tag recoveries, would be roughly four times the cost of the current CWT program for the Coho indicator stocks and roughly equal to the current costs for the CWT program BC and WA Coho salmon.

We have discussed the ideas related to improving tag recovery sampling and fisheries and escapements with several fisheries researchers, stock assessment biologist and fisheries managers in Canada and the US, and most were very interested in further exploring the feasibility of using PIT tag technology for some or all of the Chinook and Coho ER indicator stocks. Several fisheries researchers have expressed interest in how a transition from CWTs to PIT tag technology could occur. There would certainly be a period when sampling programs would need to include the capability of detecting both type of tags and combined program costs will certainly be greater during the transition years than after the transition was completed. However, a substantial reduction in the number of CWTs applied to Chinook salmon by shifting to just tag indicator stocks could save \$15 M/year and more than cover the costs of applying PIT tags to these same indicator stocks.

While a comprehensive assessment of the cost of using PIT tag technology for some or all of the Chinook and Coho ER indicator stocks was beyond the scope of this small project, the information provided in this report provides an initial assessment of the potential costs, benefits and feasibility of using existing PIT tag technology to improve the quality and quantity of information collected for the management and assessment of Chinook and Coho fisheries on the Pacific Coast.

Recommendations:

1. Obtain new information from the Carson National Fish Hatchery USFWS study to determine comparable smolt-to-adult return rates and full life-cycle tag loss rates for PIT tagged and CWTs applied to spring Chinook, which should be available in the next six months.
2. Conduct a programmatic cost analysis that includes accounting for all costs from tag application through reporting. Cost information from the USFWS comparative study should be included in this assessment.
3. Develop a framework study design and costing to conduct a pilot program implementing the use of PIT tags on select indicator stocks. Proceed to conduct a study, if the study design and cost estimates are acceptable.
4. Invite selected RFID system producers to a workshop with PSC staff to explore detailed topics and develop a framework design for implementing a pilot program for a defined group of exploitation rate indicator stocks.

Introduction

The evaluation of alternatives to the coded-wire tag (CWT) system for assessing the distribution, survival and exploitation rates for Chinook and Coho salmon stocks has been the subject of many studies and workshops over the past 20 years (e.g., Prentice et al. 1994; PSC 2005; 2015a). Passive Integrated Transponder (PIT) tags were identified in the early 1990s as a potential alternative to CWTs after initial studies showed no effect of tag type on overwinter survival for their 3 year study of two cohorts (Prentice et al. 1994; Peterson et al. 1994). More recent studies have identified concerns related to higher rates of tag loss and lower survival for PIT tagged Chinook Salmon than those marked with CWTs (Knudsen et al. 2009). These studies and the broad use of CWT and PIT tags, prompted a recent study at the Carson National Fish Hatchery to determine comparable smolt-to-adult return rates and full life-cycle tag loss rates for PIT tagged and CWTs applied to spring Chinook (USFWS 2014).

The PSC Expert Panel on the future of the CWT recovery program for Pacific salmon identified numerous deficiencies associated with the CWT program and encouraged the evaluation of alternative approaches (PSC 2005). The use of RFID technology was specifically referenced in their findings and recommendations:

“Finding 19. A number of existing or emerging electronic technologies could theoretically replace the CWT and may have substantial advantages over the CWT (e.g., tags can be read without killing the fish, unique tags for individual fish allow migration rates and patterns to be directly observed). Examples include at least Passive Induced Transponder (PIT) tags and Radio Frequency Identification (RFID) tags. PIT tags are currently too large to mark all sizes of juvenile chinook salmon released from hatcheries and are expensive relative to CWTs, but future technological improvements may reduce tag size and tag cost for these technologies.”

“Recommendation 14. We recommend that a feasibility study be conducted to determine how PIT, RFID or other electronic tags might be used to generate data suitable for full cohort reconstruction.”

This project was initiated to assess the current state of RFID technology, its suitability for application to juvenile Chinook and Coho salmon, and its potential to provide more useful and reliable information than the current CWT program.

Project Approach

We researched the current application of RFID tags for animals, birds and fish through industry and research contacts, literature, and the Web to assess the current state of technology and potential advances that may be coming in the future that could make RFID tags more suitable than current RFID tags and coded-wire tags (CWTs) for supporting the mandate and goals of the

Pacific Salmon Commission (PSC), and in particular the estimation of Chinook and Coho salmon exploitation rates.

A variety of characteristics regarding RFID application to fisheries research and management are of interest, but primarily include the suitability of RFID for application, identification, detectability, and cost. In this regard, we developed structured interview questions for each of industry and researcher (Appendix A and B). Industry questions focused on product characteristics, and researcher questions focused on what the desired attributes of a technology would be to replace CWT. Interview data were entered into a spreadsheet for documentation. A list of individuals contacted during this study is provided in Appendix C.

Consultations with members of the Committee on Scientific Cooperation (CSC) included: the kickoff teleconference in June 2016, a progress report teleconference in September 2016 and correspondence via phone and email with Alex Wertheimer. This report provides a summary of our findings regarding each of the project objectives.

Project Objectives

1) Review the current application of RFID tags for animal identification and management, including their advantages and limitations over current technologies.

There are a wide variety of RFID tags (size, shape, operating frequency, performance) and applications, although their common use is to provide the unique identification of live beings or material assets. The numerous types of RFID tags developed for hard goods are not suitable for application to fish. The largest market for RFID on animals is for pets and livestock; some tags are applied externally (e.g., ear tags) and some are injected subcutaneous (biocompatible glass capsules). Passive Integrated Transponder (PIT) tags are the most commonly used and effective RFID technology suitable for fish. PIT tags have been applied to numerous fish species and used extensively for many years to study the downstream migration of juvenile salmonids on the Columbia River and sturgeon populations on the Columbia and Fraser rivers. Regardless of the application, all RFID tags are comprised of a circuit board for operation, and an antenna for powering via a reader. Differences between tags relate mostly to their physical properties of material composition and architecture. Physical Laws strictly govern the range and limits of tag and reader performance to the extent that specific tag configurations are suitable to a similarly limited range of applications.

Physical laws strictly govern the tag size and detection range. The frequency at which a RFID tag and respective reader operate is one of the parameters which directly influences the size of tags and the distance from the reader that the tag can be energized and reliably decoded. In general, the higher the frequency, the smaller the tag and the shorter the read range. For example, 134.4 KHz PIT tags that are 1x12 mm in size will operate reliably to

50 cm, whereas 900 MHz tags that are 0.4x2.5 mm in size will operate reliably at less than 1 cm. Ultimately, there is a tradeoff between frequency, size, and read range that can't be compensated for; improvements can be made through materials and architecture (i.e., the future of RFID), however the basic physics are not changeable.

RFID tags that appropriate for insertion in fish and coding by readers in their respective environments are limited. Application of PIT tags to fish over the past 25 years has shaped the physical specifications of tags and readers produced today to provide the best characteristics of application and performance that can be achieved (i.e., 134.4 KHz) for marketable products. The smallest encapsulated *micro*-tag (6 mm operating at 13.56 MHz) is primarily used in laboratory applications where the tag and reader can be put in very close proximity (e.g., Cousin et al. 2012). *Ultra*-small wafer-style chips (non-encapsulated tags operating at 900 MHz) have been usefully applied to bees (Hitachi Chemical Co. 2015; Miller 2016; Gough 2016), bats, and birds because they are lightweight, and readers can be positioned in such close proximity to the target specimen as to be functional. However, these tags are presently not applicable or useful to the target fisheries applications of the PSC, largely because of their very small detection range (<1 cm), and the lack of proven application in fresh or salt water (Akira Nagse, Hitachi Chemical Co., pers. comm.). Further, these tags operate on a higher frequency than the more commonly used 134.4 KHz PIT tags, so they are also incompatible with the existing detection arrays in fisheries.

The use of Coded Wire Tags (CWT) to support fisheries assessment and management is longstanding and is presently the only technique used for the estimation of Chinook and Coho salmon exploitation rates by the PSC (PSC 2015a). However, changes in fish marking applications and in the time-space implementation of salmon fisheries, along with insufficient funding to operate a rigorous tag and recovery program, have made the use of CWT's less effective in achieving the goals of the PSC. Table 1-1 presents a comparison of attributes for CWT and PIT tags to context some of the similarities and differences between these methods.

Table 1-1. Attributes of CWT and RFID (PIT) tags and detection equipment.

1.	Tag suitable for insertion into subyearling salmon less than 60 mm	Y	Y	Tiffan et al. (2015) tagged 40-49 mm fish with 8 & 9 mm PIT, and 50-59 mm with 8, 9, and 12 mm PIT
2.	Tag suitable for insertion into adult salmon	Y	Y	
3.	Tag detectable in water	N	Y	NWT does not make an in-water tag detector
4.	Tag detectable in air	Y	Y	
5.	Tag can be READ in a non-lethal manner	N	Y	
6.	Tag is READ electronically	N	Y	
7.	Tag provides data number	7-10 digit binary	15 digit decimal	
8.	Tag unit cost (unit cost)	CAD \$0.12	HID CAD \$1.30 tag (bulk), Biomark \$1.95 (bulk) with needle	HID RFID USD \$1.00 (bulk). Biomark RFID USD \$1.75 just tag, \$1.50-\$1.70 (bulk) preloaded in needle. NWT CWT USD \$0.092
9.	Tag applicator (unit costs) ²	multi-shot injector CAD \$10,300 and mass injector CAD \$29,000 OR rental fee	CAD \$9 syringe implant/needle, \$52 gun implant	Biomark RFID implant & needle USD \$7 (\$5/\$2) \$40 implant gun. NWT CWT multi-shot injector USD \$7,900 and mass injector USD \$22,000
10.	Hand held scanner (unit cost)	CAD \$5,000 OR rental fee	CAD \$450 (bulk)	Biomark RFID USD \$350 (bulk). NWT CWT \$3,825 T-wand
11.	Pass By scanner (unit costs) applicable to use on captured fish	CAD \$5,000 OR rental fee	CAD \$3,900 block & ring wand	Biomark RFID USD \$3,000 block & ring wand. NWT CWT \$3,825 V-block
12.	Fishway/weir system (unit cost) applicable to use for free swimming fish	not applicable	CAD \$6,400 fixed reader and applicable antenna	Suitable for fishway or counting fence applications. Biomark RFID USD \$1,425 fixed reader plus \$3,500 pass over or \$4,000 pass through or \$4,700 pass under
13.	Tag does not have long term effects on fish survival	Y	Limited to a single study, Inconclusive	Short term survival of 95% (Dixon and Mesa 2011). Long term survival of 67% to adult with alternate analyses estimating 93%. See report appendix "Mortality and Tag Retention in PIT-tagged Fish"
14.	Long term tag loss rate is low enough to be cost effective and used for statistically valid analyses	Y	Limited to a single study, Inconclusive	Short term loss rate of 0% over 39 d (Prentice et al. 1990) to 7% over 28 d (Tiffan et al. 2015). Long term loss rate of 18% to adult (Knudsen 2009). See report appendix "Mortality and Tag Retention in PIT-tagged Fish"
15.	Tags can be detected using a mass screening process	Y	Y	Standard configurations available, but custom applications are possible
16.	Robust detectability short range (10 cm)	Y	Y	NWT v-detector 15 cm, NWT wand 5.5 cm
17.	Robust detectability long range (100 cm)	N	Y	PIT can be >100 cm for powered upward substrate applications using 12 mm tags

¹ All costs are retail pricing except where specifically indicated as bulk/discounted. RFID reader-antenna combinations are for a single antenna.

² Costs for CWT multi-shot injectors and mass injectors represent capital costs for this equipment that should last for many years, therefore, these costs are not factored into the annual costs for the CWT program provided in later tables.

The major advantages of current PIT tag technology over CWTs for fish studies are:

- a. PIT tag codes can be recovered from alive or dead fish in seconds by passing a scanner over the fish, whereas for CWT fish must be killed in order to extract and visually decode the tag. The ability to decode a PIT tag with a scanner eliminates collecting heads from fish that may or may not contain CWTs, extracting the CWT, decoding the CWT, recording the data and analytically handling errors and tags lost in this process. Therefore, PIT tags provide more opportunity for recoveries and a process that is substantially more timely and efficient;
- b. PIT tags can be detected in fish as they pass in proximity to a scanning device, including when the fish is in fresh water. CWT detectors can only be used in air. Further, standard PIT tags have a broader detection range than CWT. Therefore, PIT tags can be detected in more situations and conditions; and
- c. Release and recovery data is higher quality in that there are significantly fewer errors in reading, recording, and exchange. Therefore, quality control of data requires less effort, data analyses are more reliable, and require less time and costs for analysis.

The major limitations of current PIT tag technology relative to CWTs for fish studies are:

- a. Cost per unit cost (CAD \$1.30) of a PIT tag is approximately 11 times that of a CWT (CAD \$0.12), and it can take approximately 2 to 8 times longer to tag a fish with a PIT versus a CWT (when using a “multi-shot” device or an electronic injector, respectively)¹. Details are provided under Objective 2;
- b. Large size of PIT tags relative to CWT’s. Therefore, PIT tags have been intentionally limited in their use to fish 50 mm or greater but are being tested on salmon down to 40 mm (e.g., salmon fry); and
- c. PIT tags are generally injected into the body cavity, therefore, fish must be scanned before any at-sea or shore-based processing occurs.

Select Information from Interviews

The PSC and its Chinook and Coho technical committees are not the only groups interested in identifying marking techniques that could replace the current CWT system. This goal is shared by many in the fisheries management community; in fact, the U.S. Bureau of Reclamation conducted an “Ideation Challenge Prize Competition” titled “New Concepts for Remote Fish Detection” in 2015 to generate innovative, new ideas from the general public on technologies that might address their wish list of attributes for fish tagging and recovery (Charles Hennig, USBR, Deputy Chief, Research and Development). Their premise is that the limitations with existing technologies have resulted in data that is insufficient to address the management and fiscal challenges of today’s fisheries. The competition generated an

¹ The total cost of release, recovery, and data analysis for a fish using either PIT or CWT technology can be reasonably quantified, but a precise representation is beyond the scope of this project.

array of concepts (over 30 submissions); some were incremental improvements to existing fish tracking methods, while others were entirely new concepts. None of entries proposed solutions related to RFID technology, and none of the solutions were close to being fully developed or ready for testing (Fullard and Connolly, in draft). The USBR is presently considering its next course of action with respect to supporting directed research and/or a refined Idea-Challenge.

The industry representatives interviewed during this study identified the following areas of focus for the future development of RFID technology, as related to fisheries applications:

- Continually improve the operational performance between tags and readers in terms of detection range, detection speed, on-board data memory, and uploading of data to servers;
- Optimize shape and size for some applications as based on architecture; and
- Inform the user community regarding the variability and differences in product quality across producers.

2) Compare sizes, tag costs, and tag application costs of RFID tags (including PIT tags) with those of CWTs.

We have confirmed that the smallest available RFID tags suitable for implanting in juvenile salmonids is the Nonatec transponder; it is 1 mm in diameter and 6 mm in length, with a mass of 10 mg (<http://www.nonatec.net/>). These are high frequency tags (13.56 MHz) manufactured by Lutronic International in Rodange, Luxembourg (Cousin et al. 2012). Further details on this product were not pursued because of performance limitations; the read range is approximately 1 cm and the respective reader is designed for laboratory use rather than in the field (M. Begout, Ifremer French Research Institute for Exploration of the Sea, pers. comm.).

Biomark (Boise, ID) produces three sizes of PIT tags applicable to juvenile salmon (8, 9, and 12 mm in length, 1.0-1.4 mm in diameter). Read range for an 8 mm PIT tag (50 cm) is approximately half that for a 12 mm PIT tag (100 cm). The cost for these PIT tags are approximately CAD \$1.95 per tag, *preloaded in a needle*. Comparable tags without the needle can be obtained from HID Global for approximately CAD \$1.30 for bulk orders of 1 million tags. These tags are currently applied using manual (non-automated) techniques involving needles needle insertion or micro-surgery. A single trained staff using preloaded needles and a continuous supply of fish can tag approximately 100 fish per hour (Scott Gary, Biomark, pers. comm.). Several other likely costs (e.g., location, mobile reader, available infrastructure and services, fish anesthesia method, and related data management) would

need to be considered to provide an all-inclusive estimate of producing tagged fish for release. Assuming that these “other” costs are similar with CWT, then PIT application would cost approximately 11 times more for tags, and 8 times as much in technician labor for the same number of tagged fish. A broader programmatic comparison of PIT and CWT costs is provided in the section on Objective 5.

Standard CWT’s are 1.1 mm length and 0.25 mm diameter with options for half-length and double-length (<http://www.nmt.us/products/cwt/cwt.shtml>). Tags cost CAD \$0.12/tag plus the cost of an injector (purchase CAD \$41k or rental). A single trained staff using a standard injector and a continuous supply of fish can tag approximately 800 fish per hour (Northwest Marine Technology 2005). An auto-tagger device is also available for CAD \$1.8M.

There are a plethora of PIT tag suppliers, and much fewer PIT tag manufacturers in the world. Some manufacturers could be considered high-end, quality research and development firms, while many more could be considered high volume, knock-off producers of low quality products. Individual PIT tags can be purchased for as little as CAD \$0.50 each, but there is proportionally lower confidence in whether the tag will function when energized. Therefore, for large quantity, bulk purchase of PIT tags consideration should be given to complete a strong QAQC vetting process that includes on-site interviews at manufacturing facilities, independent testing, reference checks, and verification of performance with the fisheries research and management community. For high quality producers, tag failure rate is zero upon shipping. RFID manufacturers that were interviewed included:

Biomark (<http://www.biomark.com/>),

HID (<https://www.hidglobal.com/products/rfid-tags/identification-technologies/animal-id>),

Trovan (<http://www.trovan.com/products.html>).

3) Review detection capabilities of RFID tags, including detection distances when embedded in animal tissue and when animals are moving through freshwater or seawater.

RFID tags use radio wave frequencies to transmit the tag code and thus are largely not detectable in saltwater. PIT tags can be detected in fish moving through freshwater, but the detection range depends on the size (materials and architecture) of the tag and the amount of energy that can be transmitted through the water to energize the tag. As indicated previously, the electronic field created by a RFID reader and its antenna with a tag collapses down to several centimeters in salt water, and thereby limits the application to close proximity monitoring.

There are two aspects of detection capability for RFID tags; Read Range and Read Speed. Read Range of a tag is directly related to the physical quantity and quality of core components (ferrite and windings), and influenced by the quality of the Reader and a host of environmental factors. Assuming optimal orientation in the antenna field, the smallest ultra and micro tags (2.5-6 mm) have a Read Range of 1 cm or less. Standard 12 mm tags can have a Read Range up to 100 cm (antenna array dependent), and 8 mm tags half of that. However, more typical range is on the order of 50 cm. In general, Read Range is the same in air and freshwater and is not appreciably effected by body tissue. For comparison, CWT tags are “detected” (rather than read) by changes in a magnetic field at distances of 5.5 cm for a wand to 19x33 cm for an oval tunnel.

Bit specification (e.g., 32 or 64 bit) of a Reader effects the Read speed, or how quickly a tag can be accurately scanned in the antenna field. Typically, tags can be read on the order of milliseconds. Tags passing through a field quickly (e.g., through the spillway of dam) require a faster processing speed compared to those scanned using a hand wand.

RFID (PIT) tags can be read in a variety of conditions, both watered and in the dry, in moving or stagnant water, and in containments. Antenna have been developed to include the handheld wand, “pass by” flat substrate or floating mounted plates, and “pass through” periphery configurations such as fish transfer conduits. Detection of tags can be substantially reduced in environments where specific radio frequency noise is relatively high and in proximity to a reader-antenna. However, in practice, these conditions are not common as evidenced by the variety of installations at hydroelectric facilities where RF noise can be substantial.

4) Evaluate the feasibility for mass screening for detection and reading of RFID tags in landings of Pacific salmon.

It is technically feasible to design and implement a mass screening program that could include a variety of landing locations for Pacific Salmon. A large portion of the catch of Chinook and Coho are harvested by commercial trollers, recreational anglers, and First Nation fishers. All commercial trollers process their catch at-sea such that PIT tags in the abdominal cavity would likely be removed and lost before reaching a shore based processing facility. However, currently available PIT tag scanners are suitable for use by fishers on vessels to scan a fish before at-sea processing. On shore, creel surveyors and “fish pit” workers at fishing lodges can scan fish caught by anglers. If necessary, monitoring systems can be developed for fish processing plant operations too. As indicated under Objective 3, there are off-the-shelf reader/antenna products that could be applicable to scanning landings, and custom applications can also be designed and fabricated.

The main advantage of RFID (PIT tag) technology over CWT technology is the ability to electronically scan a fish (live or dead) to obtain its individual digital tag code. PIT tag technology has been used successfully for many years on salmon studies within the Columbia River and ongoing studies of Columbia and Fraser River White Sturgeon. On the Fraser River, guides, anglers and test fishery operators have been given PIT tag scanners and trained to scan every Sturgeon they catch and record tag recovery data (Nelson et al. 2013). It is this significant advantage with regard to the catch sampling and tag recovery that must be exploited to make PIT tag technology a viable alternative to the current CWT technology for some stocks of Chinook, and provide more useful data for Coho than the current CWT program. For example: PIT tag scanners could be provided to every major recreational fishing lodge so that every fish landed at these lodges could be scanned and the data transmitted back to a central database. In addition, scanners could be provided to active fishing guides and “avid anglers” so they could also scan every fish caught, including those released. For commercial fisheries, it would be essential to provide PIT tag scanners to at least half, and possibly all, active trollers as a large portion of commercial catch of Chinook and Coho is taken by trollers that process their catch at sea. Since PIT tags are typically inserted into the abdominal cavity, fish would need to be scanned prior to processing. Each participating troller should be able to quickly pass every fish caught through a scanner that would record the number of fish scanned and the tag codes for each tagged fish. These data could be automatically uploaded to a central database along with date and fishing location data at the end of each fishing trip. For those stocks, where potential spawners (adults and jacks) are counted through fences, fishways or weirs, PIT tag scanners could be deployed to record the passage of any tagged fish. The strategic deployment of 400 portable PIT scanners and 50 swim-by PIT scanners should be able to increase our detection rates by at least 3 times over current CWT detection rates. Comparison of the observed and estimates recovery rates for CWTs for BC Chinook indicator stocks and all Coho indicator stocks suggests that recovery rates could be increased by 3 times by providing commercial fishers, ‘avid’ recreational anglers, sport fishing lodges, creel surveyors and First Nation catch monitors with PIT tag scanners; and deploying swim-by scanners at counting locations for each of the indicator stocks. At a unit cost of CAD \$450 per handheld scanner and CAD \$6,400 per swim-by scanner, the initial capital investment in a PIT tag scanning equipment would be CAD \$500,000.

5) Evaluate the feasibility and cost of incorporating RFID microchips to replace CWT in marking juvenile salmon for coastwide Coho and Chinook salmon management.

Feasibility Assessment

The basic question of feasibility rests upon whether RFID (PIT tag) technology can provide the data/information that CWT presently supplies for implementation of the Pacific Salmon Treaty; and more specifically, to fulfill the need of making reliable inferences on stock-age-fishery exploitation rates *on natural stocks*. The PSC's Joint CWT Implementation Team concluded that "no other technology has been demonstrated to be capable of providing the coast wide data needed for PST and regional stock and fishery management" for Chinook and Coho (PSC 2015a). This statement echoed the sentiment of the PSC's earlier assessment (PSC 2005).

We have demonstrated through this present investigation that RFID (PIT) technology possesses several attributes which are preferable compared to CWT (see section on Objective 1). However, through our review of readily available information, there is insufficient data at this time for two key aspects to determine if RFID (PIT) technology can successfully replace CWT for the purposes of the PSC. Basically, there are too few robust juvenile-to-adult-return PIT evaluation studies providing information on PIT tag loss rates and effects of PIT tagging on long term survival to confidently support the estimation of exploitation rates (Appendix D). More specifically,

1. There is a lack of evidence that PIT tagged subyearling Chinook have long term survival rates on par with CWT or untagged subyearling Chinook.
2. There is a lack of evidence that PIT tagged Chinook and Coho have tag loss rates on par with CWT Chinook and Coho.

One relevant study to specifically address these issues is underway now by the US Fish and Wildlife Service (USFWS 2014). Preliminary data for the first returns of PIT and CWT marked fish show no statistically different values, and an update on the study is expected in 2017. While this study will provide valuable information, it is likely that additional studies are necessary to provide conclusive information on these aspects. In this regard, a comparative study could also serve as the information base to inform a transition from the current CWT program to a mark-recapture program based on PIT tag technology.

One consideration of feasibility for implementing the use of PIT tag technology is whether tags and reader equipment can be adapted to or integrated with existing CWT processes of tagging, recovery, and data analysis. In other words, are there aspects of PIT tag technology that can be combined or used side-by-side with the existing CWT platform to achieve

efficiencies. They do have several common requirements such as power, a platform proximate to a supply of fish, and a database in which to house tag records. Other than that, the two technologies are dramatically different in functionality and they are not interchangeable. For example, a CWT detector can't code a PIT tag, and currently available PIT tag scanners can't detect a CWT. However, at least one manufacturer thinks that the two technologies are compatible in that a single unit such as a wand could be a platform to host both detection systems, should that be a desired consumer requirement. Similarly, coded wire tags can be automatically applied (no manual handling) using NWT's AutoFish system (<http://www.nmt.us/products/afs/afs.shtml>), and it can't implant a PIT tag in the same way. However, strong interest from PIT tag users has one manufacturer considering the fabrication of such a device. In any case, industry will only design and build tools for users when there is sufficient demand to warrant the R&D and the associated financial risk that goes along with it.

Cost Assessment

Given the current minimum bulk price of CAD \$1.30/tag for PIT tags suitable for application to juvenile Coho and Chinook salmon, it would not be possible to replace the coastwide CWT marking and recapture system for all Chinook and Coho stocks using currently available PIT tag technology without a very substantial increase in funding. For example: CAD \$80.6 M would be required to purchase the PIT tags needed to replace the CWTs applied to 8.1 M Coho and 53.9 M Chinook for a single recent brood year (e.g., 2009). Consequently, we have focused our assessment on the feasibility using PIT tag technology to improve the tag recovery (detection) process and estimate the costs associated with replacing CWT with PIT tags for the Chinook and Coho exploitation rate (ER) indicator stocks where CWT data has been important for management of Canadian and US fisheries for these species.

The next step in our evaluation was to identify a set of ER indicator stocks for each species that would be a high priority for including in a mark-recapture program using PIT tag technology. For Chinook, the ER indicator stocks were those identified as "current CWT exploitation rate indicator stocks" (Table 2.1, PSC 2015b). For Coho, the initial set of BC and WA indicator stocks included just those stocks that have historically been important ER indicator stocks and have escapement monitoring facilities where a PIT tag detector could be deployed to detect most of the fish returning to their natal stream or hatchery (Chuck Parken, DFO, pers. comm.; Jeff Haymes, WDFW, pers. comm.). Once the indicator stocks were identified, we extracted the CWT release and recovery data from available mark-recapture databases for the 5-6 most recent brood years with complete returns. Table 5-1 provides a summary of the total CWT releases for each of the 13 Canadian and 35 US Chinook ER indicator stocks for brood years 2005-2009. The CWTs applied to these Chinook indicator stocks represent 23.5% of the total CWTs applied to Chinook salmon for these brood years.

Table 5-2 provides similar information on CWT release numbers for 10 BC and 9 Washington State (WA) Coho ER indicator stocks for brood years 2006-2011. The CWTs applied to the 19 indicator stocks represent 21.3% of the total CWT releases for BC and WA, which intern represent 75.5% of the total releases of CWT Coho for all areas (California to Alaska).

The release numbers from Table 5-1 and Table 5-2 were combined with observed and estimated CWT recoveries and cost estimates for tags, tag application, tag recovery sampling and tag decoding to derive comparable estimates of the complete brood year costs mark-recapture programs using CWT versus a proposed application of PIT tag technology for Chinook and Coho salmon. In Table 5-3, we used the observed and estimated CWT recoveries for the indicator stocks to derive estimates of the observed and estimated recoveries for all CWT Chinook. The CWT program costs estimated for all CWT applied to Chinook salmon was the sum of the tag costs (CAD \$0.12/tag), application costs (CAD \$0.12/fish), sampling costs (CAD \$26/observed tag), decoding costs (CAD \$5/observed tag) and the cost for making the data publicly available (CDN \$18/tag). The sampling, decoding and data processing costs are the CDN \$ equivalents of the US \$ costs reported in Clark (2004) and PSC (2005). All of these costs estimates are averages across the various agencies that pay for components of the CWT system and thus may not reflect the costs for any specific agency or group.

The CWT program costs for just the Chinook indicator stocks used the same calculations except the numbers of CWT applied and observed were just those for the indicator stocks. The cost estimates for using PIT tag technology for the Chinook indicator stocks were based on the following assumptions:

1. The number of PIT tags applied could be reduced to 1/3 of the number of CWTs applied but the numbers of tags observed could be maintained by increasing the tag recovery sampling efficiency and effort by 3 times;
2. The PIT tag costs are CAD \$1.30/tag (11 times the cost of a CWT) and PIT tag application costs are roughly twice those for CWT application;
3. PIT tags scanner would be deployed at recreational fishing lodges, with “avid anglers”, commercial fishers, at processing plants and with creel survey staff in sufficient quantities to increase the tag sampling rate by 3 times;
4. The cost to maintain the PIT tag detection program would be CAD \$10/observed tag, excluding the initial capital cost of the PIT tag scanners; and
5. The PIT tag recovery data would be digital transferred from the PIT tag readers to a central PIT tag database on a daily or weekly basis (depending on the sampling location) along with information on the number of fish scanned for each species.

The relative low sampling cost for the PIT tag approach excludes the initial capital investment in PIT tag readers and training fishers and samplers to use this equipment. We have also assumed that fishers, lodge owners, creel survey programs and other sampling programs would be willing to scan Chinook and Coho as part of their daily operations at no cost with the assurance that they would be provided all the information obtained from their portion of the sampling program. We have conducted a similar program with guides, anglers, government test fisheries and First Nations as part of a sturgeon mark-recapture program on the Fraser River for the past 16 years (Nelson et al. 2013). All the tagging and scanning of sturgeon caught is done by trained program volunteers at no costs other than providing the tags and scanning equipment. We have used and continue to use the hand held Biomark dual frequency scanners (\$450/scanner) under typically wet fishing conditions. We have tested many different types of scanners and found significant issues with some scanner types. We have also tested many different models of PIT tags. The types of tags and scanners included in our cost estimates are field tested and proven equipment.

The above assumptions and calculations suggest that the costs of replacing the CWT program for the Chinook indicator stocks with existing PIT tag technology would be roughly twice the cost of the current CWT program for the Chinook indicator stocks and roughly half the current costs for the entire CWT program for Chinook salmon.

The information and methods used to estimate the current CWT program costs for all CWT applied to Coho salmon in BC and WA were similar to those described above for Chinook. The CWT program cost estimates for the 10 BC and 9 WA Coho indicator stocks were based on the total number of tags released and observed recoveries for those stocks (Table 5-4). The cost estimates for using PIT tag technology for these Coho indicator stocks were based on the following assumptions:

1. The number of PIT tags applied would be the same as the number of CWTs applied but the numbers of tags observed would be increased 3 fold through improvements to the tag recovery process;
2. The PIT tag costs are CAD \$1.30/tag (11 times the cost of a CWT) and PIT tag application costs are roughly twice those for CWT application;
3. PIT tags scanner would be deployed at escapement monitoring sites, recreational fishing lodges, with “avid anglers”, commercial fishers, at processing plants and with creel survey staff in sufficient quantities to increase the tag sampling rate;
4. The cost to maintain the PIT tag detection program would be CAD \$10/observed tag, excluding the initial capital cost of the PIT tag scanners; and
5. The PIT tag recovery data would be digital transferred from the PIT tag readers to a central PIT tag database on a daily or weekly basis (depending on the sampling location) along with information on the number of fish scanned for each species.

These assumptions and calculations suggest that the costs of replacing the CWT program for the Coho indicator stocks with existing PIT tag technology, while tripling the number of tag recoveries, would be roughly four times the cost of the current CWT program for the Coho indicator stocks and roughly equal to the current costs for the CWT program BC and WA Coho salmon.

We have discussed the ideas related to improving tag recovery sampling and fisheries and escapements with several fisheries researchers, stock assessment biologist and fisheries managers in Canada and the US, and most were very interested in further exploring the feasibility of using PIT tag technology for some or all of the Chinook and Coho ER indicator stocks. Several fisheries researchers have expressed interest in how a transition from CWTs to PIT tag technology could occur. There would certainly be a period when sampling programs would need to include the capability of detecting both type of tags and combined program costs will certainly be greater during the transition years than after the transition was completed. However, a substantial reduction in the number of CWTs applied to Chinook salmon by shifting to just tag indicator stocks could save \$15 M/year and more than cover the costs of applying PIT tags to these same indicator stocks.

While a comprehensive assessment of the cost of using PIT tag technology for some or all of the Chinook and Coho ER indicator stocks was beyond the scope of this small project, the information provided in this report provides an initial assessment of the potential costs, benefits and feasibility of using PIT tag technology to improve the quality and quantity of information collected for the management and assessment of Chinook and Coho fisheries on the Pacific Coast.

Table 5-1. Total CWT release numbers for Canadian and US Chinook exploitation rate indicator stocks for brood years 2005-2009.

Canadian Indicator Stocks	Total CWT release by broodyear					Total
	2005	2006	2007	2008	2009	
Atnarko Summer	159,150	152,767	151,449	151,608	415,107	1,030,081
Big Qualicum	223,084	199,619	205,857	203,540	449,683	1,281,783
Chilliwack (Harrison Fall Stock)	87,801	95,382	99,465	99,451	189,707	571,806
Cowichan Fall	200,183	200,290	408,849	666,580	397,269	1,873,171
Harrison Fall Stock (Chehalis)	102,312	205,396	208,179	195,420	213,243	924,550
Kitsumkalum Summer	192,438	125,939	153,435	209,144	207,658	888,614
Kitsumkalum Yearling	247	25,888	21,657	46,999	58,546	153,337
Middle Shuswap	0	0	0	103,180	146,854	250,034
Nicola River Spring	138,728	146,476	143,178	127,215	193,131	748,728
Puntledge Summer	185,285	179,227	177,086	127,513	87,853	756,964
Quinsam Fall	208,300	228,141	531,550	237,193	537,575	1,742,759
Robertson Creek	201,013	201,524	216,442	498,054	451,196	1,568,229
Lower Shuswap River Summers	193,040	199,357	268,844	249,206	483,739	1,394,186
Total Release	1,891,581	1,960,006	2,585,991	2,915,103	3,831,561	13,184,242
US Indicator Stocks						
Alaska Central Inside	47,601	53,690	46,241	64,279	47,111	258,922
Alaska Deer Mountain	9,148	10,902	10,185	7,914	6,751	44,900
Alaska Herring Cove	76,911	79,330	76,325	65,946	66,215	364,727
Little Port Walter	133,165	212,379	208,616	235,812	184,455	974,427
Alaska Macaulay Hatchery	35,577	21,794	32,194	31,486	12,696	133,747
Alaska Neets Bay	59,615	66,107	64,273	61,948	56,247	308,190
Chilkat Spring	20,557	31,148	24,085	16,982	44,304	137,076
Cowlitz Fall Tule	178,376	201,746	202,953	199,872	196,409	979,356
Elk River	189,177	78,068	53,022	27,182	212,149	559,598
George Adams Fall Fingerling	450,473	441,061	440,889	452,919	454,699	2,240,041
Hanford Wild	203,929	208,092	53,618	202,320	201,606	869,565
Hoko Fall Fingerling	67,347	78,892	210,854	67,479	155,144	579,716
Columbia Lower River Hatchery	230,174	444,337	453,945	225,164	451,148	1,804,768
Lewis River Wild	99,452	77,629	54,717	46,476	24,380	302,654
Lyons Ferry	200,369	191,436	194,762	191,403	199,152	977,122
Nisqually Fall Fingerling	247,447	408,834	360,599	412,578	402,643	1,832,101
Nooksack Spring Fingerling	407,937	278,614	413,532	346,739	393,328	1,840,150
Queets Fall Fingerling	194,075	201,780	186,540	218,187	214,648	1,015,230
Samish Fall Fingerling	384,575	412,204	428,420	403,772	405,502	2,034,473
Skagit Spring Fingerling	249,673	254,739	220,789	253,993	265,931	1,245,125
Skagit Spring Yearling	149,100	136,619	117,117	152,435	161,000	716,271
Skykomish Fall Fingerling	410,728	411,706	399,536	403,194	401,265	2,026,429
Sooes Fall Fingerling	252,446	194,614	252,628	238,849	242,077	1,180,614
Spring Creek Tule	889,324	892,618	891,550	799,882	807,781	4,281,155
South Puget Sound Fall Yearling	163,716	154,223	160,196	101,067	76,984	656,186
Salmon River	208,080	207,362	205,216	157,478	175,033	953,169
Skagit Summer Fingerling	206,009	231,662	216,200	108,180	206,128	968,179
Stillaguamish Fall Fingerling	202,669	212,636	214,567	185,967	219,608	1,035,447
Columbia Summers	748,075	699,759	701,297	746,653	784,449	3,680,233
Taku Spring	9,843	24,022	16,063	30,804	17,698	98,430
Unuk Spring	37,521	55,578	22,167	53,125	25,953	194,344
Upriver Brights	199,445	424,706	422,322	216,131	1,646,129	2,908,733
White River Spring Yearling	57,391	56,687	54,416	58,596	56,503	283,593
Willamette Spring	806,504	751,621	722,007	846,067	1,735,282	4,861,481
Total Release	7,826,429	8,206,595	8,131,841	7,630,879	10,550,408	42,346,152
All Chinook CWT releases						
	2005	2006	2007	2008	2009	Total
AK	1,191,889	1,492,497	1,425,425	1,520,049	982,146	6,612,006
BC	2,790,440	3,042,266	3,460,940	3,704,486	4,691,301	17,689,433
CA	6,971,488	14,703,430	14,592,227	13,600,171	14,935,993	64,803,309
ID	2,499,693	2,742,247	2,903,223	3,763,301	4,080,584	15,989,048
OR	4,763,223	4,562,086	4,728,730	5,905,552	6,780,518	26,740,109
WA	20,939,636	20,774,214	19,135,113	20,839,997	22,480,827	104,169,787
Total Release	39,156,369	47,316,740	46,245,658	49,333,556	53,951,369	236,003,692
Indicator % of total CWT releases	24.8%	21.5%	23.2%	21.4%	26.7%	23.5%

Table 5-2. Total CWT release numbers for BC and WA Coho exploitation rate indicator stocks for brood years 2006-2011.

	Total CWT release by broodyear						
	2006	2007	2008	2009	2010	2011	Total
Canadian Indicator Stocks							
Big Qual	45,004	85,841	42,103	28,261	140,081	142,788	484,078
Black Cr	10,266	18,810	8,071	9,658	8,236	11,003	66,044
Coldwater	43,686	39,798	45,128	43,049	58,517	63,805	293,983
Eagle				22,252	21,956	39,009	83,217
Keogh	32,590	39,241	26,041	53,124	50,714	48,284	249,994
Quinsam	88,083	89,630	87,384	88,148	85,654	146,531	585,430
Robertson	40,272	40,381	21,099	40,161	38,982	39,899	220,794
Salmon		40,689					40,689
Toboggan	37,284	34,349	34,690	28,029	34,982	33,601	202,935
Zolzap			33,311	14,395	45,324	30,280	123,310
Sub-Total	297,185	388,739	297,827	327,077	484,446	555,200	2,350,474
US Indicator Stocks							
	2006	2007	2008	2009	2010	2011	Total
Marblemount Hatchery	94,278	88,778	86,927	87,819	83,940	90,718	532,460
Wallace River H.	90,576	90,914	84,395	85,359	89,598	88,481	529,323
Quilcene NFH	68,486	75,415	78,261	80,532	127,789	142,038	572,521
George Adams Hatchery	98,580	91,338	89,984	91,513	90,827	89,546	551,788
Big Beef Creek (Wild)	24,709	38,547	21,278	51,932	18,732	24,028	179,226
Sol Duc Hatchery	153,123	150,469	154,630	153,097	160,942	152,635	924,896
Salmon R. Fish Culture	151,879	144,023	151,365	161,183	159,441	149,903	917,794
Bingham Cr. H. (Satsop)	236,251	187,960	143,941	183,328	142,987	145,970	1,040,437
Bingham Creek (Wild)	20,046	33,916	31,471	56,110	42,376	38,584	222,503
Sub-Total	937,928	901,360	842,252	950,873	916,632	921,903	5,470,948
Total	1,235,113	1,290,099	1,140,079	1,277,950	1,401,078	1,477,103	7,821,422
% of all CWT releases	16.7%	16.2%	14.7%	15.7%	16.5%	16.7%	16.1%
% of BC & WA releases	22.5%	21.9%	19.1%	20.3%	21.4%	22.6%	21.3%
All Coho CWT releases							
	2006	2007	2008	2009	2010	2011	Total
AK	917,837	900,220	792,637	957,352	943,927	1,021,809	5,533,782
BC	513,208	705,982	614,223	794,521	874,786	941,740	4,444,460
CA	190,737	442,959	329,374	335,997	391,325	508,469	2,198,861
ID	155,137	241,722	177,022	121,547	116,811	159,954	972,193
OR	636,068	505,922	493,325	414,379	525,271	621,969	3,196,934
WA	4,970,998	5,182,072	5,346,575	5,497,802	5,662,276	5,591,408	32,251,131
Total	7,383,985	7,978,877	7,753,156	8,121,598	8,514,396	8,845,349	48,597,361
BC & WA Total	5,484,206	5,888,054	5,960,798	6,292,323	6,537,062	6,533,148	36,695,591
BC & WA %	74.3%	73.8%	76.9%	77.5%	76.8%	73.9%	75.5%

Table 5-3. Summary of total CWT release and recovery numbers for BC and US Chinook and an example of alternative cost estimates for using CWT and PIT tag technology for all BC and US Chinook indicator stocks for brood years 2005-2009.

		2005	2006	2007	2008	2009
Total Releases						
BC		2,790,440	3,042,266	3,460,940	3,704,486	4,691,301
US		36,365,929	44,274,474	42,784,718	45,629,070	49,260,068
Total		39,156,369	47,316,740	46,245,658	49,333,556	53,951,369
Indicator Stock Releases						
BC		1,891,581	1,960,006	2,585,991	2,915,103	3,831,561
US		7,826,429	8,206,595	8,131,841	7,630,879	10,550,408
Total		9,718,010	10,166,601	10,717,832	10,545,982	14,381,969
Estimated CWT Recoveries (All)						
BC		8,601	4,184	9,891	6,267	6,555
US		206,640	208,481	335,019	241,564	362,720
Total		215,241	212,665	344,909	247,831	369,275
Observed CWT Recoveries (All)						
BC		2,334	1,097	2,798	1,703	2,173
US		97,113	99,699	152,133	120,404	184,781
Total		99,447	100,797	154,931	122,107	186,954
Estimated CWT Recoveries (Indicators only)						
BC		5,830	2,696	7,390	4,932	5,354
US		44,472	38,643	63,675	40,398	77,687
Total		50,302	41,339	71,065	45,330	83,040
Observed CWT Recoveries (Indicators only)						
BC		1,582	707	2,091	1,340	1,775
US		20,900	18,480	28,915	20,136	39,576
Total		22,482	19,187	31,006	21,476	41,351
	Cost/unit	2005	2006	2007	2008	2009
CWT Costs (All)						
Tags	\$ 0.12	\$4,698,764	\$5,678,009	\$5,549,479	\$5,920,027	\$6,474,164
Application	\$ 0.12	\$4,698,764	\$5,678,009	\$5,549,479	\$5,920,027	\$6,474,164
Sampling	\$ 26.00	\$2,585,615	\$2,620,715	\$4,028,214	\$3,174,774	\$4,860,815
Decoding	\$ 5.00	\$497,234	\$503,984	\$774,657	\$610,533	\$934,772
Data process	\$ 18.00	\$1,790,041	\$1,814,341	\$2,788,764	\$2,197,920	\$3,365,180
Total		\$14,270,419	\$16,295,058	\$18,690,593	\$17,823,281	\$22,109,095
CWT Costs (Indicators only)						
Tags	\$ 0.12	\$1,166,161	\$1,219,992	\$1,286,140	\$1,265,518	\$1,725,836
Application	\$ 0.12	\$1,166,161	\$1,219,992	\$1,286,140	\$1,265,518	\$1,725,836
Sampling	\$ 26.00	\$584,532	\$498,862	\$806,156	\$558,376	\$1,075,126
Decoding	\$ 5.00	\$112,410	\$95,935	\$155,030	\$107,380	\$206,755
Data process	\$ 18.00	\$404,676	\$345,366	\$558,108	\$386,568	\$744,318
Total		\$3,433,940	\$3,380,147	\$4,091,574	\$3,583,360	\$5,477,872
PIT Costs (Indicators only)						
Tags/3	\$ 1.30	\$4,211,138	\$4,405,527	\$4,644,394	\$4,569,926	\$6,232,187
Application/3	\$ 0.96	\$3,109,763	\$3,253,312	\$3,429,706	\$3,374,714	\$4,602,230
Sampling x3	\$ 10.00	\$224,820	\$191,870	\$310,060	\$214,760	\$413,510
Decoding	\$ -	\$0	\$0	\$0	\$0	\$0
Data process	\$ 12.00	\$269,784	\$230,244	\$372,072	\$257,712	\$496,212
Total		\$7,545,721	\$7,850,709	\$8,384,160	\$8,159,400	\$11,247,927

Table 5-4. Summary of total CWT release and recovery numbers for BC and WA Coho and an example of alternative cost estimates for using CWT and PIT tag technology for all BC and WA Coho indicator stocks for brood years 2006-2011.

		2006	2007	2008	2009	2010	2011
Total Releases							
BC		513,208	705,982	614,223	794,521	874,786	941,740
WA		4,970,998	5,182,072	5,346,575	5,497,802	5,662,276	5,591,408
Total		5,484,206	5,888,054	5,960,798	6,292,323	6,537,062	6,533,148
Indicator Stock Releases							
BC		297,185	388,739	297,827	327,077	484,446	555,200
WA		937,928	901,360	842,252	950,873	916,632	921,903
Total		1,235,113	1,290,099	1,140,079	1,277,950	1,401,078	1,477,103
Estimated CWT Recoveries (All)							
BC		4,460	2,403	4,416	4,457	8,043	4,121
WA		92,483	45,855	56,526	44,322	50,121	114,425
Total		137,105	147,201	149,020	157,308	163,427	163,329
Observed CWT Recoveries (All)							
BC		961	673	1,279	979	1,566	950
WA		36,943	21,759	24,639	17,896	23,004	46,670
Total		37,904	22,432	25,918	18,875	24,570	47,620
Estimated CWT Recoveries (Indicators only)							
BC		3,029	962	2,329	2,470	5,706	2,834
WA		36,416	17,971	26,997	22,575	23,439	28,413
Total		39,445	18,934	29,326	25,045	29,146	31,247
Observed CWT Recoveries (Indicators only)							
BC		554	270	531	517	1,062	618
WA		13,948	6,923	10,195	7,691	9,436	9,570
Total		14,502	7,193	10,726	8,208	10,498	10,188
	Cost/unit	2006	2007	2008	2009	2010	2011
CWT Costs (All)							
Tags	\$ 0.12	\$658,105	\$706,566	\$715,296	\$755,079	\$784,447	\$783,978
Application	\$ 0.12	\$658,105	\$706,566	\$715,296	\$755,079	\$784,447	\$783,978
Sampling	\$ 26.00	\$985,504	\$583,232	\$673,868	\$490,750	\$638,820	\$1,238,120
Decoding	\$ 5.00	\$189,520	\$112,160	\$129,590	\$94,375	\$122,850	\$238,100
Data process	\$ 18.00	\$682,272	\$403,776	\$466,524	\$339,750	\$442,260	\$857,160
Total		\$3,173,505	\$2,512,301	\$2,700,574	\$2,435,033	\$2,772,825	\$3,901,336
CWT Costs (Indicators only)							
Tags	\$ 0.12	\$148,214	\$154,812	\$136,809	\$153,354	\$168,129	\$177,252
Application	\$ 0.12	\$148,214	\$154,812	\$136,809	\$153,354	\$168,129	\$177,252
Sampling	\$ 26.00	\$377,052	\$187,018	\$278,876	\$213,408	\$272,948	\$264,888
Decoding	\$ 5.00	\$72,510	\$35,965	\$53,630	\$41,040	\$52,490	\$50,940
Data process	\$ 18.00	\$261,036	\$129,474	\$193,068	\$147,744	\$188,964	\$183,384
Total		\$1,007,025	\$662,081	\$799,193	\$708,900	\$850,661	\$853,717
PIT Costs (Indicators only)							
Tags	\$ 1.30	\$1,605,647	\$1,677,129	\$1,482,103	\$1,661,335	\$1,821,401	\$1,920,234
Application	\$ 0.96	\$1,185,708	\$1,238,495	\$1,094,476	\$1,226,832	\$1,345,035	\$1,418,019
Sampling x3	\$ 10.00	\$435,060	\$215,790	\$321,780	\$246,240	\$314,940	\$305,640
Decoding	\$ -	\$0	\$0	\$0	\$0	\$0	\$0
Data process	\$ 12.00	\$522,072	\$258,948	\$386,136	\$295,488	\$377,928	\$366,768
Total		\$3,748,487	\$3,390,362	\$3,284,495	\$3,429,895	\$3,859,304	\$4,010,661

Recommendations

1. Obtain new information from the Carson National Fish Hatchery USFWS study to determine comparable smolt-to-adult return rates and full life-cycle tag loss rates for PIT tagged and CWTs applied to spring Chinook, which should be available in the next six months.
2. Conduct a programmatic cost analysis that includes accounting for all costs from tag application through reporting. Cost information from the USFWS comparative study should be included in this assessment.
3. Develop a framework study design and costing to conduct a pilot program implementing the use of PIT tags on select indicator stocks. Proceed to conduct a study, if the study design and cost estimates are acceptable.
4. Invite selected RFID system producers to a workshop with PSC staff to explore detailed topics and develop a framework design for implementing a pilot program for a defined group of exploitation rate indicator stocks.

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Appendix A

Pacific Salmon Commission's study on the Feasibility of RFID tag for marking juvenile salmon for management applications – Product Inquiry

- 1) Does your company manufacture RFID tags suitable for internal placement in live fish?
- 2) Are you aware of your tags being used for fish?
- 3) What is the shape and composition of the tag(s)?
- 4) What are the dimensions (mm) of the smallest tag (LxWxH)?
- 5) How many data digits does the tag have?
- 6) What is the unit price of an individual tag?
- 7) What is the mechanism and related cost of applying the tag?
- 8) Are there any specific advantages or limitations of the tag?
- 9) Are you aware of any contacts or documentation regarding the long term effects of tagging on fish or tag loss rates?
- 10) Are there plans for future tags that are smaller?
- 11) Do you manufacture Reading equipment?
- 12) What type of Readers do you manufacture?
- 13) Are you aware of any contacts or documentation regarding custom Reader applications?

Appendix B

Pacific Salmon Commission's study on the Feasibility of RFID tag for marking juvenile salmon for management applications – Researcher Inquiry

- 1) Have you considered alternative technologies, and in particular RFID, as a method to replace CWTs?
- 2) Do you want more information (quantity) or better information (quality) from an alternative technology? Describe
- 3) Are there aspects of technology of application, detectability, or recovery that would improve the quality of the dataset or make it more cost effective?
- 4) Any reason other than improved information or cost that would be desired in an alternate technology?
- 5) Where (location and process) and in what media (air or water) would you want scanning for tags to take place?
- 6) What would be the key attributes of a tag / detection system for your applications?
- 7) Are your specimens for detection live or dead or both?
- 8) If currently available PIT tag detection systems for standard 12 mm long PIT tags were deployed at commercial landing sites for major fisheries, provided to recreational and First Nations catch monitoring crews, volunteer guides/anglers, would you consider using PIT tag technology in place of CWT tagging programs for some or all of its Chinook and Coho indicators stocks?
- 9) Specific advantages or limitations of an alternative technology relative to CWT?
- 10) Are you aware of any documentation regarding the long term effects of tagging on fish or tag loss rates?
- 11) Do you have any specific questions related to our RFID Review Project Objectives that you would like answered?

Appendix C

List of individuals contacted as part of this study

Begout, Marie-Laure. French Research Institute for Exploration of the Sea.

Brignon, Bill. U.S. Fish and Wildlife Service.

Brown, Gayle. Department of Fisheries and Oceans, Canada.

Carlile, John. Alaska Dept. Fish and Game.

Chose, David. HID Global, Sales Manager.

Cook-Tabor, Carrie. U.S. Fish and Wildlife Service.

Gary, Scott. Biomark, Vice President Sales.

Hagen-Breaux, Angelika. Washington State Dept. of Fish and Wildlife.

Haymes, Jeffery. Washington State Dept. of Fish and Wildlife.

Hennig, Charles. U.S. Bureau of Reclamation, Deputy Chief of Research and Development.

Herriott, Doug. Department of Fisheries and Oceans, Canada.

Katinic, Peter. Department of Fisheries and Oceans, Canada.

LaVoy, Larrie. U.S. Fish and Wildlife Service.

Masin, Barbara. Electronic Identification Systems (Trovan), Vice President.

Nagse, Akira. Hitachi Chemical Co., RFID Group.

Parken, Chuck. Department of Fisheries and Oceans, Canada.

Ridgway, Brenda. Department of Fisheries and Oceans, Canada.

Tiffan, Kenneth. U.S. Geological Survey.

Tompkins, Arlene. Department of Fisheries and Oceans, Canada.

Webb, Dan. Pacific States Marine Fisheries Commission.

Winther, Ivan. Department of Fisheries and Oceans, Canada.

Zimmerman, Bill. Bonneville Power Administration.

Appendix D

Mortality and Tag Retention in PIT-tagged Fish

Literature providing a thorough analysis of PIT tag effects on salmon survival in the natural environment is limited. As a result, the USGS Columbia River Research Lab (CRRL) in Cook, WA has relied on the extensive lab-based literature describing PIT tagging effects. These effects are summarized in tables (Tables 1-3) created by Ian Jerozek, fisheries researcher with USGS.

Dixon and Mesa (2011) noted that several factors can affect the survival and tag retention of PIT- tagged fish, including: methodology, tagger experience, species and size of fish, and environmental conditions.

Size of Fish

Several researchers within the Columbia Basin were contacted, but none them had personal experience using 6-mm PIT tags. However, Ian Jerozek, from the Columbia River Research Lab in Cook, WA, has lately been using 9-mm PIT tags to mark Steelhead from 55 to 69-mm FL. In Steelhead 70-mm FL or greater, 12-mm PIT tags are used.

Ian Jerozek, recommended reading Tiffan's et al. (2015) publication which discusses the effects of tagging on survival, especially when fish are small relative to tag size. The ability to represent a population of migratory juvenile fish with PIT tags becomes difficult when the minimum tagging size requires a fish that is larger than the average size at which fish begin to move downstream (tag weight should be less than 5% of the fish body weight ratio, ideally less than 2%). Within the Columbia River basin, the minimum size at which juvenile anadromous salmonids can be implanted with 12-mm PIT tags ranges from 55- to 60 mm FL. Based on a review of a 15-year data set collected in Idaho (Johnson Creek), two-thirds of the sub-yearling Chinook emigrants were estimated to be smaller than 60 mm FL. Recent developments of the shorter and lighter PIT tags (8- and 9-mm PIT tags) have allowed researchers to tag smaller fish, and thereby more fully represent the population prior to size-related emigration. Tiffan et al. (2015) was the first group to evaluate the 8-mm PIT tag on juvenile salmon and reported 97.8% to 100% survival rate across all trials in the 28 day study and concluded that there was no appreciable fish-size or tag size related tagging effects. Similarly, tag retention was also very high across all tests (93%-99%). However, it was emphasized that actual implantation of the smaller tags may be a bit more challenging in the field (i.e. capture and handling stressors) compared to application in the lab.

Tagging methods

Survival

With the 9-mm PIT tags, Ian Jerozek's lab (from CRRL) uses a micro-scalpel to make the incision. With 12-mm tags they use the standard needle method. The literature does suggest that use of scalpels minimizes effects on smaller fish (Ian Jerozek, pers. comm.). The USGS and NOAA researchers (Ian Jerozek, Theresa Liedtke, and Michelle Rub, pers. comm.) all emphasize

that sharp needles and scalpels are key. However, they will use the same needle and scalpel on multiple fish, but in order to prevent horizontal transmission of disease between fish, needles are disinfected between uses (i.e. with 70% ethanol). Conversely, Biomark Inc., was recently contracted to tag approximately 750,000 endangered Snake River Fall Chinook and Sockeye salmon and their protocol is to use new needles for each fish to prevent infection (Biomark Inc., pers. comm.).

Dixon and Mesa (2011) showed that the use of the micro-surgical technique probably contributed to the high survival of their study fish (95.6%). The advantage of using the surgical technique for implanting PIT tags in small fish is that the depth of penetration can be precisely controlled with the special micro-scalpels. In preliminary experiments, they noticed the 12-gauge needles typically used for implanting PIT tags tend to dull quickly and can cause abdominal tissue tears and occasional hemorrhages from over-insertion.

Tag Retention

The US FDA requires food fish to be tagged in a non-edible location of the fish. The body cavity is the typical place for implanting PIT tags (i.e. in salmonids, Biomark Inc., pers. comm.). However, there are some researchers who tag endangered species in the muscle (i.e. endangered sturgeon are tagged in the dorsal muscle or in the muscle at the back of the head). In contrast, commercial fish hatcheries in Idaho, tag brood fish (i.e. rainbow trout) in the pelvic girdle so they can easily remove the tags without damaging the edible part of the fish. Many fish hatcheries will simply cut the pelvic girdle off the fish after the final spawning, and send the remainder of the carcass to the fish market (Biomark Inc., pers. comm.). Tagging in the pelvic girdle may increase tag retention as, Bateman et al. (2009) reported a number of PIT tags in redds of coastal cutthroat trout (up to 20) indicating that tags can be lost from the body cavity via the vent during egg release. Bateman also indicated that four tags were identified as males, suggesting that both sexes can lose tags. Therefore, body cavity tagging works quite well for most species except salmonids, if recoveries are required post-spawning.

Earlier studies conducted by researchers at the Northwest Fisheries Centre (Seattle, WA) showed insertion of a PIT tag or other foreign body into a fish may cause trauma provoking a host reaction, such as, inflammation, encapsulation, and rejection. However, the Prentice et al. (1990) study, reported 100% tag retention during the 39 day study and noted no host reaction to the tag in any of the fish, concluding that the fish did not recognise the tag as a foreign body. The glass-encapsulated PIT tag appears to be biologically inert (Prentice et al. 1990).

Tagger experience

Richard et al. (2013) evaluated the effect of 12-mm PIT tag implantation on age-0 Brown Trout. The effects of implantation methods (i.e. surgical or injection) and individual tagger on survival, tag retention and growth were assessed during a 60 day hatchery experiment. Two size classes of fish (total length) were considered: small (50-55 mm FL) and large (56-63 mm FL). Of the two size classes assessed, survival, growth and tag retention significantly varied among taggers in the smaller size class as opposed to the larger class size. Based on the results, Bateman et al. (2013) recommend a minimum fish size of 55 mm (total length) for tagging with 12-mm PIT

tags. Over this size, either surgical implantation or direct injection can be performed by different taggers without altering survival, tag retention, and growth.

Dare (2003) reported that most of the tags shed in the study were collected during the first 2-d of tagging (159 tags). Although the relationship was not quantifiable, the frequency of sheds appeared to be linked to the experience of tagging personnel at the start of the study and the continuity of personnel at the tagging station. The high shedding rates observed during the first 2 days of the tagging project were most likely attributed to the learning process of the tagging crew, which was associated with the start of the project. Shed rates declined substantially by day 3 of the tagging project as the skill the tagging crew improved.

Environmental conditions

Knudsen et al. (2009) tagged upper Yakima River hatchery spring Chinook salmon (length averaging 75-78 mm FL) with PIT tags and coded wire tags in a double-tag study to see the effects of survival, behaviour, and growth on recaptures returning 6 months to 4 years after release. The study showed a 2% loss of PIT tags in juveniles prior to release and 18.4% in recaptures returning 6 months to 4 years after release. The results indicated that tag shedding did not increase significantly over time with age as most of the tag loss occurred within the first 6 months after release. After correcting for tag loss, tag induced-mortality was as high as 33.3% over all brood years.

Knudsen et al. (2009) paper was reviewed by many Columbia River basin researchers, including USGS Connolly group. Study fish in Knudsen et al. (2009) were tagged and then held for 70 to 125 days prior to release. The Connolly group thought the Knudsen et al. (1990) study should have reported if there was a growth difference in PIT and non-PIT tagged (NPT) fish between tagging and release. The Connolly group hypothesized that in a crowded raceway or holding pond type area, PIT tagged fish would have a tougher time competing for food and experience greater stress (possibly more so than in a less crowded and competitive stream environment) as they recovered from tagging and would end up outmigrating at smaller size. Smaller size fish outmigrating would result in smaller fish returning to spawn, and fish that are more at risk for predation.

The Connolly group also remarked that the Knudsen et al. (2009) reported an average reduction in survival of PIT-tagged fish compared to NPT fish of 10.3%, but the distribution was fairly skewed by the value from the 1999 brood year (33.3%). The overall median reduction in survival value was approximately 7%; although, if 1999 brood year value was excluded it would be 4.3%. Outmigrant conditions were very tough for the 1999 brood year. However, Knudsen et al. (2009) paper records 1999 as the second highest number of fish reared, but does not address possible crowding, disease, or stress issues while rearing. After reviewing the data, the Connolly group thought the data suggested a possibility that the PIT tag mortality effect may be more pronounced with increased numbers of fish rearing. Leading to the final thought that recovery and growth potential may be higher in a natural environment than in a crowded hatchery rearing situation, particularly in streams that may not be at carrying capacity.

Summary

In conclusion, the above lab-based literature does support the experimental use of smaller PIT tags (<12 mm) for studying survival and tag retention in salmonids. However, further field trials are required to establish the actual minimum fish size for tagging and the appropriate tag size, keeping in mind the differences between laboratory and river environments. Tiffan et al. (2015) indicated that preliminary works has been initiated to determine the efficiency of PIT tag monitoring systems in detecting 8 and 9-mm tags at dams on the Snake and Columbia rivers.

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Table 1. Results from published literature from PIT tagging mortality studies on Chinook salmon *Oncorhynchus tshawytscha*, steelhead *O. mykiss*, and sockeye salmon *O. nerka*. (Created by Ian Jerozek, USGS, CRRL, Cook, WA).

Species	N	Mortality (%)	Tag loss (%)	Tag length (mm)	Fish length (mm) ^a	Implant method	Study period (d)	Statistically different from control fish?	Reference
<i>O. tshawytscha</i> ^b	201	0.5	0.0	12	66 FL	needle	139	No	Prentice et al. 1990
<i>O. tshawytscha</i> ^b	200	0.0	0.0	12	78 FL	needle	135	No	Prentice et al. 1990
<i>O. tshawytscha</i> ^b	201	0.0	0.0	12	84 FL	needle	134	No	Prentice et al. 1990
<i>O. tshawytscha</i> ^b	200	0.0	0.0	12	99 FL	needle	137	No	Prentice et al. 1990
<i>O. tshawytscha</i> ^c	200	5.0	1.0	12	66 FL	needle	139	No	Prentice et al. 1990
<i>O. tshawytscha</i> ^c	200	2.0	0.0	12	77 FL	needle	135	No	Prentice et al. 1990
<i>O. tshawytscha</i> ^c	203	5.0	0.0	12	85 FL	needle	134	No	Prentice et al. 1990
<i>O. tshawytscha</i> ^c	202	2.0	0.0	12	100 FL	needle	137	No	Prentice et al. 1990
<i>O. tshawytscha</i> ^d	- ^e	2.0	-	12	yearling	needle	14	No	Prentice et al. 1990
<i>O. tshawytscha</i> ^f	-	4.0	-	12	age-0	needle	14	No	Prentice et al. 1990
<i>O. tshawytscha</i> ^f	-	14.0	-	12	yearling	needle	14	No	Prentice et al. 1990
<i>O. tshawytscha</i> ^f	-	36.0	-	12	age-0	needle	14	No	Prentice et al. 1990
<i>O. tshawytscha</i> ^g	-	0.0	0.0	12	67 FL	needle	-	No	Prentice et al. 1990
<i>O. tshawytscha</i> ^g	-	0.0	0.0	12	89 FL	needle	-	No	Prentice et al. 1990
<i>O. tshawytscha</i> ^f	30	43.3	0.0	12	137 FL	needle	-	No	Prentice et al. 1990
<i>O. tshawytscha</i> ^f	30	70.0	0.0	12	111 FL	needle	-	No	Prentice et al. 1990
<i>O. mykiss</i> ^d	-	1.0	-	12	smolt	needle	14	No	Prentice et al. 1990
<i>O. mykiss</i> ^f	-	11.0	-	12	smolt	needle	14	No	Prentice et al. 1990
<i>O. mykiss</i> ^g	-	0.0	0.0	12	83 FL	needle	-	No	Prentice et al. 1990
<i>O. mykiss</i> ^g	-	0.0	0.0	12	112 FL	needle	-	No	Prentice et al. 1990
<i>O. mykiss</i> ^g	-	0.0	0.0	12	171 FL	needle	-	No	Prentice et al. 1990
<i>O. mykiss</i> ^f	30	30.0	0.0	12	201 FL	needle	-	No	Prentice et al. 1990
<i>O. nerka</i>	200	0.5	0.0	12	68 FL	needle	-	No	Prentice et al. 1990
<i>O. nerka</i>	200	1.0	1.5	12	83 FL	needle	-	No	Prentice et al. 1990
<i>O. nerka</i>	200	3.5	0.0	12	99 FL	needle	-	No	Prentice et al. 1990

^a Reported as mean length, length range, or life stage at time of tagging. FL = fork length, TL = total length.

^b Fish were held in well water.

^c Fish were held in stream water.

^d Run of the river fish collected and held at Lower Granite Dam, OR.

^e “-” = Not reported.

^f Run of the river fish collected and held at McNary Dam, OR.

^g Fish were held in laboratory at Big Beef Creek, WA.

Table 2. Additional results from published literature on PIT tagging mortality studies of *Oncorhynchus tshawytscha* and *O. mykiss*, and results from PIT tagging mortality studies of Atlantic salmon *Salmo salar* and brown trout *S. trutta*. (Created by Ian Jerozek, USGS, CRRL, Cook, WA).

Species	N	Mortality (%)	Tag loss (%)	Tag length (mm)	Fish length (mm) ^a	Implant method	Study period (d)	Statistically different from control fish?	Reference
<i>O. tshawytscha</i>	4,977	1.3	0.1	12	parr	needle	1	- ^b	Achord et al. 1996
<i>S. salar</i>	33	21.2	15.2	23	64-94	surgical	32	-	Roussel et al. 2000
<i>S. salar</i>	-	<1.0	<1.0	23	parr	surgical	-	-	Zydlewski et al. 2001
<i>S. salar</i>	3,037	5.7	0.2	12	115 FL	surgical	270	No	Gries and Letcher 2002
<i>S. salar</i>	135	22.0	-	12	60-69 FL	surgical	60	Yes ^c	Sigourney et al. 2005
<i>O. mykiss</i>	200	14.0	3.0	23	73-97 FL	surgical	30	Yes	Bateman and Gresswell 2006
<i>O. mykiss</i>	2,392	1.8	7.2	23	163 FL	surgical	120	Yes ^d	Hill et al. 2006
<i>S. trutta</i>	145	20.9	20-30 ^e	12	41-70 FL	needle	27	Yes ^f	Acolas et al. 2007

^a Reported as mean length, length range, or life stage at time of tagging. FL = fork length, TL = total length.

^b “-” = Not reported.

^c Fish size had a significant effect on survival.

^d Significantly higher mortality than control in 4 of 6 trials.

^e Tag loss was higher in fish <57 mm.

^f For fish ≥57 mm, mortality was 1.0%.

Table 3. Results from published literature of PIT tagging mortality studies of largemouth bass *Microterus salmoides*, African catfish *Heterobranchus longifilis*, Eurasian perch *Perca fluviatilis*, bullhead *Cottus gobio*, roach *Rutilus rutilus*, rudd *Scardinus erythrophthalmus*, gilthead seabream *Sparus auratus*, bluehead sucker *Catostomus discobolus*, mottled sculpin *C. bairdii*, bonytail chub *Gila elegans*, and Gila chub *G. intermedia*. (Created by Ian Jerozek, USGS, CRRL, Cook, WA).

Species	N	Mortality (%)	Tag loss (%)	Tag length (mm)	Fish length (mm) ^a	Implant method	Study period (d)	Statistically different from control fish?	Reference
<i>M. salmoides</i>	500	4.0	- ^b	21	254 TL	needle	-	-	Harvey and Campbell 1989
<i>H. longifilis</i>	20	10.0	10.0	-	age-0	surgery	28	-	Baras and Westerloppe 1999
<i>P. fluviatilis</i>	212	12.3 ^c	0.0	11	55-96 FL	surgery	126	- ^d	Baras et al. 2000
<i>C. gobio</i>	6	0.0	0.0	12	>70 TL	surgery	28	-	Bruyndoncx et al. 2002
<i>R. rutilus</i>	200	<6.0	0.0	23	117-163 TL	surgery ^g	37	No	Skov et al. 2005
<i>S. erythrophthalmus</i>	200	<6.0	0.0	23	117-163 TL	surgery ^g	37	No	Skov et al 2005
<i>S. auratus</i>	36	2.8	14.0	12	fingerling	surgery	30	No	Navarro et al. 2006
<i>S. auratus</i>	668	3.4	1.7	12	fingerling	surgery	52	No ^e	Navarro et al. 2006
<i>C. discobolus</i>	18	5.5	0.0	-	164-278 TL	-	2-6	-	Ward and David 2006
<i>C bairdii</i>	26	3.8	3.8	12	56-83 TL	needle	28	-	Ruetz et al. 2006
<i>G. elegans</i>	180	1.1	<3.0	12	84-132 TL	needle	30	-	Ward et al. 2008
<i>G. elegans</i>	121	14.9	6.6	12	68-143 TL	needle	30	- ^f	Ward et al. 2008
<i>G. intermedia</i>	210	1.9	<3.0	12	75-129 TL	needle	30	-	Ward et al. 2008

^a Reported as mean length, length range, or life stage at time of tagging. FL = fork length, TL = total length.

^b “-” = Not reported.

^c Mortality for fish in the three groups of largest size fish was 7.1%.

^d Mortality for the smallest size class of fish was statistically different from the other seven size classes.

^e Mortality for the smallest size class of fish was statistically different from the other three size classes.

^f Fish were allowed access to abundant prepared feed for twelve hours prior to tagging.

^g Only fishes with incisions closed with sutures dies during the experiment.

Environmental anomalies in the Northeast Pacific Ocean and
their influence on Pacific salmon run timing, abundance, growth, and survival
in 2015 and 2016

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1. Highlights

1.1 Approach

One of the major findings of the 2010 PICES report on the state of marine ecosystems of the North Pacific was a trend toward increasing variability (McKinnell & Dagg 2010) compared to what had been reported during the five year period prior to that (PICES 2005). If an update was to be written now, the same observation would likely be made. Since 2013, environmental variability has been ratcheted up another notch, with what appears to be variable consequences for North American Pacific salmon. The present report focuses on environmental and biological extrema of 2015 (and 2016 where data are available) in the salmosphere¹. In most cases, new indices of environmental variability were developed in order to focus on the environmental variability occurring within the salmosphere, or a portion thereof. This section entitled “Highlights” provides a brief written description of what was found when 2015 and 2016 years were compared with available historical records. Atmospheric, oceanic, and biological properties that did not reach extreme values are not included in the highlights but are discussed occasionally.

1.2 Environmental extrema

1.2.1 Air Temperature

The focus of recent analyses of environmental anomalies in the ocean has generally been on the development and duration of sea surface temperature anomalies (SSTa), a.k.a. The Blob, but the development of warm SST was preceded by warmer air temperatures in the salmosphere. There was an abrupt increase in surface air temperatures (SAT) in the salmosphere between May and June of 2013. Principal component analysis of SAT anomalies (SATa) found, not unexpectedly, that the dominant mode of monthly average air temperature variability in the North Pacific salmosphere was closely associated with variation in the Pacific Decadal Oscillation with maximum correspondence ($r = 0.77$) occurring in May. The only extremum recently in SATa-PC1 (since 1948) occurred in April 2016. On the other hand, the subdominant mode (SATa-PC2) had positive extrema in February and October 2015, and also in July and August 2016.

1.2.2 Sea Temperature

a) *Surface* - There is no precedent in the historical instrumental record of observations of the magnitude and persistence of high sea surface temperatures (SST) in the salmosphere. The abrupt increase in SAT that occurred in June of 2013 and was followed by an abrupt shift in SST during the last two weeks of July of 2013. Apart from a brief cooling in the fall of 2013, SST anomalies (SSTa) have generally exceeded +1 s.d. through to the writing of this report. The maximum extremum observed during this period occurred in September 2014.

b) *Subsurface* - Salmon do not live at the very surface of the ocean where the satellites are measuring SST. Their habitat is beneath the surface where the uppermost measurements by Project Argo profiling floats are typically recorded (4-5 m). Because they are so few, a relatively coarse grid is required to accumulate monthly spatial statistics. Using a 2° latitude by 5° longitude grid, there are about 7 observations per grid point per year, from which means and anomalies can be computed from 2003. The most extreme anomalies ($> \pm 4^{\circ}\text{C}$) at 5 m depth in the eastern salmosphere (eastward of 180° longitude) occurred at its southern fringe (negative) and near the Aleutian archipelago (positive). All of the most extreme

1 The current and future domain of *Oncorhynchus* and *Salmo* in the northern hemisphere.

temperature anomalies were south of 49° latitude.

c) Coastal temperature (high resolution) - A similar analysis was conducted using higher resolution data (daily, 1/4° grid) on the continental shelf (< 1000 m) since 1981. The dominant pattern (PC1) is coastwide positive covariation (PC1) throughout the entire Gulf of Alaska. The most extreme of the positive PC1 scores on the shelf occurred in 2016 rather than in 2015. Strong coastal anomalies are typical for an el Niño (McKinnell & Crawford 2007). The three highest positive PC1 scores (>3.6 s.d.) occurred over a 3-day period, May 14-16, 2016. The next 6 highest scores occurred in 2004 and in 2005. In 2015, the rank of the strongest positive score that year occurred on July 12 and it was 19th in the entire record. The strongest positive score in 2014 (50th highest) occurred on December 27. The contrast between pre-2014 average SST and 2014-2016 average SST on the continental shelf is not as great in offshore waters. There is little to no evidence of an overall linear trend in PC1 prior to 2014. PC1 is significantly correlated with survival of Chilk Lake sockeye salmon postsmolts; colder years are associated with higher survival. It has not been cold lately. Daily data collected at Kains Island (NW Vancouver Island) indicated that 2015 was the spiciest (warm-salty) year on record (since 1934).

1.2.3 Sea Level Pressure (SLP)

Due to an atmospheric teleconnection, there is a close correspondence between SLP in the western tropical Pacific in winter and air and sea temperatures along the North American coast in the following months. SLP at Darwin, Australia (the western pole of the Southern Oscillation Index) had the highest average January SLP in 2016, in a record that dates back to the 19th century. SLP extrema were found across the entire salmosphere in the North Pacific during January and February of 2016. Although strong (negative) pressure anomalies in the Subarctic are a regular feature of major el Niños, many of the anomalies that occurred in 2016 were extrema. An Aleutian Low index, restricted to the salmosphere was developed and 2016 was only the 3rd strongest in the record, behind 1983 and 1998.

1.2.4 Nutrients

At all stations along Line-P from the west coast to the middle of the Gulf of Alaska, the winter nutrient supply in 2015 was the lowest observed by DFO scientists in the past seven years.

1.2.5 Chlorophyll

a) Offshore - the most noteworthy feature of the record from 2003 was the extreme timing (late) of the fall bloom in 2016.

b) Shelf - the late timing of the fall bloom in 2016 was an extremum.

c) Coastal - the late timing of the fall bloom in 2016 was an extremum.

1.2.6 Zooplankton

a) Offshore - in the eastern Gulf of Alaska, there were no extrema of abundance, biomass, or average size of zooplankton in 2015 measured by the Continuous Plankton Recorder (CPR). This is a standard sampling device that is towed behind commercial ships as they transit the World Oceans including the North Pacific since the late 1990s. CPR data for 2016 (preliminary) had extremes of abundance in May (low), June (low), and July (high) and an extreme of biomass (April), and extremes in average size in April through June (high), shifting to July (low). Near-average biomass combined with an inverse relationship between abundances and average sizes suggests a dynamic shift in the community composition in 2016, moreso than in other years. The disappearance of large copepods from surface waters (where the CPR operates) in summer is part of the ontogeny of most of the large copepods in the Gulf of Alaska.

b) Coastal - Extrema were numerous off the coast of Oregon in 2015, mostly due to the appearance of numerous taxa of subtropical origin that had not previously been observed in nearly 50 years of sampling. Zooplankton biomass extrema also occurred in 2015 and were stronger off northwest Vancouver Island than southwest Vancouver Is. This pattern suggests a more extreme intrusion of subtropical water than has been observed before.

1.3 Salmon extrema

It was thought desirable to have a standard (comparable) approach to identifying coastwide extrema in salmonid biology. The most common form of salmon data for understanding timing/abundance are the daily counts past observation points. Preferred sites are located before fisheries occur, but these are more rare than sites located after fisheries have occurred. Where fishing is relatively heavy, the resulting observations will no doubt be affected by it. While the tools used to make salmon observations may differ (weirs, test fisheries, sonar), the data generated are suitable for fitting to a common abundance/timing model framework. The migration model developed by Schnute and Sibert (1983) was used because of its flexibility to capture various aspects of a migration. Where complex migrations were clearly evident (e.g. chinook salmon at Bonneville Dam), the data were fit to a complex migration model (McKinnell, unpublished) that allows for mixtures of populations (timing groups) to be identified in a time series. Salmon runs are often a composite of multiple pulses of fish going to one location or multiple populations going to different locations, perhaps each also with multiple pulses of abundance. The parameters estimated for each component include: abundance (A), skewness (S), compression (C), and peak date (P). Abundance is the cumulative total abundance or CPUE (catch-per-unit-effort), skewness measures the degree to which a run deviates from symmetry about an estimate of the peak date, compression measures the fraction of the run passing on the peak date (i.e. related to kurtosis). Peak date is estimated by the model based on the fit of the model to the curve so may differ slightly from the observed peak date. The model was fit to each species in each year to understand the historical interannual variability of each parameter for each run component. The results were placed in rank order to determine if any of the parameters were extrema in 2015 or 2016.

To provide a graphical overview (at the end of Highlights section) of the overall results values of each parameter were classified as high (red) or low (blue) if they were historical extrema in 2015 or 2016. If not, strong anomalies were defined as high (orange) or low (cyan) anomalies if the anomaly exceeded 2 standard deviations from the long-term mean², or “normal” within 2 s.d. of the long-term mean. Note that an extremum need not exceed ± 2 s.d. Mean size-at-age data, where available, were also ranked to determine if 2015 or 2016 were extrema, strong anomalies or normal using the same criteria. For the most part, environmental extrema are discussed only if they occurred in 2015 or 2016.

1.3.1 Bering Sea

a) Yukon River

- 2015 - highest chinook salmon count at Eagle (near the Alaska – Yukon border).
- 2016 - earliest peak date of chinook salmon and latest peak date of fall chum salmon at Eagle. Latest peak date of pink salmon and least compressed run of summer chum salmon on the Anvik River (tributary 300 mi upstream of estuary)

² Variable lengths of time series.

b) Bristol Bay

- 2015 - latest migration timing of sockeye salmon return timing ever observed at the Port Moller test fishery.
- 2016 - average weight of sockeye salmon was the smallest observed in 20 years (2.4 kg).

1.3.2 Northern Gulf of Alaska

a) Kodiak

- 2015 - highest count of early-run sockeye salmon and skewed (slow rise to peak) migration of late-run sockeye to Karluk R.
- 2016 - highest count of late-run sockeye salmon and most skewed and compressed returns of pink salmon (early pulse) to the Karluk R.

b) Prince William Sound

- 2015 - Prince William Sound had the largest pink salmon catch on record. Kodiak pink salmon harvest was a strong anomaly (high). There was a strong anomaly (high) in the abundance of early-run Copper River sockeye salmon.
- 2016 - Prince William Sound had the lowest pink salmon catch in 20 years. Russian River - Early-run sockeye salmon was most compressed, and the chinook salmon migration was most skewed and earliest peak date.

1.3.3 Southeast Alaska

- 2015 - There were no harvest abundance extrema in northern or southern SEAK, although harvest was below average in SSEAK but second highest in the past 20 years in NSEAK (outside), and average in NSEAK (inside). Considering body size, of 10 age/population combinations of sockeye salmon examined, only Chilkoot (age 1.3) had a mean length extremum (small) in 2015. This same population/age-class was also small in 2016.
- 2016 - Pink salmon harvest in NSEAK (inside) was the lowest in the past 20 years, and NSEAK (outside) was the second lowest. SSEAK was below average but not an extreme.
- Coho - No mean size extrema in 2015 nor in 2016 (including data from 2016 troll fishery).
- Chum - 2015 - Chilkat R. only - age 0.3 females were smallest, no extrema for age 0.3 males or age 0.4 males and females.
- Chinook – troll fishery - mean dressed weights in 2015 of age 1.3 and age 0.4 fish were extrema (small) but not for age 0.3 or age 1.4. The dominant feature in these data, across all age-classes, is the declining trend in mean weight over the past 35 years.

1.3.4 British Columbia

The DFO State of the Pacific Ocean report for 2016 (Chandler et al. 2016) provides a good starting point for the present study as it commented on what was known to have occurred in 2015 and what might be expected as a consequence of the environmental conditions that were expected to play out in 2016. Based on what is currently understood about the salmo-environmental linkage, the worst effects of 2015-2016, at least for those in the southern part of the salmosphere, are yet to come.

| *The 2014-2015 anomalously warm water conditions in the North Pacific Ocean did not induce widespread salmon* |

recruitment failures in 2015 due to common ocean effects as some feared but, did influence return timing, straying rates and size-at-age traits of many salmon populations originating from eastern Pacific waters from south-central Alaska, through B.C., Washington and Oregon. The impacts of a warmer than average ocean in 2014-2015 followed by the El Niño in spring 2016 suggest survival unfavourable conditions for juvenile salmon making sea entry from the B.C. central to south coast in those years so significant reductions in returns to many populations (Okanagan-Columbia River salmon; Barkley and west coast Vancouver Island salmon) may be expected in 2016-2018.

a) Nass River (fish wheel)

The data are escapement abundances from 1994. Chinook salmon and sockeye salmon were modelled as having early and late timing components. Coho salmon were modelled as a single pulse as only the first part of the migration is observed before the wheel is shut down for the season.

- 2015 - No timing/abundance extrema in early or late sockeye and chinook salmon, or coho salmon, but the abundances of sockeye and chinook salmon were strong anomalies (low). Sockeye mean size-at-age was an extremum (small) in 2015 in 3 of four age-classes, more extreme for fish that had spent 3 winters at sea.
- 2016 - Early and late-run sockeye salmon and chinook salmon abundances were extrema (high). Early run sockeye and late run chinook had extreme peak dates (late) and for the case of late run chinook salmon, the most compressed run. Coho salmon abundance (till the shutdown) was lowest, most compressed, with the earliest peak date). Mean size-at-age of 4₂ and 5₃ sockeye was small from 2014-2016, but only age 5₃ of the 4 major age-classes had an extremum in 2016.

b) Skeena River (Tyee test fishery)

- 2015 - No timing/abundance extrema occurred in sockeye, coho, pink, and chum salmon and steelhead trout. Chinook salmon had late and compressed timing extrema.
- 2016 - Sockeye salmon migration timing at Tyee was the latest with no other abundance/timing extrema.

c) Docee River (fence count)

- 2015 - no abundance/timing extrema in sockeye salmon.
- 2016 - earliest peak date of migration of sockeye salmon.

d) Fraser River (test fisheries)

The data are pre-fishery abundances (test fisheries) from 2002 to present. Gillnet test fisheries precede seine test fisheries with variable numbers of days of overlap. For simplicity, each time series for each species in each year was modelled as a single pulse of migration. The complexity of decomposing runs of all species, particularly sockeye salmon with different migration timing among cycle years, was beyond the scope of this project.

- 2015 - Of the 60 parameters examined (4 for each time series) in the Johnstone Strait (Round Is. and Blinkhorn) test fisheries, 13 were either extrema or large anomalies. Steelhead trout in the Blinkhorn seine test fishery was the only abundance extremum (high). Pink salmon were early and extremely skewed (sharp drop after an early peak) at Blinkhorn but there were no extrema for pink salmon in the Round Is. gillnet test fishery. Runs of age large sockeye salmon and steelhead trout past Blinkhorn and steelhead trout and coho salmon past Round Is. were the least compressed of all years. Although they were few, timing of age 3₂ sockeye salmon was late at Blinkhorn. Because of their small size, they are rarely caught in gillnet test fisheries. Large chinook salmon were late at

Blinkhorn but not at Round Is. yet both locations had compressed runs.

In the Juan de Fuca test fisheries (gillnet and seine), 16 of 60 parameters examined had extrema or large anomalies. High extrema occurred in the seine fishery (abundances of large and small chinook salmon, and chum salmon) while low extrema occurred in the gillnet fishery (abundances of large sockeye, small and large chinook salmon, and chum salmon). Given that the gillnet fishery starts prior to the seine fishery, this pattern suggests that chinook and chum salmon arrived later than normal, although none were extrema. As in Johnstone St., pink salmon in the gillnet test fisheries at Juan de Fuca did not indicate extrema (except for a skewed migration – slow increase) but the seine fishery did. Pink salmon in the seine test fishery had an early peak and declined more rapidly than in other years. The only other timing extremum was the late peak of coho salmon in the gillnet fishery. The most consistent extrema were found in the compression parameter; most were low values indicating more drawn out migrations. The average weight of Fraser River pink salmon was the smallest ever observed. Total abundance of pink salmon at the Fraser R. was low, much lower than expected, but not an extremum.

- 2016 - The highlight of 2016 was a report by the PSC of the lowest total return of sockeye salmon to the Fraser River since the start of records (late 19th century). Of 52 timing/abundance parameters examined in Johnstone Strait, 14 had extrema or large anomalies. All abundance extrema featured low abundance in seine test fisheries but not gillnet test fisheries (small sockeye, large chinook, and coho salmon at Blinkhorn and large sockeye, small sockeye, large chinook, and steelhead trout in Juan de Fuca). Large sockeye salmon had the earliest peak date in both Juan de Fuca and Blinkhorn test fisheries. At Blinkhorn, the sockeye run was also skewed and compressed (sharp peak). Indeed, all but one (Round Is. chum) of the 13 compression extrema had sharp peaks in 2016. It would be useful to explore the implication for 2017 of low abundances of age 3₂ sockeye salmon in both seine test fisheries in 2016. Extrema in peak dates were few (5) and all but one (steelhead trout at Round Is.) were early.

1.3.6 U.S. Mainland

a) Baker Lake

Data are reconstructed pre-fishery abundances on the Skagit River from 1992.

- 2015 - total returns of sockeye salmon were the highest in the record.
- 2016 – no abundance/timing extrema.

b) Lake Washington (Ballard Locks counts)

The daily sockeye salmon counts at the Ballard Locks were examined.

- 2015 – no abundance/timing extrema
- 2016 – no abundance/timing extrema

c) Columbia River (Bonneville Dam)

Escapement (counts at Bonneville Dam since 1980). Species analyzed included sockeye, large and small chinook, large and small coho, and steelhead trout. Returns of chinook salmon were modelled as 3 pulses, coho salmon as 2 pulses and all other species as single pulses. Data for 2016 included counts to October 21, 2015 except chinook salmon where the counts were re-run later in the season to include data into late November.

- 2015 - The largest total return of large chinook salmon occurred as a result of Summer and Fall Run extrema added to a high abundance of the Spring run. There were no other extrema in this

year although sockeye salmon abundance had a strong anomaly (high). Spring and summer small chinook salmon were extremely skewed (peaks in the first part of the run). Small Spring run chinook and large late run coho had compression extrema (low). The only peak date extremum (early) was large early run coho salmon. Although not an extremum of interest to this report, the 2014 ocean entry year produced remarkably few large coho salmon spawners in 2015, considering the sibling relationship that has persisted through the 21st century (see below).

- 2016 - Of 48 parameters examined only 1 was an extremum or strong anomaly and that was the skewed run of steelhead trout (slow rise to a peak).

Body size extrema

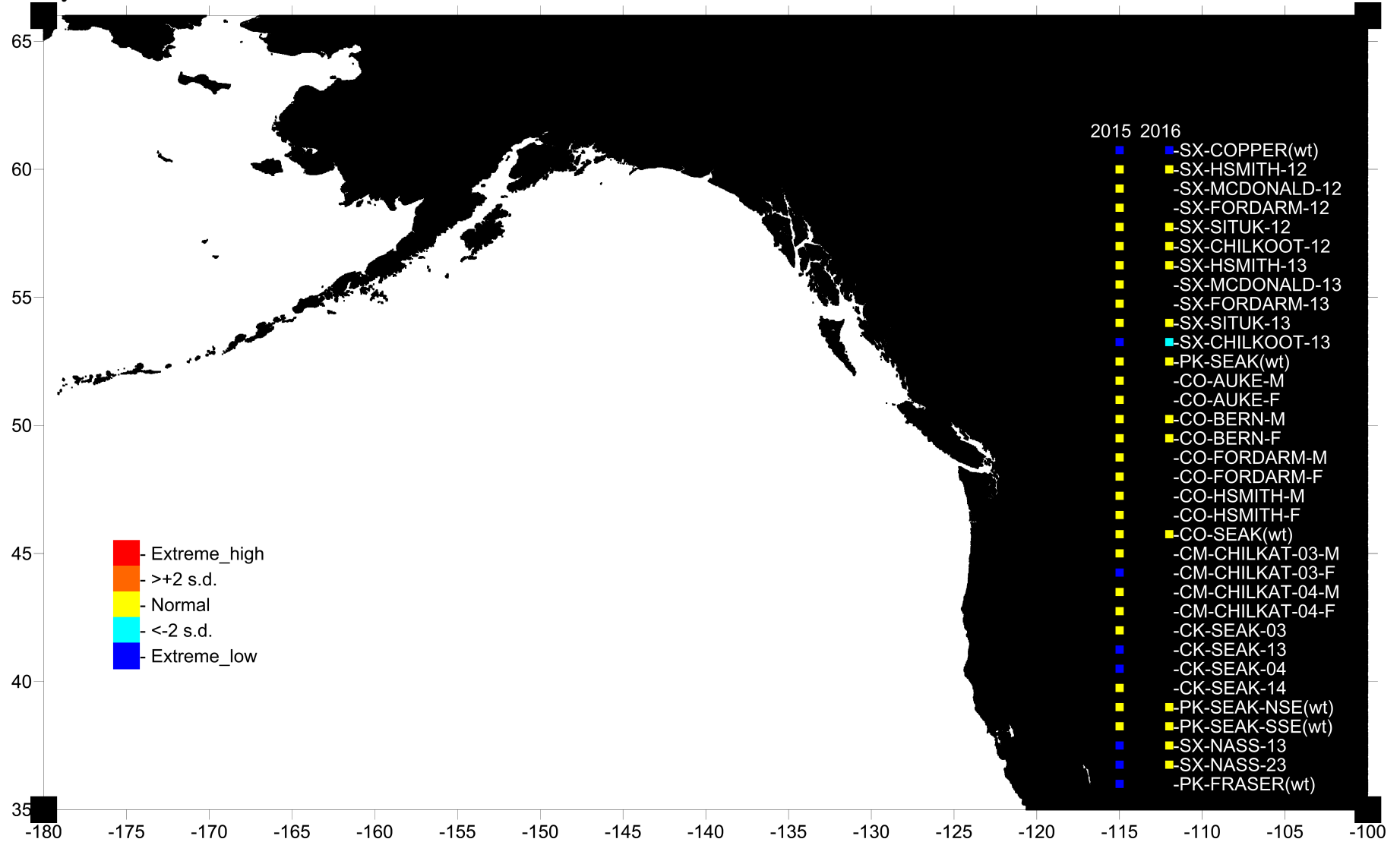


Figure 1: Anomalies and extrema in mean size at age in 2015 and 2016; most are mean length but mean weight is indicated by (wt) in the label. SX-sockeye, PK-pink, CK-chinook, CO-cobo, CM-chum, SH-steelhead. Age-at-maturity indicated as two numerals $x.y$ where x -number of freshwater annuli and y -number of ocean annuli. Total age is their sum+1 as there is no annulus formed during the first winter in freshwater (as an egg).

[illegible]

Figure 2: Determination of extrema and strong anomalies in: A= abundance, S= skewness (high [low] values have an abrupt [slow] rise to a peak followed by a long [abrupt] decline), C= compression (high [low] values have a larger percentage of the run passing near the peak date), P= peak date. (high [low] values are late [early]). Lg= large adults, Sm= small adults, E= early run, L= late run, Spr= spring, Sum= summer, Fal= autumn. SX=sockeye, PK=pink, CK=chinook, CO=coho, CM=chum, SH=steelhead. Other location codes are SJ= San Juan, BON=Bonneville Dam.

Introduction

The Northeast Pacific has been experiencing a heat-wave for the last few years (di Lorenzo and Mantua 2016). For marine fish species, the responses to various environmental phenomena, el Niño for example, are often unpredictable (Bailey et al. 1995). Throughout history, outcomes for Pacific salmon arising from an intermittently warmer ocean have varied by species and location. Certainly in the southern extremes of the salmosphere, surface ocean warmth is never considered as a sign of high survival or abundance when juvenile salmon are exposed to it (Mueter et al. 2005). On the other hand, some of the largest adult sockeye salmon returns to the Fraser River have occurred in years when the Gulf of Alaska was much warmer than average, e.g. 1958, 1997 (McKinnell et al. 2012).

At their January 2016 annual meeting, the Pacific Salmon Commission directed the CSC to collaborate with appropriate experts to develop a proposal for annual collation of data on the environment, run size, fish condition, and other metrics that may reveal anomalies in salmon survival. In response, the CSC recommended a two stage approach, the first documenting the 2015 anomalies and the second developing a PSC strategy for ongoing consideration of annual environmental variability and its impact on salmon production and management. The Commissioners directed the CSC to proceed on the first stage of this approach, documenting anomalies in environmental conditions and characteristics of salmon runs in 2015.

A Statement of Work was developed for the author to document 2015 anomalies along with preliminary observations for 2016 where available. The first part was to compile a list of anomalous characteristics of salmon runs in the NE Pacific and potentially linked environmental anomalies in 2015, and similar information for 2016 if available. The CSC will facilitate contacts within State or Federal agencies that can assist with the provision of knowledge and data. The second part, which will form part of the final report, was to conduct a comprehensive evaluation of the identified anomalies which will include:

- Assessment of each anomaly in context of the historical time series, if available.
- Implications of each anomaly to future salmon production, management, forecasting or other Commission interests.
- Recommendations regarding monitoring of each anomaly including consideration of data gaps.

Mapping the salmosphere

In general, existing knowledge of the distribution of salmon in the North Pacific Ocean beyond the continental shelf (excluding the Bering Sea) comes from an intensive period of research that was conducted by Canada, Japan, and the United States during the 1950s and 1960s under the auspices of the International North Pacific Fisheries Commission (INPFC). The Commission was interested in the oceanic distributions of salmon produced by different countries and the extent of their intermingling. Commercial and research catches of salmon on the high seas, primarily using gillnets, provided an understanding of the distributions of each species, whereas floating longline surveys by fisheries research agencies during the 1960s augmented that information with an understanding of the nature of species distributions from different regions. Longline gear was preferred because salmon could be captured alive on the high seas, allowing a tag to be attached to a fish then recovered at some later date by coastal fisheries along the coast during spawning migrations to natal streams. Less often, seine nets were used for the same purpose.

For the present study, the salmosphere in the North Pacific was defined on a 1° grid of latitude/longitude using salmon release locations in the historical high seas tag database (NPAFC 2008), and augmented in the Gulf of Alaska by the locations of longline catches made by Canada from 1961 to 1967, from which many of the tagged salmon were released. A grid point was included in the salmosphere if a salmon of any

species had been caught and/or released anywhere within the 1° cell in any year. For the Gulf of Alaska, the merging of longline catches with the historical tag release data created a relatively contiguous region where salmon of any species were caught with few obvious gaps from undersampling (see below). Likewise, grid points in the western North Pacific and parts of the Bering Sea were relatively contiguous, but the central North Pacific had a higher frequency of gaps.

To fill many of the gaps, a median filter was applied to the data. This filter replaces each grid point by the median value of the surrounding cells. Thereafter, any cell that was obviously missed by the filter was edited manually to create a contiguous domain. Although they form part of the salmosphere, the marginal seas in the northwestern North Pacific were excluded from this analysis. Of course, this approach misses some locations where salmon catches did not occur in these databases which could be improved with additional effort to find them, but for the most part researchers will recognize this domain as that of Pacific salmon. A more rigorous approach would involve defining seasonal salmospheres, perhaps for each species, but that is beyond the scope of the present study. The final grid was used to determine locations where environmental data should be selected to develop salmo-relevant indices of variability.

The predictability of outcomes for salmon as a consequence of environmental variation in any given year can be relatively poor because mechanistic understanding of cause and effect is not well developed. For example, at the onset of one of the largest el Niños of the 20th century in 1982, a relatively large abundance of age 2₂ coho salmon off the coast of Washington and Oregon that summer was followed one year later by a relatively low abundance (and small mean size) of age 3₂ coho salmon of the same cohort. The dearth of spawners in 1983 was attributed to exceptional mortality at sea during the el Niño (Percy et al. 1985). If the el Niño was indeed the cause, one might expect similar kinds of over-winter mortality during other el Niños if the local oceanographic responses to them were similar. The 1997/98 el Niño was a major climatic event (McPhaden 1999) that exhibited most of the classical oceanic and atmospheric responses in the Northeast Pacific. It did not, however, appear to cause unusual over-winter mortality in Washington/Oregon coho salmon when measured as the ratio of the counts of age 3₂ coho at Bonneville in 1998 to age 2₂ counts in 1997. Indeed, the returns of age 3₂ coho salmon to Bonneville Dam in both 1983 and 1998 were about what would have been expected from the sibling relationship of that era (but not of the recent era)(Figure 3). If there had been anomalously atypical over-winter mortality in 1983, a

strong outlier might have been expected in 1998, but it did not occur. So it seems rather difficult to reach

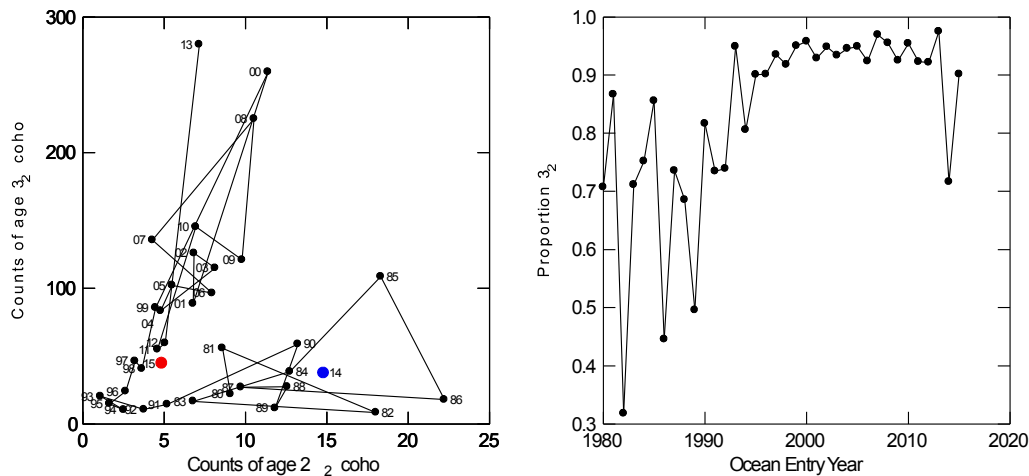


Figure 3: [left] Counts of age 3_2 coho salmon (ordinate) versus counts of age 2_2 coho salmon of the same cohort (abscissa). Plot point labels indicate ocean entry year of the cohort. Years are linked in sequence by black lines. [right] Data from the panel on the left expressed as proportion of age 3_2 spanners in each cohort. The 2013 ocean entry year produced the greatest number of total coho salmon spanners in the record. The 2014 ocean entry year (blue dot), while having relatively large numbers of age 2_2 spanners saw remarkably few age 3_2 spanners of the same cohort the following year; a ratio that had not been seen since the 1980s. Despite some of the highest juvenile growth rates ever observed, the 2015 ocean entry year (red dot) produced few spanners.

the general conclusion that el Niños kill coho salmon. What is more apparent is the division of the time series into two stanzas around the mid-1990s.

Two possible causes for a fundamental change come to mind. The first is that since the late 1990s, a greater proportion of a cohort of coho salmon (those ascending above Bonneville Dam) have delayed maturity until after one full year at sea (Figure 3, right) rather than ascending the river to spawn after one summer at sea. Likewise, the apparent change in maturity schedule could arise if late-stage mortality was more prevalent prior to the late 1990s. Generally, however, smolt to adult survival of coho salmon was greater before the 1990s than after, which tends to support the idea of a fundamental shift in the maturity schedule of these fish. Delaying maturity is one of the responses by salmon to reduced growth. On average, older maturing salmon tend to exhibit slower growth throughout their lives (Bilton 1971, McKinnell 1995). As age-at-maturity in coho salmon may be determined in freshwater prior to seaward migration, the maturity schedule is not likely determined solely in the ocean. As most coho salmon above Bonneville Dam are from hatcheries, perhaps there was a change in some aspect of feeding that led to the change in maturity schedule.

The return of age 3_2 coho salmon to Bonneville Dam in 2014 was a recent extremum (high). Likewise, the return of age 2_2 was the 4th largest since the 1980s (Figure 3). The 2015 return year (2014 OEY) of age 3_2 coho salmon failed to match the abundance of that cohort seen the previous year. Indeed, that return in 2015 was what might have been expected under the sibling relationship that existed during the 20th century when high age 2_2 abundances were associated with much lower returns of siblings the following year. Juvenile coho salmon growth off Washington and Oregon was high in 2014 (B. Beckman, NOAA/Seattle, pers. comm.) and highest in a 20 year record off the West coast of Vancouver Island (Chandler et al. 2016). Therefore, the low abundances of age 3_2 coho salmon at Bonneville in 2015 are more likely due to late-stage mortality, than a change in the maturity schedule, all else held constant.

Environmental extrema

The primary focus of this study is extrema that occurred in 2015 and 2016, yet the dominant cause of environmental variation in the salmosphere is the seasonal (annual) cycle of warming and cooling associated with the Earth's orbit around the sun. The general practice for studying unusual events is to begin by removing the effect of the seasonal cycle from the data by subtracting off seasonal average values. For example, the monthly average temperature in June 1977 at some location is transformed into a temperature “anomaly” at that location by subtracting the long-term average for the month of June from the June 1977 value. With daily data, the long-term daily average would be removed. Anomalies can be either positive or negative and the larger they are, the more extreme is the non-seasonal anomaly. The largest of these, of either sign, is what is sought in this study.

1. Surface air temperature (SAT)

Di Lorenzo and Mantua (2016) describe a marine heatwave in the Gulf of Alaska in 2014-2015 but it seems that there is evidence in the atmosphere for it starting in June of 2013, and that it continued well into 2016. Using the U.S. NCEP/NCAR Re-analysis 1 data (Kalnay et al. 1996), restricted to the Pacific salmosphere, SAT extrema (maxima) at individual grid points ($2.5^\circ \times 2.5^\circ$ latitude/longitude) are far more numerous from 2014 to 2016 than in other years (Figure 7). The greatest number of SAT extrema (maxima) observed in any one month since 1948 in the salmosphere occurred in August 2016 (31% of the entire Pacific salmosphere). The greatest number of extrema (maxima) observed in any month in 2015 was of similar geographic scale, but they occurred in the month of February. The range of latitudes of SAT maxima was more widespread in February 2015 than in August 2016 (Figure 5).

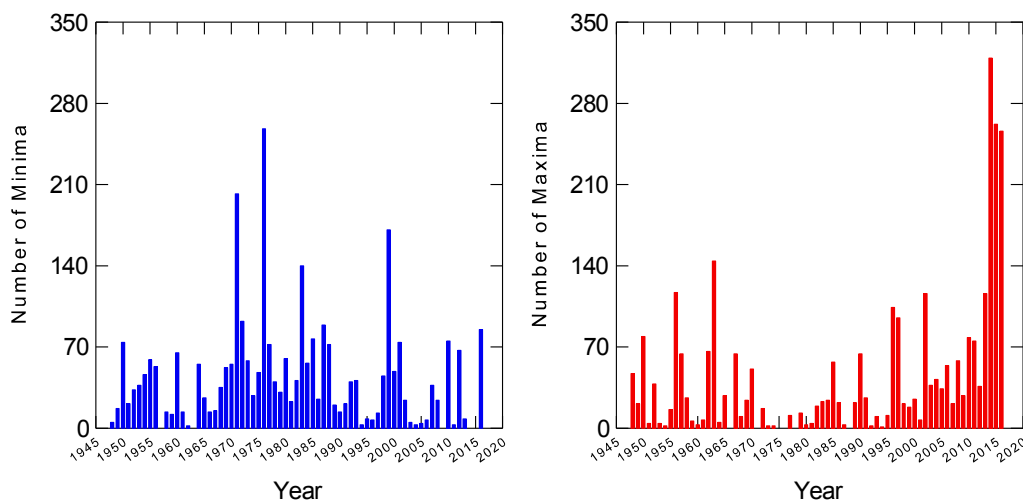


Figure 4: Number of surface air temperature minima (left) and maxima (right) by year in the salmosphere since 1948 to 2016 (September). Data source: NOAA/NCAR Re-analysis.

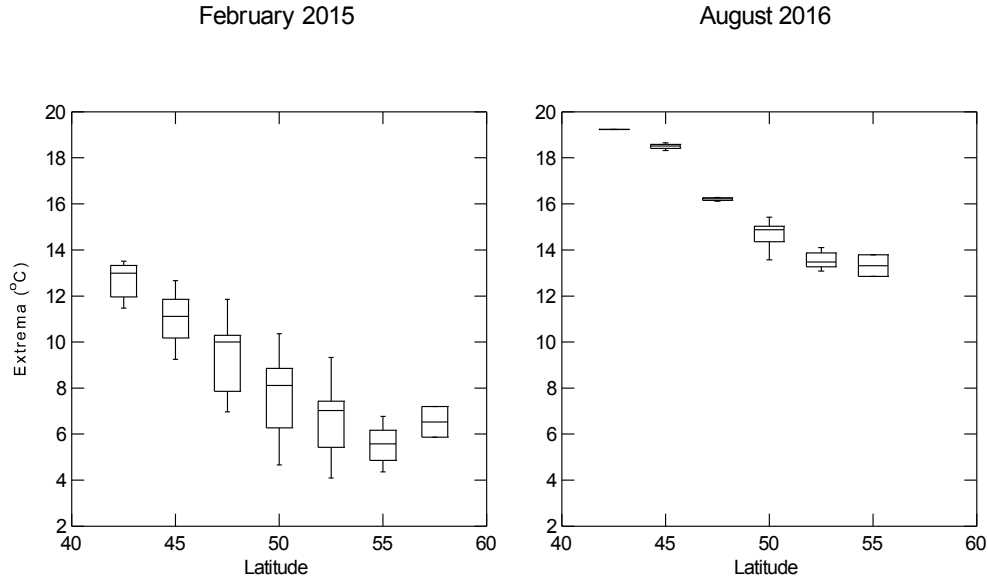


Figure 5: Surface air temperature (SAT) extrema by latitude (across longitudes) in the Gulf of Alaska (east of $165^{\circ}W$) in months when extrema were most frequent. The single horizontal bar at $42.5^{\circ}N$ indicates that only one longitude at that latitude had an extreme SAT.

Principal Component (PC) analysis of monthly SAT anomalies (SATa) in the North Pacific salmosphere since 1948 suggests that SATa variation is associated with two independent forces of nearly equal weight (27.6% for PC1 and 23.5% for PC2). The spatial pattern of PC1 (Figure 4) is an east-west dipole (seesaw) with an alternation between warm in the West and cool in the East and *vice versa*, i.e. like the subarctic portion of the Pacific Decadal Oscillation of SSTa (hereafter the SalmoDO, see Figure 16 below) but in the atmosphere. The correlation between SATa-PC1 and the SalmoDO was maximum (0.77) in May. PC2, on the other hand, is a salmosphere-wide phenomenon that is associated with the Victoria Pattern of SSTa variation (also related to the NPGO-North Pacific Gyre Oscillation). It was the Victoria Pattern that shifted abruptly to positive between May and June of 2013 and the change has persisted to at least October 2016 (Figure 6). The average increase in PC2 after June 2013 was +1.9 s.d. higher than the average of the 65 year period that preceded it. This analysis found that only April 2016 was an extremum of PC1 in any month. In the months of January and February, only 1977 exceeded 2016 in magnitude of PC1 scores. There were no extrema of PC1 in 2015. PC2, on the other hand, had extrema in February and October of 2015 and July and August of 2016.

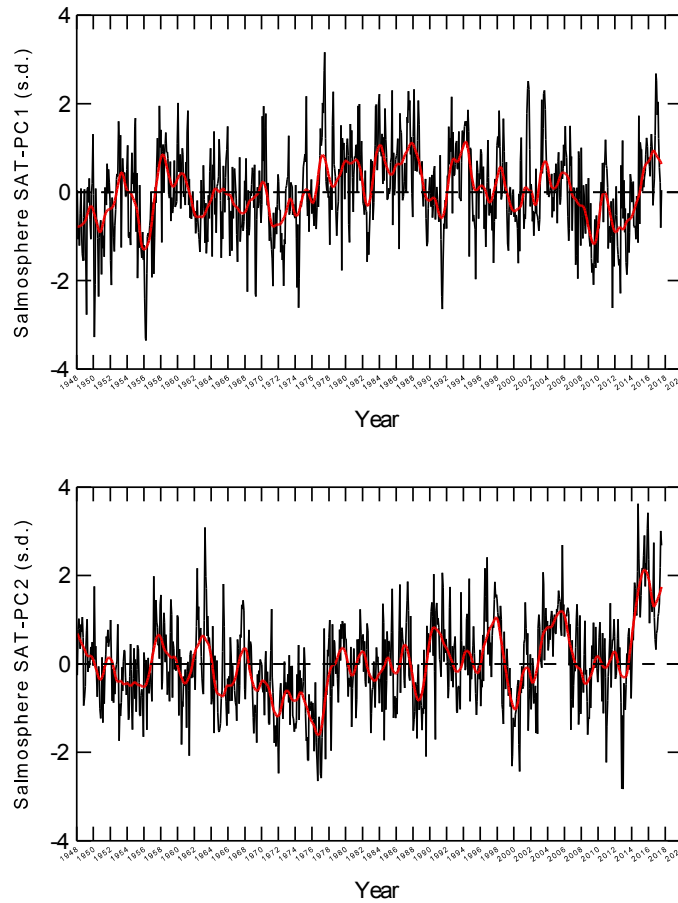


Figure 6: Principal components 1 (above) and 2 (below) of SAT anomalies in the salmosphere from 1948 to September 2016.

2. Sea level pressure (SLP)

Storms in the salmosphere and elsewhere are recognized as depressions in the sea level pressure field. Strong storms are associated with stronger, larger depressions. Integrating the pressures within these depressions over some sensible period of time generates an index of storminess during that period. Although various indices of winter storm intensity exist (North Pacific Index – Trenberth and Hurrell 1995), Aleutian Low Pressure Index (McFarlane and Beamish 1992), they have spatial domains that extend well into the subtropics. The Aleutian Low Integral Index (ALII – McKinnell 2016) was modified to compute an index of average winter (DJF) storminess in the salmosphere alone. The result was an index with high interannual variability and no trend after the 1976/77 climate regime shift. Neither the winters of 2015 nor 2016 were remarkable across the entire domain (Figure 8), but if the spatial domain is restricted to the eastern portion of the Pacific salmosphere (east of 180 ° longitude), the winter of 2016 was the 3rd highest in the time series, lagging only the 1983 and 1998 el Niños. The “knock-on” effects of a stormy winter are discussed in the section on mixed layer depth.

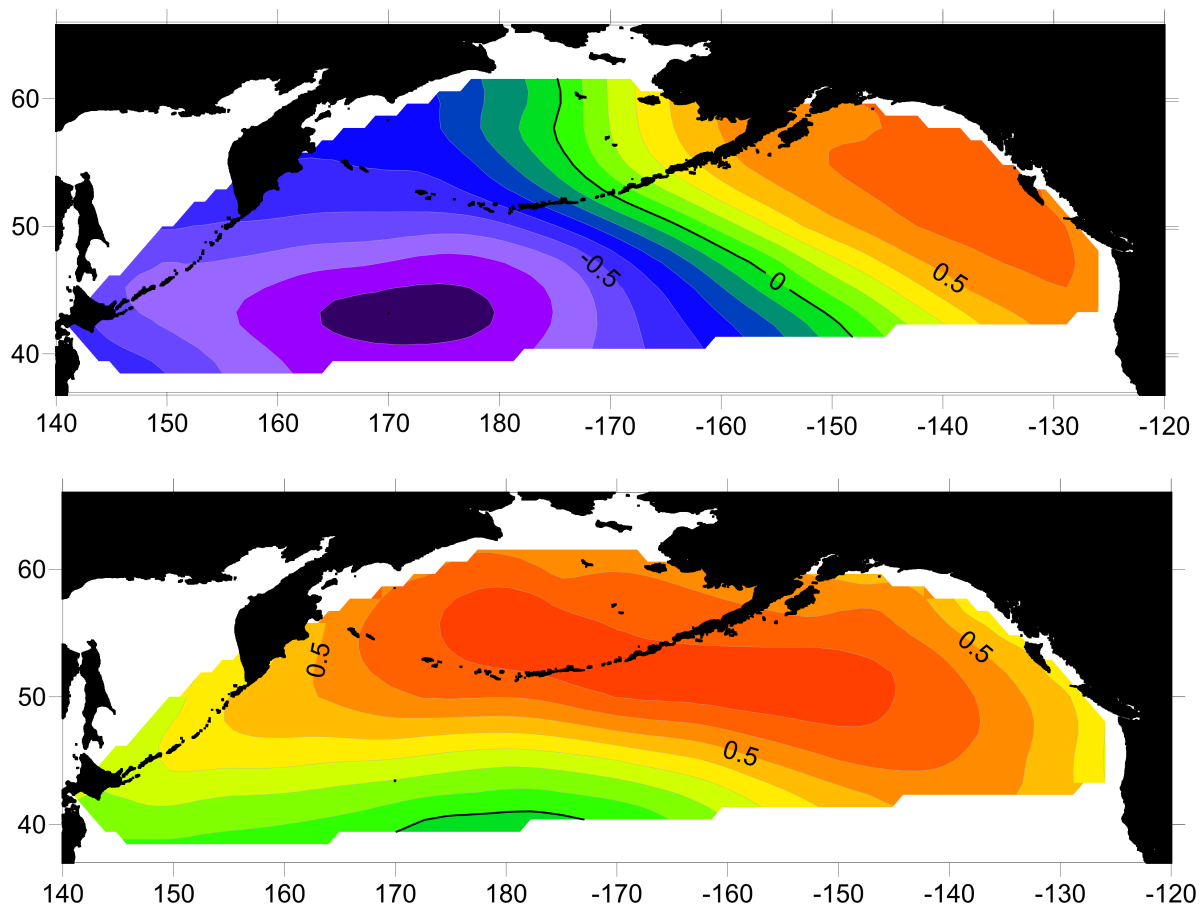


Figure 7: Spatial patterns of PC1 (above) and PC2(below) of monthly surface air temperature anomalies in the salmosphere from 1948 to 2016.

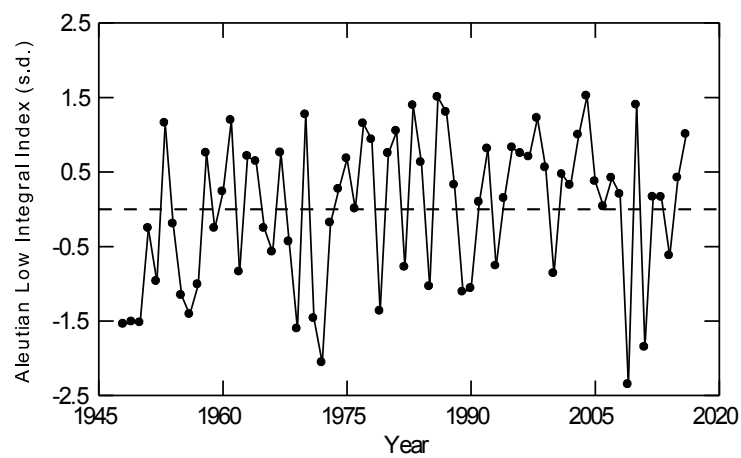


Figure 8: Aleutian Low Integral Index (ALII) is the integral of monthly sea level pressures < 1008.5 hPa, in this case restricted to locations lying within the Pacific salmosphere. This figure indicates the winter (DJF) average values to 2016.

3. Sea surface temperature (SST)

Separate analyses were conducted to examine the two dominant phases of the oceanic life of salmon. Juveniles are generally restricted to the continental shelf during their early life history (Hartt and Dell, 1986; Grimes et al. 2007), whereas older immature salmon and maturing salmon, particularly the planktivores, occupy the deeper waters. Perhaps a more appropriate approach would be to further subdivide the salmosphere into a cohosphere, etc. as oceanic distributions vary by species, however, that level of detail was beyond the scope of this project. To capture finer scale variability on the narrow continental shelf, defined as depths <1500 m, daily SST data on a $\frac{1}{4}^\circ$ grid were used rather than monthly average 1° grid used for the oceanic region.

3.1. Continental shelf

SST measured daily at one lighthouse on Kains Island (Northwest Vancouver Island) reflects the SST variation that is occurring across a broad range of latitudes along the coast and even into the Gulf of Alaska (McKinnell et al. 1999). The nature of this coastwide (defined here as depths <1500 m) covariation was studied using principal components analysis by computing daily SSTa measured by satellite on a spatial grid from California to Alaska. The dominant component of non-seasonal SST variability (PC1) had loadings of the same sign extending from Cape Mendocino, CA to Prince William Sound, AK with the maximum located in central Queen Charlotte Sound, BC (Figure 6). PC1 accounted for 55% of SSTa covariation and its loadings tended to increase away from land, likely because of local SST variability added by buoyancy-driven coastal currents (e.g. Alaska Coastal Current versus the large-scale circulation of the Alaska Current) and coastal upwelling, primarily along the U.S. West coast. The lowest correlation of SSTa with PC1 at any location on the shelf was $r = +0.4$ indicating that the entire coast is correlated with this pattern suggesting that non-seasonal SSTa variation on the continental shelf is due to large-scale environmental forcing.

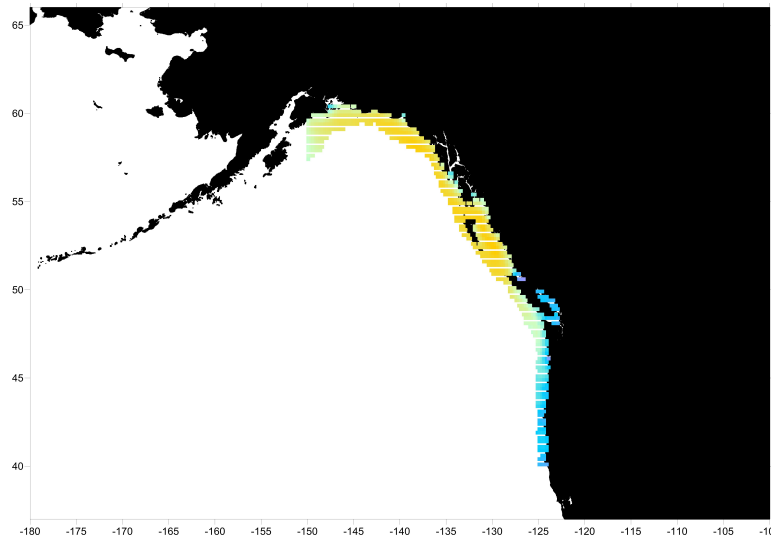


Figure 9: Correlations (loadings) between daily sea surface temperature anomaly variation (0.25° spatial grid) and SST-PC1 are shaded in

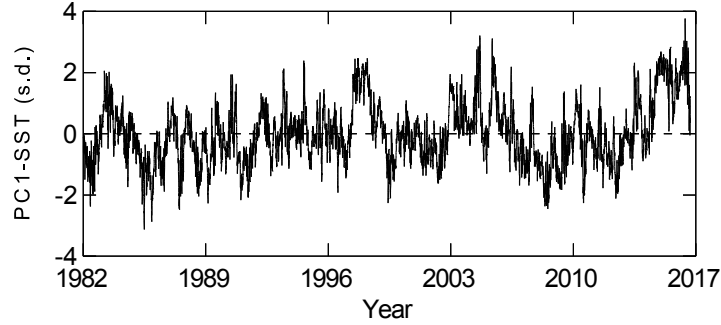


Figure 10: Daily temporal variation of $SSTa-PC1$ on the continental shelf to the end of October, 2016.

Considering temporal variation in coastal SSTs, a number of interesting features are evident. PC1 scores were generally negative (cool) for an extended period from 2006 to mid-June of 2013 when there was an abrupt warming that abated briefly in August 2013 before returning to strongly positive (warm) scores in September that persisted through the fall of 2013 before returning to negative (Figure 9). Thereafter, PC1 scores continued at relatively neutral values until the beginning of May 2014 when they became strongly positive for a few weeks. This warm spell abated briefly in mid-June then shifted to positive scores for the longest uninterrupted period since 1982. Apart from two days (August 22 and 23, 2016), PC1 has been continuously positive since June 27, 2014 (to Dec. 29, 2016), a period of 956 days. The previous record of continuously positive PC1 values was 428 days during the last major el Niño in 1997/98. Of note, the latter featured values of PC1 that were comparable with those observed since 2014 (Figure 10). Periods of unusually high surface temperatures along the North American coast occur with some regularity at bidecadal intervals and this event was not unexpected (McKinnell and Crawford 2007).

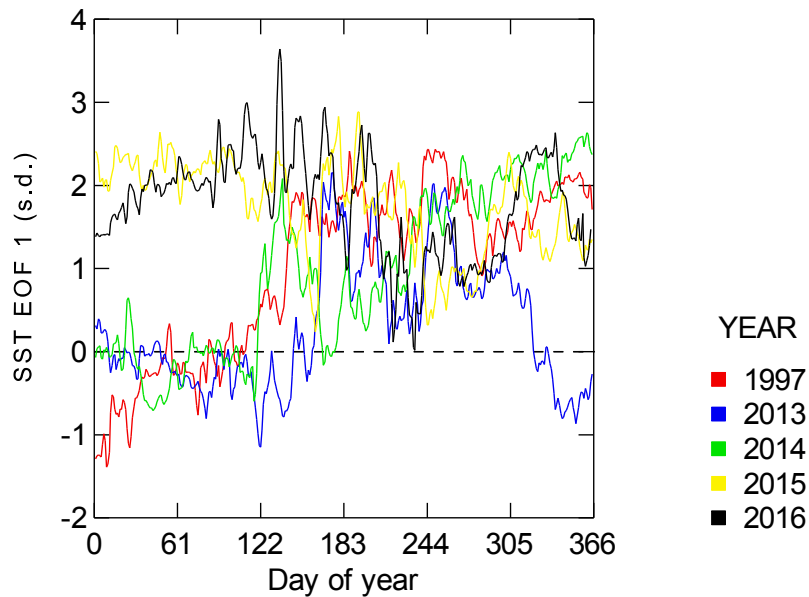


Figure 11: Continental shelf variation in PC1 of $SSTa$ covariation from California to Alaska; only years 2013-2016 are shown, along with 1997 when the last blob hit the BC coast.

The three highest positive PC1 scores (>3.6 s.d.) occurred over a 3-day period, May 14-16, 2016 (Figure 10). The next 6 highest scores occurred in 2004 and in 2005. In 2015, the rank of the strongest positive score that year occurred on July 12th and it was 19th highest in the entire record, from 1981. The strongest positive score in 2014 (50th highest) occurred on December 27. There is little evidence of an overall linear trend in this PC1 time series. If the recent stanza of strong PC1 scores from 2014 is excluded, there is no statistically significant linear trend in PC1 from 1982 to 2013.

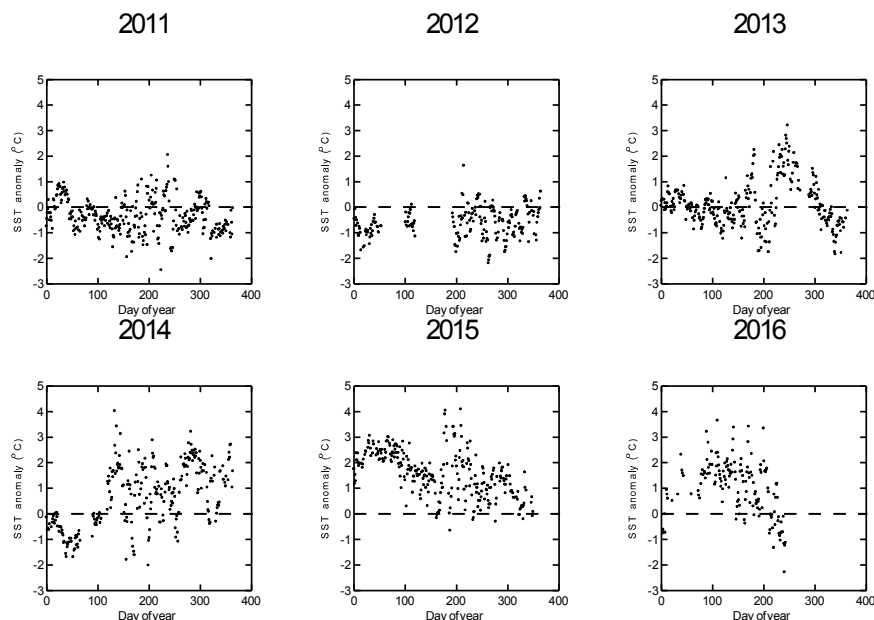


Figure 12: SST anomalies at Kains Island (NW Vancouver Island) by year from 2011.

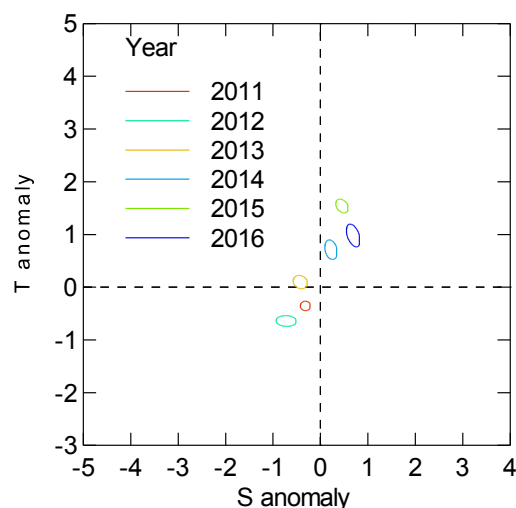


Figure 13: Bivariate ellipses indicate the location of the annual bivariate average of temperature and salinity anomalies at Kains Island. 2014-2016 are in the top right quadrant with 2015 the most extreme in the 82 year history.

Returning to Kains Island to gauge the local effect, SST and SSS have been recorded daily almost

continuously since 1934. The coastwide pattern of high values of SST-PC1 that occurred throughout 2014 did not begin at Kains Island until the beginning of May of that year (Figure 11). These strong positive anomalies were also accompanied by positive salinity anomalies rather than the normal negative anomalies (Thomson and Hourston 2010). By 2015, the combination of high SST and high SSS, sometimes called *spicy* water, was the highest observed bivariate annual average and it has persisted at least to August 2016 (Figure 12). As the salinity gradient away from Kains Island is increasing seaward, the appearance of spicy water suggests and offshore and perhaps southerly origin.

a) Chilko L. sockeye marine survival and coastal SST

There is a single timeseries of annual postsmolt survivals for Chilko Lake sockeye salmon that dates to the 1950s. If annual survival is compared with values of PC1 during ocean entry, from 1982 to 2014, the result confirms traditional scientific knowledge that warmer coastal SSTs are never good for survival of Fraser River sockeye salmon. Negative correlations between survival and PC1 scores were largest during a period between the summer solstice and the fall equinox (Figure 13).

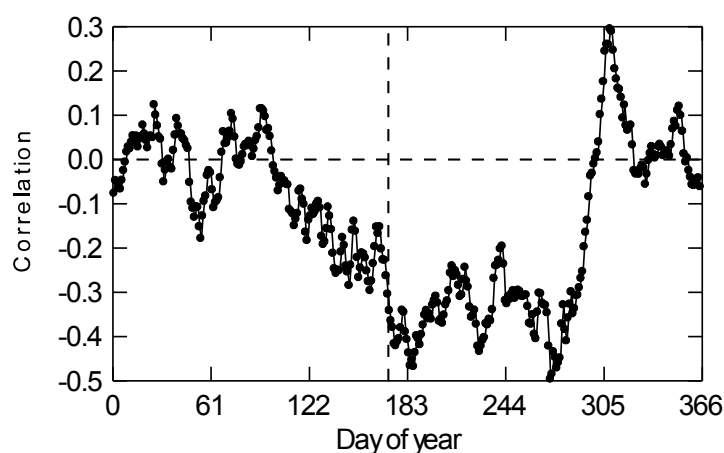


Figure 14 Correlations, calculated daily, between PC1 scores and annual postsmolt survival for Chilko Lake sockeye salmon. The vertical dashed line indicates the date of the summer solstice (June 21). At best, PC1 accounts for about 25% of annual variation in survival during the period from the summer solstice to the autumnal equinox, a period when the salmon are assumed to be on the continental shelf.

So the coastal environment is generally uncorrelated with Chilko Lake sockeye salmon postsmolt survival during winter when the fish are still in the lake. Through the spring the negative correlations gradually strengthen until an abrupt decrease occurs near the solstice, the time when these postsmolts are leaving inside waters. By November and December the correlation returns toward zero. This pattern suggests that there is no reason to expect that average to good survival will arise from the 2014-2016 ocean entry years, adult returns largely in 2016-2018.

3.2. Offshore SST

Monthly SSTa variability in the salmosphere offshore is dominated by an east-west dipole (seesaw) with centres of action in the Gulf of Alaska to the east and a widespread region associated with the Kuroshio-Oyashio mixing region in the western North Pacific (Figure 16). This pattern (SalmoDO – Salmosphere Decadal Oscillation) accounts for 34% of the covariance of SSTa in the Pacific salmosphere. As might be expected, the SalmoDO is correlated with PC1 of SATa ($r = 0.5$) but it is slightly more correlated with PC2 of SATa. The central North Pacific, south of the Aleutian archipelago varies from weakly correlated to uncorrelated with the SalmoDO pattern as its location lies between the two extremes of the dipole. The most extreme positive value of PC1 occurred in September 2014 (Figure 14) and 17 of the top 25 extreme values of the SalmoDO occurred from January 2014-August, 2016. Only 1997 (July to September) had more than one extremum in the top 25. Some may recall that the summer of 1997 was the year of the widespread straying sockeye salmon phenomenon that affected, primarily, Fraser R. populations (McKinnell 2000). Many sockeye salmon abandoned their migration to spawn in rivers along the migration route because they had begun to develop secondary sexual characteristics maturing while still at sea. The 4th highest value in the PC1 time series occurred in November 1986 but it did not appear to lead to noteworthy biological phenomena. Apart from a one month excursion into the negative in October 2013, the SalmoDO has had strong positive values since July 2013. Comparing the SalmoDO with the PDO finds that only half of the variation in the SalmoDO is associated with the PDO. The correlation between the SalmoDO and the PDO is strongest ($r > 0.8$) from November to April and weakest in summer (August $r = 0.5$). PC2, the subdominant pattern (24% of covariation), primarily captures SSTa variations in the western North Pacific so it will not be discussed further. It is highly correlated with PC2 of SATa, but only in the summer months.

3.3. Offshore (Project Argo)

The advantage of using satellites to measure SST is broad spatial coverage, but these measurements will tend to over-estimate the temperatures experienced by salmon because oceanic habitat lies beneath the surface where temperatures are generally cooler during the warm season. Project Argo (<http://www-argo.ucsd.edu/>) has populated the World Ocean beyond continental shelves with >3000

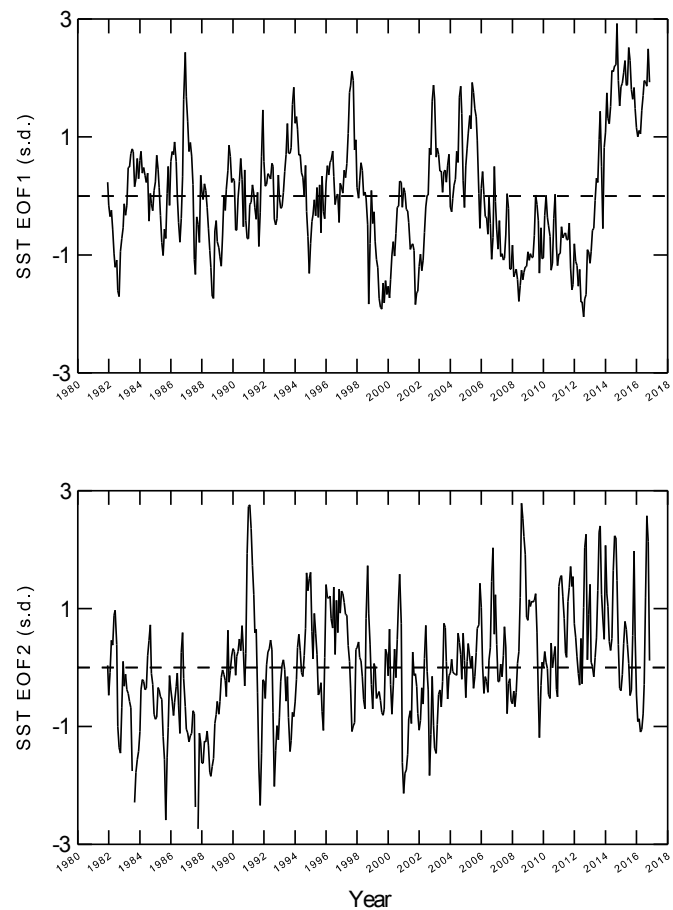


Figure 15: Temporal variation in PC1 (above) and PC2 (below) of monthly sea surface temperature anomalies in the salmosphere from November 1981 to October 2016.

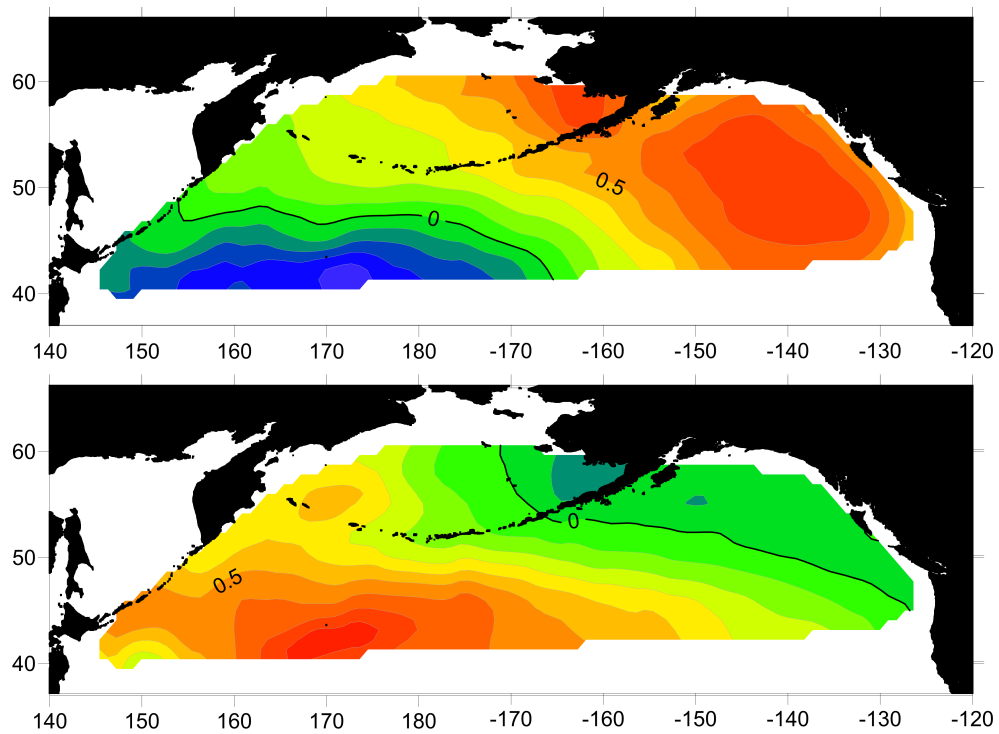


Figure 16: Spatial distribution of PC1 (above) and PC2 (below) of monthly sea surface temperature anomalies in the salmosphere, 1981 to present. The spacing between contours, indicated by difference colours, is 0.1.

profiling floats that measure temperature and salinity at depth and transmit the results via satellite to centres that distribute the data globally without charge. The Argo data allow water properties to be examined to a depth of 2000 m. For the present study, temperatures at 5 m depth were examined initially and compared with satellite based SST at or near (within) the float location to determine whether the temperature extrema in the Northeast Pacific were simply a very near surface effect, and if not, to determine the extent of the extrema with depth.

3.4. Temperature at 5 m depth

As the uppermost depths of the measurements made by the profiling floats are commonly near 5 m, all temperature and salinity readings found in the range 4 – 5.5 m in the salmosphere were selected for further analysis. See Appendix 1 for discussion of computing anomalies. A box and whisker plot (Figure 14) of all anomalies shows the range of variation found each year. Outliers in the range of $\pm 3^\circ\text{C}$ are common in the eastern salmosphere but most of the anomalies every year, as indicated by the box are $< \pm 1^\circ\text{C}$. There are clearly more extrema in 2016 than in any other year, although the median anomaly in 2015 was slightly higher than all other years. The highest positive anomalies occurred between $48^\circ - 50^\circ\text{N}$

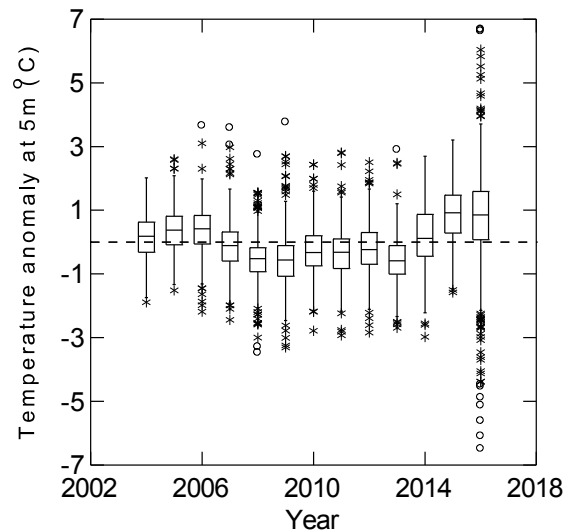


Figure 17: Box and whisker plots of monthly average temperature anomalies at 5 m depth in 2×5 latitude/longitude blocks in the salmosphere (east of 180° longitude).

(south of the Aleutian archipelago) while the most negative anomalies at about the same longitudes, were in the south 40°-42°N (Figure 15). The strongest anomalies in 2016 occurred between 180° and 170°W which is beyond the historical range of migration of many salmon populations in the eastern Gulf of Alaska.

3.5. Salinity at 5 m depth

In broad terms, salinity anomalies in the eastern salmosphere corresponded with, and likely contributed to the temperature anomalies. While the temperature anomalies were generally warm from 2003-2005, there was a sustained cool period thereafter that lasted until 2013. The salinity anomalies were generally fresh then salty, then fresh again during the heat-wave (Figure 20). Like the temperature anomalies, the largest salinity anomalies occurred in 2016 and were located near the international date line, although there were one or two strong anomalies adjacent to the North American coast. The inverse relationship between SST and SSS anomalies was described by Thomson & Hourston (2010).

3.6. Salmon and the Blob

Although the Blob covered much of the surface of the northeastern North Pacific, its centre of mass at least in its earliest stages was not in the subarctic (Figure 19) and coastal SSTs during to the end of April 2014 at Kains Is. were normal (Figure 11). Based on weekly SST data on a since 1981 there have been 11,244 weekly anomalies somewhere in the North Pacific (north of 20° N) that have exceeded +3 s.d. above the long-term mean for any particular time and location. From 2014 to 2016, the total number of these strong SST anomalies exceeded all other years. Most of these extremes occurred beyond the salmosphere, but that maybe simply from greater opportunity to exhibit a strong anomaly; there are many more grid points in the subtropics because the continents diverge with decreasing latitude.

Most of the large positive SST anomalies in 2014 occurred in January and February between 40°N to 50°N, 160°W to 140°W in the central Gulf of Alaska (Figure 17). That location places the strongest influence of this winter blob on the southern fringe of the salmosphere, although lesser positive anomalies certainly extended northward. While the range of salmons extend south of 50°N, they are not very abundant at these latitudes except in the western Pacific.

By examining all Argo profiles within the “blob domain” of early 2014, it is clear that it penetrated to about 90 m depth which is approximately the depth of the mixed layer in winter. The maximum depth of the 2014 anomaly was determined by taking slices of 10

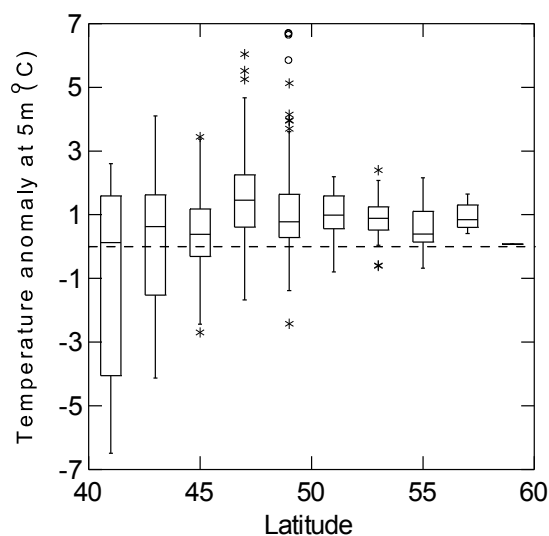


Figure 18: Temperature anomalies by latitude in the salmosphere in 2016.

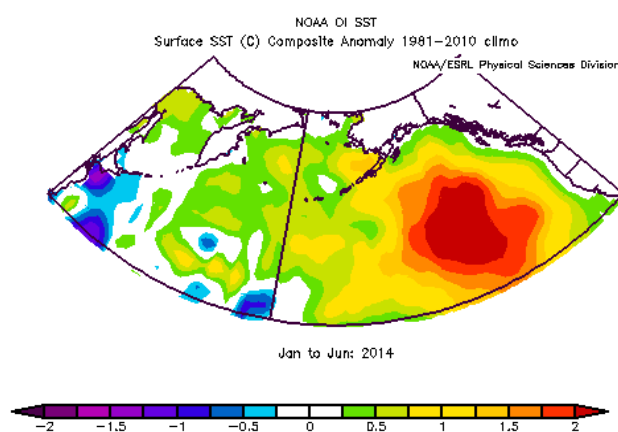


Figure 19: The Blob - an SST anomaly pattern in the Northeast Pacific (January - June 2014 average shown here).

m from the surface to depth and computing the average of all observations in each layer. Since 2002, the year 2014 had the highest average temperature in all layers down to 90 m, according to an ANCOVA (to control for the effect of latitude). At greater depths, 2015 had the highest average temperatures in all 10 m layers down to 150 m. In 2015, most of the strong positive SST anomalies occurred off Canada and the U.S. West coast in a zone that essentially highlighted the California Current region from its source near Queen Charlotte Sound to its recirculation into the subtropical North Pacific. This eastern blob in 2015 had a similar temperature vs. depth structure to the one found further offshore in 2014. Average temperature by 10 m layer in the eastern blob was highest in 2015 for all layers down to 100 m, and thereafter 2016 temperatures became higher than 2015. Although most of the discussion is about the magnitude of anomalies, it is perhaps more important to consider the absolute values of the SSTs at locations where there were strong departures from average as the SSTs may or may not be physiologically stressful.

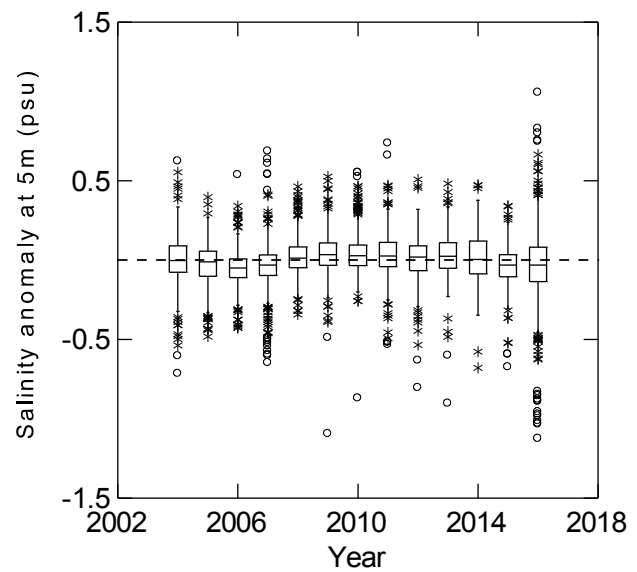


Figure 20: Box and whisker plot of salinity anomalies at 5 m depth in the eastern salmosphere.

4. Mixed Layer Depth (MLD)

The salmosphere has a strong vertical density gradient with lighter water sitting on top of heavier water, primarily caused by a vertical salinity gradient (fresh water floats on salty water) (Favorite et al. 1976). This gradient is enhanced seasonally during summer because the sea surface is warmed by solar radiation which increases the gradient, as does melting sea ice where it exists. The combination of a stronger gradient and lighter winds in summer limits the depth of vertical ocean mixing in summer approximately to the upper 25 m. Nutrients beneath the depth of the mixed layer are not available to support phytoplankton growth. Energy, primarily from stronger winds, is needed to break down the gradient in the fall and recycle nutrients back into the surface layer. In the Gulf of Alaska the mixed layer depth (MLD) is of the order of 80-125 m in winter. The exact depths depend to a certain degree on how the depth of the layer is calculated and in this report, MLD was calculated as the depth of a surface layer of uniform density. Despite a relatively stormy winter of 2014/2015, the January-April MLD anomalies of 2015 were the most extreme (shallow) anomaly in the record. This suggests that the vertical stability that had built up during the heat wave of 2014 was not destabilized by the stronger than average winds that occurred in the winter of 2014/2015. One expected result of a shallow winter MLD is low nutrient concentrations in the surface layer and this is exactly what was found on DFO's Line-P cruises in 2015 (Figure 21) where the winter nutrient (nitrate) supply in the winter of 2015 (Figure 21, top right) was the lowest observed on Line-P in the past seven years.

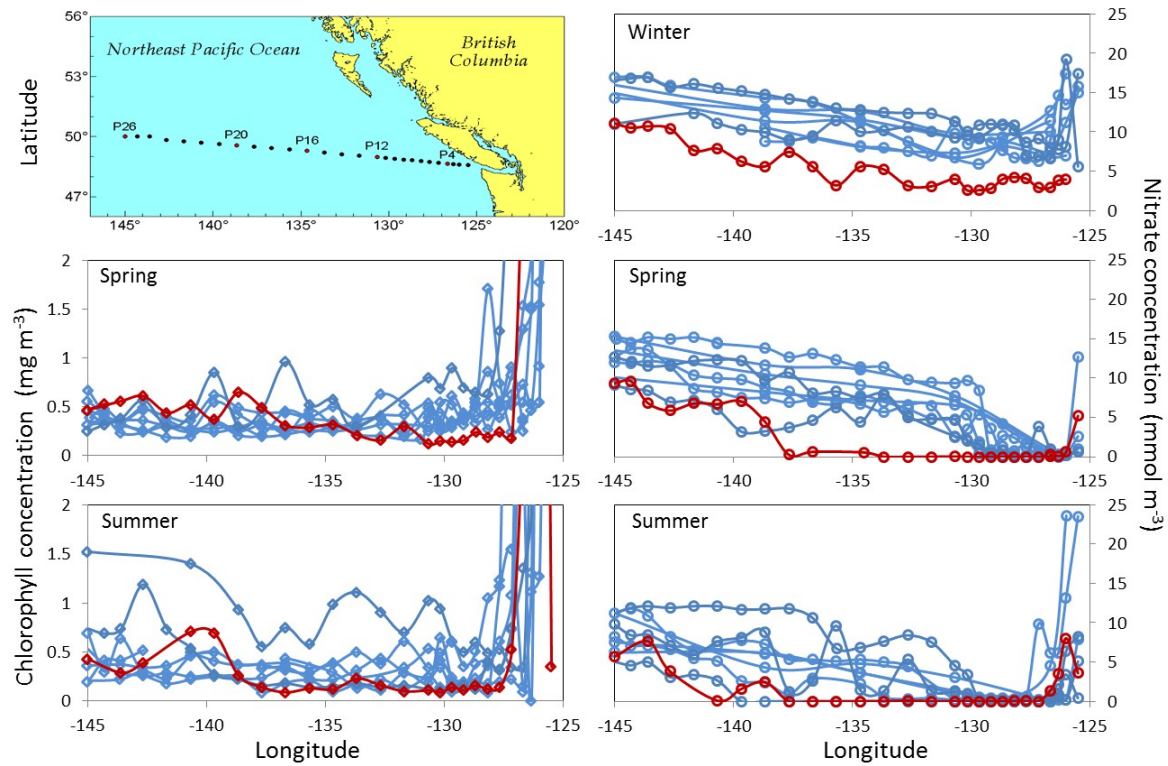


Figure 21: Location of sampling stations, chlorophyll-a (mg/m^3) and nitrate (mmol/m^3) in surface waters along Line P in winter, spring and summer of 2015 (red symbols) and 2008-2014 (blue symbols). Source: Chandler et al. (2016).

5. Sea level pressure (SLP)

Storms crossing the salmosphere tend to move as large-scale cyclones (counterclockwise) that travel from west to east. The intensity of a storm is related to the magnitude of the depression in atmospheric pressure at the sea surface. The effect on the ocean is generally strongest in fall and winter and the overall annual effect will depend on the frequency of storms, their intensity, location, timing, etc. during the winter. There are various methods of quantifying storminess and most of them are calculated from a monthly average sea level pressure grid derived from some type of global analysis such as the NOAA NCEP/NCAR Reanalysis that covers the period from 1948-present (Kalnay et al., 1996). Neither 2015 nor 2016 winters (December-February) were extrema, but 2016 was the 3rd largest since 1948, which is not unexpected as winters during major el Niño events are generally among the most stormy (Emery and Hamilton 1985). During 2015, SLP extrema were both high and low. There were no low SLP extrema during the winter of 2015, but there were many during the summer and fall months (Figure 22). The low pressure extrema

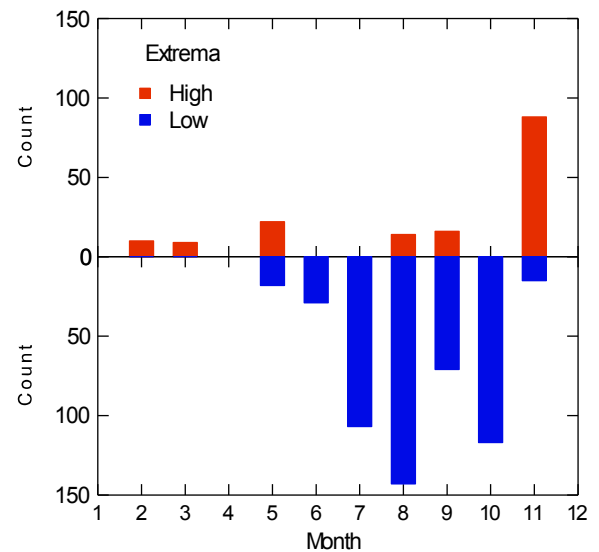


Figure 22: Number of 2.5° by 2.5° latitude/longitude grid points where sea level pressure extrema occurred in 2015 in the salmosphere.

were part of a widespread region in the subtropical North Pacific, centred approximately at Hawaii but extending northeastward to British Columbia and westward past the International Date Line (Figure 23). The few high SLP anomalies during this period were in the Bering Sea. As the mean SLP gradient in the North Pacific has a trend from high in the southeastern region to low in the northwest in summer, the summer and fall of 2015 featured a much reduced gradient which tends to reduce winds. The high SLP extrema in 2015 occurred primarily in November (Figure 23). The extrema were part of a widespread pattern of high SLP anomalies across the southern salmosphere (Figure 24). There were no SAT anomalies associated with this pattern.

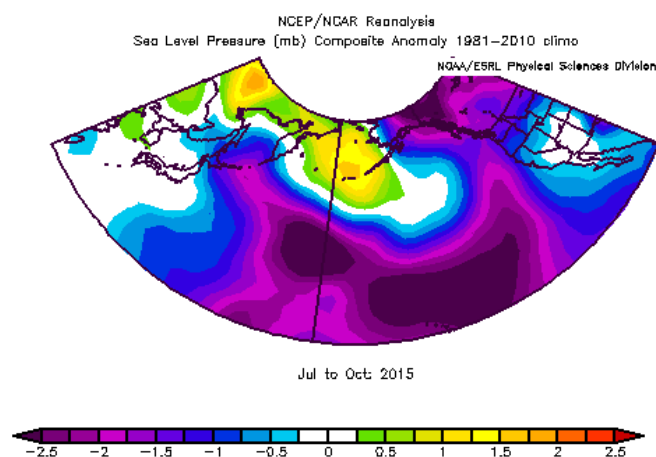


Figure 23: Average SLP anomalies from July to October, 2015.

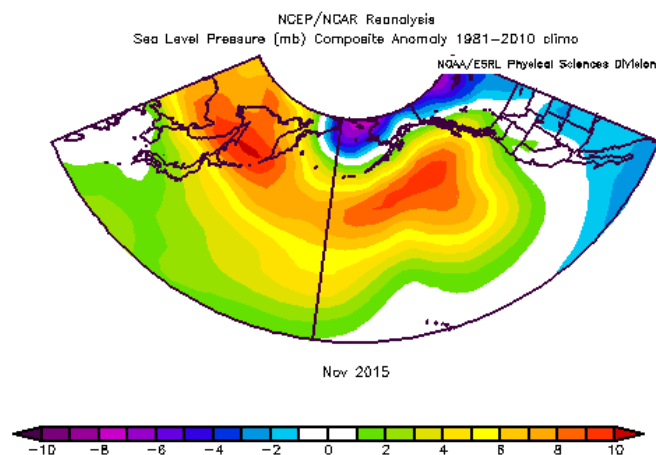


Figure 24: SLP anomalies during the month of November, 2015.

6. Chlorophyll

Phytoplankton are single celled organisms in the sea that combine energy from the sun (light) and nutrients drawn from seawater to store that energy in chemical bonds via photosynthesis. This energy is made available to animals if they consume and digest the phytoplankton. The quantities of light and nutrients determine how much energy is captured and stored at the base of the food web. Various factors influence the availability of sunlight and nutrients to phytoplankton, thereby affecting the availability of energy to herbivores and omnivores. As all have evolved together, strategies have developed among consumers to take advantage of this stored energy when and where it is available. Occasionally, the norm is substantially disrupted, and depending upon the nature of the disruption, can lead to the benefit or the detriment of consumers. One of the major disruptions involves variations in seasonal timing (Hjort 1914) and the study of this variation is known as phenology. This section of the report examines variations in the seasonal development of phytoplankton in the Northeast Pacific region of the salmosphere.

Chlorophyll concentrations in seawater are generally obtained by one of two methods: *in situ* water samples, or remotely via satellite measurements of ocean colour and generally, there is good correspondence between the two methods. In the Northeast Pacific, chlorophyll concentrations measured by ocean colour sensors on satellites (eg. SeaWiFS, MERIS, MODIS-A) indicate that the coastal zone has much higher chlorophyll concentrations than the deep water regions.

6.1. Shipboard sampling

Twice monthly *in situ* sampling at Station NH-15 in 2015 off the Oregon/Washington coast identified the onset and evolution of a widespread *Pseudo-nitzschia* algal bloom along the North American coast (Du et al. 2016). Its toxicity (they can produce a toxin; domoic acid) resulted the closure of the razor clam fishery and and first ever closure in the region of the Dungeness crab harvest. Domoic acid was transferred via the food web (sardine/anchovy) to higher trophic levels with deathly consequences for seabirds and marine mammals (Du et al. 2016). In British Columbia, high chlorophyll *a* concentrations were observed during sampling off the west coast of Vancouver Island in July 2015 (Chandler et al. 2016). *Pseudo-nitzschia fraudulenta*, a potential source of domoic acid represented 32% of all diatoms sampled and fishery closures were far fewer than in Washington/Oregon.

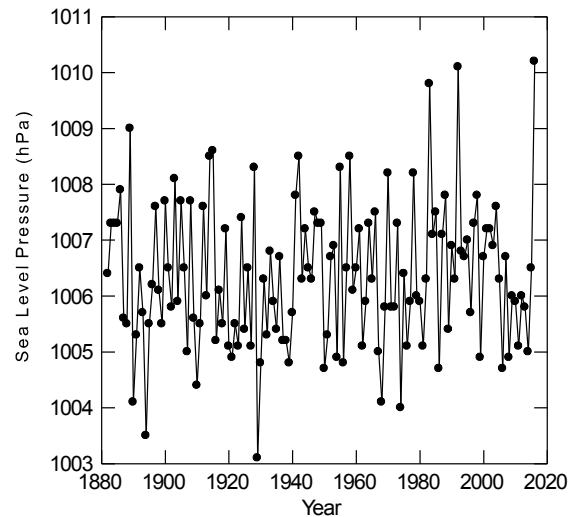


Figure 25: Sea level pressure (hectopascals) at Darwin, Australia during the month of January from 1882-2016. The highest SLP occurred in 2016, 1992, and 1983 (el Niño years) Source: <http://www.cpc.ncep.noaa.gov/data/indices/>

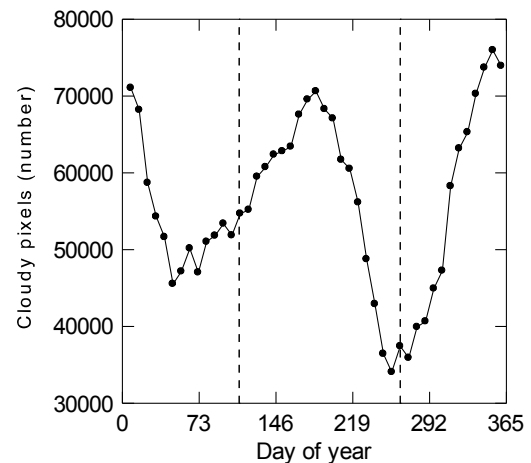


Figure 26: Annual cycle of numbers of non-visible pixels (clouds or insufficient light) in the salmosphere (East of 165°W based on counts of missing pixels in the MODIS-A ocean colour satellite (2002-present) summarized to an 8-day 9 km² grid. Late winter and the fall equinox provide the clearest views.

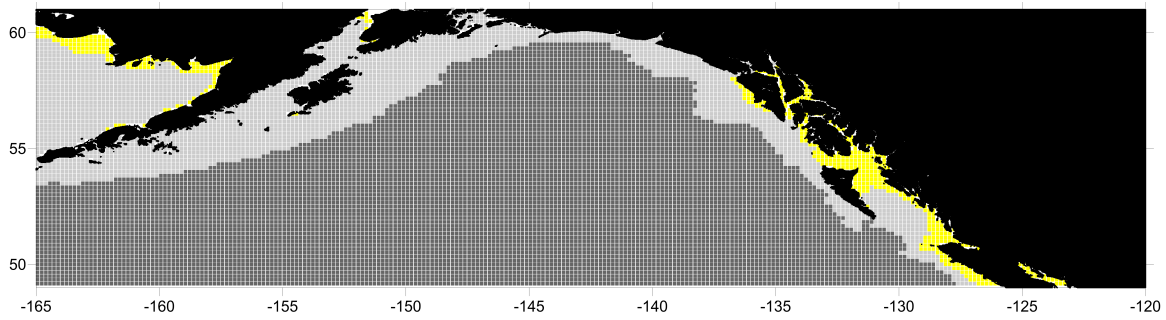


Figure 27: Cluster analysis of chlorophyll concentration time series (2002-2016) reveals coastal (yellow), shelf (light gray) and offshore (dark gray) regions. Differences in seasonal cycles between regions are portrayed in Figure 28.

6.2. Satellite chlorophyll

The ability to measure chlorophyll from satellites relies on sunlight and cloudless skies and their frequency of occurrence varies seasonally (Figure 26). To distinguish the regions, individual pixels (each representing 9 km² of ocean) were assigned group membership solely on the basis of their similarity to all other pixels during the period 2002-2016, regardless of where they were located. Similarity between pixels was based on sum-of-squared differences of the 8-daily concentrations across all years. The groups formed by cluster analysis created an intuitive division into what appear to be coastal, shelf, and offshore zones (Figure 27). The coastal zone includes what is often called the Inside Passage, including also the West coast of Vancouver Is. and the east side of Bristol Bay.

The shelf zone extends beyond the continental shelf and forms a transition region between offshore and coastal zones except in the northern Gulf of Alaska and the Alaska Peninsula (both sides) where it extends to the land. The offshore region is clearly situated over the deep waters of the Gulf of Alaska. Zones can be distinguished by their average levels, by their variance, and by the relative magnitudes of their seasonal peaks (Figure 28).

a) Coastal

The coastal zone has a prominent spring bloom with a relatively weak fall bloom (Figure 28) and generally higher chlorophyll concentrations throughout the year than the other zones. In 2015, extrema in chlorophyll concentration occurred during a 7 week period from mid-February to the end of March and again in June (Figure 30). A bloom occurring in winter was unusual in this record when compared to other years (Figure 29). See Figure 31 and Figure 32 for a comparison of high and low chlorophyll winters. The anomalous winter bloom in 2015 also featured as a precursor to the Oregon/Washington bloom with the toxic alga, *Pseudo-nitzschia* (Du et al. 2016). By the end of summer in 2015, chlorophyll extrema in the other direction (low) appeared during a week ending in mid-September and two week period during October (Figure 30).

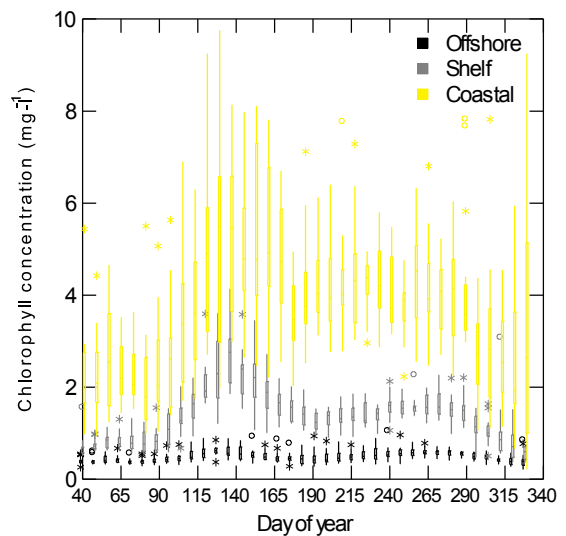


Figure 28: Average 8-daily chlorophyll concentrations by region within the salmosphere. Regions (Figure 27) are coastal (yellow), shelf (gray), and offshore (black).

b) Shelf

The shelf zone has lower average chlorophyll than the coastal zone and its seasonal characteristics are intermediate between that of the coastal zone and that found in the offshore (Figure 28). In 2015, it also exhibited atypically high chlorophyll concentrations in February-March of 2015 (blue line on the left in Figure 30).

c) Offshore

The offshore region has much lower average chlorophyll concentrations than the coastal region and lacks a dominant spring bloom so the spring and fall blooms are of approximately the same magnitude (Figure 26). Analysis of offshore chlorophyll anomalies was restricted to satellite data for the eastern salmosphere in the North Pacific (east of 165° W) which also includes a portion of the southeastern Bering Sea. The seasonal cycle of chlorophyll concentrations is relatively weak (Thomas et al. 2012). Nevertheless, despite its low amplitude, an annual cycle with spring and fall peaks is evident. Higher average chlorophyll occurs during winter (January-April) and fall (October-November) and lower average chlorophyll during the summer (June-August) with rapid transitions between seasons in May and September. Low summer chlorophyll values are due to zooplankton grazing (McAllister et al. 1960) but summer is also a period of extensive cloud cover. The least cloud cover occurs just before the equinox in spring and at the equinox in fall (Figure 24).

As had occurred in the coastal region in 2015, lesser chlorophyll extrema also occurred in the offshore region in early February and through most of March (Figure 30). Unlike the coastal region, however, the offshore region had positive extrema in October 2015. A strong fall bloom may have occurred because of the oncoming of an el Niño winter when Gulf of Alaska winds tend to be stronger than average in the winter, but perhaps not as early as October. Following two years of a marine heat wave (di Lorenzo and Mantua 2016), the mixed layer was relatively shallow with high concentrations of nutrients stored beneath the mixed layer. The nutrients would be released (mixed to the surface waters) by vertical mixing when the autumnal winds arrived and because of the nutrient gradient with depth, more nutrients may be available if the winds are stronger than average.

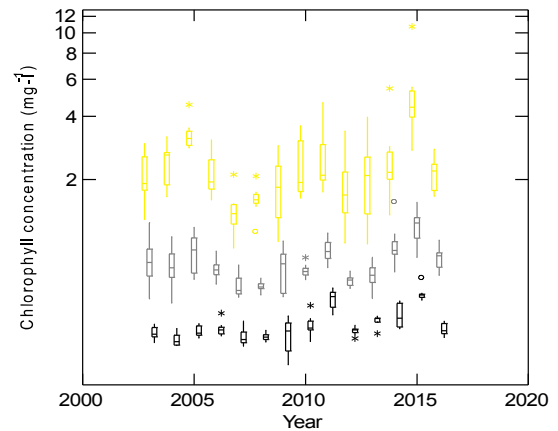


Figure 29: By region and year, box and whisker plots of average chlorophyll concentrations during only the 8-day periods of extreme anomalies in 2015 (February-March). The median value was highest in 2015 in all 3 regions with the largest anomaly in the coastal zone adjacent to coastlines. Regions coloured as in Figure 28.

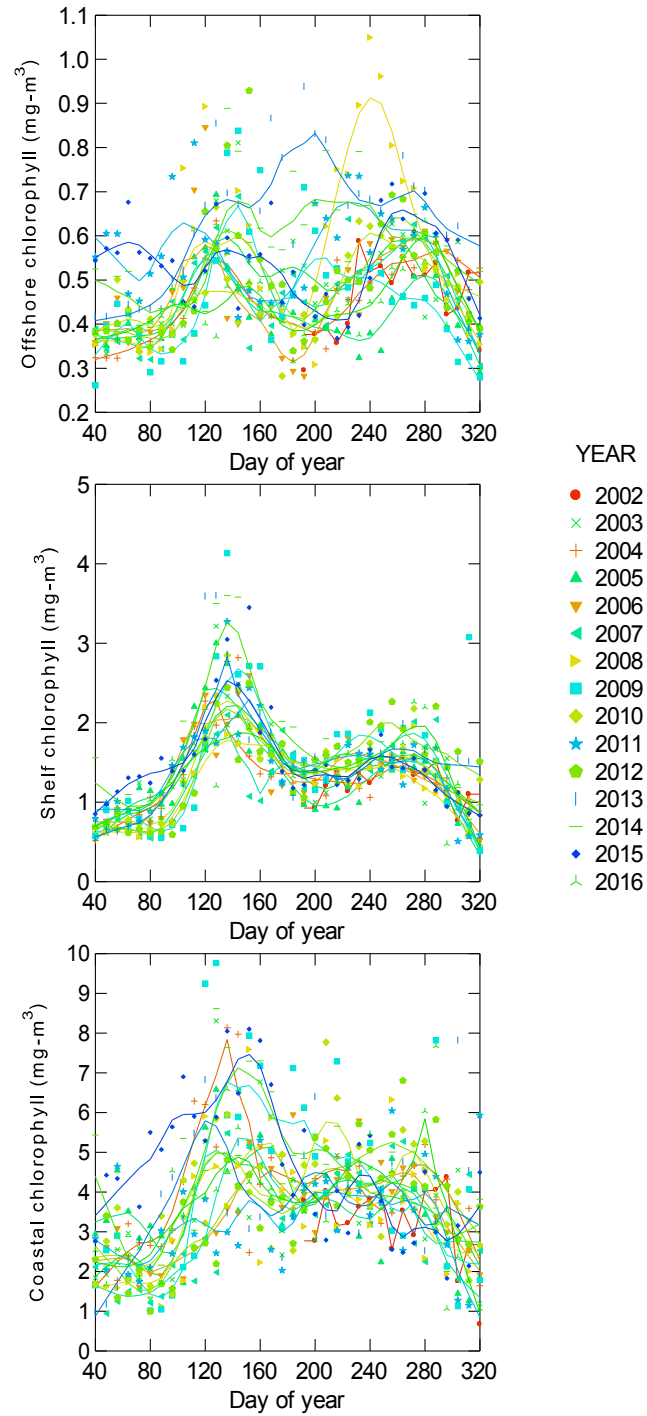


Figure 30: Lowess smoother applied zone-wide average chlorophyll concentrations by year in 3 regions: Offshore, Shelf, Coastal. In each region, the line for 2015 (blue) begins above that for the other years. Higher than average chlorophyll offshore later in 2008 (top panel) is the Kasatochi volcano effect while the origin of the 2013 summer peak there is not known.

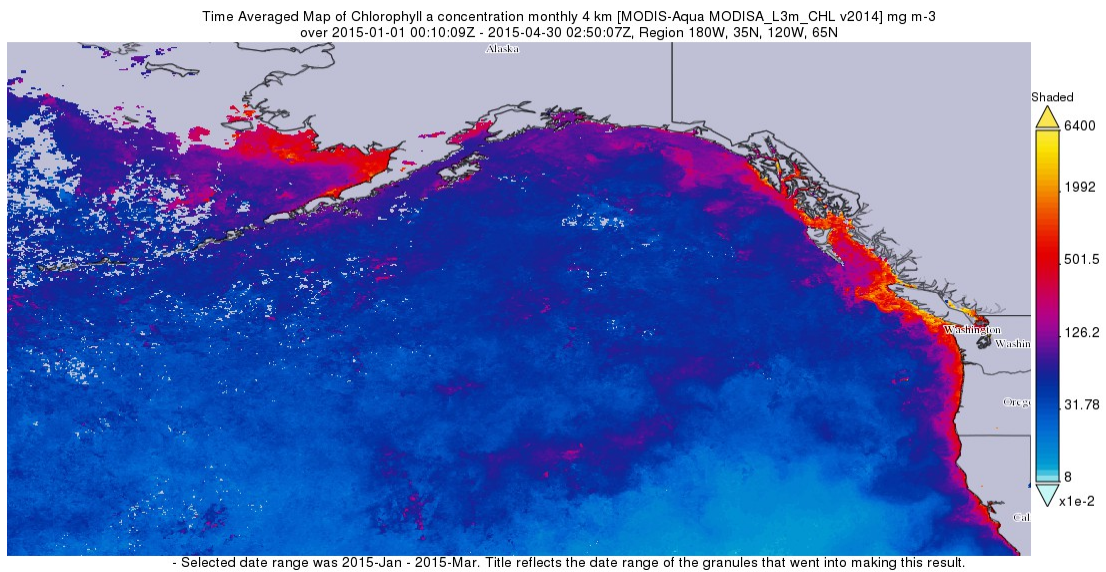


Figure 31: Chlorophyll concentration in the Northeast Pacific in winter (Jan-Apr) of 2015.

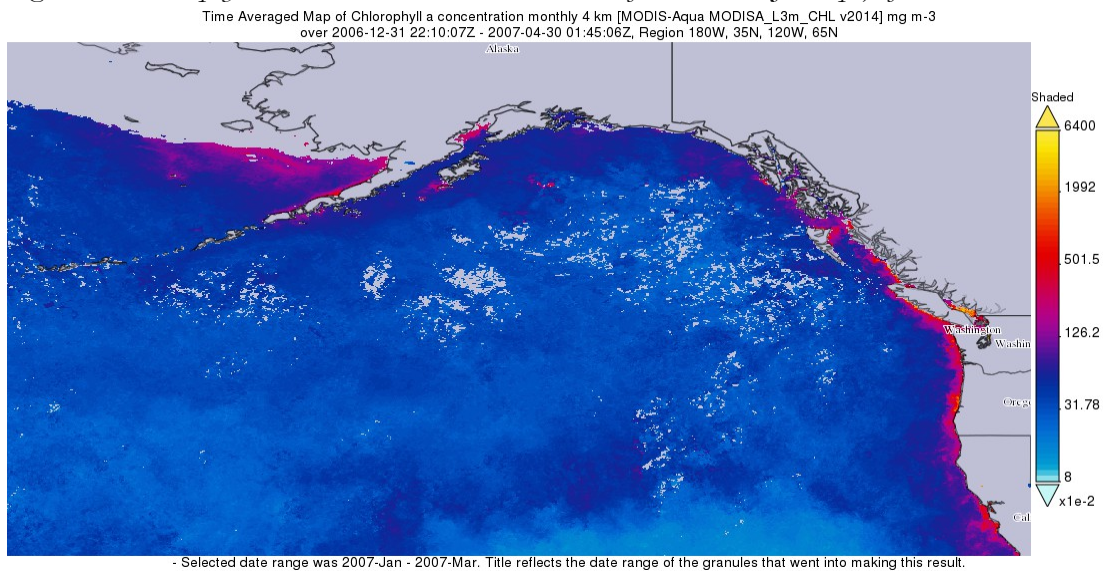


Figure 32: Chlorophyll concentration in the Northeast Pacific in winter (Jan-Apr) of 2007.

6.3. Chlorophyll phenology

Phenology in the eastern salmosphere was examined by evaluating the seasonal development of chlorophyll in each of 3 zones identified above. To increase the spatial coverage within each 8-daily period and to fill in gaps found at individual pixels, average chlorophyll concentrations were calculated on a $1^\circ \times 1^\circ$ grid from the basic 9 km^2 resolution, for each year and 8-day period. If no data were available due to low light (December-January), the time series was shortened by a few weeks at each end. Timing was evaluated by fitting curves to the cumulative chlorophyll concentration at each grid point, seeking points of inflection during a year where chlorophyll was most rapidly increasing. Initially a single curve (single peak) was fit to each time series, but if there was a substantial improvement in the fit (R^2 increase $>5\%$) by entertaining two seasonal peaks, spring and fall, then this result was adopted. The “fall” peak may be a misnomer here as the second peak found by the algorithm was typically in the fall (Figure 28) but may have occurred earlier.

a) Offshore

Most of the grid points exhibited evidence (improvement in R^2) of weak spring and fall chlorophyll peaks. The peak day of year of spring chlorophyll concentration in the offshore is highly variable, which is not too surprising given that it is a region known for little or no evidence of a bloom. Box and whisker plots were used to indicate, across the zone, where the peak dates were concentrated in each season (Figure 31). Within the zone, the timing peaks were more or less concentrated near a median date depending on year. There was no outstanding shift in median spring timing or extrema in 2015, however, there is an extremum (late) in median date of the fall bloom in 2016.

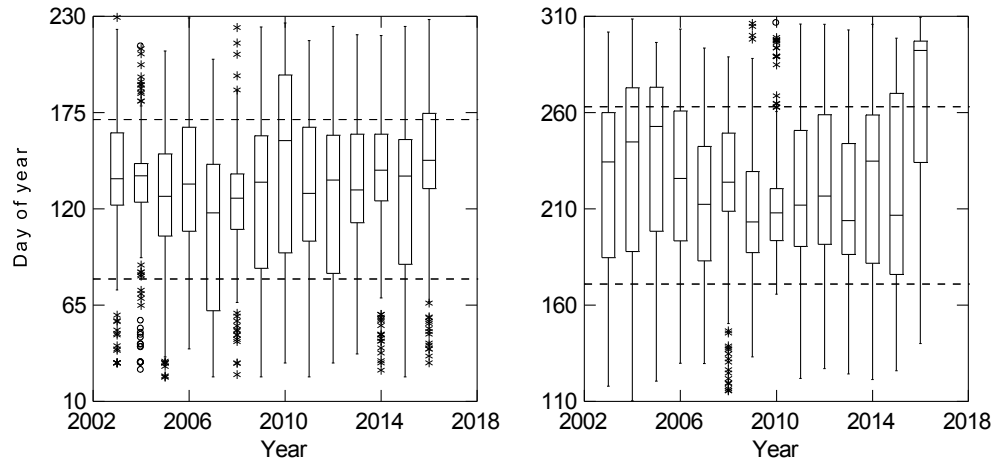


Figure 33: Box and whisker plots of peak spring (left) and peak fall (right) chlorophyll concentration offshore (east of $165^\circ W$) estimated by curve fitting. Each dot represents 1 grid point in 1 year. The dates of the equinoxes and summer solstice are indicated as dashed lines to provide a seasonal timing reference.. * indicate timing that was an outlier (within that year).

b) Shelf

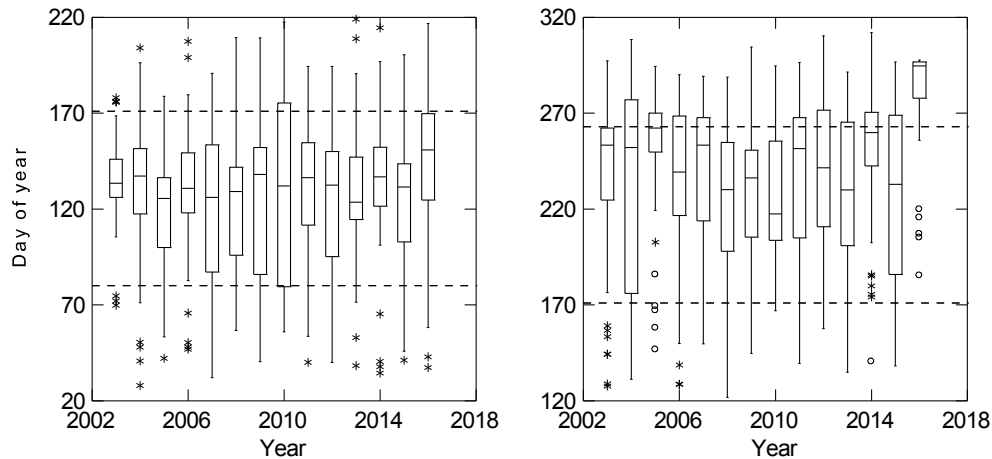


Figure 34: Box and whisker plots of peak spring (left) and peak fall (right) chlorophyll concentration in the shelf region (east of $165^\circ W$) estimated by curve fitting. Each dot represents 1 grid point in 1 year. The dates of the equinoxes and summer solstice are indicated as dashed lines. * indicate timing that was an outlier (within that year) at a grid point.

As in the offshore region, median peak date of bloom timing in the shelf region was an extremum

(late) in 2016 in fall, but also had a late median date in spring (Figure 32). As this is somewhat of a transition between the nearshore and offshore, it is not too surprising that it picks up some of the characteristics of each. This region is expected to have additional variability because of the relatively greater influence of mesoscale eddy activity (Brickley and Thomas 2004; Crawford et al. 2005; Ladd 2007). To date, the role of eddies in salmon biology is not well known. For the most part, studies have focused on their role in affecting migration timing (Hamilton and Mysak 1986; Hamilton et al. 2000).

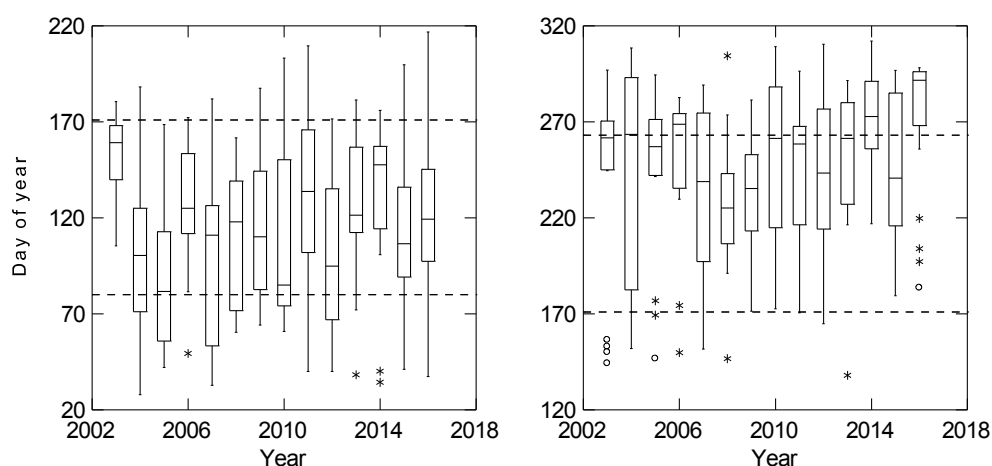


Figure 35: Box and whisker plots of peak spring (left) and peak fall (right) chlorophyll concentration offshore (east of 165°W) estimated by curve fitting. Each dot represents 1 grid point in 1 year. The dates of the equinoxes and summer solstice are indicated as dashed lines. * indicate timing that was an outlier (within that year) at a grid point.

c) Coastal

Median peak date in the coastal region was latest in 2003 and earliest in 2010 (Figure 33). The variability, measured by the lengths of whiskers, was greatest in 2016. The fall bloom was latest in 2016 and earliest in 2008, a relatively cool year that was associated with an abundant return of Fraser River sockeye salmon but that may simply be a coincidence. Based on the previous analysis of coastal chlorophyll, there was an expectation that 2015 would have the earliest spring median date but that did not appear. There is a possibility that 2015 should have been modelled as a year of three peaks; a small but anomalous peak in winter, with normally timed spring and fall peaks. The early winter peak was probably swamped by the spring peak in a two-peak model.

6.4. Zooplankton

a) Coast/shelf

The current paradigm for juvenile salmon survival along the southeastern coast of the Gulf of Alaska is that survival is associated with the movement of different water masses along the North American coast making the environment more or less favourable for survival. A cooler (warmer) ocean in the south (north) is generally better (worse) for survival than a warmer (cooler) ocean (Mueter et al. 2002). Since the 1950s, dramatic changes in zooplankton communities have been observed regularly along the British Columbia, Washington, Oregon coastline (Beklemishev and Lybny-Gertsyk 1959; Frolander, 1962; Cross and Small 1967; Mackas 1984; Fulton and Lebrasseur 1985, Mackas et al. 2001, Mackas et al. 2007, Keister et al. 2010).

The taxonomic composition of the zooplankton community (primarily copepods) and its total biomass can change abruptly (Frolander 1962).

- Oregon

Regular and frequent sampling has shown the predominant role of low frequency variation in the coastal ocean since the late 20th century (Figure 37). Peterson classified the major differences as southern and northern communities. Their phasing implies a strong association with large-scale oceanographic features involving currents, water masses. It is also a region of strong upwelling but the dominant pattern in these time series is not the seasonal scale. The southern community is dominated by copepod taxa that do not store lipids and reproduction is continuous providing that adequate food is available. The northern community is dominated by large lipid-storing copepods that enter diapause after the spring feeding season with sufficient energy stored to survive to reproduce the following spring. The current paradigm is that the latter provide an enriched food web for juvenile Pacific salmon. At Newport, the southern community has prevailed since mid-2014 with the largest anomaly occurring in 2015 (data for 2016 were not available). Qualitatively, these strength of these anomalies does not look particularly different from similar periods in the past (Figure 37).

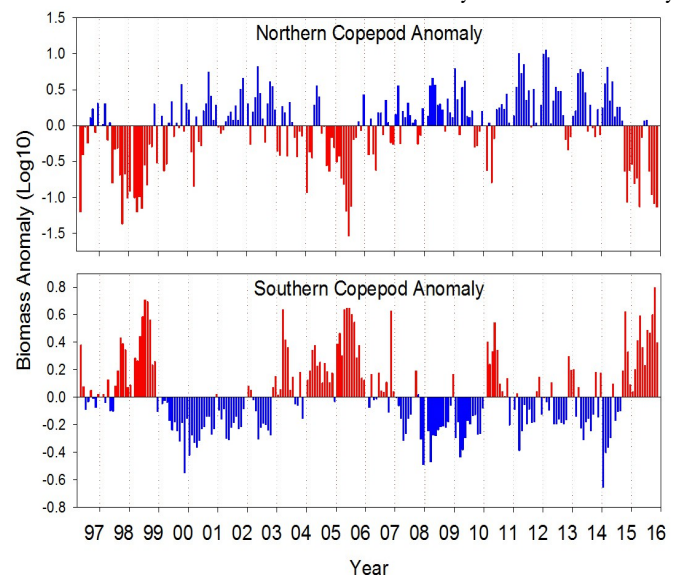


Figure 37: (W.T. Peterson's) biweekly zooplankton community composition off Newport, OR indicates variation in biomass of boreal versus subtropical copepod species. Source: <https://www.nwifsc.noaa.gov/research/divisions/fe/estuarine/oebp/eb-copepod-anomalies.cfm#NSC-01>

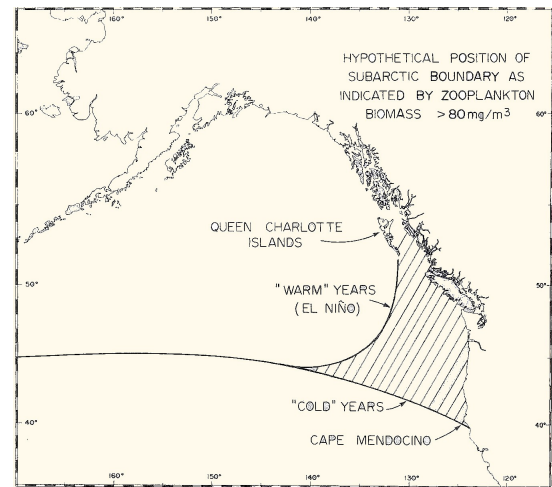


Figure 36: Schematic of variation of the copepod biomass in association with variation in ocean circulation. Source: Fulton and Lebrasseur (1985).

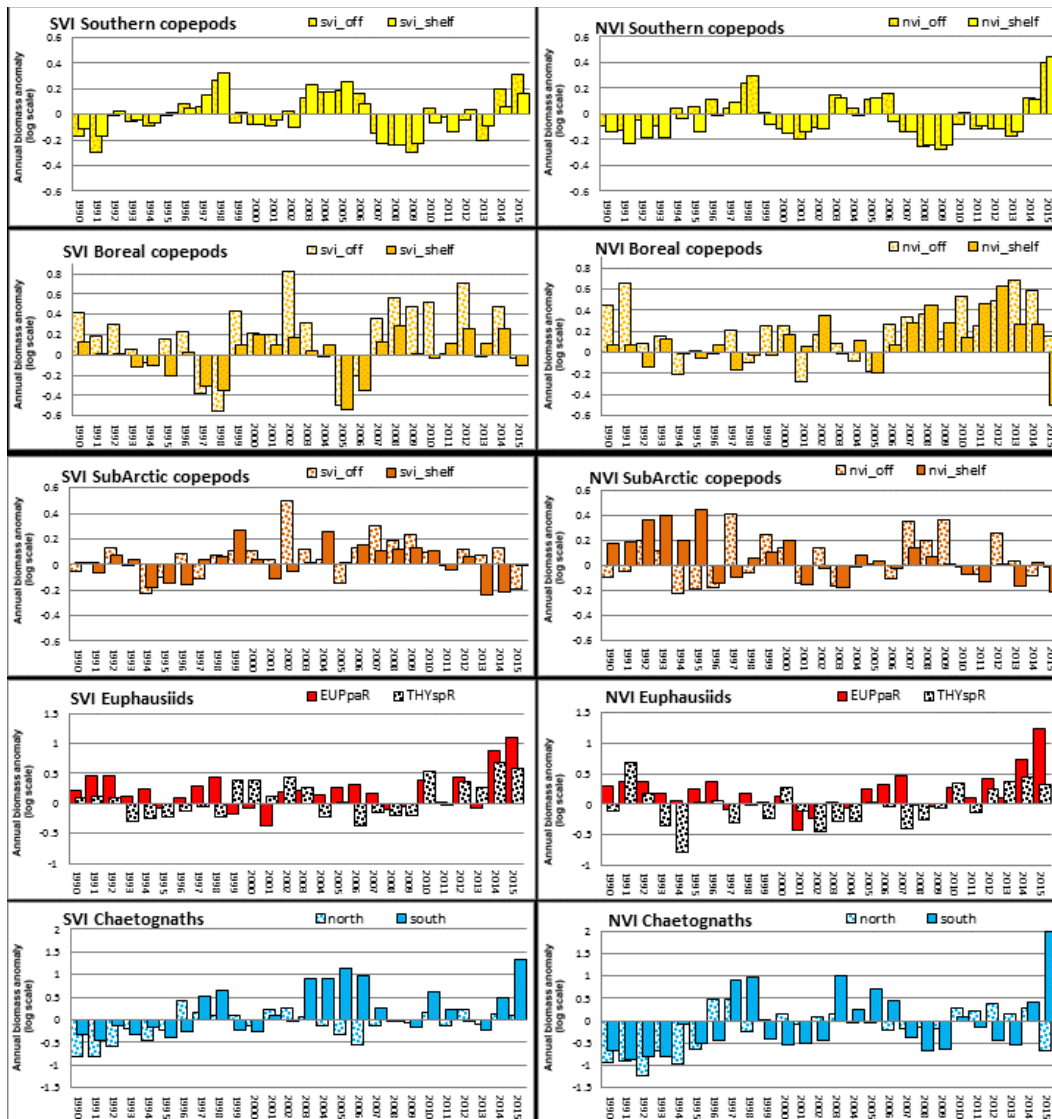


Figure 38: Zooplankton species-group anomaly time series (vs climatological baseline) for southwestern Vancouver Is. (left) and northwestern Vancouver Is. (right) regions. Ordinate is annual log scale anomalies. R in Euphausiids represents: corrected for day/night tows. EUPpa: *Euphausia pacifica*; THYsp: *Thysanoessa spinifera*; CHAET; *Chaetognaths* divided into north/south species group. Source: Chandler et al. 2016.

- West Coast Vancouver Island

A sufficiently large-scale climate event can affect the zooplankton communities in a similar way along much of the North American coastline (Mackas et al. 2006). Extrema in 2015 were widespread among many taxa along the Vancouver Is. coastline but were more extreme along its northwestern coast (Figure 38). This effect could have arisen from a stronger or more prominent poleward circulation of southern waters, creating stronger anomalies in the north. Southern latitudes along Vancouver Is. experience zooplankton anomalies regularly, in association el Niños (Fulton and LeBrasseur 1985) so the appearance of southern taxa and diminished northern taxa is not as unusual. Adult salmon returns in southern British Columbia, following zooplankton anomalies such as these, will tend to be poorer rather than better.

a) Offshore

- Continuous Plankton Recorder

Data for the NE Oceanic Region (a CPR-defined region) were made available by the Director of CPR-Pacific as final results for 2015 and preliminary results for 2016 (to July). Preliminary results are based on 25% of a normal annual sample size for the program. 2015- no extrema were found in the zooplankton samples taken in the Oceanic Region (eastern Gulf of Alaska) during the CPR survey (Figure 39).

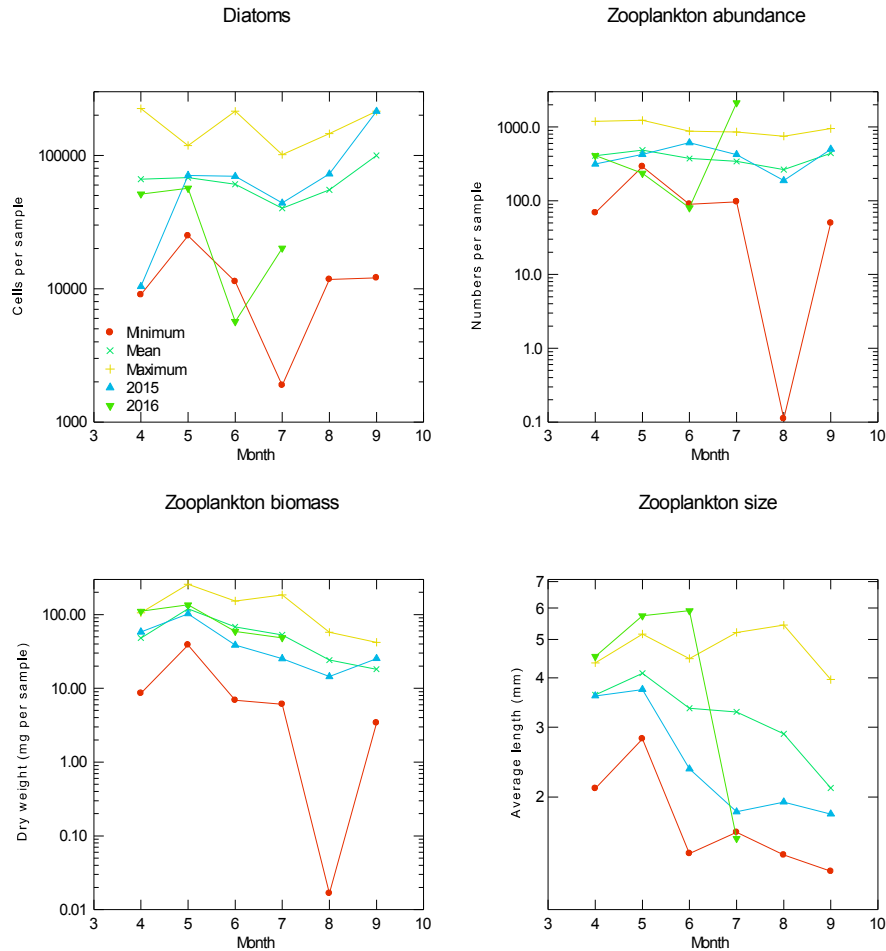


Figure 39: Indices of high seas plankton community based on Continuous Plankton Recorder data (courtesy of Dr. Sonia Batten, Director, CPR - Pacific). Statistics are based on 2000-2015 average monthly values. Colour legend for all panels appears in the top left panel. All ordinates are log-scale. Data for 2016 are available only to July. Minimum, maximum and mean statistics are based on data from 2000-2015 so extrema in 2016 can exceed the minimum and maximum.

Salmon Extrema

Bering Sea

Yukon River

- Eagle - Since 2005, the counts of chinook salmon at Eagle in 2015 was an extremum (high) and the return timing in 2016 was an extremum (early). In contrast to the early return of chinook salmon in 2016, the extrema (since 2006) for fall chum in 2016 was the most skewed return and latest peak.
- Anvik - The summer run of chum at Anvik R. (since 1980) was the most skewed (slow rise to a peak), but the date of the peak was not an extremum. Even year pink salmon had the latest peak date (since 1994) in 2016.

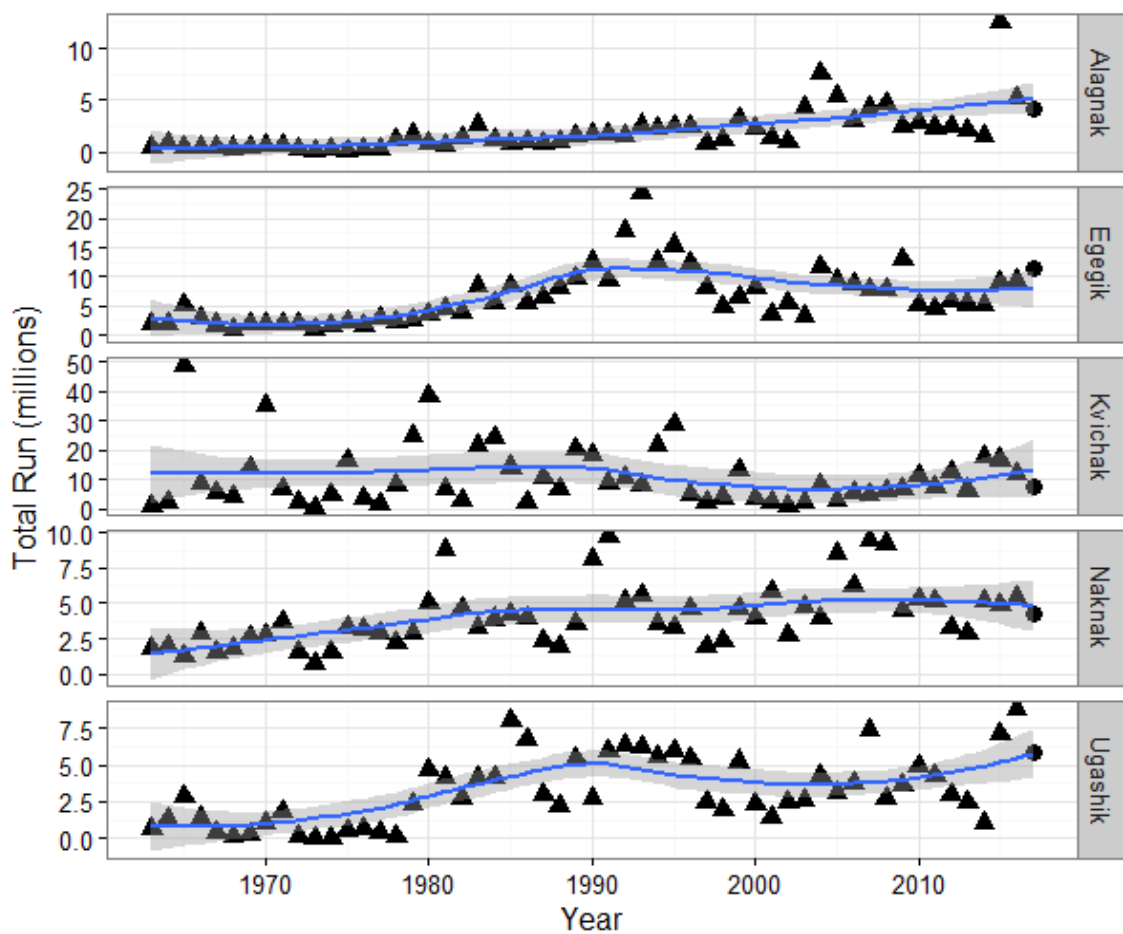


Figure 40: Total returns of sockeye salmon to east side rivers in Bristol Bay 2016 and forecast for 2017 (solid circle). Source: <http://www.adfg.alaska.gov/static/applications/dc/newsrelease/756093217.pdf>

Bristol Bay

- anomalies in the sockeye salmon return recently have been in timing rather than abundance. For example, 2015 was the latest return of sockeye salmon past the Port Moller test fishery, in contrast to 2013 which was the earliest return on record. An abundance extrema (positive) occurred in the

Alagnak R. in 2015 and the Ugashik R. in 2016 (Figure 40). No other total return extrema occurred in other rivers in either year. There were no abundance extrema in 2015 or 2016 in west side rivers (Figure 41).

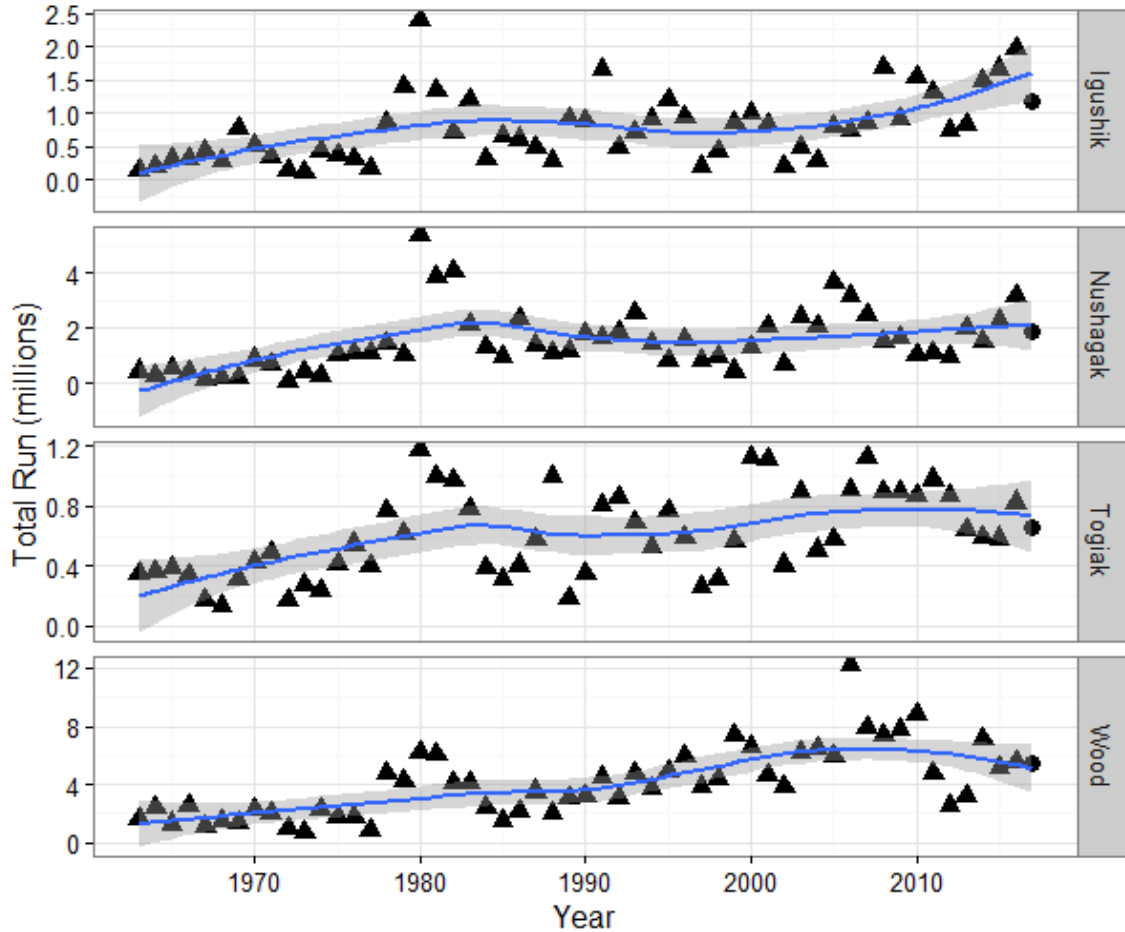


Figure 41: Total returns of sockeye salmon to west side rivers in Bristol Bay 2016 and forecast for 2017 (solid circle). Source: <http://www.adfg.alaska.gov/static/applications/defnewsrelease/756093217.pdf>

Northern Gulf of Alaska

Copper River

- Coho salmon commercial harvest was the largest since 2004.
- Chinook and sockeye salmon runs in 2016 were bad and average, respectively.
- Mean size of sockeye salmon (without regard to age) was an extremum (small) in 2015 (Source: <http://www.alaskajournal.com/2016-05-26/recent-trend-small-sockeye-continues-copper-river>)
- The early-run sockeye salmon abundance was an extremum in 2015 but no other timing/abundance anomalies were found for this species.

Kodiak

- In 2016, pink salmon harvest was the lowest since the 1970s. (Source: <http://www.adfg.alaska.gov/index.cfm?adfg=commercialbyfisherysalmon.bluesheetsummary>). The pink salmon run to the Karluk R. was front loaded (most arriving early but without a peak date

extremum) with a protracted finish.

- The abundance of the early-run sockeye salmon to the Karluk River in 2015 was an extremum (high) as was the late-run abundance in 2016.

•

Russian River (Cook Inlet)

- Sockeye salmon had no anomalies in 2015 but the return of early-run sockeye salmon in 2016 was the least compressed in the record.
- Chinook salmon had no extrema in 2015, but in 2016 was the earliest found and the run timing shape was front loaded.

Southeast Alaska

Chinook summer troll fishery

Although the mean length of age 1.3 and age 0.4 chinook salmon in the summer (statistical weeks 27-29) troll fishery was the smallest in the record in 2015, the dominant feature of temporal change is the overall decline during the past 35 years (Figure 42). The rate of decrease increases with ocean age.

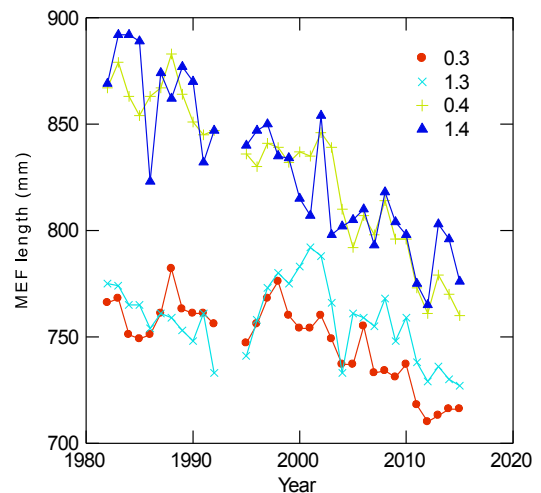


Figure 42: Mean mid-eye to fork (MEF) length (mm) of 4 age-classes of chinook salmon in the SEAK troll fishery during statistical weeks 27-29. Data courtesy of L. Shaul, ADFG.

Pink salmon

Forecasts of pink salmon harvests in Southeast Alaska based on juvenile pink salmon abundances in Icy Strait the previous year are relatively reliable in most years (Figure 43); 2015 and 2016 are noteworthy negative anomalies but not extrema. In 2016, harvests of pink salmon in Southeast Alaska were approximately 18 million whereas 30 million was the forecast based on a juvenile index value of 2.2. Harvests in 2015 were well below forecast. The annual mean weight of pink salmon caught in northern SEAK and southern SEAK fisheries is highly correlated ($r = 0.9$) suggesting that they share common growing conditions in the Gulf of Alaska. There were no body size extrema in 2015 or 2016.

Sockeye salmon

Time series of mean length of age 1.2 and age 1.3 sockeye salmon were available from Hugh Smith Lake, McDonald Lake, Ford Arm Lake, Situk Lake, and Chilkoot Lake. A principal component analysis of mean length of 10 age/population combinations indicated that they share only 43% of covariation in common but all load positively on the leading PC. The shared component is much lower than for SEAK pink salmon mean weight. The subdominant PC distinguished age 1.2 fish from age 1.3 fish. In northern BC sockeye populations, these two age-classes tend to occupy different locations in the Gulf of

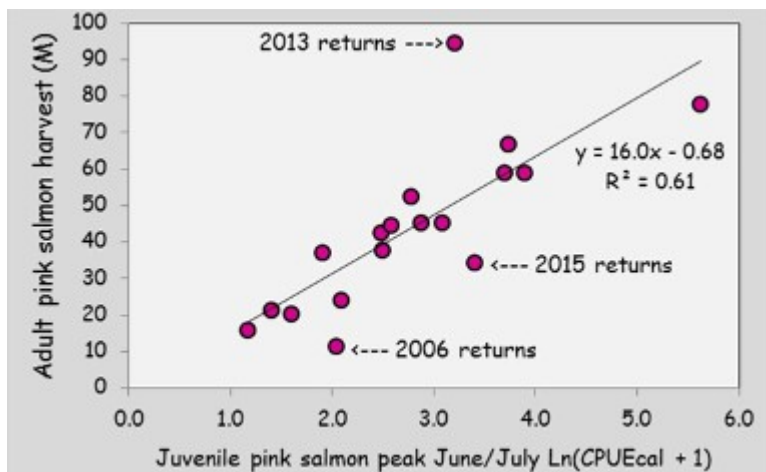


Figure 43: Correlation of juvenile pink salmon peak CPUE in Icy Strait (June or July) and SEAK adult pink harvest the following year. The observed value of the abscissa in 2015 was 2.2, implying a harvest in 2016 of ~30 million. Source: Orsi et al. (NOAA/ABL)

Alaska (McKinnell 1995). Only Chilkoot R. (age 1.3) had a mean length extremum (small) in 2015. Some sites (McDonald L.) was not sampled in 2015 and 2016, nor was Ford Arm Lake in 2016. Data for Situk L. for 2016 were not available at the time of writing but will be later, so mean length was interpolated (L. Shaul, ADFG, pers. comm.).

Coho salmon

Average dressed weight data are available from the coho troll fishery from the 1970s. There were no extrema in mean weight in 2015 (2016 not available). The mean length of coho salmon spawners has declined generally over the past 35 years (Figure 44) although the past year or two has seen increases above the recent average in 3 of 4 of these populations. There were no extrema in mean length in 2015 or 2016 in these populations.

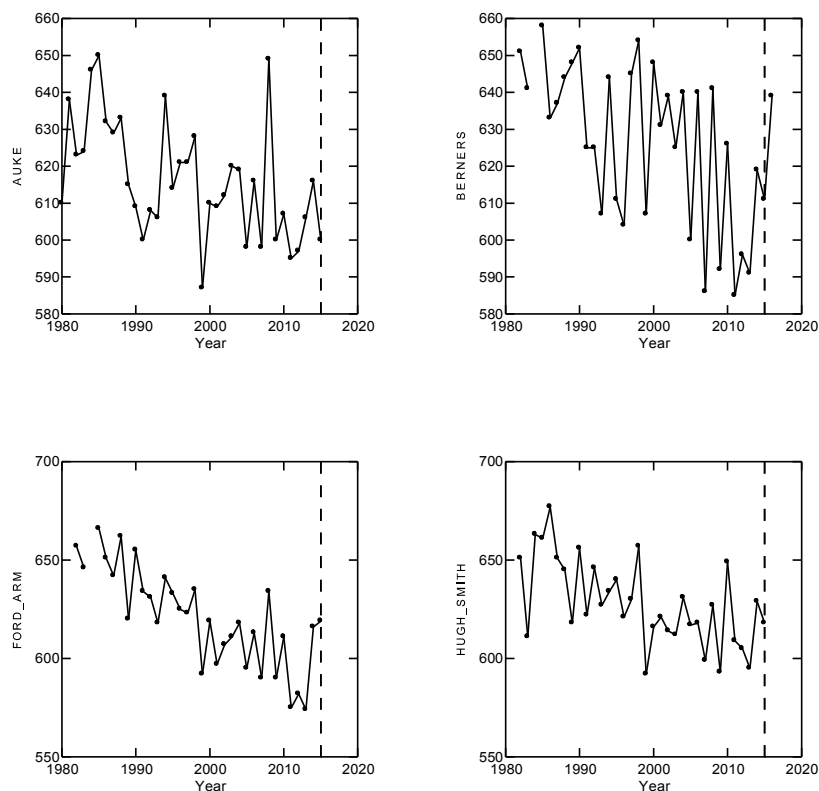


Figure 44: Mean length of coho salmon spawners (male and female average) at four locations in Southeast Alaska: Auke Creek, Berners River, Ford Arm Lake, and Hugh Smith Lake. Data courtesy of L. Shaul, ADFG. The dashed vertical line indicates 2015.

British Columbia

Nass River

Data collected at a fish wheel in the lower river since 1994. Sockeye salmon and chinook salmon are better described by two pulses of migration.

- 2015 - the abundances of early and late running sockeye and early and late running chinook salmon

were extrema (low). There were no other extrema.

- 2016 – the abundances of early and late running sockeye and chinook salmon were extrema (high). The peak date of the early running sockeye salmon and the late running chinook salmon was an extremum (late) and the latter was very compressed (extremum). Coho salmon abundance was an extremum (low) and timing was early and brief (both extrema).

Skeena River

Data are from the Tyee gillnet test fishery in the lower river since 1956. The later running species (chum, coho) continue migrating after the test fishery closes so the data will only reflect catch-per-unit-effort until that date. The abundance extremum (low) for sockeye salmon occurred in 2013.

- 2015 - the return of chinook salmon was late and compressed. There were other extrema for any species.
- 2016 – the sockeye salmon run was late. There were no extrema in abundances or timings for any species.

Long Lake

The migration of sockeye salmon through Docee fence can, in most years, be described adequately by a single pulse of spawners passing through the fence. Infrequently, as in 2005, the migration has multiple pulses of spawners passing through the ladder and a single pulse model is inadequate. In 2016, the run was the earliest observed during the period from 1980. No other characteristics of the run were extreme in either 2015 or 2016, when the migration modelled as a single pulse.

Strait of Georgia and WCVI

The marine survival of coho salmon in the Strait of Georgia declined abruptly after the 1980s (Figure 46). For the last two decades, it has remained low; less than half of what occurs on the West coast. The last two decades are one continuous extremum.

Fraser River

The Fraser River approach route test fisheries for sockeye salmon and pink salmon in Johnstone Strait and the Strait of Juan de Fuca are both unique and valuable because they provide information on salmon timing, abundance, and size, prior to fishing, although years with later opening dates tend to miss the beginnings of early returning sockeye populations in the Upper Fraser, Baker Lake and Lake Washington. Other salmon species are caught as well although some are not on spawning migrations. For coho salmon and chum salmon these test fisheries are closed before spawning migrations of begin in earnest so catches

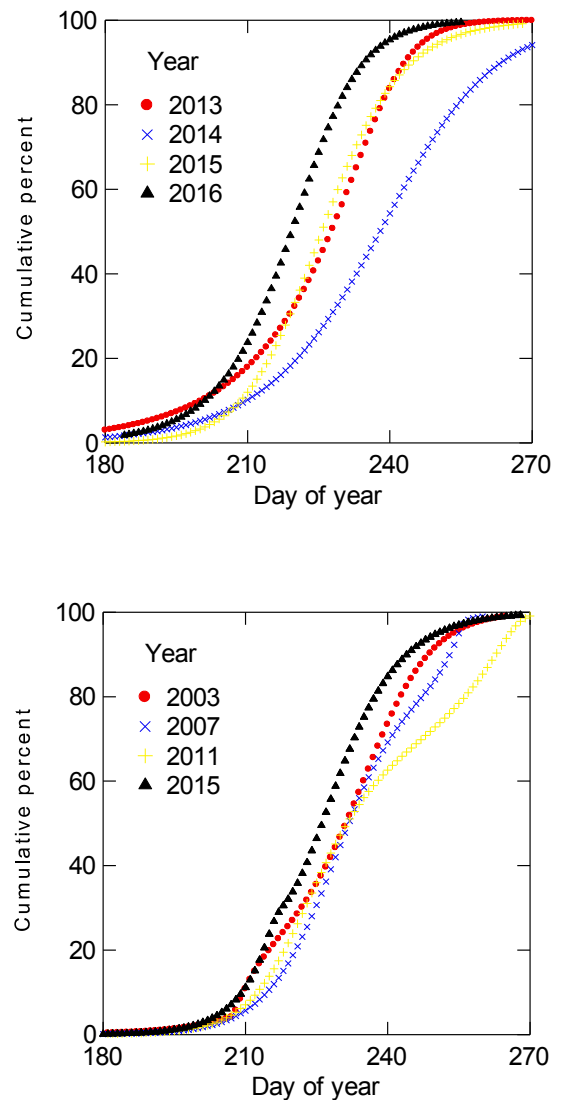


Figure 45: [upper] Single pulse fits to cumulative timing at the Whonnock test fishery (Fraser R.) from 2013 to 2016. [lower] Two pulse fits to the same test fishery by 2015 cycle year.

may not necessarily be well described by a model that anticipates migration peaks. Nevertheless, the shapes of cumulative abundance curves provide an opportunity for comparison among years.

As any biologist or manager can attest, the migration of Fraser River sockeye salmon is complicated. Since 2002, and likely before that, there have been relatively consistent differences in timing/abundance curves for the total return among cycle years. The 2016 cycle, for example, is distinguished from other cycles because of its earlier average timing (Figure 45, upper panel), which is caused for the most part by low average abundance in the late run populations. Therefore, in not dealing with stock-specific timing curves, anomalies should be calculated with respect to this four year cycle. However, with the available data, the number of years available to compute an average for any cycle year is only three or four. Furthermore, because there are so many populations, some of remarkable abundance, interannual variations in their relative abundances can easily affect the characteristics of any annual timing curve. Added to this source of variability are the effects of differences among test fisheries in their ability to detect the abundance signal, plus variable start and end dates.

Given the numbers of species×ages involved (8), the numbers of test fisheries (5), and variations in patterns among years, only single pulse models were fit to each, but there are clearly some years and species where multiple pulses would markedly improve the fit. In general, a single pulse model accounts for >50% of the variation in CPUE (e.g. > 70% in the San Juan seine test fishery) but there are also some years and species with misfits ($R^2 < 10\%$) but they do not occur often. Example of fitting multi-pulse models is seen in Figure 47 (sockeye) and Figure 49 (pink) compared to a single pulse in Figure 45.

The most remarkable migration timing anomaly in Fraser River sockeye salmon in recent memory occurred in 2005 (2013 cycle), a year of many remarkable environmental and biological extremes (see special issue on this event in *Geophysical Research Letters* Vol. 33) and subsequently low abundances of adult Fraser River sockeye salmon in 2007. Indeed, 2005 was so unusual that even greater timing extrema are almost unimaginable without digging into the distant past for a reminder.³

Sockeye salmon

- 2015
 - Regardless of whether a single pulse or multi-pulse migration model was used, the sockeye salmon return timing past the Whonnock test fishery (within the Fraser River) in 2015 had an intermediate timing when compared with four recent years, but it was generally earlier than the other years on that cycle (Figure 45). Early timing in a warm year is inconsistent with the “cold early-warm late” pattern that has been relatively consistent through the last half century (Blackburn 1987, McKinnell et al. 2012). In that sense, 2015 was an extremum because a later than average return would have been expected based on the coastal heatwave of that year. On the other hand, DFO had forecast an early return of Summer-run stocks (Fraser R. panel news release of 2015). Subsequent news releases noted the Early Summer and Summer runs were protracted as had occurred during the last heat-wave (McKinnell 2000).
 - There were no timing/abundance extrema for large sockeye salmon in 2015 at the Round Is. (gillnet) test fishery but the Blinkhorn Is. (seine) test fishery was the least compressed (protracted), as was noted in the in-season Fraser River Panel reports. In contrast to the Round Is. test fishery, the abundance of large sockeye salmon in the gillnet test fishery at San Juan was an extremum (low) in 2015. There were no sockeye salmon extrema in the San Juan seine

³ Peak catch of sockeye salmon in 1926, a major el Niño year, occurred during the week of October 2 (Clemens & Clemens 1927).

fishery in 2015.

- 2016
 - large sockeye salmon in the Round Is. test fishery were the earliest observed, which coincided with an extremum in skewness (peak early). Large sockeye salmon in the Blinkhorn test fishery were the earliest in the record. The early timing in a warm year is inconsistent with historical norms.
 - Small sockeye salmon (age 3₂) are not caught in the gillnet test fisheries as they are too small. Their abundance in 2016 was an extremum (low). In cycle years where larger average abundances of small sockeye are expected (2014 cycle), their abundance is an index of large sockeye salmon returns the following year (McKinnell et al. 2012) but it is not clear how well this index might work in years when average abundances are expected to be low. The low abundance extrema of small sockeye salmon that was observed in the Blinkhorn test fishery in 2016 was also observed in the San Juan seine test fishery.
 - There were no extrema in the San Juan gillnet test fishery in 2016, but the 2016 Blinkhorn test fishery had the most extreme abundance (low), skewness (early), compression (high), and peak date (early).

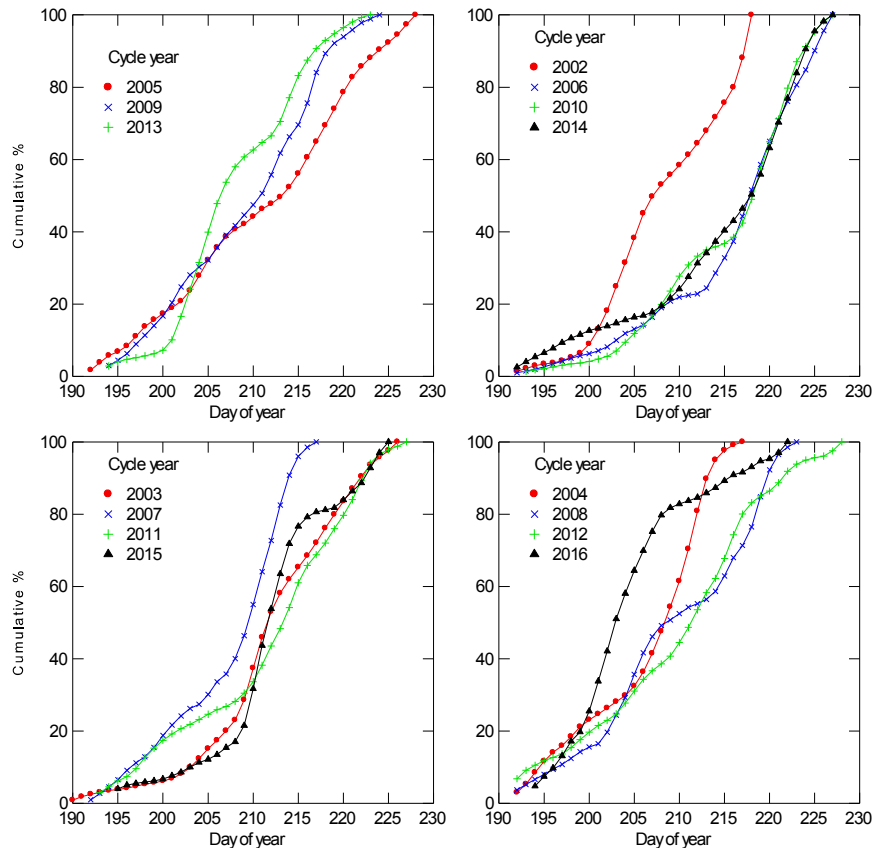


Figure 47: Large sockeye salmon catch in the Round Island gillnet test fishery (fit to a 3 pulse model rather than a 1 pulse model).

Pink salmon (2015 only)

- The body weight of Fraser River pink salmon has exhibited a long-term decline since 1950s (Figure 48). Although different sampling methods have been used to determine annual average weight, the average weight in 2015 was the lowest in the record. No equivalent body size extremum was found in Southeast Alaska even though historical tagging records indicate a common oceanic environment.

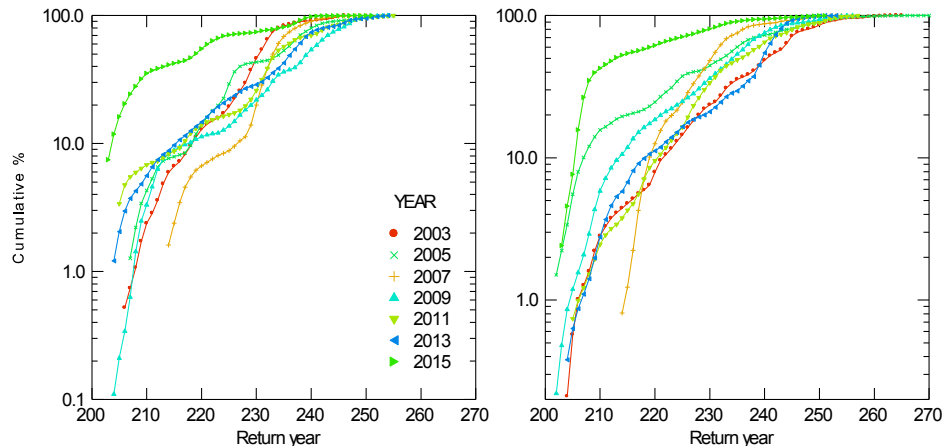


Figure 49: Cumulative CPUE of pink salmon (% of total) at San Juan (left) and Blinkhorn (right) test fisheries in odd years from 2003 to 2015.

- From 2002-2016 there are seven years of pink salmon returns to the Fraser River as they appear in abundance only in odd years. Migration through the San Juan seine test fishery on the West coast of Vancouver Island indicated that in some years (2007, 2009) a single peak describes the passage of fish, with improvements in R^2 in those years of only 2.5% and 5.6%, respectively, for considering that there may be two pulses of migration. In the other years, 2003, 2005, 2011-2015, there were significant improvements in fit with R^2 increasing by as much as 19-42% by modelling this part of the migration as two pulses. A similar pattern appeared in the Blinkhorn seine test fishery, but some years differed in whether there was an improvement in the model fit by contemplating two peaks (Figure 49).
- The Blinkhorn seine test fishery has the added complication of greater abundances of local (non-Fraser) pink salmon in the catch. The worst fit to a two pulse model occurred in 2015 in the San Juan seine test fishery because there were three obvious peaks that year. This San Juan gillnet test fishery began relatively late in 2015 and first sets yielded catches there were the largest in first sets in the 21st century indicating that the pink salmon migration was already underway when the test fishery began, confirming the early arrivals seen in the seine test fisheries.

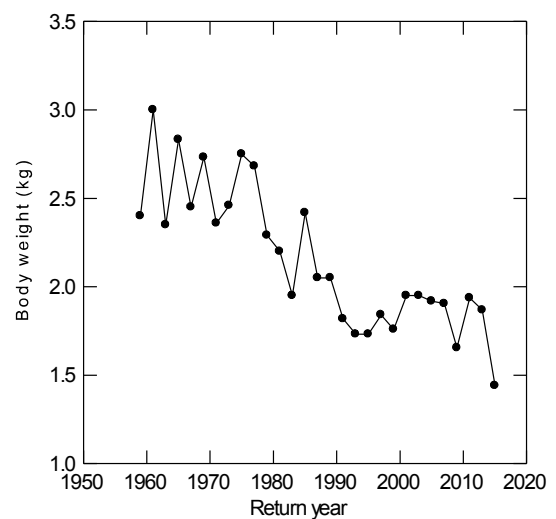


Figure 48: Mean body weight (kg) of pink salmon returning to the Fraser River.

Chinook salmon

- 2015 - the only extremum for large chinook salmon in Johnstone Strait was a late peak in the Blinkhorn test fishery. Small chinook salmon in the Blinkhorn test fishery had a skewness extremum (slow build to a peak) that was consistent with the late timing of the large chinook salmon. There were numerous extrema at the San Juan test fisheries; both small and large chinook salmon were the least abundant in the record in the gillnet test fisheries and most abundant in the record in the seine test fishery, suggesting a late migration timing, but the estimated peak dates were not extrema. The San Juan seine test fishery was the least compressed for small chinook salmon.
- 2016 - large chinook salmon had a compressed run in the Round Is. test fishery and the small chinook salmon had a skewed return with most arriving early. Large chinook salmon had an abundance extremum (low) and a compressed run in the Blinkhorn test fishery. There were no extrema for small chinook salmon at Blinkhorn. Small and large chinook salmon in the San Juan gillnet test fishery was the most compressed in the record. In the San Juan seine test fishery, small chinook salmon had the most skewed run (slow build to a peak) but no other extrema. Large chinook salmon on the other hand were the least abundant, a strong skewness anomaly (slow build to a peak), and a compressed peak.

Coho salmon

Coho salmon spawning migrations occur primarily later than these test fisheries operate.

- 2015 -the seasonal pattern of catch of coho salmon in the Round Is. was the least compressed in the record but there were no extrema at the Blinkhorn test fishery. At San Juan, the seasonal pattern of catch in the seine fishery was the least compressed and the peak date of the gillnet fishery was the latest in the record.
- In 2016, there were no extrema in the Round Is. test fishery but in the Blinkhorn test fishery, the abundance was lowest and compression was the highest. At the San Juan gillnet test fishery, abundance was lowest and in the San Juan seine fishery, compression was greatest.

Chum salmon

Chum salmon spawning migrations occur primarily later than these test fisheries operate.

- 2015 - there were no abundance/timing extrema in the Johnstone Strait test fisheries. In the Strait of Juan de Fuca test fisheries, there was an abundance extremum (low) in the gillnet fishery and a abundance extremum (high) in the seine test fishery.
- 2016 - the Blinkhorn Is. test fishery had the lowest abundance of chum salmon. Chum salmon caught in the Round Is. test fishery had the least compressed (most protracted) catch. These extrema also appeared at the San Juan gillnet and seine test fisheries.

Steelhead trout

- 2015 - the steelhead trout passing the Johnstone Strait test fisheries had low compression in both, but they also had an abundance extremum (high) at the Blinkhorn Is. test fishery. There were no extrema at either of the San Juan test fisheries.
- 2016 - the peak date of the steelhead passage past the Round Is. test fishery was latest in the record but there were no extrema of any kind in the Blinkhorn test fishery. Like other salmonids, the compression of the passage of steelhead trout catch in the San Juan gillnet test fishery was highest. Abundance in the San Juan seine fishery was the lowest.

U.S. Mainland

Baker Lake

The data from Baker Lake are reconstructed pre-fishery abundances of sockeye salmon. In 2015, their abundance was an extremum (high). There were no other extrema in 2015 or 2016.

Lake Washington

The data are sockeye salmon counts at Ballard Locks on the ship canal into Lake Washington. There were no extrema in either 2015 or 2016.

Columbia River

Juvenile salmon surveys - Annual trawl surveys conducted by NOAA along the Washington-Oregon coast typically find the highest abundance of coho salmon and chinook salmon near the Columbia River in May and June. CPUE varies from year to year with lowest abundances occurring during years of strong environmental anomalies such as the 1998 el Niño and the 2005 downwelling year (Figure 50). There were no extreme abundance anomalies in 2014 or 2015. The highest CPUE occurred in 2013. Growth rates of juvenile coho salmon measured in 2015 off the West coast of Washington and Oregon were second highest in the past decade (Brian Beckman, NOAA, pers. comm.); 2014 was highest.

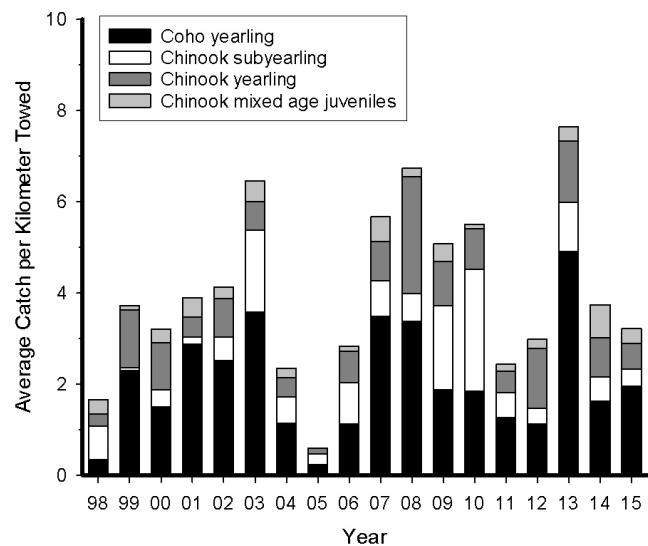


Figure 50: Annual variation in juvenile coho and chinook salmon CPUE during June trawl surveys, 1998-present.

Source:

<https://www.nmfs.noaa.gov/research/divisions/fe/estuarine/oeip/eb-juvenile-salmon-sampling.cfm>

Chinook salmon - Chinook salmon return to spawn above Bonneville Dam at various ages. Larger individuals are counted as adults and smaller individuals as jacks, although both should be considered as adults according to their sexual maturity. Three run timing groups are recognized: Spring, Summer, and Fall. The Spring and Fall runs generally have prominent peaks of abundance and relatively compressed timing. The Summer group has a less compressed migration and when abundant, a peak is evident.

- 2015 - the total return of large chinook salmon was an extremum (Figure 51) as a result of Summer and Fall Run extrema added to a relatively high abundance of the Spring run. Spring and summer small chinook salmon were extremely skewed (peak during the first part of the run) and small Spring run chinook had a compression extremum (low).
- 2016 - No extrema.

Sockeye salmon - There are three populations of sockeye salmon in the run but they are so dominated by the abundance of the Osoyoos Lake population that the run was modelled as a single pulse.

- No extrema occurred in 2015 or 2016, although abundance was high in 2015.

Steelhead trout - The run of steelhead trout was modelled as a single pulse.

- 2015 - No extrema
- 2016 - Most protracted in the 21st century. Abundance was also low but not extreme.

Coho salmon - The fraction of coho salmon run ascending to spawn above Bonneville Dam is relatively small compared to the total run to the river (L. Weitkamp, NOAA, pers. comm.). Nevertheless there are at

least two regular peaks annually for large coho salmon. The only peak date extremum (early) was found in the large coho early-run component.

- 2015 - The timing of large coho in the early run was extreme (early) and the run of late run coho was protracted.
- 2016 – There were no extrema in either run timing component in 2016. Although not an extremum of interest to this report, the 2014 ocean entry year produced remarkably few large coho salmon spawners in 2015, considering the sibling relationship that has persisted through the 21st century (Figure 8).

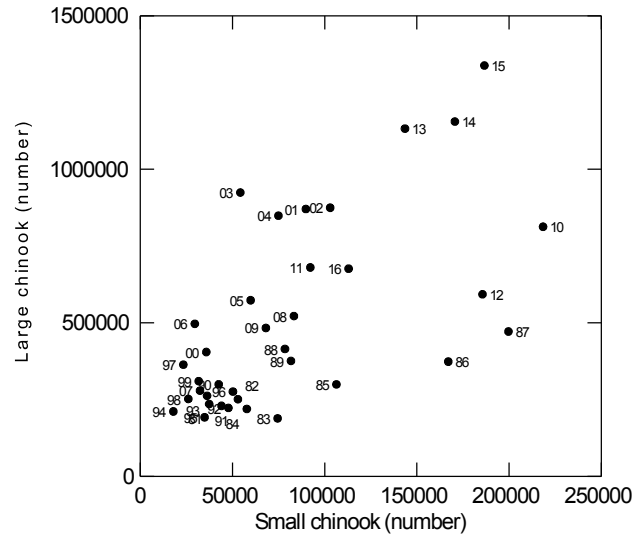


Figure 51: Annual numbers of large adult chinook salmon (year indicated on each plot point) returning to Bonneville Dam (Columbia River) versus the number of small adult salmon returning the previous year.

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Appendix 1. Oceanographic data and methods

1. Surface Air Temperature

Monthly average surface air temperatures from the NOAA NCEP/NCAR Re-analysis at

<http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html>

Monthly anomalies were calculated by removing the monthly 1948-2016 long-term mean.

2. Sea Level Pressure

Monthly average surface air temperatures from the NOAA NCEP/NCAR Re-analysis at

<http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html>

Monthly anomalies were calculated by removing the monthly 1948-2016 long-term mean.

3. Sea Surface Temperature

3.1. Monthly average data are from

ftp://ftp.emc.ncep.noaa.gov/cmb/sst/oimonth_v2/YEARLY_FILES/.

3.2. Weekly average data are from

ftp://ftp.emc.ncep.noaa.gov/cmb/sst/oisst_v2/YEARLY_FILES/.

3.3. Daily average data are from <ftp://eclipse.ncdc.noaa.gov/pub/OI-daily-v2/NetCDF/>

SST anomalies were calculated by removing the appropriate (monthly, weekly, or daily) 1981-2016 long-term mean.

3.4. Kains Island lighthouse

This lighthouse and many others, has been the site of daily measurements of SST and salinity since a program of sampling was started by the Fisheries Research Board of Canada in the early 20th century.

Anomalies were computed as deviations from the long-term (1935-2016) daily averages. Data were downloaded from <http://www.pac.dfo-mpo.gc.ca/science/oceans/data-donnees/lighthouses-phares/index-eng.html>

4. Sea temperature and salinity depth at 5m depth.

These data were collected and made freely available by the International Argo Program and the national programs that contribute to it (<http://www.argo.ucsd.edu>, <http://argo.jcommops.org>). The Argo Program is part of the Global Ocean Observing System. Because of their relatively sparse distribution (compared to satellite data), developing a climatology has some challenges. Two approaches were used to compute temperature climatology. The first computed average temperature and salinity in 2° latitude by 5° longitude blocks by month. Monthly average temperatures were computed from all observations made within a block/month. Long-term monthly averages for the block were calculated by summing across years (2003-2016) and dividing by the number of years with valid data. Anomalies were created by subtracting each monthly average from the long-term average in a block. A second approach was to use a satellite-based SST climatology made at a much finer spatial (1/4° grid) and temporal (daily). When a float surfaced, its daily 1/4° location was noted and the temperature it observed at 5 m was subtracted from the average for that time/location. Using a surface climatology to compute anomalies at 5 m will underestimate the true anomaly at 5 m because the average value at the surface is slightly warmer than the average value at 5 m.

5. Mixed Layer Depth (MLD)

Mixed layer depth was determined according to the following definition: the expected standard deviation of repeated sampling of water properties (t, s, density) is equal to zero in a mixed layer. Each profile can be examined from surface to depth where this property should hold if the layer is truly

mixed. A gradient in any property indicates that the layer is not fully mixed. In practical terms, the standard deviation can only approach zero in the mixed layer because of the precision of the instrument and other factors associated with making observations. As a consequence, an arbitrary tolerance level is needed. In the present study, it was set at 99%, meaning that each measurement at depth is compared with the distribution of measurements taken at shallower depths. Assuming a normal distribution, if a deeper measurement had less than a 1% probability of coming from the distribution with the mean and s.d. of values measured above it, then the MLD was set as half the distance of the depth of that measurement from the one above. The rationale for the latter is that one doesn't know where in the last depth interval the change occurred so the midpoint was chosen.

6. Chlorophyll from satellite ocean colour

Chlorophyll concentration data products served by the NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Ocean Biology Processing Group were used in this analysis. The initial download of data occurred in October 2015 with subsequent files downloaded intermittently since then. Analyses included data up to November 2016 (eg. http://oceandata.sci.gsfc.nasa.gov/MODIS-Aqua/Mapped/8Day/9km/chlor_a/2016). SeaWiFS sensor data (1997-2002) were downloaded from https://oceandata.sci.gsfc.nasa.gov/SeaWiFS/Mapped/8Day/9km/chlor_a/). Phenology was determined within each 1° x 1° cell within the salmosphere by fitting a McKinnell growth curve configured with two pulses (spring and fall) to a cumulative curve of 8-daily average chlorophyll concentrations. The average in an 8-day period in a cell was computed as the mean of all valid pixels within each time/space stratum. Missing data were replaced by the long-term mean of that day and grid point. Each time series was then smoothed by a 3-weekly running mean.

7. Plankton

7.1. Continuous Plankton Recorder (Pacific project)

Data for the current year are preliminary, based on processing 25% of the samples. Values are monthly means compared to the long-term monthly mean and minimum/maximum monthly values found in the time series to date since 2000. Numbers for 2016 will change as more samples are processed and quality-controlled. Four variables have been selected: total diatom abundance, mesozooplankton abundance, estimated mesozooplankton biomass (dry weight), and average copepod community size (based on Richardson et al., 2006 where the published length of the adult female represents all individuals of the species). These variables are thought to provide a useful summary of the plankton, but there are some caveats and limitations: 1) The CPR diatom numbers are biased towards the larger, chain forming varieties which may only be a small portion of the phytoplankton community, 2) the number of samples that the provisional data are based on is small, especially for smaller regions. Regions with the best sample density are: Oceanic NE Pacific, Alaskan Shelf, and S. Bering Sea. Three regions are sampled only by the east-west transect which runs only three times a year in spring, summer and fall (W. GoA, Aleutian Shelf and S Bering Sea). Monthly data for the Oceanic NE Pacific Region were provided by and courtesy to Dr. Sonia Batten, Director, CPR-Pacific). Reference: <http://www.pices.int/projects/tcprstnp/main.aspx>.

7.2. Coastal sampling

a) British Columbia

- figures were obtained from DFO's State of the Pacific Ocean report (Chandler et al. 2016).

b) Newport, Oregon

- There is a relationship between water type, copepod species richness, and the PDO. Two

indices were developed based on the affinities of copepods for different water types. The dominant copepod species occurring off Oregon at NH 05 were classed into two groups: those with cold–water and those with warm–water affinities. The cold–water (boreal or northern) group included the copepods *Pseudocalanus mimus*, *Acartia longiremis*, and *Calanus marshallae*. The warm–water group included the subtropical or southern species *Mesocalanus tenuicornis*, *Paracalanus parvus*, *Ctenocalanus vanus*, *Clausocalanus peregians*, *Clausocalanus arcuicornis* and *Clausocalanus parapergens*, *Calocalanus styliremis*, and *Corycaeus anglicus*. Source: <https://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/eb-copepod-anomalies.cfm>.

8. Appendix 2. Salmon data and methods

Modelling migration

Regular observations of salmon abundance at fixed locations are standard tools in a fishery manager's tool bag. The data collected are generally of two types: counts of individual fishes as might occur at the fish ladder, or numbers caught per unit of effort as might occur at a test fishery that is intended to gauge the abundance of passing fish. These types of regular sequential observations can be described by parametric models such as the 2 parameter Gaussian (normal model which assumes that a salmon migration can be described by a mean date and its standard deviation). More complex models such as that of Schnute and Sibert (1983) allow greater flexibility by using additional parameters to capture traits such as skewness (asymmetry) of the run and compression (similar to kurtosis) which permits curves with shapes ranging from a sharp peak in abundance through to no peak. The 4 parameter Schnute-Sibert curve can be expanded to entertain runs that exhibit multiple peaks (McKinnell, unpublished) that need to be “decomposed” from the composite data. The improvement in the fit as a result of entertaining multiple components (run timing groups) can be measured and compared with simpler curves by examining the improvement of the fit of the model to the data (R^2). Where long-term observations suggest a fixed number of peaks, such as the Spring, Summer, and Fall runs of chinook salmon to the Columbia River, the expected number of components in the run was fixed, in this case at 3 components. The model then estimates the peak date, skewness, compression, and abundance of each component from the data. This differs somewhat from traditional practice which uses fixed dates (May 31, August 31) to separate Spring/Summer and Summer/Fall. The McKinnell approach allows for year to year variability in the timing of passage of each component, i.e. a late Spring run might allocate too much abundance in the Summer run. The two approaches should not differ too much in this case because the Spring and Fall peaks are clearly identifiable. In some years, however, the end of the Spring run and the beginning of the Summer run may be more difficult to detect. Small numbers of missing data appear in most time series.

As the model fitting procedure relies on cumulative abundances, missing observations (primarily in test fisheries) were estimated by linear interpolation using the abundance on the day before and the day following the gap. To make each year comparable, regardless of abundance, each cumulative count or CPUE time series was converted to per cent. This also allowed greater stability in model fitting. Numerical instabilities arose when runs with millions of fish were run with the same tuning as runs with hundreds of fish. The solution to this problem was to convert all to cumulative per cent, then back transform this to absolute abundances after a solution was found. Prior to fitting each series was smoothed using 3-day average smoother to reduce the influence of high frequency (day to day) variability. As the analyses were done in the fall of 2016, before all returns were in for 2016, a cutoff date in 2016 was set at October 21. In reality, this affected only the Bonneville Dam analyses as other observation sites had stopped operating by this date. To make cumulative counts at Bonneville in 2016 comparable with other years, long-term average counts were used in place of observations from October 22 to November 30, 2016. By the 2016 cutoff, the peaks of all species and all timing components within each species have been seen so the effect on the 2016 results should not be too great.⁴

Escapement monitoring

8.1. Test fisheries

⁴ The coho salmon returns (large and small) at Bonneville were re-run with 2016 data to November 24.

a) Nass River

The Nisga'a Fisheries Program provides weekly in-season updates on program activities including in-season Nass salmon and steelhead run size forecasts and up-to-date harvest information. These updates are available in the above-linked document. This data, public announcements and Nisga'a fishery openings and closures can be accessed from the FTP site at: <ftp://ftp.lgl.com/Nass%20Stock%20Assessment%20Updates/>.

(See also: <http://www.pac.dfo-mpo.gc.ca/fm-gp/northcoast-cotenord/nass-eng.html>)

b) Tyee (Skeena River)

A gillnet test fishery has operated at Tyee since 1955 to determine the abundance of salmon and steelhead trout entering the lower Skeena River. The test fishery was developed to provide daily estimates of sockeye salmon escapements after removals by the commercial fishery. Tidal amplitudes exceeding 6 m are common in the region during spring tides, generating tidal currents of three to four knots. The net is allowed to drift within a channel measuring two to five kilometres long and 0.8 km wide. Until 2002, an undyed, fibrous nylon gillnet of 200 fathoms total length and 20 feet depth, made up of 10 equal length panels of mesh sizes 3.5 inches to 8 inches. Starting in 2002 a 6 strand "Alaska Twist" net has been used. Sets (1 hour) are made on both high and low water slack during daylight hours which usually means three sets per day. Daily escapement estimates are calculated for sockeye salmon while relative abundance and timing are calculated for the other species.

(Source: <http://www.pac.dfo-mpo.gc.ca/fm-gp/northcoast-cotenord/skeenatee-eng.html>)

c) Fraser River



The Pacific Salmon Commission (PSC) manages in-season test fishing programs in Fraser River Panel waters and coordinates with Fisheries and Oceans Canada on other marine test fisheries off northern Vancouver Island. The primary pre-fishery sites for the Fraser River are Round Is. (gillnet) and Blinkhorn Is. (seine) in Johnstone St. and San Juan (gillnet and seine) at the entrance to the Strait of Juan de Fuca. At the beginning of the season, gillnet is used in the approach routes in the Strait of Juan de Fuca and Johnstone Strait before switching to seine nets when abundances tend to be at a peak. Test fishing with gillnets only occurs within the river. The starting and ending dates of each gear vary from year to year. Fishing effort is relatively constant but there are variations so the daily data were converted to CPUE.

As there are generally considered, for management purposes, to be four main run timing patterns

for sockeye salmon in a season (Killick 1955), each year of data at Whonnock was fit to a composite run timing curve that entertained up to four timing curves as this fishery registers all timing groups. Because of the mid-season gear change in the San Juan and Johnstone Strait test fisheries, each generally sees only three groups. Likewise in most years, the migration of pink salmon is described better by a model that entertains two pulses of migration. Nevertheless, a single pulse model will capture much of the variation in migration timing/abundance. For simplicity of analysis and interpretation, only single pulse models were fit for the test fisheries on the approaches to the Fraser R.

(Source: Pacific Salmon Commission; <http://www.psc.org/publications/fraser-panel-in-season-information/test-fishing-results/>)

8.2. Fish Counts

a) Alaska

Counts and descriptions of the counting locations were obtained from the Fish Counts webpage on the ADF&G website (<https://www.adfg.alaska.gov/sf/FishCounts/index.cfm?adfg=main.home>). Locations were selected primarily for their duration and abundances. ADF&G retains intellectual property rights to data collected by or for ADF&G. Any dissemination of the data must credit ADF&G as the source, with a disclaimer that exonerates the department for errors or deficiencies in reproduction, subsequent analysis, or interpretation.

- Yukon River (Eagle)

This sonar project is located approximately 1,200 miles up the Yukon River, 6 miles below the village of Eagle and 16 miles below the U.S./Canada border.

- Anvik River

The Anvik River is a tributary of the Yukon R. located about 300 mi. from the estuary. This is sonar project that estimates the passing abundances of pink salmon (even year) and summer-run chum salmon.

- Russian River

The weir is located at the outlet of Lower Russian Lake, about 78 miles from the mouth of the Kenai River. It takes approximately 7 to 10 days for sockeye salmon to travel from the lower Kenai River to the weir depending on water levels. Travel times are estimates and can vary significantly from this depending on conditions. The escapement goal is 22,000 – 42,000 Early-Run sockeye salmon and 30,000 – 110,000 Late-Run sockeye salmon.

- Karluk River

Karluk weir is located on the west side of Kodiak Island. The weir is near the mouth of the river just upstream from the lagoon and near the village of Karluk. It produces what usually is the largest run of sockeye salmon on Kodiak Island.

- Copper R. (Miles L.)

The Sonar on the Copper River is located at the outlet of Miles Lake, about 70 miles from the Chitina dipnet fishery. It takes approximately 2 weeks for salmon to travel this distance, but this is highly variable depending on the water level. The water levels listed here are an indication of the

general trends in the Copper River but may not be indicative of what is occurring at Chitina. The current escapement goal for Sockeye is 360,000 to 750,000.

b) British Columbia

- Nass River

The Nisga'a Lisims Government's Fisheries and Wildlife Department has conducted extensive fisheries research on the Nass River since 1992 in partnership with Fisheries and Oceans Canada (DFO) and BC Ministry of Environment. The Nisga'a Fisheries Program celebrated 20 years of operation in 2011 and currently operates twenty annual stock assessment, catch monitoring, habitat, and management projects. The current objectives and priority activities of the Nisga'a Fisheries Program are to: monitor Nass salmon and steelhead escapement, monitor salmon and non-salmon harvests in Nisga'a fisheries, in accordance with the Nisga'a Final Agreement, determine factors limiting the production of Nass salmon and non-salmon species; and promote and support Nisga'a participation in the stewardship of Nass Area fisheries. (source: <http://www.pac.dfo-mpo.gc.ca/fm-gp/northcoast-cotenord/nass-eng.html>). Weekly fish wheel catches were obtained from <ftp://ftp.lgl.com/Nass%20Stock%20Assessment%20Updates/>).

- Docee Fence (Long Lake)

The Docee River is located in the Central Coast district of British Columbia in Management Area 10. The Docee River is less than one kilometre long and drains Long Lake into Wyclees Lagoon which drains into Smith Inlet. The Docee River Fence is located at the outlet of Long Lake. The Docee River counting fence has been in operation since 1972. A counting tower was in operation from 1962 to 1971. Daily sockeye escapement information recorded at the fence is used for the management of the commercial gillnet fishery in Smith Inlet. The counting fence generally operates from late June or early July to mid August. Sockeye are sampled from the fence for post orbital to hypural plate length and tip of nose to the fork of the tail length. Scales are taken from each fish for age determination. In 1998, the fence operation was expanded to include coho and chinook. (Source: <http://www.pac.dfo-mpo.gc.ca/fm-gp/northcoast-cotenord/docee-eng.html>)

c) Washington

- Baker River Trap (Skagit)

Adjusted daily Baker Trap counts, covering years 1992-2015 and 2016 (to September 28) are the sum of the raw daily trap counts plus fish harvested in Skagit Bay/River fisheries moved forward in time to when we think they would have reached the trap if they were not harvested. For example, if we assume an estimated travel time of X days from the mouth of the river to the trap, then the "adjusted" trap count for a given day would be the raw trap count on that day + fish harvested at the mouth X days earlier. We use these adjusted counts when looking at timing for in-season run size updates, etc., rather than the raw counts, because in recent years there have been substantial commercial/sport fisheries in the bay and river below the trap that could affect the raw timing curve. There are 4 different river catch areas, plus the bay, each with its own assumed travel time from the catch area to the trap. The estimated travel times we use are based on the results of a recent sockeye tagging study. I can provide you with more details if interested. Since these adjusted counts include trap + harvest, the sum of the daily adjusted counts for each year is the total terminal run size for that year.

(Source: Peter Kairis, Biologist, Snowonish Tribe, WA, email: PKairis@skagitcoop.org)

d) Lake Washington (Ballard Locks)

- Lake Washington sockeye salmon have been counted each year since 1972 as they enter freshwater at the Hiram M. Chittenden Locks. The Washington Department of Fish and Wildlife (WDFW) counted the sockeye from 1972 through 1992, and currently Muckleshoot Indian Tribe and WDFW staffs conduct the counts cooperatively. Although small numbers of sockeye enter the system in May and early June, the period from the second week of June through the end of July is the standard counting interval used to determine if there are sufficient sockeye to open fishing seasons. Sockeye counts begin on June 12th each year to provide consistent data from year to year. The sockeye are sample counted daily during set time periods as they pass through both the locks and the fishway, and the counts are converted into a daily total number of fish passing upstream.

(Source: Aaron Dufault, WDF; <http://wdfw.wa.gov/fishing/counts/sockeye/>)

e) Columbia River

The Fish Passage Center provides technical assistance and information to fish and wildlife agencies and tribes, in particular, and the public in general, on matters related to juvenile and adult salmon and steelhead passage through the mainstem hydrosystem in the Columbia River Basin.

(Source: Fish Passage Center; www.fpc.org)

8.3. Body size-at-age

- a) Fraser River – average weights of pink salmon were provided by Michael Lapointe (Pacific Salmon Commission).
- b) Nass River – Nisga'a Fisheries Program
- c) Southeast Alaska – Leon Shaul, ADF&G

8.4. Marine survival

- a) West Coast Vancouver Island and Strait of Georgia
 - Survival estimates for hatchery and wild coho salmon are prepared and maintained by Steve Baillie, DFO – South Coast office

Extrema in the Northeast Pacific Ocean
and their influence on Pacific salmon biology;
Analysis and Recommendations

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1 Introduction

History of Blobs

The images in Figure 1 leave one with a memorable impression of the development and evolution of the 2014 “blob” of unusually warm water that appeared in the southern Gulf of Alaska in the winter of 2013/2014 and spread eastward in the following months and years. A good technical description of its properties at the ocean surface can be found in DiLorenzo and Mantua (2016). They called it a *heat wave* because of its persistence to 2015 (and has continued through 2016).

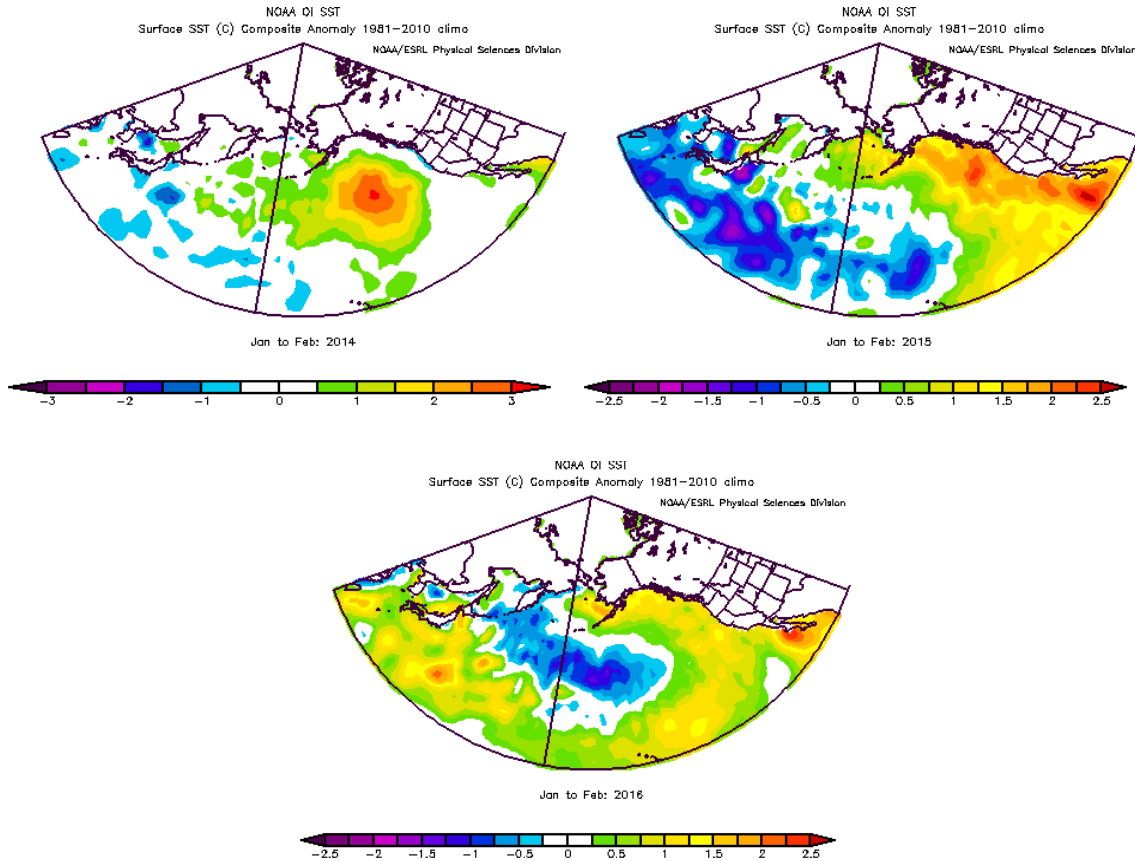


FIGURE 1: WINTER SEA SURFACE TEMPERATURE ANOMALIES IN 2014, 2015, AND 2016. THE COLOURS IN THE PANELS OF FIGURE 1 REPRESENT DEPARTURES FROM AVERAGE TEMPERATURE (°C) AND THE MAGNITUDE OF THE DIFFERENCE IS INDICATED BY THE INTENSITY OF THE COLOURS, WHICH CAN BE CHECKED AGAINST THE COLOUR BAR BENEATH EACH PANEL.

The warm blob of 2014-2016 was not entirely unique although some aspects of it certainly are. The most recent blob¹ prior to this one began 19 years ago in the spring of 1997 (Figure 2). It was of sufficient magnitude that, now as then, scientists dropped what they were doing to investigate. The PICES Science Board set aside a day-long symposium at their 1998 annual meeting in Fairbanks, Alaska for a discussion of and presentations on that event (Freeland et al. 1999).

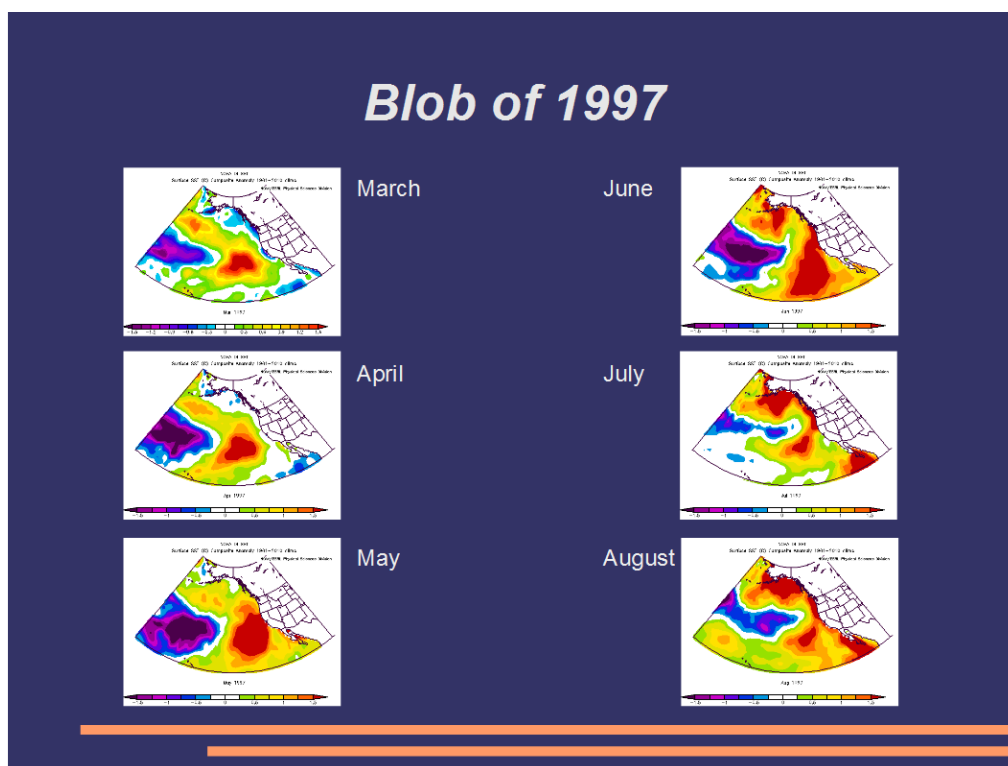


FIGURE 2: MONTHLY SEA SURFACE TEMPERATURE ANOMALIES DURING THE SPRING AND SUMMER OF 1997.

Salmon were involved then too. One of the more newsworthy events of 1997 was the straying of Fraser River sockeye salmon into rivers and streams along their normal oceanic migration route (McKinnell 2000). Toward the end of the run, maturation of some individuals had reached such an advanced stage while at sea that they abandoned their migration in favour of spawning. In several of these rivers, sockeye salmon had never been seen before. Spawning occurred but as far as has been determined, no new populations were established by the strayers. Most of the sockeye salmon made it to their destinations on the spawning grounds that year. The event was ephemeral and does not feature prominently in any of the long-term evolution of salmon fisheries or biology. As this is being written, the SST anomalies of 2016 have abated and even reversed sign, except in the Bering Sea (Figure 3).

1 It had triangular shape so it was called a triangle of anomalies.

Ten years ago, McKinnell and Crawford (2007) found statistical evidence in tree ring records and long-term temperature records that major el Niños tended to occur at slightly less than a bidecadal interval that coincided with the minima of one of the long-period tidal cycles (18.61 y). To test their idea, they published a forecast that a *major* el Niño should occur “around 2015” if their ideas about long-term variations in coastal temperatures had any substance. It was not a forecast for one of the garden variety el Niños that tend to occur at 4-7 y intervals and which has a high probability of occurring no matter what year is picked as the forecast, but a rip-roaring, equator-rattling, California-soaking, Okanagan vintage producing event, and that is what occurred during 2015/2016. What remains to be explained is why the recent event was so extreme (DiLorenzo and Mantua 2016), and perhaps why these events have been much more prominent since the mid-1970s. The next tidal cycle minimum will occur in 2034.

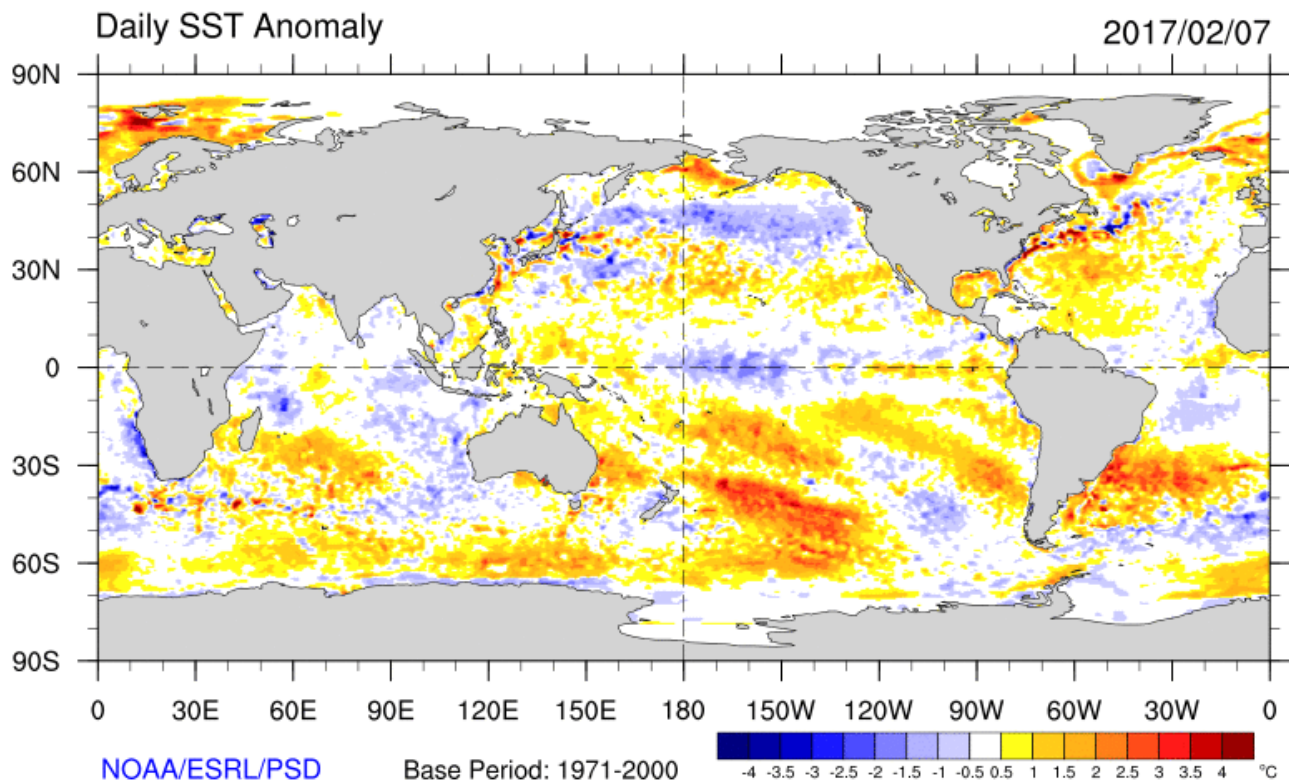


FIGURE 3: GLOBAL SEA SURFACE TEMPERATURE ANOMALIES ON FEBRUARY 7, 2017.

Extrema Project

The Extrema² Project (McKinnell 2017) examined some aspects of ocean-climate variability in the North Pacific Ocean during a recent period of environmental extremes that extended from the equatorial to the subarctic Pacific Ocean. Perhaps as a direct consequence of these extremes, some attributes of salmon

² Unprecedented events.

biology (migration timing, abundance, mean size-at-age) in the northeastern Pacific Ocean were more extreme than anything observed, if not in history, at least in prior records. A healthy skeptic's view of this coincidence is that it was just that; the joint extremes in salmon biology and in the environment were unrelated. While this may be possible, it seems rather unlikely because the coincidence happens too frequently. Historical accounts of joint environmental and fisheries extrema on the North American coast indicate that extreme events in marine ecology and climate have been connected in some way. Scientists across disciplines have documented rather diligently how extreme environmental events are associated with extreme fisheries/biological events, beginning in North America with the CalCOFI report on the consequences of the 1957/58 el Niño (Sette and Isaacs 1960), the 1982-83 el Niño (Wooster and Fluharty 1985), the 1997/98 el Niño (Freeland et al. 1999). One career might normally expect to encounter only one or two of these so the topic may not always be foremost in thinking.

With the advent of programmable calculators, microcomputers, and spreadsheets, a correlation calculation became a button waiting to be pushed. In untrained hands, it has been pushed often. “*Seldom, if ever, has thought been given to possible mechanisms of these correlations*” (Laevetsu 1983) is a sentiment that persists to the present. Progress in understanding has been made during international programs such as GLOBEC (Barange et al. 2010). The Northeast Pacific is not without its own set of correlations, some of them well known (Beamish and Bouillon 1993; Mantua et al. 1997) but their value for prognostic purposes has yet to bear fruit. The average intensity of one of these purported explanators of salmon production variability, the intensity of the Aleutian Low, has risen and fallen for 25 years without much evidence that its variation is of much value in predicting salmon production (McKinnell 2016). Nevertheless, causal forces and biological responses to those forces should indeed be correlated if that signal is stronger than other causes of variation.

The first phase of the Extrema Project sought to find environmental and biological extremes in 2015 (and in 2016 if data were available). Biological extrema appeared in both years from the Columbia River to the Yukon River but there were many populations where extrema did not occur. Most were related to some aspect of variability in the nature of salmon spawning migrations. Extremes in population abundance or escapements, on the other hand, were both high and low but the full effect of the 2015 and 2016 extrema will not be resolved fully until 2018 for species with older age-at-maturity. Most of the survivors of these ocean entry years were still at sea when this report was written. Perhaps the most newsworthy event on the entire West coast was finding that the estimated abundance of sockeye salmon returning to the Fraser River in 2016 was the lowest ever recorded since the fishery began in the 19th century. While preseason

forecasts had called for low abundance, primarily because of the cyclic pattern of abundance seen in Fraser River sockeye salmon, are return this low return was unexpected. Fishwheels on the Nass River in northern British Columbia, on the other hand, recorded highest abundances of early-run sockeye salmon and late-run chinook salmon in 2016. At Bonneville Dam, 2015 was year of record high abundance (since 1980) of large chinook salmon. More often than not, measures of average body size of salmon were normal (within 2 standard deviations of the long-term average) in the populations examined (See Illustration 1 in the Appendix). The Trophic Gauntlet Hypothesis (McKinnell et al. 2014) offers one explanation for why Fraser River sockeye salmon might experience significantly higher mortality than other southern sockeye salmon populations, but its application to extreme ocean entry years has not yet been evaluated. Not all of the Fraser River sockeye salmon populations of the 2014 ocean entry year had poor (total) survival so the differences need to be examined more closely (S. Grant, DFO, pers. comm.). Where body size extrema were found in 2015, all were small, suggesting poor feeding and/or metabolic stress (warmer temperatures accelerate metabolic rates) for at least some of the populations. There were fewer records of body size available from 2016 returns but the one extremum was also small.

There was a broad and varied range of unusual behaviours by salmon populations in 2015 and 2016. Whether they were a direct result of environmental variation in the ocean in 2015 and 2016 cannot be known for certain, but given that salmon populations have changed their behaviours in the past in response to significant changes in the ocean (McKinnell et al. 1999), environmental extrema are the likely candidate for a cause. Whether the same responses would arise from a repeat of these years is not known; perhaps in some but not others.

Salmon are subarctic animals; they do not occur in the subtropics and they are not very abundant in the Arctic suggesting that their fate in the ocean is a function of the state of the subarctic ocean. When it was last examined, subtropical oceans of the world were expanding (Polovina et al. 2008). As the area of the ocean is not expanding (apart from sea level rise), some part of the World Ocean must be contracting as the World warms and the subarctic is a logical candidate. So salmon may be the canary in the mine, but the canaries that are most affected by such changes are probably those living at the limits of the range. Placing a canary on Kodiak Is. may not be the best indicator of a slowly changing system as it lies well within the interior of salmon oceanic habitat. Likewise, the coast of the U.S. mainland may be buffered somewhat from change because the entire coast is dominated by upwelling winds. On the other hand, if change occurs abruptly, in many places simultaneously, having canaries distributed from the Yukon to San Francisco can provide clues to the nature and scope of the change.

Continuing the avian metaphor, the Extrema Project was a canary hunt but what was found was a mixture of budgies, terns, parakeets and coots; that is, considerable diversity in what was recorded, but even moreso in what data were available. An original objective of the project was to identify anomalies, describe each, and provide advice on its implications and future monitoring. Almost everywhere on the coast there was some aspect of basic salmon biology in 2015 and 2016 that was more extreme than previously observed, at least in the last 40 years. In fact, so many large anomalies occurred that the focus of the investigation was restricted to the extrema among them, and there were so many of these that the discussion and recommendations had to be general rather than specific. As the environmental anomalies that gave rise to the project were found mostly in the ocean, no attempt was made to examine the effects of terrestrial expressions of this climate event (e.g. early spring in 2015) but it would be worth exploring. Following a brief review (Section 2) of the approach used in this study, an attempt was made to evaluate common patterns where and if they were found. Section 3 attempts to evaluate the environmental and salmon extrema with a view in Section 4 to determine how the former affected the latter. Section 5 has a few key messages that emerged from the study and Section 6 provides some thoughts on where to go from here. Section 7 identifies some of the challenges to expect. Data sources and their treatment are described in Appendices 1 and 2 to the report of the first phase of this study (McKinnell 2017).

2 Data, methods, and definitions

a·nom·a·ly
əˈnäməlē/

noun: **anomaly**; plural noun: **anomalies**

-something that deviates from what is standard, normal, or expected.

"there are a number of anomalies in the present system"

Courtesy to Google for its definition

For the most part, the world view of “standard, normal, or expected” in the definition of anomaly above suggests some knowledge of what is average, calculated over some arbitrary period of time, and/or area of the globe. An anomaly is sometimes considered to be an oddity but that is not the correct meaning in the statistical sense that climate/salmon scientists might use the word. Daily experience with weather offers widespread familiarity with the concept of a statistical anomaly, for example when weathermen describe today's temperature and compare it to today's normal temperature. Years of watching weather reports

reveals that today's temperature is almost never “normal” but varies above or below and typically by a small amount. This departure from normal is the anomaly; positive when greater than normal and negative when less than normal. Occasionally, some phenomenon occurs that is very different from normal and as a consequence, the anomalies are much larger than normal. Any anomaly that is unprecedented in an historical record, is an extremum (pl. extrema) which can be either positive or negative.

The early 1980s was used as a starting point for comparison, primarily as this was the beginning of the satellite-era of global sea surface temperature observations and historical data on salmon populations tend to be rather sparse prior to this period, although there are some notable exceptions. A popular historical climate reconstruction database begins in 1948 (Kalnay et al. 1996) so searches for extrema in atmospheric temperature and pressure or winds can be span a longer period, however, evidence of climate regime shifts in these data (1976/77 for example) suggests that it makes more sense to restrict comparisons in this report to periods of variability that are relatively homogeneous. If an individual time series did not extend back to 1980, an extremum was assessed on the basis of whatever record was available. The online salmon test fishery data from the PSC, for example, begin in 2002 and relatively consistent satellite-derived estimates of chlorophyll concentration began in 1997.

Anomalies were classified as either: extrema, or normal (within ± 2 standard deviations), or strong anomalies ($> |2|$ standard deviations from the mean but not an extremum). Two standard deviations encompasses about 95% of observations in a Gaussian (bell) curve. Strong anomalies, as defined here, must be among the most extreme 2.5% negative or 2.5% positive to qualify. An extremum is simply the strongest positive or negative anomaly in the record examined, but could be less than 2 standard deviations and still be the most extreme in the time series.

Salmon model

Salmon runs in 2015 and 2016 were assessed by fitting daily abundances at fish weirs/ladders or catch-per-unit-effort (CPUE) in test fisheries to a timing/abundance model (Schnute and Sibert 1983) with parameters measuring: 1) abundance, 2) skewness³, 3) compression⁴, and 4) peak date. If only a single peak occurred in a run the Schnute-Sibert model was used. If a time series was a composite of multiple runs, the parameters for each component were estimated using a pulse model (McKinnell, unpublished) that decomposed the run into its component parts (eg. Spring, Summer, Fall chinook at Bonneville Dam) with

³ Parameter to indicate a long tail in either direction.

⁴ Parameter to indicate if the run compressed into a few days or protracted.

four parameters for each component. Each species and size-class (if distinguished) was fit to all years of data available (back to 1980) to allow the parameters estimated from 2015 and 2016 runs to be compared to historical results, to determine whether extrema had occurred in those years. Extrema, strong anomalies, and normal values were determined according to the criteria described above. A summary of the results using colour coded symbols for each run and year appears in Illustration 2 in the Appendix to this report.

Building climate indices

Salmon biology typically generates few data points per annum, like the annual number of salmon of each species passing through a fence. Environmental data on the other hand exist as time series at varying intervals (hourly, daily, weekly, etc.) and different geographic scales (1 km, 4 km, 9 km, 1° lat/long, etc.) and often everywhere on the globe. So the challenge is to reduce these data to a manageable level that will capture the main signals and allow the indices to be comparable with biological time series at geographic and temporal scales that are meaningful to salmon biology. A desirable property of an index is that it is resonant, which is to say that it represents variation in some property of nature across a broad geographic scale. One technique, among several that are regularly used for creating these indices, is principal component⁵ (PC) analysis. At a geographic grid resolution of 1° latitude by 1° longitude there are over 4,500 time series in the region used to compute the Pacific Decadal Oscillation (PDO) index⁶. Typically, the value of a PC⁷ is determined by the amount of covariation it reflects, often expressed as a percentage. The PDO index reflects about 20% of SST covariation. If it was 100%, it would mean that the PDO index reflected all of the covariation in SST in the North Pacific Ocean north of 20°N latitude. At 20%, it means that much of the covariation in SST is not reflected in the PDO index. It is also possible from the analysis to determine where the PDO has greatest influence. As the PDO is a seesaw (cooler in the west while warmer in the east and vice versa), there are two “centres of action” both of which are in the subtropical North Pacific. The Extrema Project focused on developing new indices that reflect environmental variation only in that part of the North Pacific that is used by migrating salmonids – the *salmosphere*.

Scale

Whether about salmon biology or the environment, anomaly time series can be affected by local, regional, basin-scale or global processes. To understand why any particular time series varies as it does, whether

⁵ Different scientific disciplines give different names to this method.

⁶ Mantua et al. (1997) use at 5° grid to compute their PDO index.

⁷ Called a *mode* or and *EOF* in some scientific disciplines.

it be salmon or the environment, demands attention to scale. Because of the availability of global databases⁸, it is possible to determine how resonant some ancient time series from a specific location may be. The spring temperature of the ocean at the Kains Island lighthouse on northwestern Vancouver Island, for example, is strongly influenced by atmospheric variability on a North Pacific basin scale (Figure 4). High sea level

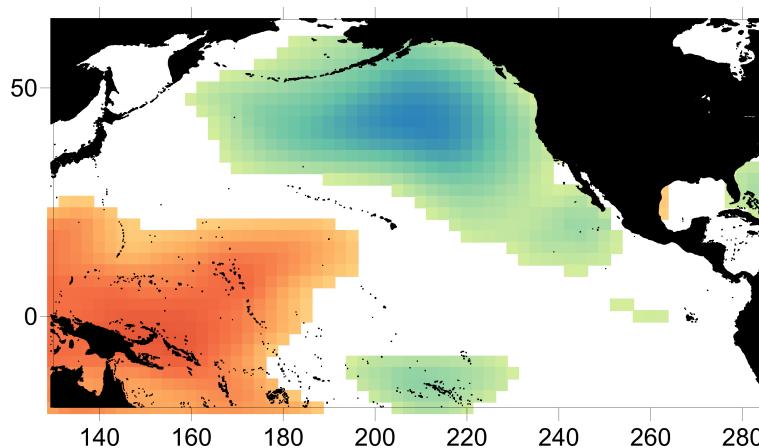


FIGURE 4: CORRELATION BETWEEN KAINS ISLAND LIGHTHOUSE SEA SURFACE TEMPERATURE IN MARCH AND ATMOSPHERIC PRESSURE (PACIFIC-NORTH AMERICA PATTERN). ONLY STATISTICALLY SIGNIFICANT CORRELATIONS ARE COLOURED.

pressure in the western tropical Pacific is associated with low sea level pressure in the Gulf of Alaska via an atmospheric teleconnection, the PNA Pattern. Their combined effect when the PNA Pattern is positive is to warm the North American coastal atmosphere which in turn warms the coastal sea surface including Kains Island. When it is negative, the Kains Is. ocean is cool. Furthermore, the PNA Pattern has such a large footprint that it can affect coastal sea surface temperatures similarly from Scripps Pier in La Jolla California to Alaska. It is difficult to imagine, but sea level pressure in March in Darwin, Australia could be used as a crude indicator of the northern diversion of sockeye salmon to the Fraser River.

Salmon data

Based largely on on-line data, Phase 1 of the Extrema Project examined run timing and abundance of 69 species/timing/stock groups by fitting a model describing daily/weekly observations of abundance. Their geographic distribution ranged from the Bering Sea to the Columbia River although there were some notable gaps in southern British Columbia beyond the Fraser River watershed. Most time series came from the Fraser (30) and Columbia rivers (12). The Fraser River has multiple test fisheries catching all species but focused on sockeye salmon (and pink salmon in odd years). Because there are two major approaches to the river, an extremum in any year may also reflect migration route rather than abundance so caution is needed when interpreting these extrema. Observations from the Columbia River were taken from Bonneville Dam. More data were available from Alaska than were used but largely because of lack of time available to download them but representative locations and species with longer histories were selected.

⁸ Largely due to the efforts of NOAA/Climate

3 Review of extrema

Temperatures

Di Lorenzo and Mantua (2016) describe what occurred in surface layer of the Northeast Pacific Ocean in their analysis of sea surface temperature anomalies (SSTa) and sea level pressure anomalies (SLPa) from 2013 to 2015. Previous studies had identified a tropical role in Northeast Pacific SLPa during the winter of 2013-2014 (Whitney 2015; Bond et al. 2015). As there is also a relatively intimate connection between SSTa and surface air temperature anomalies (SATA), this connection and its evolution through 2016 was explored in the Extrema Project. As we know what causes summer to be warm and winter to be cold in most places in the ocean, the focus of study is the anomalies. In the first phase of this project, it appeared that most of the variation in SATA in the salmosphere was primarily a result of two dominant modes of variability. The first PC (28% of covariance) is a seesaw between the eastern and western salmosphere that is correlated with the Pacific Decadal Oscillation. When this index is positive, is is warm on the North American side and cool on the Asian side, and when negative the SATA are warm on the Asian side and cool on the North American side. The second PC (24%) causes salmosphere-wide warming when positive or cooling when negative across the region. Canonical correlation analysis (not shown here) indicated that both of these atmospheric patterns are needed to describe the dominant pattern of variation in SSTa within the salmosphere.

Air Temperature and Sea Level Pressure

By examining how SATA are related to SLPa throughout the Pacific Ocean (e.g. Figure 5), which are largely responsible for the wind anomalies in the North Pacific, it is apparent that the east/west seesaw mode in SATA has a global connection that is related to a large-scale atmospheric pattern in the Pacific that spans both hemispheres (Figure 5). Low SLPa in the eastern equatorial Pacific and the subarctic North Pacific are associated with higher SATA in the eastern salmosphere (Gulf of Alaska) and cooler temperatures in the western North Pacific (Asian side). SATA PC2 is associated with warming (when positive) or cooling (when negative) everywhere in the salmosphere, but is restricted to SLP variations within the northern hemisphere (Figure 6). When the Subtropical High Pressure system over Hawaii is weaker than average and the northern Gulf of Alaska has higher than average SLP, PC2 of SATA tends toward warming in the entire salmosphere. This pattern resembles the North Pacific Oscillation (Walker 1924), first described as an SLP seesaw between Alaska and Hawaii. Sometimes these two SATA modes are in phase and sometimes out of phase. A key point is that the connection of the salmosphere to the global climate system is needed to understand the nature of variability that is seen locally.

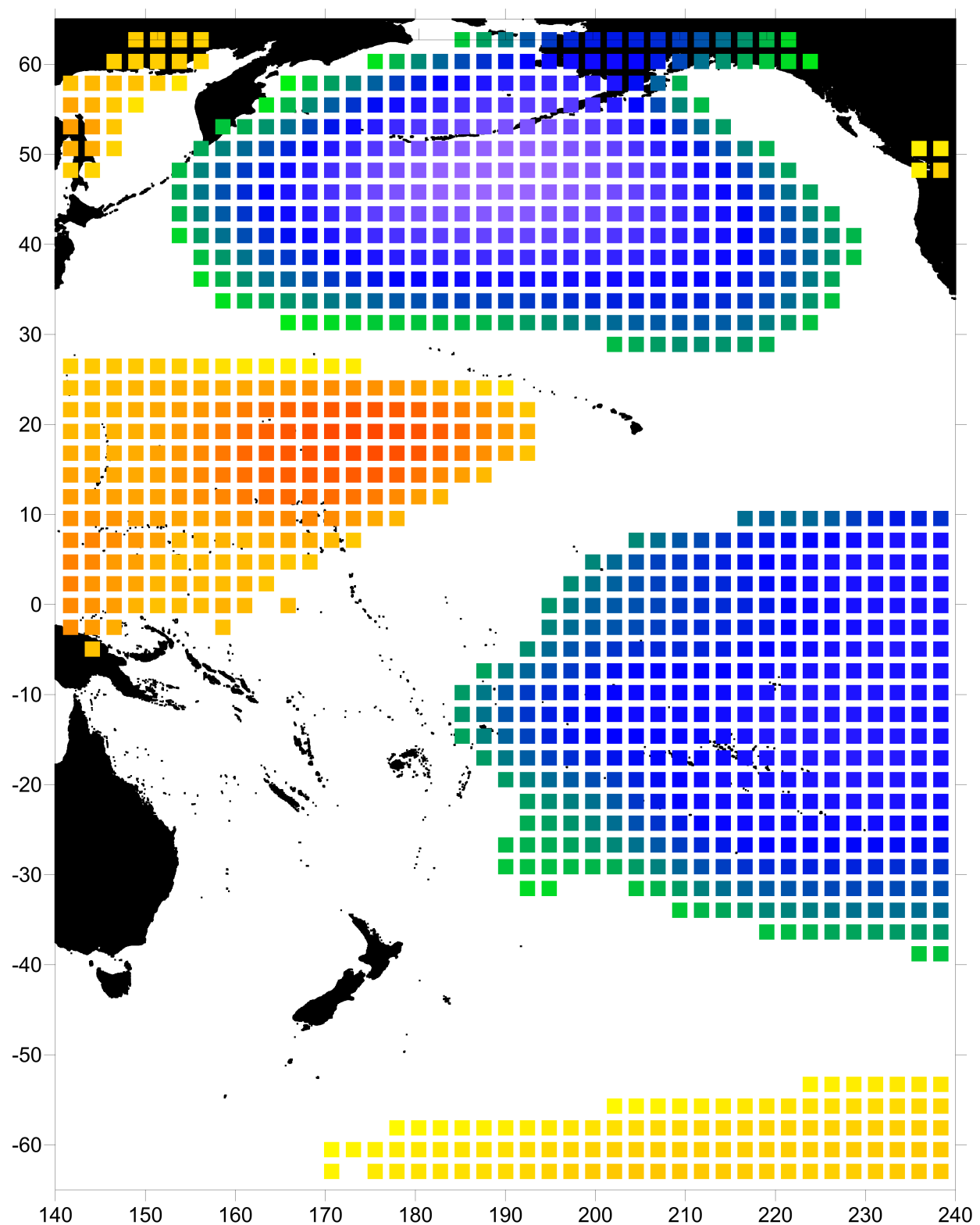


FIGURE 5: STATISTICALLY SIGNIFICANT CORRELATIONS BETWEEN PC1 OF SURFACE AIR TEMPERATURE IN THE SALMOSPHERE (THE SEESAW MODE) AND SEA LEVEL ATMOSPHERIC PRESSURES IN THE PACIFIC OCEAN. STRONGER REDS ARE HIGHER POSITIVE CORRELATIONS AND STRONGER BLUES ARE STRONGER NEGATIVE CORRELATIONS. THE RANGE OF CORRELATIONS IS -0.5 TO $+0.5$.

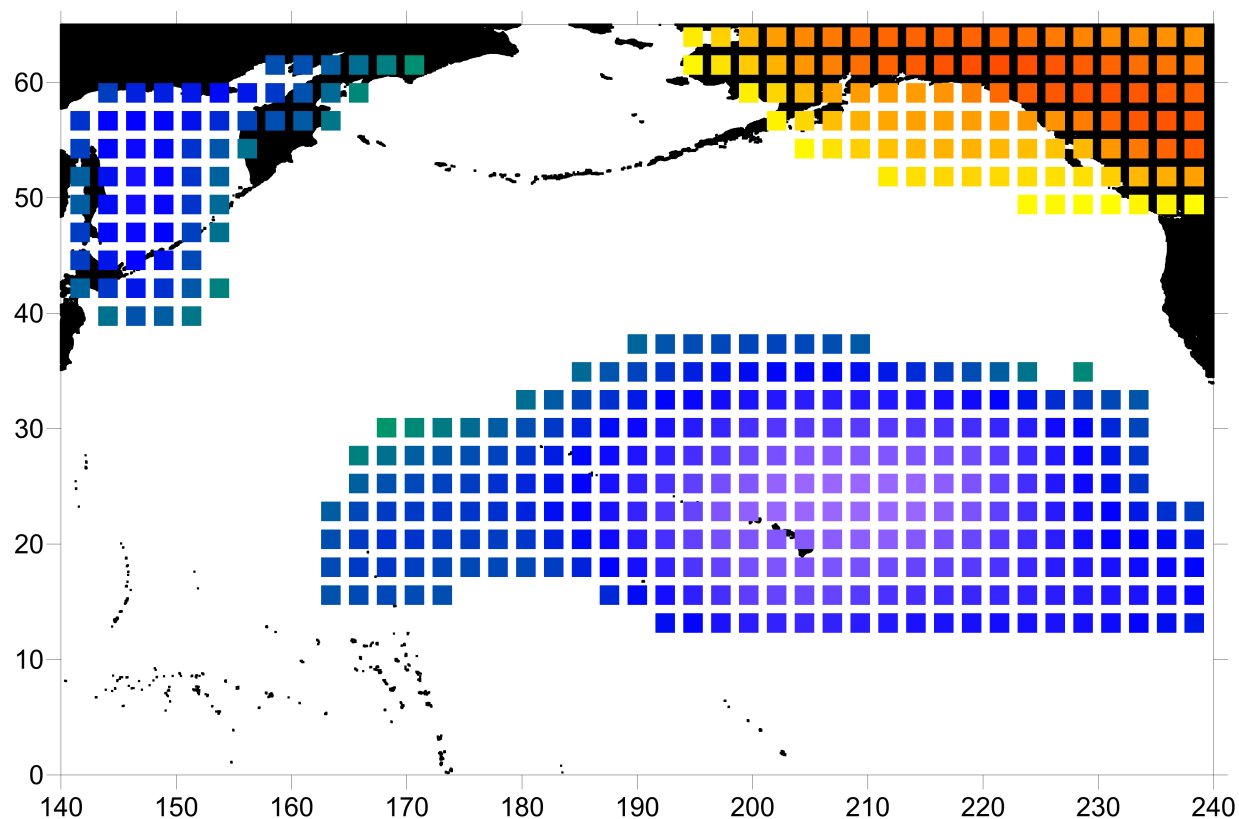


FIGURE 6: STATISTICALLY SIGNIFICANT CORRELATIONS BETWEEN PC2 OF SURFACE AIR TEMPERATURE IN THE SALMOSPHERE-WIDE MODE AND SEA LEVEL ATMOSPHERIC PRESSURES IN THE PACIFIC OCEAN NORTH OF THE EQUATOR. STRONGER REDS ARE HIGHER POSITIVE CORRELATIONS AND STRONGER BLUES ARE STRONGER NEGATIVE CORRELATIONS. THE RANGE OF CORRELATIONS IS -0.5 TO $+0.5$.

When the two major SATa modes are in phase and positive, as they have been since 2013, the Gulf of Alaska, the eastern Bering Sea, and the State of Alaska tend to be warmer than average. By selecting only those months when both modes are $> +1$ s.d. and plotting them by year, some regular patterns are evident (Figure 7). The first is that the joint positive anomalies are always associated with years of el Niños, and primarily the larger ones: 1957/58, 1986/87, 1991/92, 1997/98, 2002/03, and 2015/16. A second feature is that the number of months in each event is not directly related to the strength of the el Niño, as measured by contemporary ENSO indices. For example, the 1982/83 el Niño is not included in this collection or years, primarily because air temperatures were generally cooler in the salmosphere during that event. Thirdly, the occurrences of these jointly high values are not tightly restricted to the winter of the el Niño but span a period of one or two years before/after the el Niño, except for 1997 when all months occurred in that one year. Finally, the number of months in each event after 1997 has increased, but the time series is too short to know whether this is a trend. In conclusion, many el Niños energize both modes which leads to a warmer subarctic.

While this is not a new result, it is noteworthy that the warm temperatures appears to have arisen from existing modes of variation rather than some new pattern. The intensity recently was novel and is as yet unexplained (DiLorenzo and Mantua 2016). The oceanic temperature extrema seem to have arisen from an enhancement of two existing pre-dominant modes of SATa variability, one global and one hemispheric in scale. When the two modes are positive, as recently, they are associated with a generally warmer northeastern Pacific region.

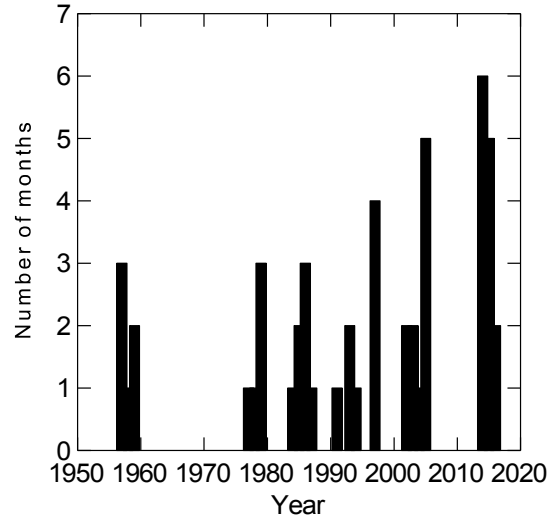


FIGURE 7: NUMBERS OF MONTHS, BY YEAR, WHEN THE DOMINANT AND SUBDOMINANT MODES OF SATa VARIATION JOINTLY EXCEED $+1$ STANDARD DEVIATION.

Sea Surface Temperatures

The most extreme sea surface temperate anomalies (SSTa) were located in the Bering Sea, far from the iconic image of the blob. This implicates the atmosphere as the cause rather than ocean circulation. The time series in Figure 8 is taken from a principal component analysis of weekly SSTa in the Bering Sea. It reflects SSTa throughout the Bering Sea in a single index, with positive values being generally warm and negative values being generally cool. It shows that the recent warm episode was similar in duration (to date) as a similar period that occurred in the first half of the decade of the 2000s, but the recent spikes of nearly 4.5 s.d. were far greater than found in a similar analysis of the entire salmosphere, or the continental shelf SSTa. The spikes in the Bering Sea occurred primarily in the warm season (none in winter) and were more frequent in 2014 and 2016 than 2015.

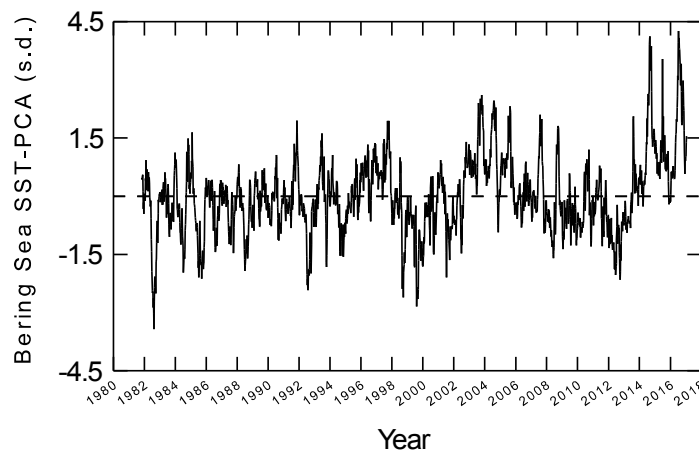


FIGURE 8: PC1 OF WEEKLY SEA SURFACE TEMPERATURE ANOMALIES IN THE BERING SEA FROM NOV 1981 TO JAN 2017.

Biological oceanography and juvenile salmon indicators

Since the late 1990s, oceanographers and salmon biologists from Alaska to California have been surveying the continental shelf and meeting annually to review the state of the coastal ocean and the state of the juvenile salmon found there. This coastwide interaction of researchers has led to a better understanding of the interaction between the environment and the salmon that live there by facilitating regional comparisons (Grimes et al. 2007). The region with the most anomalous phytoplankton and zooplankton anomalies was the U.S. West coast where salmon habitat indicators for the months of June in 2014, 2015, and 2016 were among the lowest in a 19 year record.

“Locally, strong upwelling winds kept the Blob offshore of Oregon during summer 2014, but by mid-September, winds relaxed and the Blob flooded continental shelf waters with anomalously warm tropical/subtropical water. This resulted in a complete replacement of the “cold water, lipid-rich” food chain with a “warm-water, lipid poor” food chain. By winter (Jan-Mar) 2015, the SST pattern across the Pacific resembled the positive PDO pattern and this SST pattern continued through all of 2015 and 2016.” (<https://www.nwfsc.noaa.gov/research/divisions/jc/estuarine/oeip/latest-updates.cfm>)

Typically, large-scale phenomena that give rise to warmer than average spring ocean temperatures along the North American coast are not favourable for the survival of juvenile salmon, as in 1998 and 2005, at least in the southern part of their range (up to Queen Charlotte Sound). From the results obtained to date in Bonneville Power Administration trawl surveys in these years, salmon survival on the U.S. West coast has been lower than average from the 2014 ocean entry year, as is typical in warmer years, but survival has not been as extreme (low) here as the habitat might suggest (Figure 9). In part, this may be due to a later arrival of the warm water along the Oregon coast. Upwelling winds could easily have kept a thin surface layer at bay until they abated.

Off the coast of British Columbia, in 2014 at least, coho salmon survival was as bad as the habitat

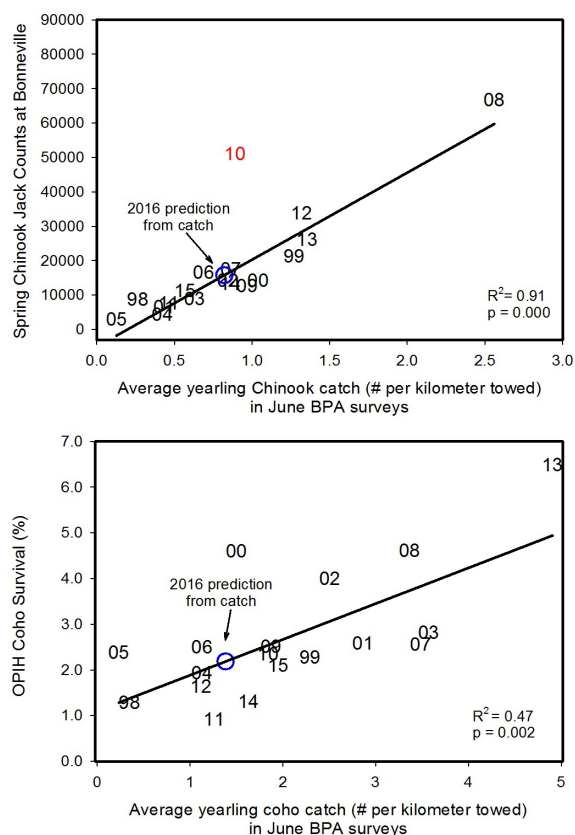


FIGURE 9: RELATIONSHIPS BETWEEN JUVENILE COHO SALMON ABUNDANCE IN JUNE IN BPA SURVEYS AND HATCHERY COHO SALMON SURVIVAL (BELOW) AND JUVENILE CHINOOK SALMON ABUNDANCE IN THE SAME SURVEYS AND SUBSEQUENT RETURNS OF AGE X.2 CHINOOK SALMON TO BONNEVILLE DAM. (NOAA/NWFSC)

indicators might have suggested (Figure 10). The 2014 smolt year in southern British Columbia had the lowest average survival in 30 years (S. Baillie, DFO unpublished). Surprisingly, juvenile coho salmon growth in 2014 was the highest ever recorded since the 1990s, perhaps because there was no competition among the few survivors.

Growth in 2015 was also above average. In spite of two years of poor large-scale and local habitat indicators, growth was good (Chandler et al. 2015, 2016) but survival was not. A local wild population (Carnation Creek) on the

West coast of Vancouver Island had the second lowest marine survival (0.3%) in the 2014 smolt year in a series that dates back to 2001 smolt year. Perhaps the coastal upwelling zone on the US. West coast provides a type of refuge that is not available to coho salmon in British Columbia.

A similar survey approach has been used in SE Alaska (Icy Strait survey) as the basis for developing a forecast of harvests of pink salmon in subsequent years. In 20 years of juvenile salmon surveys, the 2015 harvest arising from the 2014 ocean entry year, was the first significant overforecast of an odd year run in the history of the time series. The harvests in 2016 followed suit (Figure 11). Returns of pink salmon to the Fraser R. in 2015 were also much lower than expected (Fraser Panel News Release #10, 2015).

Adult Salmon

In the time available for this study, the more biological aspects of salmon extrema were given greater prominence than the commercial aspects (catch) although a better result might have been had if the two were integrated. Environmental extrema have a potential to affect body growth and size-at-maturity, age-at-maturity, migration timing, etc., so examining these properties across broad geographic scales can lead to a better understanding of how salmon currently use the ocean in the face of widespread environmental influences. The key results were summarized in Figures 1 and 2 of McKinnell (2017) and these figures are reproduced in the Appendix to this report. What is apparent by the prevalence of non-yellow colours in these figures is that salmon were either behaving very differently and/or were more or less abundant in 2015 and 2016 than in previous years⁹ but the degree of abnormality varied from place to place. Across all 69 time series that were examined, there were 18 abundance extrema in 2015 (10 high) and 16 in 2016 (7 high). In both years, it appeared as though there was a mixture of highs and lows, but given the ocean ages

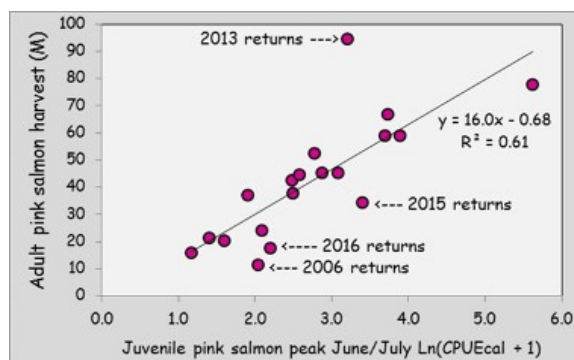


FIGURE 11: SE ALASKA PINK SALMON HARVESTS IN RELATION TO JUVENILE PINK SALMON CPUE DURING THE PRIOR YEAR. SOURCE: [HTTP://WWW.AFSC.NOAA.GOV/ABL/EMA/EMA_PSF.HTM](http://www.afsc.noaa.gov/ABL/EMA/EMA_PSF.HTM)

⁹ Where data are available to make a comparison.

of some of the migrants, there is a non-trivial probability that the cohort size was established before the oceanic extrema had a substantial influence on the salmosphere. The Columbia River had but one extrema in 48 parameters in 2016 despite being the southernmost river examined. Extrema there in 2015 tended to be the occurrence of highest abundances, but for species whose cohort size was likely established before the onset of the major oceanic anomalies in the salmosphere. Baker Lake and Lake Washington sockeye salmon showed similar results. Moving northward, the first strong anomaly in timing occurred with sockeye salmon at Long Lake (Docee River fence) with an early peak date in 2016 but not in 2015. On the other hand, the peak date of Skeena River sockeye at the Tyee test fishery was a late extremum, but fisheries seaward could have affected the shape of the run. The Nass River went from low abundance extrema in 2015 to high abundance extrema in 2016 for sockeye and chinook salmon, but a low extremum of coho salmon in 2016. Timing of the pink, chum, and chinook salmon populations in the Yukon River drainage was not extreme in 2015 but three different outcomes occurred in 2016: early (chinook), normal (summer chum), and late (fall chum and pink) extrema.

The Fraser River seems to be the oddity. Abundance/timing model results involved 4 parameters, 15 years of test fishery data, and 15 fishery-taxonomic-size combinations found numerous extrema in 2015 and 2016 at the test fisheries on the approaches to the Fraser River. If the extrema had all occurred in one year, there was a theoretical maximum of 60 that could be either minima or maxima. Therefore there should be 120 extremes (a minimum and a maximum for each combination of species and fishery) to be distributed somewhere among the 15 years (2002-2016) of data, or an average of 8 extrema per year based on chance, or 16 extrema in any two years. The results found that the total number of model parameter extrema in the two years of 2015 and 2016 was 52. Even a “chi-by-eye” suggests that something substantially non-random occurred in those two years. Despite the high number of extrema, there were more “normal” parameters (within ± 2 s.d.) in those years than extrema or strong anomalies.

In 2016, all species in the Fraser River had at least one extremely protracted migration in one of the four test fisheries. Likewise these extrema appeared at least once in all test fisheries in 2016. The only other protracted run extrema was in the Nass River (late run chinook). All peak date extrema were early, with the exception of steelhead trout which were late extremum (Round Is. only). All run size extrema in 2016 were low: coho, steelhead, large chinook, small and large sockeye salmon, depending on the test fishery. There were no high abundance extrema in 2016. In 2015, all abundance extrema were low in the San Juan gillnet test fishery, but high in the San Juan seine test fishery. This suggests a timing event because the gillnet fishery precedes the seine test fishery, but none of the peak dates were extrema so more likely, it reflects

abundance in Juan de Fuca. Some of that low abundance would be due to extreme northern diversions, at least for sockeye and pink salmon, in 2015. Rather than the protracted runs that had occurred during 2016, most of the migration extrema in 2015 had highly compressed runs.

In 2015, the returns of pink salmon in Prince William Sound and further west were good but they weakened toward the southern end of the range of the species (A. Wertheimer, pers. comm.). Low returns in 2016 in northern SEAK (Inside) were due in part to very low escapement in 2014, but the outside populations had better escapement in 2014 yet it resulted in low returns in 2016. In 2016, however, runs were poor from northern SEAK along the Gulf of Alaska to Prince William Sound and Kodiak. The spatial scale of these salmon anomalies almost exactly matched the SSTa in the winter before they went to sea (Figure 1). The full effects of environmental extrema in 2015 and 2016 on sockeye, chinook, and chum salmon and steelhead trout abundances will not be known with any certainty until the 2017 and 2018 returns.

4 Consequences

The occurrence of extrema in the salmosphere is not novel. For much of the 20th century, they came and went with little thought to their persistence. The last 50 years of experience suggests that that view needs to change but not necessarily because of blobs. In 1978, when the northern diversion of sockeye salmon returning to the Fraser River reached about 80%, it was considered as a simple anomaly as had occurred in 1926, 1936 or 1958 but then largely forgotten. It occurred to none in the late 1970s that the northern diversion would not return to average historical levels. The coincidence of the change in migration with a major shift in the climate system in 1977 eventually drew attention to the idea that large-scale physical forces were affecting at least some aspects of salmon biology (Hare and Francis 1995; McKinnell et al. 1999).

Human responses to such findings will range from indifference to high anxiety depending on whether the occurrence of extrema are perceived as beneficial or detrimental to interests, immediate or long-term, in some aspect of the resource. At issue is a need to understand how, and how quickly the salmosphere is changing. Most climate projections of the IPCC¹⁰ show relatively smooth transitions from now into the future and all involve warming. Because of inherent variability, some of it random, in the observations of salmon made each year, the general consequences may not be understood without having a relatively broad view of what is occurring on the coast.

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A new scientific imperative has emerged; to determine whether any strong anomaly is simply an extreme of random variation about a long-term average, or whether the anomalies of the kind observed recently in the Northeast Pacific, are the beginning of some new state of nature from which future anomalies should be calculated. The actions taken by managers now, in response, will have greater or lesser influence on the resource depending on which type of anomaly is occurring. There are recent examples that we are not yet very good at distinguishing one from the other, at least in a timely fashion.

Within living memory of some¹¹ there was an abrupt and persistent reduction in abundance of coho salmon in the Strait of Georgia (and Puget Sound). Abundances plummeted in the early 1990s, have never recovered, nor has a cause has been identified. The collapse was first reported (in Canada) by a scientist working in the Cowichan River (Holtby 1993) who attributed the cause of rapidly declining abundance, accurately as it turned out, to declining smolt survival rather than fishing. Response to this news was “*we need more details re specific, testable hypotheses*” (Humphreys et al. 1994) which was followed shortly thereafter by a request to scientists to reconsider the data to determine whether an increase in coho salmon exploitation was warranted, despite of growing evidence that the change in abundance was widespread and trending downward (Kadowaki et al. 1994). The response time to take management measures that were commensurate with the magnitude of the collapse of coho populations was about 5 years (almost 2 coho generations), and a change of Minister. Lack of experience with a simultaneous collapse of many populations was likely one of the reasons for the slow response. One hopes that in the 21st century, we have become more aware of the idea that fundamental changes may persist. The implications for future salmon production, management, forecasting and other needs depend on two things: 1) understanding the difference between an anomaly and a regime change, and 2) understanding the consequences for salmon of whatever the novel state of nature might be. A warmer ocean, especially in the south, has never been good for salmon survival. Global climate models are not predicting ocean cooling.

It was not possible to understand the full effects of environmental extrema on salmon species that spend more than one year in the ocean because these cohorts have yet to return to spawn, but coho salmon, pink salmon, and small sockeye salmon spend only one year at sea before maturing. In the Fraser River test fisheries, where coho salmon are caught incidentally, there were no extrema in coho salmon catches in 2015 (2014 ocean entry year) even though it was the year of worst average survival generally in southern British Columbia. On the other hand, two of four of these test fisheries had low abundance extrema for coho salmon in 2016. Fraser River pink salmon abundance in 2015 was much lower than expected (but not an extremum) but their mean body weight was the smallest in a record that dates back to 1959. Puget Sound

11 The author had just been appointed Chairman of the DFO PSARC Salmon Subcommittee during this era.

coho salmon were also small and in low abundance in 2015 (L. Weitkamp, NOAA/pers. comm). Because pink salmon and coho salmon mature after only one year at sea, their migrations do not extend far offshore. Sharing an ocean environment with insufficient prey could explain coincident anomalies in different species. Historical high seas tagging suggests that Fraser River pink salmon and Southeast Alaska pink salmon shared the same ocean habitat (50 years ago) but there were no body size extrema in SEAK pink salmon. Whether they share a common environment in the 21st century is unknown but the lack of synchrony in mean weight in 2015 suggests that they were not in the same oceanic environment. For longer lived species such as chum, sockeye, and chinook salmon and steelhead trout, the full effects of environmental extrema in 2015 and 2016 on abundances are not yet evident because oceanic anomalies tend to be more important for juvenile salmon than for maturing salmon. The low abundance extremum in small sockeye salmon catches in Fraser River test fisheries in 2016 may be telling. Generally, in the south there is no reason to expect that warm anomalies in 2015 and 2016 will translate into positive outcomes for returns. At one time, there was an idea that the productivity of salmon populations had a north-south seesaw; low (high) in the North while high (low) in the South (Mantua et al. 1997; Hare and Francis 1995) but this idea does not appear to hold in the 21st century.

The current study has focused on covariation of salmon extrema in extreme years. Understanding the scales of variability will help to determine the scope and nature of monitoring for change. In the populations examined to date, biological extrema in salmon populations were widespread, but the responses were not consistent between the years examined nor among populations. Some consistencies among species and test fisheries were found within the Fraser River. In part, the differences in salmon responses between 2015 and 2016 may have arisen because the nature of the environmental conditions differed between years, with 2015 following the year of the blob then leading into an el Niño and 2016 feeling the brunt of the el Niño before tailing away in the autumn from its major effects. SST extrema were more abundant in the Gulf of Alaska in 2016 than the preceding years.

5 Key messages

Although it is always difficult to generalize about salmon, a few key messages seemed to emerge from this study:

- The ocean-climate events of 2014-2016, although extreme in the instrumental records and widespread in the salmosphere, are likely to be ephemeral if this event is similar to what occurred in 1997/98. It came and went without leaving permanent effects either positive or negative on

most salmon populations. The next one should occur around 2034.

- Where widespread changes (declines) in survival have occurred, as in salmon associated with the Salish Sea, they began in the early 1990s and have persisted to the present. These are fundamental changes that are not well understood but have lasting consequences.
- Extreme responses by salmon to ocean-climate extrema in 2015 and 2016 were coastwide and diverse but varied among species and region. Some runs were the most abundant during the years studied and some were the least abundant. More often than not, the salmon anomalies were in behaviour as they navigated their way around the novel environment.
- Evidence of late-life mortality in salmon in the sea is relatively rare. Most of what occurred in the last few years would have affected the juvenile salmon. Those with longer oceanic lives have yet to “show their hand.” We have already seen the effects on pink salmon and coho salmon as they live only one year at sea. Southeast Alaska pink salmon have been much below forecast for two years, as was the case for the 2015 return to the Fraser River. Furthermore, the region-wide survival of coho salmon in southern British Columbia was the lowest on record for the 2014 ocean entry year.
- On a more practical note, assembling a coast-wide perspective on ocean-climate environmental variation and even developing new indices tailored to the salmosphere was easy. Doing the same for salmon biology was not. The main difference is that agencies responsible for the former have committed to collecting, organizing and distributing standard data products online to a diverse set of clients in different regions/countries. It requires an interagency commitment that has yet to occur in salmon biology, and may not be necessary if regional comparisons are not needed.

6 Moving forward

If salmon populations responded to extreme environmental conditions independently, and did so in unpredictable ways, there would be little value added with a coast-wide monitoring program. Marine survival of coho salmon has shown that in some cases, populations in entire regions can vary coherently but the only way this was known was to monitor coho salmon populations at a scale that could detect the pattern. The recommendations are offered with the assumption that the Commission is not getting the broad-scale perspective that it may wish to have and is interested in developing a coast-wide view of the salmon resource as it emerges each year.

1. The Commission needs a ***Salmoscope*** that would allow any Commissioner, or anyone with an

interest in salmon to understand, at the press of a button, how salmon returns are developing coast-wide, in-season. For example, imagine the figures at the end of this report as a computer screen that is updated daily, without requiring human intervention, that will identify strong anomalies (positive or negative) or extremes and issue alerts on these on a day to day basis.

2. The Salmoscope will require a Salmon Data Network (SDN) to facilitate the collection, organization, and dissemination of data from observing locations across international boundaries with the intent of increased understanding of the state of the resource. An expert group should be formed to design a network system that will provide real-time access to salmon data coast-wide, in-season. In the 21st century, it is technically feasible for a datum to be entered (once) into a computer on the SDN and served immediately to a global community. Impediments to developing such a system are not technical.
3. The Salmoscope will require at least two national salmon data servers offering identical data in identical formats that do not require human intervention to obtain (as is currently the case) and non-proprietary software must be the primary format. There are precedents in the climate and oceanography communities. Project Argo, for example, serves identical data from redundant servers in France and the United States. An expert group, perhaps working in concert with the SDN expert group, should be formed to advise on what data to serve in what format from what locations. There will be a need for a Salmon Data Archive (SDA) to serve as a repository for historical data, presumably served by the same servers.
4. The Salmoscope will require an expert group to design the Salmoscope around information needs of major clients by determining what needs to be seen to understand coast-wide, or regional phenomena.
5. The Commission should invest in the development of technologies to speed up the timeliness of obtaining salmon data. For example, in the 21st century it has become possible because of innovation to know today's depth of the ocean mixed layer, its heat content and salinity anywhere in the World Ocean without sending a ship to sea. Salmon biology needs equivalent scales of innovation to address the basic problem of getting an understanding of what is happening to salmon populations. We need to know the age of a fish when we catch it, not next November. It would be useful to know how it has been growing when it is caught, not waiting 5 years to apply for a grant (several times), to eventually learn how something grew 10 years ago. These kinds of advances will require automation that will only come from innovative thinking and a commitment

to improving the life of a salmon biologist. An expert group might be formed to identify areas where technical advancements are required and to set priorities on which challenge to address first.

6. After the expert groups have done their work and reported to the Commission, say in 3 years, implement the vision with a small pilot project of about half a dozen rivers (with willing participation) to understand feasibility and issues associated with delivery of the system. More rivers and sites can be brought on-line once the bugs have been worked out.
7. Environmental indices should be developed for the Salmoscope that reflect environmental variation broadly across the salmosphere, and regionally as appropriate, with a view to determining their predictive value for various aspects of salmon biology.
8. As a general rule, a census of salmon abundance should be taken as late in (a salmon's) life as is practical but before substantial fishery removals occur. If taken at or near the time when the juveniles enter the sea, some division of mortality between freshwater and marine sources is possible. There is little doubt that prior knowledge of spawner abundance has value: preparing for fisheries, as an indicator of management success, and as a basis for predicting future returns. Concerning the latter, the worst (easiest) time in the life history of salmon is a census made on the spawning grounds, while the best (most difficult) time for census of spawner abundance is made just prior to a fishery.

7 Challenges

Where they exist, a variety of data systems have been created by agencies to report in-season abundance of adult salmon. Presumably, they are meeting the needs of local users of the information but if they are not, now would be a good time to expand the dialogue to include those who wish to have a broader perspective on the resource. It is not currently possible to compare, even retrospectively, annual salmon runs along the North American coastline without significant human “intervention” in the process. It is not currently possible to compare runs in real-time within a season. Both are technically possible but there are impediments to progress that will take vision, leadership and time to overcome.

1. Currently, no person, entity, or organization has a responsibility, authority, and resources to obtain and serve salmon data coast-wide.
2. Data serving culture is not well established. Where exceptions, all use different approaches. There is no vision for how to organize salmon data to serve a coast-wide perspective.

3. No coast-wide data standards.
4. Limited access to parameters other than abundance or relative abundance. It is not possible, for example, to determine whether a brood year is “missing” from a run of multiple age-classes. This would be evident if salmon could be aged quickly. The extent of any anomaly could be understood if multiple rivers were examined.
5. Data access
 1. Finding the data; there is no online catalogue of coast-wide salmon data.
 2. When online sites are found, the effort required to get the data varies from site to site.
 3. Without exception, all online salmon data required human intervention to obtain, sometimes involving multiple steps. It is impossible, for example, to analyze salmon data reported in a pdf file, or displayed on a website without reformatting.
 4. If data were available to download, sometimes it was stored in a proprietary software format (eg. Excel) that is not readable by other kinds of software.
6. Weak history of innovation in salmon biology

While there have been some notable exceptions, such as the development of genetic stock identification techniques, obtaining the basic biological information about salmon has not changed much since Gilbert started his program in 1914. Salmon biologists need counts, length, weight, age, and sex to begin to make sense of what they are observing. This minimal set of measurements is rarely met in most sampling programs.

8 Acknowledgements

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10 **About the Author**

Dr. Stewart (Skip) M. McKinnell [B.Sc. (Zoology, with distinction) UVIC, Ph.D. Sveriges Lantbruksuniversitet] began his career in marine science in 1979 as an oceanographic technician (UBC) serving on a coastal tanker in British Columbia before taking over as head of scientific computing at the Pacific Biological Station for 10 years. Beginning in 1989, he lead Canada's high seas research into the effect of large-scale driftnet fishing by Asian fisheries in the North Pacific. After the United Nations moratorium on this type of fishing was achieved, he served as Chairman of the DFO PSARC Salmon Subcommittee for two years and started the Atlantic Salmon Watch project to understand the fate of Atlantic salmon escapees from salmon farms. His Ph.D. described the interplay between Atlantic salmon biology and fisheries in the Baltic Sea. He was the first lead author of DFO's Wild Salmon Policy before leaving DFO in 1999 to take a position as Deputy Executive Secretary of the North Pacific Marine Science Organization (PICES) located at the Institute of Ocean Sciences, Sidney, BC where he worked for 15 years. Some of that time was spent as Editor-in-Chief of two international reports on the state of marine ecosystems of the North Pacific Ocean. He contributed to the 5th Assessment Report of the United Nations Intergovernmental Panel on Climate Change. While at PICES, Dr. McKinnell was lead author of an invited report to the Cohen Commission on the relationship between marine ecology and Fraser River sockeye salmon and the cause(s) of their decline, their extremely low abundance in 2009, and extremely high abundance in 2010. This work led to the Trophic Gauntlet Hypothesis for Fraser River sockeye salmon marine survival. He is an author or co-author of 50 primary publications and editor of a dozen special issues in the primary literature. He has written 75 technical reports on various fisheries and oceanographic subjects. He left PICES in 2014 to work as an consulting salmon oceanographer and in 2017 became master and commander of a personal research vessel, *R/V Gauntlet*.

11 Appendix

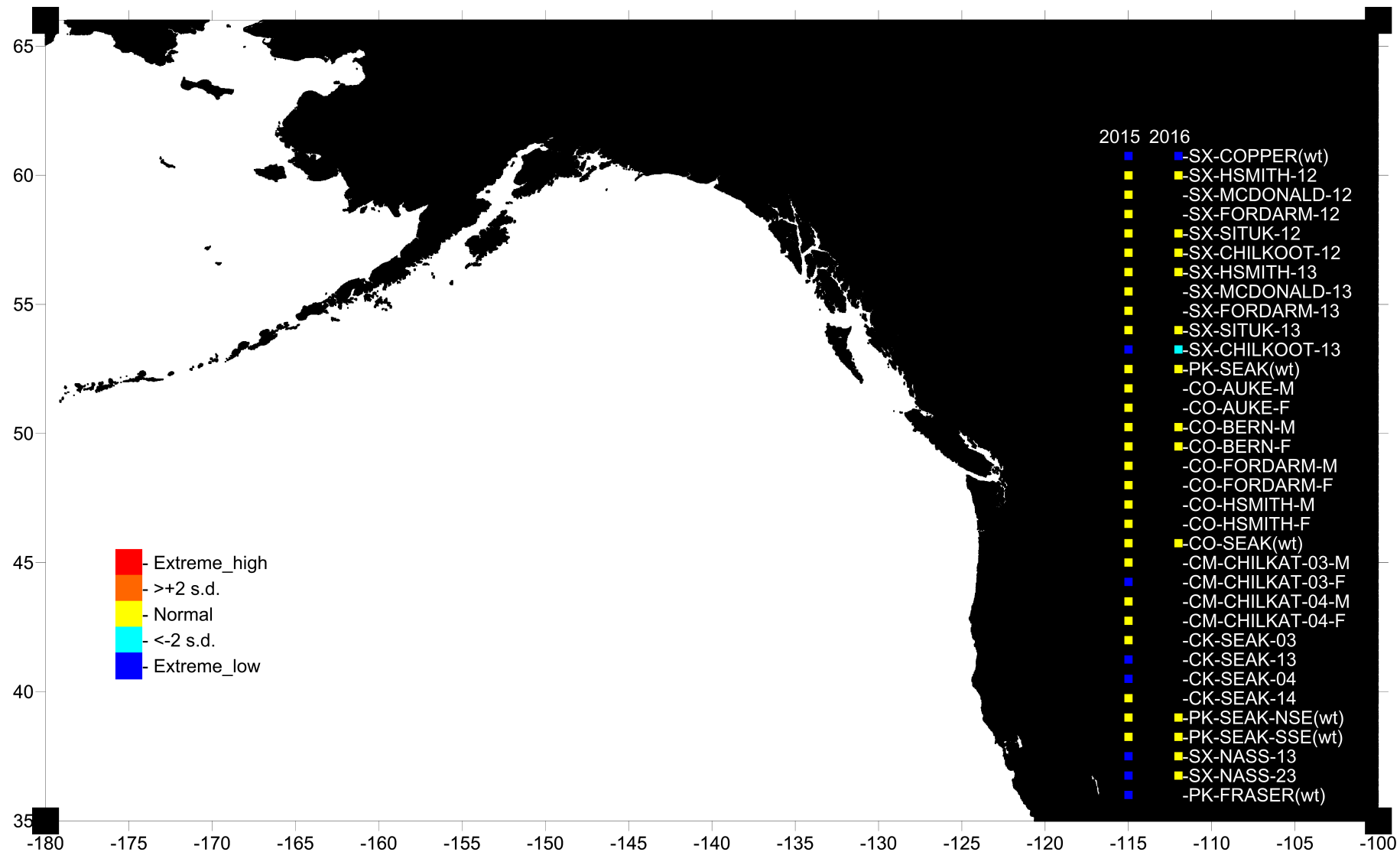


ILLUSTRATION 1: ANOMALIES AND EXTREMA IN MEAN SIZE AT AGE IN 2015 AND 2016; MOST ARE MEAN LENGTH BUT MEAN WEIGHT IS INDICATED BY (WT) IN THE LABEL. SX-SOCKEYE, PK-PINK, CK-CHINOOK, CO-COHO, CM-CHUM, SH-STEELHEAD. AGE-AT-MATURITY INDICATED AS TWO NUMERALS X.Y WHERE X-NUMBER OF FRESHWATER ANNULI AND Y-NUMBER OF OCEAN ANNULI. TOTAL AGE IS THEIR SUM+1 AS THERE IS NO ANNULUS FORMED DURING THE FIRST WINTER IN FRESHWATER (AS AN EGG).



Report of the Standing Committee on Finance and Administration February 17, 2017

The Standing Committee on Finance and Administration met on several occasions throughout 2016 (on September 29, October 6, and December 12), as well as 2017 on January 12 (Post-Season Meeting), on February 6, and on February 16 (Annual Meeting). The Committee addressed a number of issues and made recommendations for the Commission's consideration as noted below.

Budget proposal for FY 2017/2018 and forecast through FY 2019/2020

The Committee reviewed the proposed budget for FY 2017/2018 and forecast budget for FY 2018/2019 and 2019/2020. It was agreed that certain costs (Test Fishing Manager's partial salary, seasonal test fishing field staff, and shipping) would be permanently re-incorporated into the ordinary budget, after a temporary allocation of these to test fishing budgets from 2014 to 2016.

Accordingly, the Committee recommends that the Commission adopt the proposed budget for FY2017/2018 as shown in Attachment 1.

Unfunded pension liability

In 2015, the Parties worked with the Secretariat to identify supplementary funding for FY 2016/2017, 2017/2018 and 2018/2019 to mitigate the unfunded pension liability and relieve budgetary pressure on the Commission. To date, Canada has contributed \$330,000 (\$110,000 for each of the three years), while the U.S. has contributed \$110,000 for FY 2016/2017. The U.S. has been invoiced \$110,000 for FY 2017/2018.

The next actuarial valuation of the pension will be made available in April 2017 and the Secretariat expects to see higher unfunded pension liability payments beginning January 1, 2018 as a result of the new valuation. Pending the results of the April 2017 actuarial valuation, the Secretariat has included its best estimate of higher liability payments for budget planning in 2017/2018 and beyond.

The Secretariat will inform the Committee of the results of the new actuarial valuation and will work with the members to determine whether increased supplementary funding for the unfunded pension liability will be required beyond 2017/2018.

Test fishing

Test fishing finances continue to be a significant issue for the Parties, after extremely low returns of Fraser River sockeye and pink salmon in 2015 and 2016. Those low returns precluded the capture and sale of adequate fish to recover test fishing costs in those years and lowered the Test Fishing Revolving Fund (TFRF) to a balance of \$467,000 CAD (after supplemental contributions from each Party in early 2016).

The addition of supplemental funds remains an outstanding question between the Parties with regard to whether each Party is in a position to contribute additional funds to the TFRF to support an agreed upon test fishing schedule. This issue will need further discussion within each government and between the Parties in order to understand the level of investment each Party might be able to supplement the TFRF.

The Committee has coordinated with the Fraser River Panel and the Secretariat to discuss a test fishing schedule for 2017. The Panel is expected to approve this schedule and retain flexibility to adjust it in season in accordance with run size and evolving assessment needs. The Committee has provided the caveat that the Panel cannot incur operational deficits greater than \$467,000 CAD (the TFRF balance) without prior consultation with the Committee.

The Committee recognizes that test fishing finances should not be handled through ad hoc yearly agreements, and is hopeful that the PSC test fishing workshops underway will offer guidance or solutions in the near term.

In order to better understand drivers of inter-annual budget variability, including test fishing expenses, the Executive Secretary will liaise with national contacts to develop a discussion paper on the topic. This paper will describe drivers of expense variability and offer options for controlling them in the near term. The Committee expects to discuss this paper in May 2017 via teleconference, and will report any findings to the Commission at the 2017 Fall Meeting.

TABLE I

PACIFIC SALMON COMMISSION

FORECAST BUDGETS

	Forecast results 2016/2017	Proposed Budget 2017/2018	Forecast Budget 2018/2019	Forecast Budget 2019/2020	NOTES
1 INCOME	(none)	(pink)	(Adams)	(pink)	
A. Contribution from Canada	1,879,636	1,879,636	1,879,636	1,879,636	
Special contribution pension CA	110,000	110,000	110,000	148,000	1
B. Contribution from U.S.	1,879,636	1,879,636	1,879,636	1,879,636	
Special contribution pension U.S.A.	110,000	110,000	148,000	148,000	
Sub total	3,979,272	3,979,272	4,017,272	4,055,272	
D. Interest	22,000	22,000	22,000	20,000	
E. Other income	183,000	175,000	175,000	175,000	
Carry-over from previous fiscal year	710,720	938,988	501,118	93,151	
F. Total Income	4,894,992	5,115,260	4,715,390	4,343,423	
2 EXPENDITURES					
A. 1. Permanent Salaries and Benefits	2,525,174	2,680,973	2,730,122	2,804,938	
2. Unfunded pension liability payments	221,412	240,162	296,412	296,412	
3. Temporary Salaries and Benefits	172,446	267,004	285,780	260,774	
4. Total Salaries and Benefits	2,919,032	3,188,139	3,312,314	3,362,124	
B. Travel	82,766	117,307	99,883	99,530	
C. Rents, Communications, Utilities	123,632	229,527	154,123	154,346	
D. Printing and Publications	4,000	4,800	4,800	4,800	
E. Contractual Services	623,211	775,180	779,435	760,345	
F. Supplies and Materials	31,807	76,189	48,684	47,730	
G. Equipment	171,556	223,000	223,000	223,000	
H. Total Expenditures	3,956,004	4,614,142	4,622,239	4,651,876	
3 BALANCE (DEFICIT)	938,988	501,118	93,151	(308,453)	2
Carry-over generated (expended) in the year	\$228,268	(\$437,870)	(\$407,967)	(\$401,604)	

NOTE

1. To date, Canada has contributed \$330,000 (\$110,000 for each of the years 2016/17, 2017/18 and 2018/19).

As the unfunded pension liability payments may increase based on the next actuarial valuation, additional contributions may be required.

2017/2018: Special contributions for unfunded pension liability \$110K/ per Party, as invoiced and/or received by the Secretariat.

2018/2019: Special contribution - Canada: \$110,000 received. Additional contribution may be required, depending on actuarial valuation.

- USA: assume \$148,000 will be required. Actual amount will be based on actuarial valuation as of Jan1/17

2019/2020: Special contribution for Canada and USA assumed to be 50% each of the unfunded pension liability payments.

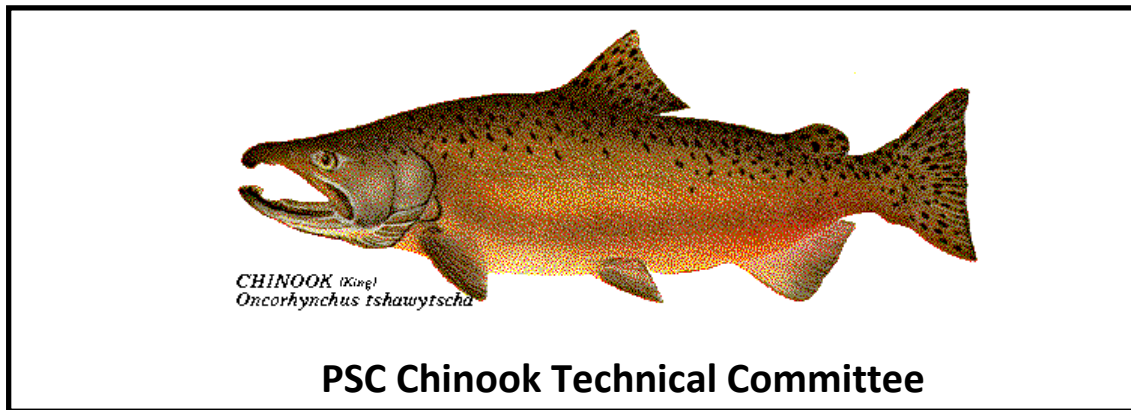
Actual amount will be determined by the actuarial valuation as of January 1, 2017.

2. Cumulative deficit presented at the January meeting was \$150,930 at the end of FY 2019/2020.

Adding test fishing expenses back into the budget would result in an increase of \$157,523 in the cumulative deficit.

The increase comprises of:

2017-2018 TF expenses	58,923
2018-2019 TF expenses	48,700
2019-2020 TF expenses	49,900
	<u>157,523</u>



TO: Pacific Salmon Commission

FROM: Chinook Technical Committee

DATE: February 16, 2017

SUBJECT: Review of PSC expert panel report on forecasting

On October 21, 2016 the CTC received a memo from PSC Commissioners requesting a response and review to an expert panel report "Review of Methods for Forecasting Chinook Salmon Abundance in the Pacific Salmon Treaty Areas". Specifically commissioners requested that the CTC "provide a summary of its views on the feasibility of implementing the key recommendations specific to the three elements we charged the panel with reviewing".

The CTC has chosen to respond to this request by providing comments for each of the issues identified by the expert panel. The expert panel organized issues into three categories: general issues and conclusions, regional agency forecasts and PSC Chinook model forecasts. These issues are organized accordingly in the tables below with corresponding CTC comments provided alongside those issues. For the latter two categories of issues, the expert panel also provided a priority code (near-term, intermediate and long-term) to each issue. Those priority codes are included herein. Additionally, the CTC included a feasibility ranking wherein the recommendations were rated on a scale of 1 to 5 where a 1 is highly feasible and 5 is not feasible without significant reprioritization of core CTC functions and the addition of resources. Many of the expert panel recommendations are directed at forecasts supplied by the agencies; the CTC did not provide a feasibility assessment for such recommendations.

The expert panel identified a number of different issues and improvements for forecasts. The CTC found that there were a number of different issues that could easily be remedied and others that were generally cost-time prohibitive. To this extent, the CTC would like to emphasize that while many of the expert panel's suggestions were technically sound, they were also unrealistic given agency budgets and staff availability. The ForecastR package is capable of implementing many of the highly technical suggestions identified by the expert panel, and many agencies plan to use this tool upon its completion. However, this tool alone currently is not capable of implementing all of the panel's suggestions.

The CTC would also like to emphasize that many of the CTC members do not conduct the forecasts that are supplied to the PSC Chinook model. In these cases, the CTC can only provide recommendations to the agency forecasters, but cannot necessarily force that they follow a recommendation. In order for the CTC to track agency forecasts, and whether or not these forecasts follow recommendations from the expert panel, we propose to develop a template that agencies could fill out when their forecasts are complete. This template will provide a platform to communicate CTC data needs and ask for information and clarification on the technical aspects of forecasts. This will promote an understanding of the methods and assumptions used in the generation of each agency forecast.

The expert panel also provided extensive comments on the PSC Chinook Model. In the CTC's response to these comments, identification of model improvement funds to carry out such tasks was a common theme in our response. Another consideration is the priority level identified by the expert panel and the time it would take the CTC to implement these recommendations. With treaty negotiations currently underway, and a new imminent agreement, it is unlikely that most of the issues and recommendations related to the PSC Chinook model could feasibly be implemented and tested prior to a new agreement.

Finally, the CTC would like to note that many of the methods identified by the expert panel will be constrained by the quality and availability of the data to inform the models. More sophisticated models are not always a remedy for inadequate data and have a tendency to shift the focus from the inadequacy of the data to the complexity of the model. The CTC generally agrees that the first priority is to improve the quality of the forecast data being collected, and then to apply progressively more complex models when the data can support that level of complexity.

6. GENERAL ISSUES AND CONCLUSIONS from the Expert Panel report and CTC comments

	Page	Issue	Expert Panel Conclusion	CTC Comments
6.1 Documentation of Agency Forecasting Methods and Results				
1.	43	Current documentation of agency forecasts of abundance that are sent annually to the CTC does not provide sufficient information for PSC modelers to identify the long-term accuracy and precision of those forecasts, let alone uncertainty about the current year's forecast.	More comprehensive documentation is needed by the CTC from regional agency forecasters regarding the agencies' methods, critical assumptions and uncertainties, and accuracy and precision of past stock-specific forecasts. Agencies should also state the uncertainty in each stocks' annual forecasted abundance. More frequent in-depth communication between PSC modelers and agency staff is also required.	The CTC recognizes that documentation is desirable, but also recognizes that this may represent an onerous task for the agencies especially given the time constraints for when forecasts are needed. The CTC proposes to develop a simple, clear template that includes a request for specific information that would be helpful to the CTC to inform annual calibration.
6.2 Requirements for Stock Forecasts as Inputs to the PSC Chinook Model				
2.	44	Efforts by agencies to provide forecasts as inputs to the PSC model are hampered by an incomplete understanding of (1) the PSC model's information requirements, (2) how those forecasts are used in that model, and (3) how those uses differ from those of fishery managers within regions.	More explicit direction from the Chinook Technical Committee is needed by agency-based stock forecasters regarding the annually requested forecasts.	See response to #1. The CTC AWG could include language from the proposed template describing the CTC's model requirements, explanation of how forecasts will be used, etc.
6.3 Limitations of Existing Stock Assessment Data				
3.	45	Accuracy and precision of stock forecasts are limited by the available stock assessment data; this is more of a problem for some Chinook stocks than others.	Substantial improvements in basic assessments of some Chinook stocks are needed to support current PSC model and management applications, otherwise expectations need to be rescaled/reduced to recognize existing data limitations. Further expansion of the PSC model's number of stocks and fishing areas may need to be postponed until the quality of relevant data is deemed suitable.	Agreed. Continue to include in LOA RFP and specify needed data as high priority for N and S Funds, and for directed resources to be sought under the next annex. Additionally, there are stocks and stock aggregates that do not have forecasts. It may be a worthwhile endeavor to identify such stocks and pursue development of forecasts.

6.4 Definitions and Best Practices for Agency Stock Assessment and Forecasting				
4.	46	There are substantial differences among regional agencies in how stock forecasts are produced and described.	Establishment of a set of "best forecasting practices" and standard definitions can improve the statistical foundation of methods for stock forecasting	Complete ForecastR and have workshops to facilitate usage of it.
6.5 Statistical Rigor of Agency Forecasting Methods				
5.	51	Forecasting methods for some stocks have not fully incorporated knowledge of changing parameters or recent advancements in statistical methods of analysis.	Accuracy, precision, and transparency of stock forecasting methods might be substantially improved by application of more formal model-selection criteria that match clearly defined management objectives. Forecasts might also improve by use of more advanced statistical methods that allow for time-varying parameters.	Roll out ForecastR to make it easier to investigate and evaluate multiple forecasting approaches. Processes that do not use ForecastR, but use rigorous methods and are well-documented are also supported. The CTC notes that the application of more advanced statistical methods is dependent on the quality and availability of data.
6.6 Limitations of Existing Agency Models for Forecasting				
6.	52	Existing forecasting models used by agencies, especially sibling relationships, are reasonably effective in representing average conditions but are vulnerable to performing poorly for years of very low or very high returns.	Development of new models and advanced parameter estimation methods may improve the accuracy and precision of agencies' annual forecasts. Regardless of any such improvements, large uncertainties in forecasts should be expected, especially when they are based on data outside the range of past observations.	Agreed. This is a limitation of forecasting.
6.7 Documentation of the PSC Model's Forecasting Methods				
7.	54	Incomplete and out-of-date documentation of the current PSC Chinook model and its calibration and projection procedures (1) threatens loss of institutional knowledge as key staff move on, (2) increases challenges to new CTC members who want to understand the model and its procedures, and in the worst case, (3) increases the chance of	Comprehensive up-to-date documentation of the PSC Chinook model in a single, central location is necessary to support its effective and credible use and improvement. A succession plan for training new model users is also critical.	Agreed, better documentation of the PSC Chinook model is needed. However, this will require resource allocation. Systematic review and update of model documentation, including expansion of help menus, is needed.

		errors in the model's application and interpretation.		
6.8 Statements of Uncertainty about the PSC Model's Output Forecasts				
8.	55	The deterministic nature of the PSC model and paucity of routine sensitivity analyses do not provide information about uncertainties in the model's forecasts of abundance in the three AABMs and terminal areas, thereby hampering well-informed decision making by PSC Commissioners and fishery managers in AABM areas.	Point estimates of forecasts of abundance indices in the three AABM areas from the PSC model should be accompanied by descriptions of uncertainties in those forecasts. Uncertainties can be derived from extensive sensitivity analyses of effects of different assumptions and input parameters. Expression of uncertainty in these forecasts is essential for determining the confidence to be placed in them and allowing for appropriate consideration by fishery managers.	This process will be dependent on receiving additional forecasts from agencies or in development of procedures for evaluating effects of uncertainty reported for agency forecasts. Differences in AIs could be evaluated, especially in a retrospective analysis, but forecast or PSC Chinook model calibration selection method should be determined prior to calibration. Evaluating multiple outcomes is particularly difficult in the compressed time available for calibration. The CTC would need to develop procedures for deciding among calibrations based on different forecast inputs. Procedures for considering how to deal with the influence of particularly uncertain forecasts in the calibration results would also be needed.
6.9 Limitations of the Existing PSC Chinook Model				
9.	57	The PSC model's structure, parameterization, and calibration are complex and subject to substantial structural and parameter uncertainties.	Substantial revision, testing, or possibly even replacement of the existing PSC Chinook model is necessary to effectively serve continuing needs, including the need for statements of uncertainty in the model's forecasts. A subgroup of CTC members should be created to explore such revisions and new models.	Agreed. The CTC already has Model Improvement (MI) Group, but it needs continued MI funding to proceed. The availability of a functional DGM will facilitate the exploration of alternative models or management regimes.
6.10 Consistency of Management Structures/Policies with the Limitations of Information and Assessments				
10.	58	Limitations of data and uncertainties associated with stock assessments and	Alternative frameworks, as well as ways of using forecasts of abundance, should be	Investigation of alternative frameworks would require commitment of resources.

		forecasting models challenge effective implementation of abundance-based management of Chinook under the Pacific Salmon Treaty.	considered for Chinook if current information and resources are not sufficient to effectively conduct adequate analyses and implement provisions of the current Treaty. Those provisions may need to be changed during current negotiations.	Likely there will not be enough time to explore alternative frameworks prior to the new annex. Prior to implementation, an alternative model would need to be fully-functioning, tested, and reviewed. If the Commission requests this work, the CTC will need DGM and MI funding.
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7. REGIONAL AGENCY FORECASTS OF CHINOOK ABUNDANCE

The CTC recognizes that many of the Forecast Review Panel comments are applicable to work conducted by the agencies and there is no authority to commit the agencies to undertake these tasks.

Priority Code as assigned by the expert panel

- N = Near-term. Relatively straightforward to implement with likely immediate benefit (within 1 year).
- I = Intermediate. Would require moderate investment of time and effort (1-2 years)
- L = Long-term. Would likely require substantial time and effort, but with high potential for long term improvements (3-5 years).

Feasibility Code as assigned by the CTC

Rated 1 to 5 where a 1 is highly feasible and 5 is not feasible without significant reprioritization of core CTC functions and additional resources. The CTC did not provide a feasibility assessment for Forecast Review Panel comments directed at the agencies (denoted as 'agency').

	Priority	Page	Recommendation	CTC Comments	Feasibility
	7.1	<i>General Comments about Agency Forecasts</i>			
1.	N	59	When regional agency forecasters send their stock-specific annual forecasts to the CTC, they should document their model-ranking procedures as well as the past performance of their methods (bias and precision).	The CTC is developing a template to collect desired information on forecasts and will provide this to agencies. Methodology/tools for assessing bias and precision could also be developed and provided. The CTC recommends this work be completed in time for the 2018 model calibration.	1
2.	I	60	Agency forecasters should not choose just one best model for forecasting abundance in each age class. Instead, they should conduct analyses across different models that make different assumptions and report the resulting set of forecasts to the CTC for use as inputs to the PSC model. The generally large prediction intervals (not confidence intervals) around point forecasts should also be reported.	Not a near term assignment/priority. Part of future analysis of model uncertainty. Most agencies already conduct analyses across different models, but only report the outcome from a single model for clarity and to avoid confusion. Can incorporate definition and methodology for desired prediction intervals in template in Recommendation 1. The reporting of prediction intervals can be informative but are only useful if decision-making procedures are developed to make use of this additional information. Currently, these do not exist within the Chapter 3 framework. A process to determine whether an agency forecast should be included or excluded in an annual calibration relative to the forecast that would be produced in its absence by the Chinook Model does not exist.	Agency
3.	I	61	Agency forecasters should also send to the CTC a set of forecasts, each one based on a different model-ranking criterion, as determined by	Intermediate term. Part of future analysis of uncertainty. This task would require agencies to provide multiple forecasts and documentation methods, or a forecast with measure of uncertainty.	4

			stated management objectives. As described in section 8.2, the CTC can then conduct sensitivity analyses with the PSC model to determine their effect on forecasts of abundance in the AABMs.	The CTC could define desirable attributes of forecasts (minimization of bias, maximization of precision, etc.) that could then be included in the template to agencies. This would reduce the volume of information received by the CTC from agencies. CTC could develop methods to evaluate impact of forecast uncertainty on AI estimation. A decision-making framework would also be required to determine the final annual calibration. This work would need to take place during the timeframe when the CTC-AWG is working on the model calibration and resources are already fully committed.	
4.	N	61	We encourage all agency forecasters to try applying ForecastR to their regions' stocks. As well, the CTC should run workshops to familiarize agency scientists with the ForecastR program.	The ForecastR tool is in development. CTC supports use of ForecastR pending completion and review. The CTC will need <u>funding</u> for workshops to make this tool available to the agencies and for further development.	1
5.	N	61	Agency forecasters should try applying a hybrid sibling model, especially to cases in which the fit of data to a standard sibling model is weak.	Need to specify methodology and develop tools. Not required for all stocks, but the CTC can make formal request to agencies to do this work. There are some capabilities that could be incorporated in ForecastR, which would facilitate the model selection process. Resources would be required to implement this function.	Agency
6.	N	62	We recommend that agency forecasters try using a Kalman filter estimation procedure for fitting their sibling relationships to account for time-varying parameters.	Intermediate. Need to specify methodology and develop tools. Not required for all stocks but can make request of agencies. Roll out ForecastR to make it easier to investigate and evaluate multiple forecasting approaches. Could incorporate time series filter capabilities in further development of ForecastR.	Agency
7.	L	63	Continue to improve upon the ability to estimate the contribution by stock to all AABM and ISBM fisheries with the objective of obtaining reliable stock contribution estimates by age. The Panel encourages the commitment of extra funding for the implementation of techniques to estimate stock contributions in a timely enough manner that the results can be used for forecasting in the subsequent year.	Dependent on high quality fishery sampling and age composition data by stock. Need continued funding for high quality assessment and indicator programs. Improving and maintaining current programs needs to be a long term commitment.	1
	7.2	Columbia River			

8.	N	64	The Columbia River Technical Advisory Committee (TAC) should explore whether using formal statistical model-selection criteria improves the accuracy and precision of their forecasts.	This request could be made to TAC and implementation of formal statistical model-selection criteria could be evaluated in the general template provided to agencies.	Agency
9.	N	64	Explore the use of natural-log transformations for sibling regressions. The examination should evaluate both the effect on meeting the regression assumptions and forecasting performance.	Incorporate exploration of transformations for sibling regressions as a desirable element for the template in recommendation 1.	Agency
10.	N	73	The Columbia River Technical Advisory Committee and the Pacific Salmon Commission's modeling group should communicate with each other to ensure that they are both working with the same definition of the Columbia River Summer stock and the same sets of data, and that any historical information reflects this change.	Need near term validation that TAC forecast is consistent with new base period calibration data. Need to explore treatment of subyearlings vs. yearlings in forecasts and validity of single mixed indicator stock in CTC model.	Agency
	7.3	<i>West Coast Vancouver Island</i>			
11.	N	78	The CTC modeling group and WCVI forecasters should decide (1) which type of forecast is required from WCVI (based on base-period data or recent years, for example), and (2) the forecast performance values (bias and precision) beyond which an extensive review of forecasting methods should be triggered.	Documentation that describes the Model's forecasting procedures and settings used in the calibration needs to clearly delineate how forecasts are used in stage 1 and stage 2 calibration process, i.e., in "base period units" or not, due to variable terminal harvest impacts.	1
12.	I	78	An evaluation of the WCVI sampling program should be undertaken to determine if (1) there has been a dramatic change in sample collection methods and sampling intensity over the years, and (2) whether the sample design and intensity is adequate to obtain meaningful age composition estimates. If the sample design appears to be adequate, then explore other ways to estimate the age-3 and age-6 components of the returns.	This objective and the expected result of pursuing this recommendation is not clear. Despite lack of understanding, the following comments are offered: The WCVI Model stock aggregate includes many stocks and ideally requires numerical and age composition estimates for all the escapements and terminal fisheries. It is not clear how effort spent in investigating effects of sample data quality and quantity through time will result in near term improvements to the forecast. Rather, improvements in forecast accuracy and bias are anticipated from increased sampling intensity achieved through a currently funded NEF	Agency

				project, 'WCVI Chinook Terminal Abundance'. The objective is to collect additional samples in the WCVI terminal area (R12).	
13.	I	80	The use of recent harvest rates and maturation rates should be explored for the WCVI forecasting model. These analyses should estimate model sensitivity to uncertainties in these rates, and all results of these sensitivity analyses, including the associated forecasts, should be provided to CTC modelers along with estimates of uncertainty in the forecasts.	The use of recent harvest rates has already been incorporated into the WCVI forecast procedure starting with the forecast provided in 2014. In the near term, recommendations to use recent maturation rates and data transformations can be explored. Sensitivity analyses to estimate the forecast procedure's sensitivity to the recommended changes is a longer term activity.	Agency
14.	I	82	Explore a different and simpler method of forecasting terminal return to WCVI. The preferred method would reduce the complexity of the forecast by reducing the number of data manipulations and number of parameters and assumptions in the forecasting procedure. As with all new methods, it should be thoroughly evaluated to determine whether an increase in performance is actually obtained in terms of bias and precision, and sensitivity analyses should be performed to determine the influence of uncertainties in model parameters.	The current forecast method for the WCVI stock produces pre-fishing ocean abundances by age to which estimated pre-terminal exploitation rates must be applied to arrive at the expected terminal run size by age. This differs from forecasting methods employed in the Southern US which consist of sibling forecast or similar models which do not explicitly take into account ocean abundances or pre-terminal exploitation rates. Alternative forecast methods for WCVI, including simpler ones like those used in the Southern US, can be explored. ForecastR is a tool that can be used to accomplish this. The yearly stage 2 calibration of the Chinook model uses recent FP times RT averages to estimate the fishery exploitation rates for the projection years. The projected fishery exploitation rates when combined with the stock forecasts from the agencies refine the projected EV scalars from stage 1 which then determine the projected abundances by stock.	Agency
	7.4 North Oregon Coast				
15.	N	83	We recommend that ODFW forecasters examine In e - In e sibling regressions, a hybrid sibling model, and a Kalman filter estimation procedure, the latter to account for possible temporal changes in parameters of the sibling relationship.	Many of the mentioned recommendations will be options within the analysis capable with updated versions of ForecastR. ODFW anticipates the utilization of these tools in the near future.	Agency
16.	N	83	A list of the alternative forecasting models examined and the criteria used to select among those models for producing a forecast for the Northern Oregon Coast should be clearly stated in the forecast document provided to the PSC	This will be accomplished using the reporting capabilities of ForecastR, given the utilization of this tool. If alternative models are employed, a rationale behind the selection of these models will be provided along with the results of this model.	Agency

			model group, as suggested in recommendations at the start of section 7.		
17.	N	85	All assumptions underlying the annual forecast, as well as data related to those assumptions, should be listed in the document provided to the PSC modelers so that everyone is aware of the forecast's strengths and weaknesses.	Agency response given within the proposed forecast template should easily address this recommendation.	Agency
18.	N	85	Continue the increased sampling in the Northern Oregon Coast for age, rapid reading of scales for age, and improvements in escapement estimation.	Given appropriate resources and agency prioritization, the maintenance of these critical data sources will be secured. Without additional resources, which are currently competed for annually, the quality, availability and timeliness of this sampling and the subsequent data will be degraded.	Agency
19.	I	85	As the population assessment models continue to evolve, NOC researchers should determine the sensitivity of the resulting forecasts to the uncertainty in estimated parameters in the models and quantify the uncertainty in the forecasts.	Evolving spawner assessments will necessitate evolving forecast assessments. The sensitivity of both estimations will be further informed for a greater understanding of the uncertainty inherent in these estimates.	Agency
20.	I	86	If more detailed data can be obtained from terminal fisheries for NOC, the forecast for this aggregate stock should change to a terminal run forecast instead of an escapement forecast.	Within the current time constraints of the need for forecasts, it is not likely ODFW will be able to comply with this suggestion. If future developments allow for expeditious estimation of terminal fisheries impact, this constraint would be removed.	Agency
21.	N	86	The Panelists encourage the continued use of ForecastR for Northern Oregon Coast Chinook Salmon.	OK.	Agency

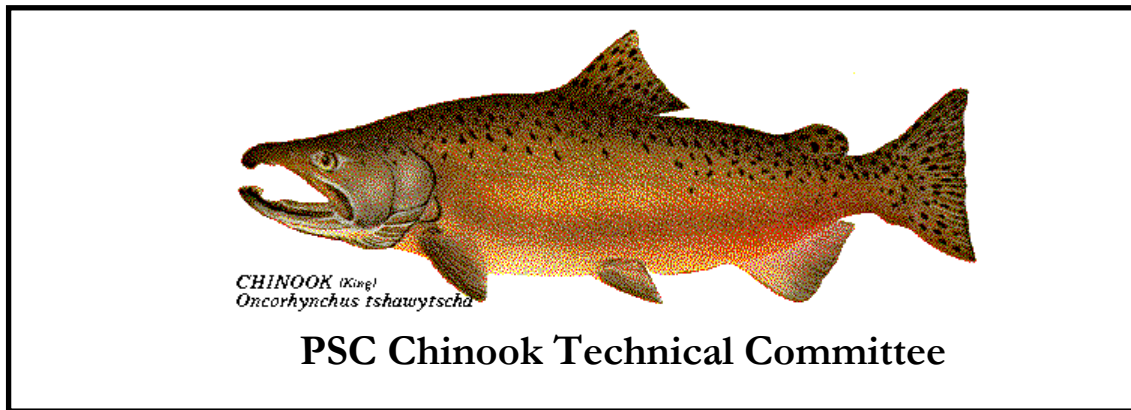
8 PACIFIC SALMON COMMISSION'S CHINOOK MODEL FORECASTS

	Priority	Page	Recommendation	CTC Comments	Feasibility
	8.2	<i>Unclear management objectives and the PSC Chinook model</i>			
22.	N	92	The CTC should request each regional agency to provide to PSC modelers the forecasts of abundance for the model deemed best for each of the "relevant" ranking criteria (such as MRE, MAE, or RMSE), where "relevant" is defined as those that fit with stated management objectives for the AABMs.	See recommendation #1 in section 7.1 above. The CTC recognizes that agencies may choose other criteria, but the CTC would like documentation on which criteria were used to choose the forecast provided.	1
23.	I	93	A series of projection runs should be conducted with the PSC model to produce a range of AIs for each AABM area. These AIs would reflect the different agencies' stock-specific model-ranking criteria that are deemed relevant to AABM management objectives.	Dependent on receiving additional forecasts from agencies that met other ranking criteria. Differences in AIs could be evaluated, especially in a retrospective analysis, but forecast or AI selection method should be determined prior to calibration. Evaluating multiple outcomes is particularly difficult in the compressed time available for calibration. Clear procedures would need to be developed to determine the final AI among a range of possible AIs for each AABM fishery. This is a time intensive endeavor.	4
	8.3	<i>Structural uncertainty in the PSC Chinook model</i>			
24.	I	93	Functionality of the PSC Chinook model might be enhanced by including, where appropriate, nonlinear relationships such as those found in many other fisheries models, including the effect of fishing on reducing the fish abundance available to subsequent fisheries during a given year.	Long term consideration contingent upon model improvement funds required to commence work on alternative model structure or frameworks. Incorporating nonlinear relationships would require restructuring the model, and would likely require additional data on effort. This is also dependent on the DGM being completed.	5
25.	I	94	Effects of changes in marine spatial distribution of Chinook stocks on functionality of the PSC Chinook model need to be evaluated.	Long term consideration contingent upon model improvement funds required to commence work on alternative model structure or frameworks. The PSC could convene a workshop or special investigation to examine evidence for distributional changes related to environmental conditions.	4
26.	I	95	Sensitivity analyses with the PSC model should be used to explore different assumptions about (1) age structure for stocks without historical	Sensitivity analyses as suggested in (1) and (2) could be carried out but would require dedication of CTC time and resources. This work	5

			age composition data, (2) body-size structure used in the current method for estimating PNV, and (3) alternative structural formulations of the PSC model to calculate changes in age at maturity as a function of changes in body-size distributions. Some of those analyses could also assume various correlations with age-at-maturity schedules of other stocks.	could be conducted outside of the CTC but would require funding for a contractor. Alternative model structures or frameworks are a longer term consideration. This could be part of analysis with DGM and sensitivity analyses. Implementation in the Chinook Model would require time and effort.	
27.	L	95	The differences between pre-season and post-season abundance indices in each of the three AABMs might be reduced by including in the PSC model tendencies for multiple stocks to have positively correlated time series in productivities.	The CTC could be tasked to discuss how the current Model structure could be modified to incorporate common survival patterns among stocks. Long term consideration contingent upon model improvement funds required to commence work on alternative model structure or frameworks. Evaluate the properties with simulated data using DGM.	4
28.	L	96	The PSC model might be improved if factors such as EV and RT were calculated as functions of other variables.	The CTC could be tasked to discuss whether alternative approaches may be used to calculate or modify the EVs and RTs. This would involve structural changes to the current Model framework. Long term consideration contingent upon model improvement funds required to commence work on alternative model structure or frameworks. Possibility to evaluate the properties with simulated data using a modified DGM.	5
29.	L	96	Uncertainty in estimates from the PSC Chinook model should be explicitly represented either by making the model stochastic or running it across numerous sets of assumptions using sensitivity analyses.	This would require long term consideration contingent upon model improvement funds required to commence work on alternative model structure or frameworks. Making the Chinook model stochastic would require significant revisions, whereas running it across numerous sets of assumptions is more feasible with the current model. Numerous sets of assumptions would require numerous model calibrations, and the expenditure of additional resources to follow-through with this recommendation. Management frameworks, as currently configured, would need to be adjusted to handle uncertainty.	5
30.	L	97	Ideally, the existing PSC Chinook model and/or its procedures should either be tested and refined or an entirely new model (or models) should be developed.	Long term consideration contingent upon model improvement funds required to commence work on alternative model structure or frameworks. Evaluate the properties with simulated data using DGM.	5
	8.4	<i>Uncertainty in parameters of the PSC Chinook model</i>			

31.	I	100	Testing of the PSC model (and all other contemplated models) should be a high priority when the Data Generating Model is released.	Agreed. This would require prioritization that the CTC focus on this recommendation as substantial time and effort would be needed, similar to what was required in the 'harvest rate index investigation' of 2007-09. Additional MI funding would assist this task.	3
32.	N	101	Evaluations of the PSC model should include: (1) a check whether there is confounding of parameter estimates in the stage 1 calibration; (2) a series of sensitivity analyses/calibrations exploring alternative values for assumed age-specific natural mortality rates that might affect all other subsequent calculations and forecasts of abundance, and (3) consideration of whether the PSC model is being over-fit.	Requires substantial MI funding, time and effort; thus this is unlikely in the near term. Maturation rates and survivals are known to be confounded. To some extent this has already been investigated (i.e., Crandall et al (2003) and TCCHINOOK (16)-01). Sensitivity analysis requires a systematic approach.	4
33.	I	101	Documentation should be provided on the basis of estimates of Ricker stock-recruitment parameters, as well as uncertainty in those estimates. Also, some improvement in performance of the PSC model might be obtained if the AWG used a Kalman filter that allows for a time-varying maximum productivity parameter in a given stock's Ricker stock-recruitment model. That Kalman filter procedure will explicitly take into account observation error as well as natural variation.	At this point in time, this will have little effect on the overall calibration. This task would take a considerable amount and time to recode the model. The cost/benefit is not high under the current configuration of the model.	5
34.	I	102	Given the large number of input parameters, all possible combinations of low, medium, and high values for each parameter may be impossibly time consuming. However, only a subset of those combinations would be needed to produce a range of forecast abundances.	The AWG could review the sensitivity analysis completed in 2001 as a starting point to identify which parameters the model is most sensitive to. This could shed light on where to prioritize investments. A range of forecast abundances will only lead to further contention unless there is an objective and predetermined selection procedure for what will be agreed to.	4
35.	I	102	Additional evaluation and documentation are needed of the PSC model's methods for dealing with stocks for which age-composition data and/or forecasts of terminal abundance or escapement are not available, given the large relative abundance of those stocks in some AABM areas.	The CTC is currently engaged in the documentation of the new base period calibration.	2

36.		103	The Panel generally recommends use of stock-specific forecasts provided by agencies rather than forecasts derived solely from the PSC model in the absence of clear evidence of improvements in accuracy and precision across multiple years.	The CTC typically uses agency forecasts when provided.	1
	8.5	<i>Outcome uncertainty in the PSC Chinook model</i>			
37.	L	105	Considerations of outcome uncertainty (deviation between desired and realized outcomes such as catches), as well as uncertainties in forecasts, will influence expectations of managers of these AABM fisheries when they choose annual fishing regulations.	We are cognizant of this. No specific action required.	Agency
38.	L	105	The PSC Chinook model should take into account outcome uncertainty when making forecasts and presenting uncertainties in them.	This would require adjustments to the model structure. A range of forecast abundances will only lead to further contention unless there is an objective and predetermined selection procedure for what will be agreed to.	5
	8.6	<i>Other issues related to the PSC Chinook model's forecasts</i>			
39.	I	105	The calibration procedure for the PSC model should be standardized and thoroughly documented to such an extent that a new member of the Analytical Working Group could repeat previous example analyses and come to the same stopping point about which calibration is deemed "final".	Additional resources are needed to facilitate further documentation. The CTC recognizes the need for better documentation of the inputs and decisions made during the calibration process. Some work on improved documentation has already been completed or is in progress. The prioritization of this task should reflect the imminent retirement of some key AWG members.	1
40.	L	106	The abundance forecasts for AABMs areas produced by the PSC Chinook model should convey to managers the net effect of all of the major uncertainties described previously -- structural uncertainty, parametric uncertainty, uncertainty about management objectives, and outcome uncertainty.	On-going discussion within the CTC as to how to respond to and incorporate the recommendations of the Forecast Review Panel. The CTC agrees that this task is something to work towards, but also recognizes that within the current management framework of Chapter 3, how to incorporate uncertainty in AIs would be a policy decision.	Not Applicable



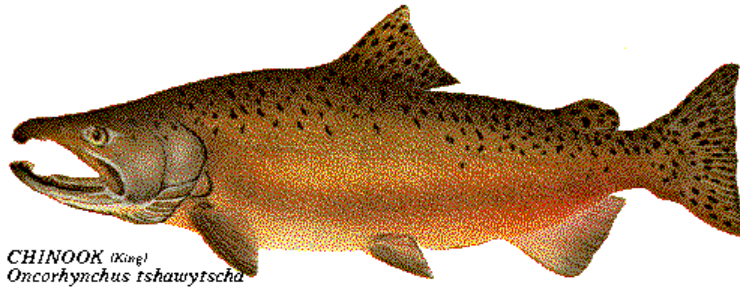
TO: Chinook Technical Committee
FROM: John Carlile, Gayle Brown, and Robert Kope: CTC Co-chairs
DATE: February 17, 2017
SUBJECT: CTC Progress Report for the Week of February 13-17, 2017

The bilateral CTC completed the following tasks during the week of February 13-17, 2017:

1. The 2016 Exploitation Rate Analysis and Model Calibration Supplement (Data Notebook).
2. The feasibility review of PSC expert panel report on forecasting.
3. Strategic advice regarding 2018 high priority Chinook project priorities.
4. Received a progress report on the development of the CIS exploitation rate analysis and model calibration system.
5. Received a progress report on the development of the mark-selective fishery algorithms for the annual exploitation rate analysis.
6. Received a progress report on the development of the stock forecasting tool ForecastR.
7. Received a progress report on the development of the Data Generation Model.

The following CTC tasks were worked on during the week and are still ongoing:

1. Phase 2 of the Base Period Calibration and the review of Phase 2.
2. The 2017 Exploitation Rate Analysis.
3. The 2017 Catch and Escapement report.



PSC Chinook Technical Committee

TO: PSC Commissioners

CC: John Field, PSC Executive Secretary

FROM: John Carlile, Robert Kope and Gayle Brown (CTC co-chairs)

DATE: February 16, 2017

SUBJECT: CTC response to the assignment to provide strategic advice regarding 2018 high priority Chinook project priorities

The CTC was tasked by the PSC Commissioners at the January 2017 Post-Season Meeting to complete the following task:

The CTC will provide advice to the Commission at the conclusion of their May 2017 meeting consistent with the level of detail provided in their April 2016 memo. The CTC's advice will cover very high priority chinook issues to help inform the development of requests for proposals for 2018 projects (i.e., as occurred April 2016).

The Commission chairs will consider the CTC advice and provide the Commission's views to the JFC in advance of 2017 RFPs.

Subsequently, the CTC was asked to provide such advice by the end of the February annual meeting in 2017.

In response to this assignment, the CTC reached agreement on a list of priority activities to support the 2018 implementation of Annex IV, Chapter 3. The CTC recommends use of the following project themes, in no particular priority order, to guide development of requests for proposals for high priority Chinook projects by the Endowment Fund committees:

- A. Sampling in fisheries and escapements, lab processing, and data reporting to support the recovery of adequate numbers of coded-wire tags to support estimation of precise statistics produced by the cohort analysis procedure.

- B. Coded-wire tagging of CTC exploitation rate indicator stocks (single index and double index tagging) designed to improve the quality and quantity of CWT data identified in PSC CWT guidelines.
- C. Continued or improved estimates of catch, terminal returns, forecasts and escapements to meet CTC data standards.
- D. Development of additional escapement goals and stock-specific exploitation rate management objectives needed to implement the Chinook management regime.
- E. PSC Coast Wide Chinook model and Exploitation Rate Analysis improvements.
- F. Improvement of methods for stock and fishery assessments (e.g., estimation of spatial/temporal stock-age distribution, projection of maturation rates for incomplete broods, systematic evaluation of current analytical methods using the Data Generation Model)

These recommendations are largely consistent with the advice the CTC provided in our April 2016 memo, with the addition of improved forecasts.

2017 SFEC Report

Pacific Salmon Commission
February 2017, Portland, OR
Rob Houtman
Gary S. Morishima

Duties of SFEC

1. Serve as a coastwide clearinghouse for coordination and reporting on MM and MSF programs;
2. Provide advice on potential adverse impacts of MM and MSFs on the CWT program;
3. Assess and monitor the cumulative impacts of MSFs on stocks of concern;
4. Receive and review MM and MSF proposals to identify potential issues and concerns regarding impacts on the CWT program.

SFEC is to establish a technical review process for MM/MSFs that will

- Identify potential impacts on other jurisdictions and the CWT program;
- Review procedures and protocols for marking, sampling, and evaluation;
- Establish standard formats and reporting requirements to provide post-season information and estimates of mortalities on stocks of concern;
- Identify information needs or request modifications of proposals to meet concerns regarding impacts on the CWT program; and
- Periodically assess impacts of MM/MSF programs regarding the integrity of the CWT program.

Overview

- Proposals have been received and review is underway
- MM Proposals

Species	# 2015 Mass Marked	# 2016 Mass Marked	#2017 Mass Mark Proposals
Coho	34.3 million	33.5 million	34.2 million
Chinook	117.3 million	117.1 million	116.2 million

- MSF Proposals

Species	# Proposed for 2015	# Proposed for 2016	# Proposed for 2017
Coho	25	23	23
Chinook	33	37	37
Coho & Chinook	1	1	1

MM Proposals

- All MM proposals were received within the requested timeframe,
- MM levels for Chinook remain relatively constant; slight increase for coho, slight decrease for chinook
- Change in CWT releases for both Chinook and coho
- DIT groups continue to be eliminated
- MM of Coho & Chinook releases are not all accompanied by CWT releases
 - Difficulty estimating source of MM'd encounters

MM Proposals for 2017 (excluding marked CWT'd fish)

Agency	Coho (million fish)	Chinook (million fish)
ADFG	0	0
CDFO	3.7	0
USFWS	1.7	25.0
WDFW/Tribes	22.5	70.9
ODFW/Tribes	6.2	20.3
IDFG	0	0
TOTAL	34.2	116.2

MSF Proposals

- Number of proposals similar to 2016
- Some MSFs are being conducted without proposals
- Continuing concerns regarding complex regulations and inadequate catch and CWT sampling programs for some MSFs
- ETD and Visual CWT sampling areas remain unchanged
- SFEC recommends that agencies consider the expected mark rate in a fishery when making decisions regarding implementation of MSFs

MSF Proposals for 2015-17

	Coho			Chinook		
<u>Agency</u>	<u>2015</u>	<u>2016</u>	<u>2017</u>	<u>2015</u>	<u>2016</u>	<u>2017</u>
ADFG	0	0	0	1	1	1
CDFO	6	5	5	1	1	1
WDFW	10	11	11	20	24	24
ODFW	5	5	5	6	6	6
WDFW/ODFW	2	2	2	4	5	5
IDFG	0	0	0	1	0	0
CDFG	0	0	0	0	0	0

SFEC “Stop-light” Evaluation Approach

Color	Level of concern to SFEC
#	None
#	Moderate
#	Major

- Numbers relate to specific characteristics identified in a table of the SFEC annual report
- Fill color indicates SFECs level of concern

Example: “Stoplight” Review Attributes For MSF Proposals

- 1) Fishery regulation
- 2) CWT sampling method
- 3) CWT detection method
- 4) CWT composition estimation method
- 5) Alignment of time/area strata boundaries of regulations and catch estimation and CWT sampling programs
- 6) Catch estimation by size/mark/retention status
- 7) Indicator stocks expected to be impacted by the fishery
- 8) DIT release groups expected to be impacted by the fishery

MSF Proposals Evaluation Attributes

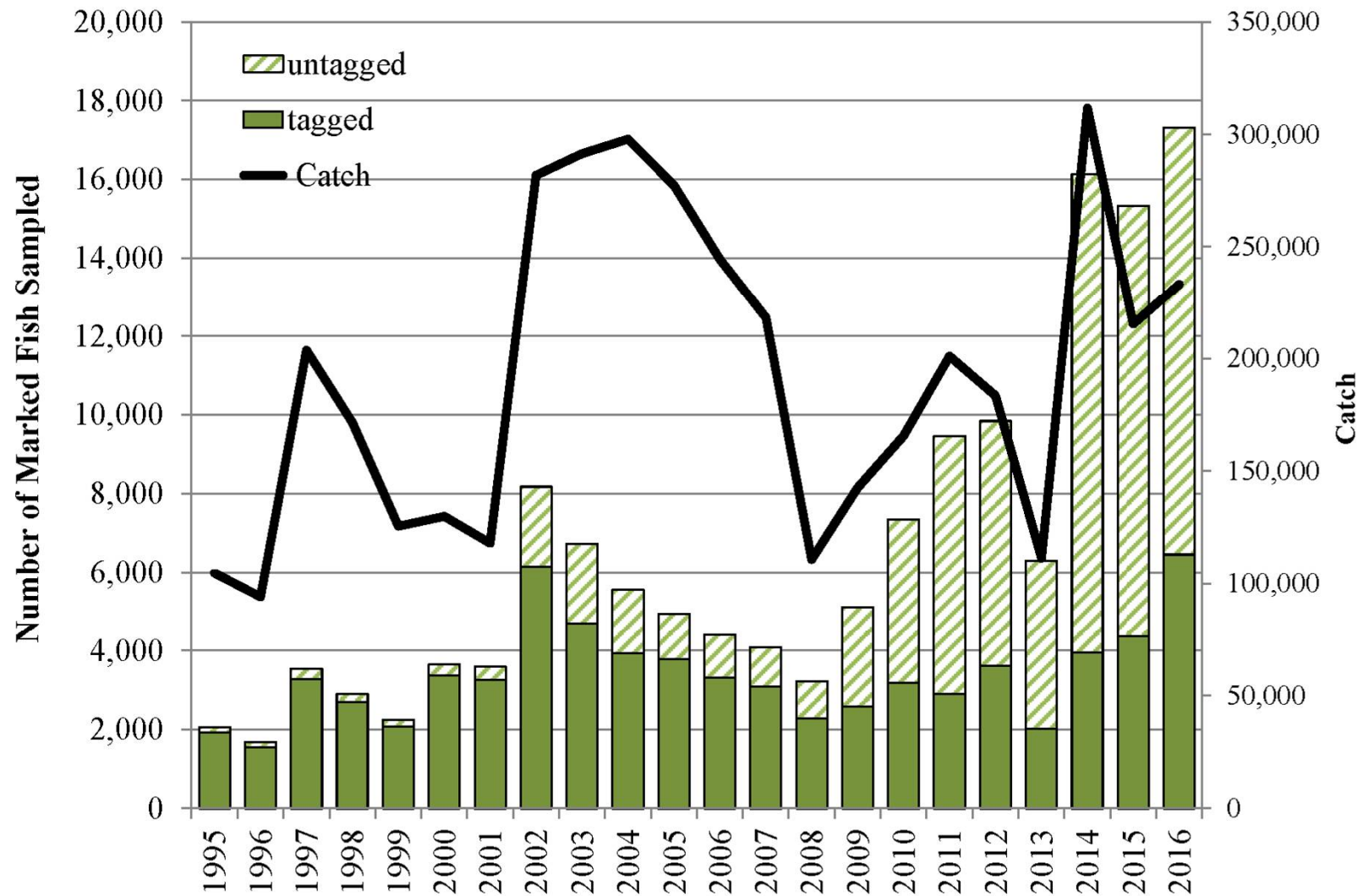
	COHO				CHINOOK			
AGENCY	# Attr	G	Y	R	# Attr	G	Y	R
ADFG	0				8	75%	25%	
FOC	47	57%	23%	19%	8	38%	38%	25%
WDFW	67	49%	16%	34%	185	80%	11%	9%
WDFW/ODFW	16	94%	6%		24	88%	13%	
ODFW	54	80%	15%	9%	46	67%	22%	11%

Example of variations in MSF Regulations

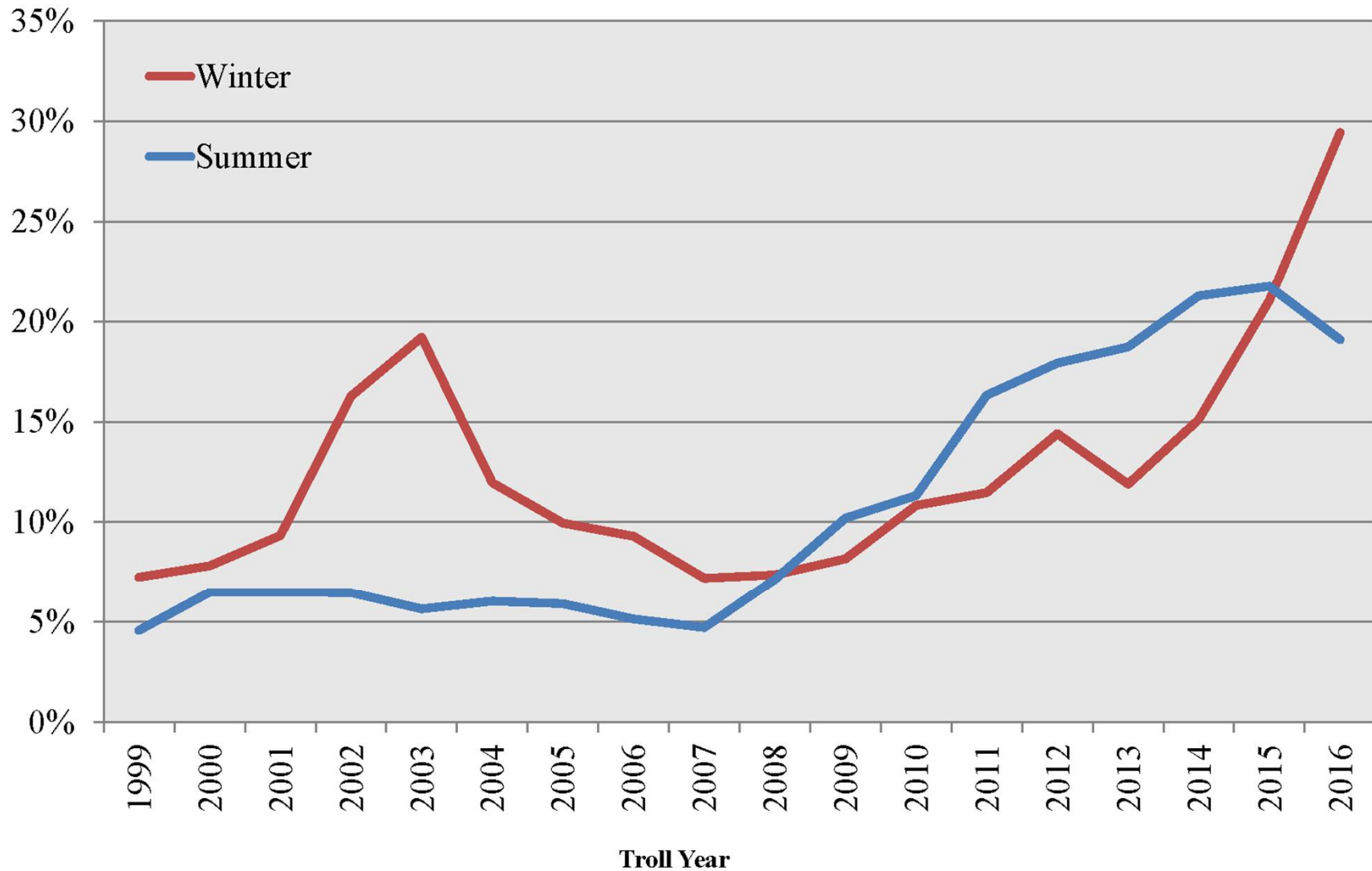
Category	Description
Simple	Only marked fish can be retained.
Marked mixed bag limit	A portion of total bag limit can be unmarked. This can be a daily limit bag or a seasonal bag limit
Mark and size-mixed bag limit	Size-range-specific allowances for retention of unmarked fish .

- Complex regulations make it more difficult to estimate MSF impacts on unmarked fish

SEAK Troll Chinook "No Pins"



SEAK Troll Chinook Ad-Clip Rate



Issues

- MSF proposals
 - required before details are known
- Post Season and detailed monitoring and reporting of MSFs, except WA Coastal and Puget Sound Marine Areas
- ADFG 2016 MSF, post season statistics provided to SFEC, indicating 459 chinook retained, but no estimates of encounters or releases. ADFG presented a report to PSC Jan 2016.

Types of Information Needed

1. MSF location, timing, regulations
2. CWT sampling method
3. CWT estimation method
4. Estimates of encounters, retentions, releases for marked and unmarked, legal, and sub/extra legal sized fish

Issues – Budget Pressures

- Concerns for maintaining base sampling programs
- Lack of DIT programs and ETD sampling.
- Dependency on CWT system – concern for erosion of cornerstone for management, stock & fishery assessments
- Support for technical and policy processes to develop agreements and to clarify responsibilities for maintaining a functional CWT program

Data-driven to Assumption-based management

- Uncertainty, risk, and precautionary approaches
 - Compensatory buffers
 - Fishing patterns (decreased reliance on mixed-stock fisheries)
- Additional funding needed to maintain stock and fishery assessment capabilities and the viability of the coastwide CWT system
- **Recommend:** Initiate multi-TC evaluation of impacts of budgetary pressures on the ability to implement PSC regimes (letter from TC Co-Chairs), specifically SFEC support for analysis of MSFs for incorporation into stock and fishery assessment methods and management models.

Future Plans

- 2017 MM/MSF reviews: target completion date Spring 2017
- MSFs
 - Focus on new or substantially changed proposals and post season reporting
- Coho DIT update – draft still in progress for PS, WC, & B C. Chinook DIT reported by CTC in exploitation rate analysis and calibration reports- differences are becoming apparent.
- Expand MSF database, e.g., NWIFC/WDFW pilot Recreational Angling Impact Database (RAID), to facilitate storage of postseason MSF estimates. Coordinate with Data Sharing and Data Standards Committees.
- Need archival/storage capability for version control of master documents

2017 PRE SEASON PSC MEETING

February 13-17, 2017

SOUTHERN PANEL MEETING REPORT

Session Activities:

- *The Bilateral Panel met and received the presentations on:*
 - *The 2015 Post-Season assessment of the Coho Exploitation Rates*
 - *ESSA presented their final draft report of the Coho Alternative management strategy workshop.*
 - *Laurie Weitkamp's review of environmental indicators.*
 - *Updates on the status of the Chum TC research projects*
 - *CHUM and COHO TC SEF priorities.*
- *The majority of the session was spent in sections and bilaterally, advancing proposals for renegotiation of Chapters 5 and 6. The US advanced new proposals on the modifications to both chapters in response to Canada's previous proposals. Canada provided a response to each of those. While the parties have come to agreement on some items in each, there remains substantive disagreement on key issues.*
- *Finally, an agenda was planned out for the upcoming early May meeting of the panel to continue the renegotiation process as well as describing steps that could be taken between the February meeting and the planned May meeting.*

Attachment 1. Draft Revised 2017 Southern Panel and CoTC Workplan			
When	Who	Location	Purpose
November 28-29, 2016	Bilateral Southern Panel, CoTC, other participants	Workshop, Arlington, WA	<p><i>Southern Coho Alternative Management Strategies Workshop</i> to evaluate strengths, weaknesses, and trade-offs among a set of hypothetical alternative strategies for Southern Coho Management.</p> <p>The Parties can subsequently consider the type of strategy (and components) to develop in more detail (and vet domestically) to bring into the negotiations.</p>
December 2016	U.S, Canadian Sections	Conference calls	<p>Hold separate Section conference calls in December to start developing Section proposals, immediately following the November 2016 <i>Southern Coho Alternative Management Strategies Workshop</i> when analysis of potential strategies and trade-off discussions are fresh in people's minds.</p> <p>Start information out (domestic consultations) on workshop results.</p> <p>Consider revising Southern Panel Workplan to defer estimation 2015 ERS for Coho Management Units (MUs) until after renegotiations are largely complete in favor of devoting time in Jan & Feb to support renegotiation and advancing meetings previously proposed for summer and fall 2017. Note aspects of this potential workplan change are reflected in this tentative schedule. The Coho TC will require direction from Southern Panel on priorities (especially between renegotiation support and 2015 ER calculation work)</p>
Jan 9-13, 2017 PSC Post Season Meeting	Southern Panel, CoTC, ChumTC	Vancouver, BC	<p>U.S. presents proposal for chum chapter revisions prior to January session (provided Jan. 3rd).</p> <p>The bilateral Southern Panel will receive a presentation from ESSA on initial findings and a status report following the November 2016 <i>Southern Coho Alternative Management Strategies Workshop</i>.</p> <p>Sections present preliminary thinking on Chapter 5 (Coho) proposals to bilateral session.</p> <p>Focus on Section work to develop and refine Country proposals, for Chum and Coho Chapters of the PST.</p> <p>For the Coho Chapter, confirm components of new strategies where there is sufficient level of agreement to move to chapter re-drafting.</p> <p>Identify areas where agreement not yet achieved and what work is required (policy analysis, tech committee analysis) to move towards agreement. Work plan for Coho Technical Committee updated.</p> <p>Briefing to PSC on Coho Workshop outcomes, status of Chum and Coho Chapter renegotiation.</p> <p>If they are required to work on other priorities, defer CoTC preparation of estimates for 2015 ER estimates until after June.</p> <p>Submit proposal for revised Southern Panel workplan for PSC consideration as needed.</p>
Late January- Early February 2017	Drafting group, U.S.-Canadian Sections sub- group Coho TC	Conference calls, email	<p>Draft initial Chapter 5 (Coho) proposals for consideration based on January Panel direction on areas of agreement.</p> <p>Advance technical or policy analysis as directed in Jan session.</p> <p>Exchange Chapter 6 (Chum) proposed language revisions.</p>
Feb 13-17, 2017 PSC Annual Meeting	Southern Panel CoTC, ChumTC	Portland, OR	<p>The bilateral Southern Panel will receive the final report from ESSA, with results and recommendations, following the November 2016 <i>Southern Coho Alternative Management Strategies Workshop</i></p> <p>Ongoing work towards and if available, review results of any policy or technical analysis related to proposals.</p> <p>Update from group working on Chapter 5 (Coho) and 6 language revisions.</p> <p>Option to defer CoTC preparation of estimates for 2015 ER estimates until after June depending on amount of technical work required to support renegotiations.</p>

Attachment 1. Draft Revised 2017 Southern Panel and CoTC Workplan			
When	Who	Location	Purpose
			Complete Chapter 6 (Chum) negotiations in bilateral So Panel meetings. Briefing to PSC on remaining work needed to complete Coho Chapter renegotiation. SEF priorities developed by TCs and endorsed by Panel.
March 2017	Panel chairs, select members of Coho Working Group as required	Electronic data exchange as needed; possible face-to-face as in 2016 (TBD)	Annual manager-manager information exchange; including preseason stock forecasts and fishery plans.
March-April 2017	U.S.-Canadian Sections	Emails, Conference Calls	Exchange proposals on areas requiring further work to achieve agreement. Continue domestic consultations, vetting of draft proposals as feasible given involvement in 2017 fishery planning processes. Fishery planning processes are anticipated to be completed in April and June, for the US and Canada, respectively.
Late April 2017	Bilateral Coho WG, Full Sections of So Panel (<i>conf call</i>) – if required	Bellingham, WA (TBD) or Canada	Support for renegotiation of Southern Coho Agreement. Continue exchanging proposals on areas requiring further work to achieve agreement. Review any updated draft language that has technical implications. - Key questions to tech committee to support development of proposals; Identify key areas needed additional work to advance negotiations. Provide direction to CoTC for additional work / analysis needed. <i>Need to plan for <u>extended</u> CoWG meeting (3 or 4 days)</i> <i>Canadian 2017 fishery planning in process.</i>
May 2017	CoTC (replaces typical summer session)	TBD	Conduct technical work needed in support of renegotiation of Coho Chapter. <i>Canadian 2017 fishery planning in process.</i>
May-June 2017	U.S., Canadian Sections	--	Continued domestic consultations, vetting of draft proposals. <i>Canadian 2017 fishery planning in process.</i>
June 2017	U.S., Canadian Sections; PSC Input	Conference calls, email	<i>Canadian 2017 fishery planning anticipated to be complete.</i> More in-depth domestic consultations on proposals. Near finalization of new proposals. Assess ability to achieve negotiating timelines. Update PSC; receive PSC input (section-level).
Summer 2017	CoTC	TBD	Prepare estimates for 2015 ERs on Coho MUs (if deferred).

2017 PACIFIC SALMON COMMISSION ANNUAL MEETING

BRIEFING FOR THE COMMISSIONERS

Transboundary Panel (Chapter 1)

Bilateral Report – Friday February 17, 2017

- The Canadian and U.S. sections met independently on Monday February 13.
- The Transboundary Panel met subsequently in bilateral sessions between 09:00 and 16:00 on Tuesday February 14 followed by a variable schedule of negotiation sessions on Wednesday February 15 and Thursday February 16.

Daily Summary:

- Tuesday February 14:
 - The Panel received reports on pre-season forecasts for PST defined Stikine, Taku and Alsek River salmon stocks. Notably, 2017 Chinook salmon returns are forecast to be well below average, and in the case of the Taku, below the lower bound of the spawning escapement goal range. Sockeye salmon returns are forecast to be relatively strong – at, or above recent 10 year average returns while coho salmon returns are forecast to be near average.
 - 2017 bilateral Sockeye Enhancement Project Plans were approved for the Stikine and Taku Rivers while the result of the 2012 Stikine Sockeye Enhancement Production Plan (5 years post initiation) was approved.
 - The Panel recommended the continuation of the interim coho salmon harvest share allocation for Canadian Taku River fisheries in 2017 (renewal of the same arrangement confirmed in 2015 and 2016).
 - The Panel completed the annual “Paragraph 4” management performance evaluation exercise.
 - Chapter 1 Renewal – The Canadian section of the Transboundary Panel presented a response paper for Appendix to Chapter 1, outlining proposed changes.
- Wednesday February 15:
 - The Panel engaged in bilateral meeting sessions focused on the renegotiation and renewal of Chapter 1.
 - The Panel reached bilateral agreement on recommended language for the renewal of Chapter 1 for the 2019 to 2028 fishing seasons respectively.
- Thursday February 16:
 - The Panel met to finalize editorial changes to Chapter 1 and associated appendix, in advance of the presentation to Commissioners on Friday February 17.

Fraser River Panel Report to the Pacific Salmon Commission February 17, 2017

Post-Season 2016:

- Panel received a presentation on near-final spawning escapement estimates from 2016 and concluded discussions on the 2016 fishing season.

Pre-Season discussions for 2017:

- Panel discussed the 2017 forecast for Fraser River sockeye and pink salmon and had initial discussions regarding pre-season planning considerations.
- The sockeye forecast covers a range (p10 is 1.3 M and p90 is 17.6 M) and at the median (p50), which normally forms the basis of pre-season planning, is for 4.4 million Fraser River sockeye. The p50 forecast for pink salmon in 2017 is 8.7 million.
- The forecast has inherent some additional uncertainty compared with most years, given that almost 50% of the forecast return is anticipated to be Chilko sockeye, and the Chilko sockeye forecast is highly uncertain given that the usual methodologies (based on assessing smolt outmigration from Chilko Lake) could not be used (water was too high to install the counting fence during the outmigration time).

Fraser River Sockeye Spawning Initiative (FRSSI):

- Fraser River Panel had some initial discussions regarding possible changes to escapement plan approaches for the 2018 season (Adams dominant return year), including consideration of possible changes to harvest rules in a year of high abundance.

FSRC:

- FRP leadership, key FRP Tech Ctee members, and PSC staff (referred to as the Oversight Committee) met with the FSRC Committee twice during February session.
- Analytical work will continue to complete commitments as set out in the approved hydroacoustics work plan.
- A detailed plan will be developed by the Hydroacoustics Oversight Group (subset of Panel and Technical Ctee members and some PSC staff) for the remaining work, identifying specific work items, timelines and responsibilities to ensure all requirements of the approved work plan are addressed and on track for completion by mid-June 2017.
- John Field will arrange a series of calls with the FSRC to receive progress reports and updated information. The Hydroacoustics Oversight Group will engage with the FSRC on

possible outcomes so that thinking continues to evolve as information becomes available. This will inform development of the synthesis report to the FSRC, which will in turn inform recommendations of the FSRC to the Commission, regarding the future of the hydroacoustics program, in the fall of 2017.. Elements of the Test Fishing review will be brought into the Hydroacoustics review as appropriate.

- The Oversight Committee will remain in contact with the FSRC on a regular basis and will report key findings as work elements are completed, as well as draft reports.

Test Fishing

- The Panel worked to prepare a proposal for test fisheries for 2017 that would be agreeable to the Finance and Administration Committee, operating within the bounds of available resources while providing critical information to inform fisheries management decisions.

Other Business:

- The Panel discussed the status of several reports and review of minutes, and associated deadlines for completion.

Pacific Salmon Commission
Northern Panel
February 13 – 17, 2017
Final Report to the Commissioners

- Both the US and Canada met domestically on Monday through Thursday at this session of the PST and focused our attention to responding to the exchange of papers emanating from the January session in Vancouver.
- A subgroup of the panels and tech committees met bilaterally on Tuesday to review and discuss supporting data for their positions, and to clarify their interpretations of the data.
- The Northern Panel bilaterally also developed a communication and information exchange protocol for the 2017 season. In association with this protocol will be the development of further exchanges over the course of the season including a tour of each Parties fishery in the Northern Boundary and SEAK areas.
- The Northern Panel will be preparing a paper for the Commissioner at their May meeting in which we will describe the key issues of concern to the Panel and supporting data that supports these concerns. Therefore the Northern Panel has yet to conclude our recommendations to the Commissioners on Chapter 2 language and will continue with our exchanges over the summer and fall.
- The Northern Panel bilaterally provided instructions to the Northern Boundary Technical Committee to exchange coho information and prepare a report for the Northern Panel by 2020.